STANDARD SPECIFICATIONS

for

TRANSPORTATION MATERIALS

and

METHODS OF SAMPLING AND TESTING

Thirtieth Edition

2010

PART 1A SPECIFICATIONS

Adopted by the

AMERICAN ASSOCIATION OF STATE HIGHWAY
AND TRANSPORTATION OFFICIALS

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INTRODUCTION

PART 1
SPECIFICATIONS

This Thirtieth Edition of Transportation Materials is published in two parts. Part 1 contains specifications for materials, and Part II includes methods of testing and specifications for testing equipment. Part 1 contains 162 materials specifications and 48 Standard Practices, of which most contain both English and Metric units of measure. Technical revisions were made in 26 of the standards since the Twenty-Ninth Edition, 14 standards were reconfirmed, six standards were updated, eight new standards were added, nine standards were discontinued, and one standard was deleted. A number of specifications were included in this publication at the request of the AASHTO Subcommittee on Bridges and Structures.

Many of these specifications agree with those of the American Society for Testing and Materials (ASTM). In all cases where the Association and ASTM standards are technically identical, or substantially identical with some changes, reference to the ASTM designation number is shown in the heading of the specification.

In past editions, AASHTO has printed ASTM standards which have been adopted by AASHTO and given an AASHTO designation. This was done under a long-standing copyright arrangement between AASHTO and ASTM. The Thirtieth Edition includes 32 AASHTO-approved ASTM specifications. These specifications appear in this edition as the actual ASTM specification preceded by a cover page with the AASHTO designation number. Any AASHTO exception to the ASTM specification is indicated on this cover page. The numerical order of the specifications has been retained. A list of the affected AASHTO specifications is included following the Table of Contents.

General jurisdiction over Association standards in this field rests with the AASHTO Highway Subcommittee on Materials, which has members representing each of the 50 States, the Commonwealth of Puerto Rico and the District of Columbia, that constitute the Member Departments of the Association, and the U.S. Department of Transportation. In addition, the Subcommittee has representation from several of its Associate Members, including the New Jersey Turnpike Authority, the Pennsylvania Turnpike Authority, and the Port Authority of New York and New Jersey. Also represented on the Subcommittee are most of the Association's International Associate members, including the Canadian Provinces of New Brunswick, the Northwest Territories, Nova Scotia, Ontario, and Saskatchewan.

Beginning in 1993 with the Sixteenth Edition, material specifications and test methods are published by AASHTO each year. Annual revisions are voted upon by the Association's 52 Member Departments prior to the publication of each new edition of this book, and if approved by at least two-thirds of the Member Departments, they are included in the edition as standards of the Association.

Comments regarding these specifications are welcomed and should be addressed to the Executive Director of AASHTO, 444 North Capitol Street, N.W., Suite 249, Washington, D.C. 20001. AASHTO's Web site and internet address is http://transportation.org.

STANDARD SPECIFICATIONS

for

TRANSPORTATION MATERIALS

and

METHODS OF SAMPLING AND TESTING

Thirtieth Edition

2010

PART 2A TESTS

Adopted by the

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INTRODUCTION

PART 2
METHODS OF SAMPLING AND TESTING

This Thirtieth Edition of Transportation Materials is published in two parts. Part 1 contains specifications for materials, and Part 2 includes methods of testing and specifications for testing equipment. Part 2 contains 215 test methods and equipment standards, of which most contain both U.S. Customary and Metric units of measure. Since the Twenty-Ninth Edition, technical revisions were made in 44 of the standards, 22 standards were reconfirmed, 1 standard was updated, 2 new standards were added, 2 standards were discontinued, and 5 standards were deleted. A number of specifications were included in this publication at the request of the AASHTO Subcommittee on Bridges and Structures.

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The following specification has been deleted from the 30th Edition:

M 20-70 (2004)	Penetration-Graded Asphalt Cement

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DELETED SPECIFICATIONS

The following specification has been deleted from the 30th Edition:

M 20-70 (2004)	Penetration-Graded Asphalt Cement

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DELETED SPECIFICATIONS

The following specifications have been deleted from the 30th Edition:

T 67-08	Standard Practices for Force Verification of Testing Machines
T 68-05	Tension Testing of Metallic Materials
T 70-08	Brinell Hardness of Metallic Materials
T 80-08	Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
T 235-96 (2004)	Bearing Capacity of Soil for Static Load on Spread Footings

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NUMERICAL SEQUENCE

DELETED SPECIFICATIONS

The following specifications have been deleted from the 30th Edition:

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Standard Specification for

Fine Aggregate for Hydraulic Cement Concrete

AASHTO Designation: M 6-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Fine Aggregate for Hydraulic Cement Concrete

AASHTO Designation: M 6-08

1. SCOPE

1.1. This specification covers the quality and grading of fine aggregate for hydraulic cement concrete used in pavements or bases, highway bridges, and incidental structures.

1.2. This specification is for use by a contractor, concrete supplier, or other purchaser as part of the purchase document describing the material to be furnished.

Note 1—This specification is regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, it may be either more or less restrictive than needed. For example, where aesthetics are important, more restrictive limits may be considered regarding impurities that would stain the concrete surface. The specifier should ascertain that aggregates specified are or can be made available in the area of the work, with regard to grading, physical, or chemical properties, or combination thereof.

1.3. This specification is also for use in project specifications to define the quality of aggregate, the nominal maximum size of the aggregate, and other specific grading requirements. Those responsible for selecting the proportions for the concrete mixture shall have the responsibility of determining the proportions of fine and coarse aggregate and the addition of blending aggregate sizes if required or approved.

1.4. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5. The text of this standard references notes and footnotes that provide explanatory material. These notes (excluding those in tables and figures) shall not be considered as requirements of this standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 92, Wire-Cloth Sieves for Testing Purposes
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 21, Organic Impurities in Fine Aggregates for Concrete
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 103, Soundness of Aggregates by Freezing and Thawing

- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 113, Lightweight Pieces in Aggregate
- T 161, Resistance of Concrete to Rapid Freezing and Thawing
- T 303, Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

2.2. *ASTM Standards*:

- C 227, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
- C 289, Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- C 586, Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates(Rock-Cylinder Method)
- C 1260, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
- C 1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
- STP 169D, *Significance of Tests and Properties of Concrete and Concrete-Making Materials*

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3. ORDERING INFORMATION

3.1. The purchaser shall include the following information in the purchase order or contract when applicable:

3.1.1. Reference to this specification, M 6, and year of issue;

3.1.2. Whether the deleterious substances limits for Class A or Class B apply, and limits on other deleterious substances (Section 7.1 and Note 4);

3.1.3. If the sulfate soundness requirement is waived (Section 8.5);

3.1.4. In the case of the sulfate soundness test (Section 8.1), which salt is to be used; if none is stated, either sodium sulfate or magnesium sulfate may be used;

3.1.5. If the supplementary requirement for reactive aggregates applies (Section S1); and

3.1.6. Any exceptions or additions to this specification.

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4. GENERAL REQUIREMENTS

4.1. Fine aggregate shall consist of natural sand or manufactured sand or combinations thereof, having hard, strong, durable particles.

4.2. Fine aggregate from different sources of supply shall not be mixed or stored in the same pile.

5. GRADING

5.1. Fine aggregate, when tested by means of laboratory sieves, shall conform to the requirements of Table 1, except as provided in Sections 5.2 and 5.3:

Table 1—Grading Requirements

Sieve	Mass, Percent Passing
9.5 mm ($^3/_8$ in.)	100
4.75 mm (No. 4)	95 to 100
2.36 mm (No. 8)	80 to 100
1.18 mm (No. 16)	50 to 85
600 µm (No. 30)	25 to 60
300 µm (No. 50)	10 to 30
150 µm (No. 100)	2 to 10

5.2. The minimum percent shown above for material passing the 300-µm (No. 50) and 150-µm (No. 100) sieves may be reduced to 5 and 0, respectively, if the aggregate is to be used in air-entrained concrete containing more than 237 kilograms of cement per cubic meter (400 lb/yd^3) or in non-air-entrained concrete containing more than 297 kilograms of cement per cubic meter (500 lb/yd^3) or if an approved mineral admixture is used to supply the deficiency in percent passing these sieves. Air-entrained concrete is here considered to be concrete containing air-entraining cement or an air-entraining agent and having an air content equal to or greater than 3.5 percent.

5.3. The fine aggregate shall have not more than 45 percent passing any sieve and retained on the next consecutive sieve of those shown in Section 5.1, and its fineness modulus shall be not less than 2.3 nor more than 3.1.

5.4. Fine aggregate failing to meet the sieve analysis and fineness modulus requirements of Sections 5.1, 5.2, or 5.3, may be accepted provided that concrete made with similar fine aggregate from the same source has an acceptable performance record in similar concrete construction; or, in the absence of a demonstrable service record, provided that it is demonstrated that concrete of the class specified, made with the fine aggregate under consideration, will have relevant properties at least equal to those of concrete made with the same ingredients with the exception that a reference fine aggregate be used which is selected from a source having an acceptable performance record in similar concrete construction.

Note 2—Fine aggregate that conforms to the grading requirements of a specification, prepared by another organization such as a state transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by grading.

Note 3—Relevant properties are those properties of the concrete, which are important to the particular application being considered. STP 169D provides a discussion of important concrete properties.

6. UNIFORMITY OF GRADING

6.1. For continuing shipments of fine aggregate from a given source, the fineness modulus shall not vary more than 0.20 from the base fineness modulus. The base fineness modulus shall be that value that is typical of the source. If necessary, the base fineness modulus may be changed when approved by the purchaser.

Note 4—The base fineness modulus should be determined from previous tests, or if no previous tests exist, from the average of the fineness modulus values for the first 10 samples (or all preceding samples if less than 10) on the order. The proportioning of a concrete mixture may be dependent on the base fineness modulus of the fine aggregate to be used. Therefore, when it appears that the base fineness modulus is considerably different from the value used in selecting proportions for the concrete mixture, a suitable adjustment in the mixture may be necessary.

7. DELETERIOUS SUBSTANCES

7.1. The amount of deleterious substances shall not exceed the following limits: (See Table 2.)

Table 2—Deleterious Substances Limits

	Class A, Max Mass, percent	Class B, Max Mass, percent
Clay lumps and friable particles	3.0	3.0
Coal and lignite	0.25	1.0
Material finer than 75-µm (No. 200) sieve:		
a. In concrete subject to surface abrasion not more than	2.0	4.0
b. All other classes of concrete, not more than	3.0	5.0
Other deleterious substances (such as shale, alkali, mica, coated grains, and soft and flaky particles)	Note 5	Note 5

Note 5—The purchaser or specifier, due to knowledge of the requirements of the work and the constituents of locally available aggregate, should insert appropriate requirements when needed.

7.2. *Organic Impurities*:

7.2.1. Fine aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

7.2.2. A fine aggregate failing in the test may be used, provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

7.2.3. A fine aggregate failing in the test may be used, provided that, when tested for the effect of organic impurities on strength of mortar, the relative strength at seven days calculated in accordance with T 71 is not less than 95 percent.

7.3. Fine aggregate used in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any components that are known to be reactive with soluble alkalies from the concrete paste in an amount sufficient to cause deleterious expansion of mortar or concrete without the accompanying use of some form of remediation in the concrete which is known to prevent deleterious expansion due to alkali-silica reactivity. The method chosen for prevention of ASR in any one situation will depend on the materials available for remediation, the relative effectiveness of the available materials in preventing excessive expansion due to alkali-silica reactivity, and the reactivity of the aggregate intended for use in the concrete. (See Supplementary Requirement S1 and Appendix X1.)

8. SOUNDNESS

8.1. Except as provided in Sections 8.2 through 8.5, fine aggregate subjected to five cycles of the soundness test shall have a weighted average loss not greater than 10 percent when sodium sulfate is used or 15 percent when magnesium sulfate is used.

8.2. Fine aggregate failing to meet the requirements of Section 8.1 may be accepted, provided that concrete of comparable properties, made from similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

8.3. Fine aggregate not having a demonstrable service record and failing to meet the requirements of Section 8.1 may be accepted, provided it gives satisfactory results in concrete subjected to freezing and thawing tests. (See T 161.)

8.4. Fine aggregate failing to meet the requirements given in Section 8.1 may, at the option of the purchaser or specifier, be subjected to an alternate freezing and thawing test of unconfined aggregate and may be accepted provided it gives satisfactory results.

Note 6—The purchaser or specifier should determine the details of the evaluation and criteria for determining satisfactory performance in Sections 8.2, 8.3, and 8.4.

8.5. The requirements for soundness given in Section 8.1 may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

9. METHODS OF SAMPLING AND TESTING

9.1. Sampling and testing of fine aggregate shall be in accordance with the following methods of the American Association of State Highway and Transportation Officials:

9.1.1. *Sampling*—T 2;

9.1.2. *Sieve Analysis and Fineness Modulus*—T 27;

9.1.3. *Clay Lumps and Friable Particles*—T 112;

9.1.4. *Lightweight Pieces in Aggregate*—T 113, using a liquid of 2.0 specific gravity to remove the particles of coal and lignite; only material that is brownish-black, or black, shall be considered coal or lignite; coke shall not be classed as coal or lignite.

9.1.5. *Materials Finer than 75 µm (No. 200)*—T 11;

9.1.6. *Organic Impurities*—T 21;

9.1.7. *Effect of Organic Impurities on Strength*—T 71;

9.1.8. *Sulfate Soundness*—T 104;

9.1.9. *Soundness (Unconfined Freezing and Thawing)*—T 103; and

9.1.10. *Freezing and Thawing of Concrete*—T 161.

SUPPLEMENTARY REQUIREMENT

The following supplementary requirement applies only when specifically stated in the order or contract.

S1. REACTIVE AGGREGATE

S1.1. *Potential Reactivity of Siliceous Aggregates*—Alkali-silica reactions shall be mitigated either by a performance specification as given in S1.1.1 or a prescriptive specification as given in S1.1.2:

S1.1.1. *Performance Type*—One of the following options shall be used:

S1.1.1.1. Obtain a service record of the aggregate in a service condition at least as severe as that in which it is intended to be used, with similar cementitious materials having similar alkali content. If satisfactory, no mitigation is necessary.

S1.1.1.2. Test the aggregate in accordance with T 303, ASTM C 1260, or ASTM C 1293. If the expansion is less than 0.10 percent at 14 days after initial reading when tested in accordance with T 303 or ASTM C 1260, or less than 0.04 percent at 1 year with ASTM C 1293, no mitigation is necessary.

S1.1.1.3. If reactive aggregates are used, testing shall be performed using the proposed materials (aggregates, cementitious, and supplementary materials) in proportions to be used on the project according to the selected test method(s). Selection of appropriate test methods to evaluate mitigation effectiveness shall be based on the procedure's ability to identify behavior of materials that correlate well with field performance. An example of a test that has been used to evaluate deleterious expansion and effectiveness of mitigation is T 303.

S1.1.1.4. If specified, T 303 test shall be used with the pozzolan or slag or blended cements to detect the potential for deleterious expansion. The test shall be performed by using 440 grams of the proposed blended cementitious materials, in the proportion to be used on the project, and 990 grams of the combined aggregates, in the proportions to be used on the project. For acceptance using T 303, the expansion shall not exceed 0.10 percent at 14 days.

S1.1.2. *Prescriptive Type*—Use of prescriptive methods may not be adequate to prevent Alkali-silica reactions for every combination of materials in all service environments. Limits and properties established in prescriptive methods utilized by an agency should be based on proven field performance of locally available materials. One of the following options shall be used:

S1.1.2.1. Select aggregates with proven field performance when similar cementitious materials having similar alkali content are used.

S1.1.2.2. Use varying percentage of pozzolan or slag for different levels of alkali content of cement.

S1.1.2.3. Use lithium salts at a dosage rate of 1:1 $LiOH.H_2O$: equivalent Na_2O in the portland cement.

APPENDIX

(Nonmandatory Information)

X1. METHODS FOR EVALUATING POTENTIAL REACTIVITY OF AN AGGREGATE

X1.1. A number of methods for detecting potential reactivity have been proposed. However, they do not provide quantitative information on the degree of reactivity to be expected or tolerated in service. Therefore, evaluation of potential reactivity of an aggregate should be based upon judgment and on the interpretation of test data and examination of concrete structures containing a combination of fine and coarse aggregates and cements for use in the new work. Results of the following tests will assist in making the evaluation:

X1.1.1. *ASTM C 295*—Certain materials are known to be reactive with the alkalies in cements. These include the following forms of silica: opal, chalcedony, tridymite, and cristobalite; intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite; and certain constituents of some phyllites. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. Some of these materials render an aggregate deleteriously reactive when present in quantities as little as 1.0 percent or even less.

X1.1.2. *ASTM C 289*—In this test, aggregates represented by points lying to the right of the solid line of Figure 2 of Method C 289 usually should be considered potentially reactive.

X1.1.2.1. If R_c exceeds 70, the aggregate is considered potentially reactive if S_c is greater than R_c.

X1.1.2.2. If R_c is less than 70, the aggregate is considered potentially reactive if S_c is greater than $35 + (R_c/2)$.

X1.1.2.3. These criteria conform to the solid line curve given in Figure 2 of Method C 289. The test can be made quickly and, while not completely reliable in all cases, can provide helpful information, especially where results of the more time-consuming tests are not available.

X1.1.3. *ASTM C 227*—The results of this test, when made with a high-alkali cement, furnish information on the likelihood of harmful reactions occurring. The alkali content of the cement should be substantially above 0.6 percent (preferably above 0.8 percent) expressed as sodium oxide. Combinations of aggregate and cement, which have produced excessive expansions in this test, usually should be considered potentially reactive. While the line of demarcation between nonreactive and reactive combinations is not clearly defined, expansion is generally considered to be excessive if it exceeds 0.05 percent at three months or 0.10 percent in six months. Expansions greater than 0.05 percent at three months should not be considered excessive where the six-month expansion remains below 0.10 percent. Data for the three-month tests should be considered only when six-month results are not available.

X1.1.3.1. In addition to its usefulness in research, this test method has been found useful in the selection of aggregates of the so-called “sand-gravel” type found mainly in some parts of Kansas, Nebraska, and Iowa, which contain very little coarse material, generally 5 to 15 percent retained on the 4.75-mm (No. 4) sieve. Much work has been done on the problems of using these aggregates successfully in concrete and is reported in summary in the “Final Report of Cooperative Tests of Proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate

Combinations," Appendix to *Committee C-9 Report*, Proceedings, ASTM, Volume 54, 1954, p. 356. It indicates that cement-aggregate combinations tested by this procedure in which expansion equals or exceeds 0.200 percent at an age of 1 year may be considered unsatisfactory for use in concrete exposed to wide variations of temperature and degree of saturation with water. In that geographical region, the problem has been reduced through the use of partial replacement of the "sand-gravel" with limestone coarse aggregate.

X1.1.4. *Potential Reactivity of Carbonate Aggregates*—The reaction of the dolomite in certain carbonate rocks with alkalies in hydraulic cement paste has been found to be associated with deleterious expansion of concrete containing such rocks as coarse aggregate. Carbonate rocks capable of such reaction possesses a characteristic texture and composition. The characteristic texture is that in which large crystals of dolomite are scattered in a finer-grained matrix of calcite and clay. The characteristic composition is that in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Except in certain areas, such rocks are of relatively infrequent occurrence and seldom make up a significant proportion of the material present in a deposit of rock being considered for use in making aggregate for concrete. ASTM C 586 has been successfully used in (1) research and (2) preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

Standard Specification for

Mineral Filler for Bituminous Paving Mixtures

AASHTO Designation: M 17-07
ASTM Designation: D 242-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Mineral Filler for Bituminous Paving Mixtures

AASHTO Designation: M 17-07

ASTM Designation: D 242-04

AASHTO M 17-07 is identical to ASTM D 242-04 except for the following provisions:

1. All references to the ASTM standards contained in ASTM D 242-04, listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standards

ASTM	AASHTO
C 183	T 127
D 546	T 37
D 4318	T 90

2. Add a new Section 4.3 after Section 4.2 that contains the following:

   "Fly ash used as a mineral filler shall have a maximum loss on ignition of 12 percent."

3. Add a new Section 5.5 after Section 5.4 that contains the following:

   "Determine the loss on ignition of fly ash according to ASTM C 311."

Standard Specification for

Fine Aggregate for Bituminous Paving Mixtures

AASHTO Designation: M 29-03 (2007)
ASTM Designation: D 1073-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Fine Aggregate for Bituminous Paving Mixtures

AASHTO Designation: M 29-03 (2007)

ASTM Designation: D 1073-06

1. SCOPE

1.1. This specification covers fine aggregate for use in bituminous paving mixtures.

1.2. This specification is intended to describe material from a single supplier. When material from two or more suppliers is to be blended to produce a grading to meet requirements as described in a specification for bituminous paving mixtures, the grading requirements of Table 1 of this specification need not apply.

Table 1—Grading Requirements for Fine Aggregates

	Amounts Finer Than Each Laboratory Sieve (Square Openings), Mass, %				
Sieve Size	Grading No. 1	Grading No. 2	Grading No. 3	Grading No. 4	Grading No. 5
9.5 mm ($^3/_8$ in.)	100	—	—	100	100
4.75 mm (No. 4)	95 to 100	100	100	80 to 100	80 to 100
2.36 mm (No. 8)	70 to 100	75 to 100	95 to 100	65 to 100	65 to 100
1.18 mm (No. 16)	40 to 80	50 to 74	85 to 100	40 to 80	40 to 80
600 μm (No. 30)	20 to 65	28 to 52	65 to 90	20 to 65	20 to 65
300 μm (No. 50)	7 to 40	8 to 30	30 to 60	7 to 40	7 to 46
150 μm (No. 100)	2 to 20	0 to 12	5 to 25	2 to 20	2 to 30
75 μm (No. 200)	0 to 10	0 to 5	0 to 5	0 to 10	—

1.3. The values stated in SI units are to be regarded as the standard. Inch-pound units, shown in parentheses, are for information only.

Note 1—When obtaining materials from two or more suppliers that do not meet the gradings in Table 1 and that are to be blended, it is recommended that the specifying or the ordering agency specify the alternative gradings to be supplied.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 89, Determining the Liquid Limit of Soils

- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- D 8, Standard Terminology Relating to Materials for Roads and Pavements
- D 3665, Standard Practice for Random Sampling of Construction Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. For definitions regarding aggregate types, see ASTM C 125 and D 8.

4. ORDERING INFORMATION

4.1. Orders for material under this specification shall include the following:

4.1.1. Reference to this specification, M 29, and year of issue;

4.1.2. Grading (Section 6.2 and Table 1), or alternate grading designated by the purchaser;

4.1.3. Supplementary requirement for sulfate soundness, if required, including salt to be used (Section S1); and

4.1.4. Any exceptions or additions to this specification.

5. GENERAL CHARACTERISTICS

5.1. Fine aggregate is aggregate passing the 9.5-mm ($^3/_8$-in.) sieve and almost entirely passing the 4.75-mm (No. 4) sieve. It shall consist of natural sand, or of sand prepared from stone, or of crushed blast-furnace slag, or gravel, or combinations thereof. It shall consist of hard, tough grains, free of injurious amounts of clay, loam, or other deleterious substances.

6. PHYSICAL REQUIREMENTS

6.1. To determine conformance to this specification, each value for grading (and sulfate soundness, when required) shall be rounded to the nearest 1 percent, and each value for plasticity index shall be rounded to 0.1 unit, both according to the rounding off method of ASTM E 29.

6.2. *Grading*—The grading of the fine aggregate shall conform to the grading in Table 1 for the grading number specified in the order, or other grading designated by the purchaser.

6.3. *Grading Variability Limits*—For continuing shipments of fine aggregate from a given source, the fineness modulus shall not vary more than 0.25 from the base fineness modulus. The base fineness modulus shall be that value that is typical of the source, and shall be determined from previous tests, or if no previous tests exist, from the average of the fineness modulus values for the first 10 samples (or all preceding samples if less than 10) on the order. If necessary, the base fineness modulus may be changed when approved by the purchaser.

Note 2—The proportioning of a bituminous mixture may be dependent on the base fineness modulus of the fine aggregate to be used. Therefore, when it appears that the base fineness modulus is considerably different from the value used in the bituminous mixture, a suitable adjustment in the mixture may be necessary.

6.4. *Plasticity Index*—The plasticity index of the fraction passing the 425-µm sieve (No. 40) shall not exceed 4.0.

7. METHODS OF SAMPLING AND TESTING

7.1. The aggregate shall be sampled and the properties enumerated in this specification shall be determined in accordance with the following methods:

7.1.1. *Sampling*—T 2;

7.1.2. *Random Sampling*—ASTM D 3665;

7.1.3. *Grading*—T 27 and T 11, Procedure B;

7.1.4. *Fineness Modulus*—T 27; and

7.1.5. *Plasticity Index*—T 89 and T 90.

8. KEYWORDS

8.1. Aggregate; bituminous paving; fine aggregate; paving mixtures.

SUPPLEMENTARY REQUIREMENT

The following supplementary requirement shall apply only when specified by the purchaser in the contract or order.

S1. SULFATE SOUNDNESS

S1.1. The fine aggregate, when subjected to five cycles of the soundness test according to T 104, shall have a weighted loss of not more than 15 percent when sodium sulfate is used or 20 percent when magnesium sulfate is used. If the salt to be used is not stated by the purchaser, the fine aggregate shall be acceptable if it meets the requirements when tested with either salt.

Standard Specification for

Sizes of Aggregate for Road and Bridge Construction

AASHTO Designation: M 43-05 (2009)[1]
ASTM Designation: D 448-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Sizes of Aggregate for Road and Bridge Construction

AASHTO Designation: M 43-05 (2009)[1]

ASTM Designation: D 448-08

1. SCOPE

1.1. This specification defines aggregate size designations and ranges in mechanical analyses for standard sizes of coarse aggregate and screenings for use in the construction and maintenance of various types of highways and bridges.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates

3. SIGNIFICANCE AND USE

3.1. Some contract documents specify certain aggregate sizes for specific uses or may suggest one or more of these sizes as appropriate for the preparation of various end-product mixtures. In some cases, closer limits on variability of the aggregate grading are required.

4. MANUFACTURE

4.1. The standard sizes of aggregate described in this classification are manufactured by means of any suitable process used to separate raw material into the desired size ranges. Production of standard sizes by blending two or more different components is also permitted.

5. STANDARD SIZES

5.1. Standard sizes of coarse aggregate shall comply with the sizes given in Table 1. All sizes shall be determined by means of laboratory sieves having square openings and conforming to M 92.

6. BASIS OF CLASSIFICATION

6.1. Classification is based upon the size number and size ranges shown in Table 1 with the aggregate sampled in accordance with T 2 and tested for grading by T 27.

Table 1—Standard Sizes of Processed Aggregate

Size Number	Nominal Size, Square Openings	Amounts Finer Than Each Laboratory Sieve (Square Openings), Mass, percent														
		100 mm (4 in.)	90 mm ($3^1/_2$ in.)	75 mm (3 in.)	63 mm ($2^1/_2$ in.)	50 mm (2 in.)	37.5 mm ($1^1/_2$ in.)	25.0 mm (1 in.)	19.0 mm ($^3/_4$ in.)	12.5 mm ($^1/_2$ in.)	9.5 mm ($^3/_8$ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No. 50)	150 µm (No. 100)
1	90 to 37.5 mm ($3\,^1/_2$ to $1\,^1/_2$ in.)	100	90 to 100	—	25 to 60	—	0 to 15	—	0 to 5	—	—	—	—	—	—	—
2	63 to 37.5 mm ($2\,^1/_2$ to $1\,^1/_2$ in.)	—	—	100	90 to 100	35 to 70	0 to 15	—	0 to 5	—	—	—	—	—	—	—
24	63 to 19.0 mm ($2\,^1/_2$ to $^3/_4$ in.)	—	—	100	90 to 100	—	25 to 60	—	0 to 10	0 to 5	—	—	—	—	—	—
3	50 to 25.0 mm (2 to 1 in.)	—	—	—	100	90 to 100	35 to 70	0 to 15	—	0 to 5	—	—	—	—	—	—
357	50 to 4.75 mm (2 in. to No. 4)	—	—	—	100	95 to 100	—	35 to 70	—	10 to 30	—	0 to 5	—	—	—	—
4	37.5 to 19.0 mm ($1\,^1/_2$ to $^3/_4$ in.)	—	—	—	—	100	90 to 100	20 to 55	0 to 15	—	0 to 5	—	—	—	—	—
467	37.5 to 4.75 mm ($1\,^1/_2$ to No. 4)	—	—	—	—	100	95 to 100	—	35 to 70	—	10 to 30	0 to 5	—	—	—	—
5	25.0 to 12.5 mm (1 to $^1/_2$ in.)	—	—	—	—	—	100	90 to 100	20 to 55	0 to 10	0 to 5	—	—	—	—	—
56	25.0 to 9.5 mm (1 to $^3/_8$ in.)	—	—	—	—	—	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	—	—	—	—
57	25.0 to 4.75 mm (1 to No. 4)	—	—	—	—	—	100	95 to 100	—	25 to 60	—	0 to 10	0 to 5	—	—	—
6	19.0 to 9.5 mm ($^3/_4$ to $^3/_8$ in.)	—	—	—	—	—	—	100	90 to 100	20 to 55	0 to 15	0 to 5	—	—	—	—
67	19.0 to 4.75 mm ($^3/_4$ to No. 4)	—	—	—	—	—	—	100	90 to 100	—	20 to 55	0 to 10	0 to 5	—	—	—
68	19.0 to 2.36 mm ($^3/_4$ to No. 8)	—	—	—	—	—	—	100	90 to 100	—	30 to 65	5 to 25	0 to 10	0 to 5	—	—
7	12.5 to 4.75 mm ($^1/_2$ to No. 4)	—	—	—	—	—	—	—	100	90 to 100	40 to 70	0 to 15	0 to 5	—	—	—
78	12.5 to 2.36 mm ($^1/_2$ to No. 8)	—	—	—	—	—	—	—	100	90 to 100	40 to 75	5 to 25	0 to 10	0 to 5	—	—
8	9.5 to 2.36 mm ($^3/_8$ to No. 8)	—	—	—	—	—	—	—	—	100	85 to 100	10 to 30	0 to 10	0 to 5	—	—
89	9.5 to 1.18 mm ($^3/_8$ to No. 16)	—	—	—	—	—	—	—	—	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5	—
9	4.75 to 1.18 mm (No. 4 to No. 16)	—	—	—	—	—	—	—	—	—	100	85 to 100	10 to 40	0 to 10	0 to 5	—
10	4.75 mm (No. 4 to 0)[a]	—	—	—	—	—	—	—	—	—	100	85 to 100	—	—	—	10 to 30

[a] Screening.

7. KEYWORDS

7.1. Coarse aggregate; standard sizes; classification.

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[1] This specification is technically equivalent to ASTM D 448-08.

Standard Specification for

Aggregate for Masonry Mortar

AASHTO Designation: M 45-06[1]
ASTM Designation: C 144-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Aggregate for Masonry Mortar

AASHTO Designation: M 45-06[1]
ASTM Designation: C 144-04

1. SCOPE

1.1. This specification covers aggregate for use in masonry mortar.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 6, Fine Aggregate for Hydraulic Cement Concrete
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 21, Organic Impurities in Fine Aggregates for Concrete
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 113, Lightweight Pieces in Aggregate

2.2. *ASTM Standard*:
- C 270, Standard Specification for Mortar for Unit Masonry

3. MATERIAL

3.1. Aggregate for use in masonry mortar shall consist of natural sand or manufactured sand. Manufactured sand is the product obtained by crushing stone, gravel, or air-cooled iron blast-furnace slag specially processed to ensure suitable particle shape as well as gradation.

4. GRADING

4.1. Aggregate for use in masonry mortar shall be graded within the following limits, depending upon whether natural sand or manufactured sand is to be used. (See Table 1.)

Table 1—Aggregate Grading Limits

	Percent Passing	
Sieve Size	Natural Sand	Manufactured Sand
4.75 mm (No. 4)	100	100
2.36 mm (No. 8)	95 to 100	95 to 100
1.18 mm (No. 16)	70 to 100	70 to 100
600 µm (No. 30)	40 to 75	40 to 75
300 µm (No. 50)	10 to 35	20 to 40
150 µm (No. 100)	2 to 15	10 to 25
75 µm (No. 200)	0 to 5	0 to 10

4.2. The aggregate shall not have more than 50 percent retained between any two consecutive sieves of those listed in Section 4.1 nor more than 25 percent between 300-µm (No. 50) and the 150-µm (No. 100) sieve.

4.3. If the fineness modulus varies by more than 0.20 from the value assumed in selecting proportions for the mortar, the aggregate shall be rejected unless suitable adjustments are made in proportions to compensate for the change in grading.

Note 1—For heavy construction employing joints thicker than 12.5 mm ($^1/_2$ in.), a coarser aggregate may be desirable. For such work a fine aggregate conforming to M 6 is satisfactory.

4.4. When an aggregate fails the gradation limits specified in Sections 4.1 and 4.2, it may be used provided the mortar can be prepared to comply with the aggregate ratio, water retention, air content, and compressive strength requirements of the property specifications of ASTM C 270.

5. COMPOSITION

5.1. *Deleterious Substances*—The amount of deleterious substances in aggregate for masonry mortar, each determined on independent samples complying with the grading requirements of Section 4 shall not exceed the following:

Item	Max Permissible Mass, percent
Clay lumps and friable particles	1.0
Lightweight particles, floating on liquid having a specific gravity of 2.0	0.5[a]

[a] This requirement does not apply to blast-furnace slag aggregate.

5.2. *Organic Impurities*:

5.2.1. The aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

5.2.2. Aggregate failing in the test may be used provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

5.2.3. Aggregate failing in the test may be used provided that, when tested for the effect of organic impurities on strength of mortar by T 71, the relative strength at seven days is not less than 95 percent.

6. SOUNDNESS

6.1. Except as herein provided, aggregate subjected to five cycles of the soundness test shall show a loss, weighted in accordance with the grading of a sample complying with the limitations set forth in Section 4, not greater than 10 percent when sodium sulfate is used or 15 percent when magnesium sulfate is used.

6.2. Aggregate failing to meet the requirements of Section 6.1 may be accepted, provided that mortar of comparable properties made from similar aggregates from the same source has been exposed to weathering, similar to that to be encountered, for a period of more than 5 years without appreciable disintegration.

7. METHODS OF SAMPLING AND TESTING

7.1. Sample and test the aggregate in accordance with the following procedures:

7.1.1. *Sampling*—T 2,

7.1.2. *Sieve Analysis and Fineness Modulus*—T 27,

7.1.3. *Amount of Material Finer Than 75-µm (No. 200) Sieve*—T 11,

7.1.4. *Organic Impurities*—T 21,

7.1.5. *Effect of Organic Impurities on Strength*—T 71,

7.1.6. *Clay Lumps and Friable Particles*—T 112,

7.1.7. *Lightweight Constituents*—T 113, and

7.1.8. *Soundness*—T 104.

7.1.9. *Density*—Determine the bulk specific gravity (oven dry basis) of the fine aggregate in accordance with T 84. The specific gravity equals the density expressed in units of g/cm^3. The density of the fine aggregate in g/cm^3 is used in the calculation of the air content of the mortars, as required by ASTM C 270.

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[1] Except for Sections 5.1 and 7.1.6, this specification is identical to ASTM C 144-04.

Standard Specification for

Coarse Aggregate for Hydraulic Cement Concrete

AASHTO Designation: M 80-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Coarse Aggregate for Hydraulic Cement Concrete

AASHTO Designation: M 80-08

1. SCOPE

1.1. This specification covers coarse aggregate, other than lightweight aggregate, for use in concrete. Several classes and gradings of coarse aggregate are described (Notes 1 and 2).

Note 1—This specification is regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, it may be either more or less restrictive than needed.

Note 2—Definitions of terms used in this specification may be found in ASTM C 125.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 43, Sizes of Aggregate for Road and Bridge Construction
- M 92, Wire-Cloth Sieves for Testing Purposes
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 113, Lightweight Pieces in Aggregate
- T 303, Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 227, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
- C 289, Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete

- C 586, Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock Cylinder Method)
- C 1260, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
- C 1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
- STP 169D, Significance of Tests and Properties of Concrete and Concrete-Making Materials

3. ORDERING INFORMATION

3.1. The purchaser or specifier shall include the following information in the purchase order or contract documents:

3.1.1. Reference to this specification, M 80, and year of issue;

3.1.2. Grading to be furnished (Size No.) (Section 5.1);

3.1.3. Class designation of aggregate (Section 6.1 and Table 2);

3.1.4. In the case of the sulfate soundness test (Table 2), which salt is to be used. If none is stated, either salt may be used;

3.1.5. Whether the restriction on reactive materials applies (Section 6.2); and

3.1.6. Any exceptions or additions to this specification.

4. GENERAL CHARACTERISTICS

4.1. Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, crushed air-cooled blast-furnace slag, or crushed concrete, or a combination thereof, conforming to the requirements of this specification.

5. GRADING

5.1. Coarse aggregates shall conform to the requirements prescribed in M 43 for the size number specified.

Note 3—The ranges shown in M 43 are by necessity very wide in order to accommodate nationwide conditions. For quality control of any specific operation, a producer should develop an average gradation for the particular source and production facilities, and control the gradation within reasonable tolerances from this average. Where coarse aggregate sizes numbers 357 or 467 are used, the aggregate should be furnished in at least two separate sizes.

6. DELETERIOUS SUBSTANCES AND PHYSICAL PROPERTIES

6.1. Coarse aggregates shall conform to the limits given in Table 2 for the class specified, except as provided in Section 6.3 (Notes 4 and 5).

Note 4—Aggregate conforming to the requirements for the various classes should generally be suitable for the following uses as shown in Table 1.

Note 5—The purchaser or specifier, due to his knowledge of the requirements for concrete aggregates for specific uses in specific areas, may wish to supplement the requirements of Table 2 by placing limits on the amount of local deleterious substances permitted.

Table 1—Typical Uses for Aggregate Conforming to the Requirements for the Various Classes

Typical Uses (Suggested)	Weathering Exposure	Class of Aggregate
Architectural concrete, bridge decks, other uses where surface disfigurement due to popouts, etc., is objectionable	Severe	A
	Moderate	B
	Negligible	C
Concrete pavements, base courses, sidewalks where a moderate number of popouts can be tolerated	Severe	B
	Moderate	C
	Negligible	D
Concealed concrete not exposed to the weather: footings, structural members to be covered by a facing material, interior floors, etc.	—	E

Table 2—Limits for Deleterious Substances and Physical Property Requirements of Coarse Aggregate for Concrete

	Maximum Allowable Percent						
Class Designation	Clay Lumps and Friable Particles	Chert (Less Than 2.40 sp gr SSD)[a]	Sum of Clay Lumps, Friable Particles, and Chert (Less Than 2.40 sp gr SSD)[a]	Material Finer Than 75-µm (No. 200) Sieve	Coal and Lignite	Abrasion[b]	Sodium Sulfate Soundness (5 Cycles)[c]
A	2.0	3.0	3.0	1.0[d]	0.5	50	12
B	3.0	3.0	5.0	1.0[d]	0.5	50	12
C	5.0	5.0	7.0	1.0[d]	0.5	50	12
D	5.0	8.0	10.0	1.0[d]	0.5	50	12
E	10.0	—	—	1.0[d]	1.0	50	—

[a] These limitations apply only to aggregate in which chert appears as an impurity. They are not applicable to gravels that are predominantly chert. Limitations on soundness of such aggregate must be based on service records in the environment in which they are used.

[b] Crushed air-cooled, blast-furnace slag is excluded from the abrasion requirements. The unit mass (by rodding or jigging) of crushed air-cooled blast-furnace slag shall be not less than 1120 kg/m^3 (70 lb/ft^3). The grading of slag used in the unit mass test shall conform to the grading to be used in the concrete. Abrasion loss of gravel, crushed gravel, or crushed stone shall be determined on the test size or sizes most nearly corresponding to the grading or gradings to be used in the concrete. When more than one grading is to be used, the limit on abrasion loss shall apply to each.

[c] The allowable limits for soundness shall be 18 percent if magnesium sulfate is used. If the salt to be used is not designated, the aggregate will be acceptable if it meets the indicated limit for either sodium sulfate or magnesium sulfate.

[d] In the case of crushed aggregates, if the material finer than the 75-µm (No. 200) sieve consists of the dust fraction, essentially free of clay or shale, this percentage may be increased to 1.5.

6.2. Coarse aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, the coarse aggregate may be used with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Supplementary Requirement S1 and Appendix X1.)

6.3. Coarse aggregate having test results exceeding the limits specified in Table 2 may be accepted provided that concrete made with similar aggregate from the same source has given satisfactory service when exposed in a similar manner to that to be encountered, or, in the absence of a demonstrable service record—provided that the aggregate produces concrete having satisfactory relevant properties when tested in the laboratory.

Note 6—Relevant properties are those properties of the concrete that are important to the particular application being considered. ASTM Special Technical Publication 169D provides a discussion of important concrete properties.

7. METHODS OF SAMPLING AND TESTING

7.1. Sample and test the aggregates in accordance with the following methods of the American Association of State Highway and Transportation Officials, except as otherwise provided in this specification. Make the required tests on test samples that comply with requirements of the designated test methods. The same test sample may be used for sieve analysis and for determination of material finer than the 75-µm (No. 200) sieve. Separated sizes from the sieve analysis may be used in preparation of samples for soundness or abrasion tests. For determination of all other tests and for evaluation of potential alkali reactivity where required, use independent test samples.

7.1.1. *Sampling*—T 2;

7.1.2. *Grading*—T 27;

7.1.3. *Amount of Material Finer than 75-µm (No. 200) Sieve*—T 11;

7.1.4. *Soundness*—T 104;

7.1.5. *Clay Lumps and Friable Particles*—T 112;

7.1.6. *Coal and Lignite*—T 113, using a liquid of 2.0 specific gravity to remove the particles of coal and lignite; only material that is brownish-black, or black, shall be considered coal or lignite; coke shall not be classed as coal or lignite;

7.1.7. *Unit Mass of Slag*—T 19M/T 19 using the procedure for unit mass by rodding or jigging; and

7.1.8. *Abrasion*—T 96.

SUPPLEMENTARY REQUIREMENT

The following supplementary requirement applies only when specifically stated in the order or contract.

S1. REACTIVE AGGREGATE

S1.1. *Potential Reactivity of Siliceous Aggregates*—Alkali-silica reactions shall be mitigated either by a performance specification as given in S1.1.1 or a prescriptive specification as given in S1.1.2:

S1.1.1. *Performance Type*—One of the following options shall be used:

S1.1.1.1. Obtain a service record of the aggregate in a service condition at least as severe as that in which it is intended to be used, with similar cementitious materials having similar alkali content. If satisfactory, no mitigation is necessary.

S1.1.1.2. Test the aggregate in accordance with T 303, ASTM C 1260, or ASTM C 1293. If the expansion is less than 0.10 percent at 14 days after initial reading when tested in accordance with T 303 or ASTM C 1260, or less than 0.04 percent at 1 year with ASTM C 1293, no mitigation is necessary.

S1.1.1.3. If reactive aggregates are used, testing shall be performed using the proposed materials (aggregates, cementitious, and supplementary materials) in proportions to be used on the project according to the selected test method(s). Selection of appropriate test methods to evaluate mitigation effectiveness shall be based on the procedure’s ability to identify behavior of materials that correlate well with field performance. An example of a test that has been used to evaluate deleterious expansion and effectiveness of mitigation is T 303.

S1.1.1.4. If specified, T 303 test shall be used with the pozzolan or slag or blended cements to detect the potential for deleterious expansion. The test shall be performed by using 440 grams of the proposed blended cementitious materials, in the proportion to be used on the project, and 990 grams of the combined aggregates, in the proportions to be used on the project. For acceptance using T 303, the expansion shall not exceed 0.10 percent at 14 days.

S1.1.2. *Prescriptive Type*—Use of prescriptive methods may not be adequate to prevent alkali-silica reactions for every combination of materials in all service environments. Limits and properties established in prescriptive methods utilized by an agency should be based on proven field performance of locally available materials. One of the following options shall be used:

S1.1.2.1. Select aggregates with proven field performance when similar cementitious materials having similar alkali content are used.

S1.1.2.2. Use varying percentage of pozzolan or slag for different levels of alkali content of cement.

S1.1.2.3. Use lithium salts at a dosage rate of 1:1 $LiOH.H_2O$: equivalent Na_2O in the portland cement.

APPENDIX

(Nonmandatory Information)

X1. METHODS FOR EVALUATING POTENTIAL REACTIVITY OF AN AGGREGATE

X1.1. A number of methods for detecting potential reactivity have been proposed. However, they do not provide quantitative information on the degree of reactivity to be expected or tolerated in service. Therefore, evaluation of potential reactivity of an aggregate should be based upon judgment and on the interpretation of test data and examination of concrete structures containing a combination of fine and coarse aggregates and cements for use in the new work. Results of the following tests will assist in making the evaluation:

X1.1.1. *ASTM C 295*—Certain materials are known to be reactive with the alkalies in cements. These include the following forms of silica: opal, chalcedony, tridymite, and cristobalite; intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite; and certain constituents of some phyllites. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. Some of these materials render an aggregate deleteriously reactive when present in quantities as little as 1.0 percent or even less.

X1.1.2. *ASTM C 289*—In this test, aggregates represented by points lying to the right of the solid line of Figure 2 of ASTM C 289 usually should be considered potentially reactive.

X1.1.2.1. If R_c exceeds 70, the aggregate is considered potentially reactive if S_c is greater than R_c.

X1.1.2.2. If R_c is less than 70, the aggregate is considered potentially reactive if S_c is greater than $35 + (R_c/2)$.

X1.1.2.3. These criteria conform to the solid line curve given in Figure 2 of ASTM C 289. The test can be made quickly and, while not completely reliable in all cases, can provide helpful information, especially where results of the more time-consuming tests are not available.

X1.1.3. *ASTM C 227*—The results of this test, when made with a high-alkali cement, furnish information on the likelihood of harmful reactions occurring. The alkali content of the cement should be substantially above 0.6 percent (preferably above 0.8 percent) expressed as sodium oxide. Combinations of aggregate and cement, which have produced excessive expansions in this test, usually should be considered potentially reactive. While the line of demarcation between nonreactive and reactive combinations is not clearly defined, expansion is generally considered to be excessive if it exceeds 0.05 percent at 3 months or 0.10 percent in 6 months. Expansions greater than 0.05 percent at 3 months should not be considered excessive where the 6-month expansion remains below 0.10 percent. Data for the 3-month tests should be considered only when 3-month results are not available.

X1.1.3.1. In addition to its usefulness in research, this test method has been found useful in the selection of aggregates of the so-called "sand-gravel" type found mainly in some parts of Kansas, Nebraska, and Iowa, which contain very little coarse material, generally 5 to 15 percent retained on the 4.75-mm (No. 4) sieve. Much work has been done on the problems of using these aggregates successfully in concrete and is reported in summary in the "Final Report of Cooperative Tests of Proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations," Appendix to *Committee C-9 Report*, Proceedings, ASTM, Volume 54, 1954, p. 356. It indicates that cement-aggregate combinations tested by this procedure in which expansion equals or exceeds 0.200 percent at an age of 1 year may be considered unsatisfactory for use in concrete exposed to wide variations of temperature and degree of saturation with water. In that geographical region, the problem has been reduced through the use of partial replacement of the "sand-gravel" with limestone coarse aggregate.

X1.2. *Potential Reactivity of Carbonate Aggregates*—The reaction of the dolomite in certain carbonate rocks with alkalies in portland cement paste has been found to be associated with deleterious expansion of concrete containing such rocks as coarse aggregate. Carbonate rocks capable of such reaction possesses a characteristic texture and composition. The characteristic texture is that in which large crystals of dolomite are scattered in a finer-grained matrix of calcite and clay. The characteristic composition is that in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Except in certain areas, such rocks are of relatively infrequent occurrence and seldom make up a significant proportion of the material present in a deposit of rock being considered for use in making aggregate for concrete. ASTM C 586 has been successfully used in (1) research and (2) preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

Standard Specification for

Lightweight Aggregates for Structural Concrete

AASHTO Designation: M 195-06
ASTM Designation: C 330-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Lightweight Aggregates for Structural Concrete

AASHTO Designation: M 195-06
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1. SCOPE

1.1. This specification covers lightweight aggregates intended for use in structural concrete in which the prime considerations are reducing the density while maintaining compressive strength of the concrete. Procedures covered in this specification are not intended for job control of concrete.

1.2. The values stated in SI units are to be regarded as the standard. The values shown in parentheses are for information purposes only.

1.2.1. With regard to other units of measure, the values stated in inch-pound units are to be regarded as standard.

1.3. The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

Note 1—This specification is regarded as adequate to ensure satisfactory lightweight aggregates for most concrete. It is recognized that it may be either more or less restrictive than needed for some conditions and for special purposes, such as fire resistance, fill, and concrete constructions, the use of which is based on load tests rather than conventional design procedures.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 2, Sampling of Aggregates
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 21, Organic Impurities in Fine Aggregates for Concrete
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 105, Chemical Analysis of Hydraulic Cement
- T 107, Autoclave Expansion of Hydraulic Cement
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete

- T 161, Resistance of Concrete to Rapid Freezing and Thawing
- T 198, Splitting Tensile Strength of Cylindrical Concrete Specimens
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- C 567, Standard Test Method for Determining Density of Structural Lightweight Concrete
- C 641, Standard Test Method for Iron Staining Materials in Lightweight Concrete Aggregates

2.3. *ACI Standard*:

- ACI 211.2, Standard Practice for Selecting Proportions for Structural Lightweight Concrete

3. GENERAL CHARACTERISTICS

3.1. Two general types of lightweight aggregates are covered by this specification, as follows:

3.1.1. Aggregates prepared by expanding, pelletizing or sintering products such as blast-furnace slag, clay, diatomite, fly ash, shale, or slate; and

3.1.2. Aggregates prepared by processing natural materials, such as pumice, scoria, or tuff.

3.2. The aggregates shall be composed predominately of lightweight-cellular and granular inorganic material.

4. CHEMICAL COMPOSITION

4.1. Lightweight aggregates shall not contain excessive amounts of deleterious substances, as determined by the following limits:

4.1.1. *Organic Impurities—T 21*. Lightweight aggregates that, upon being subjected to test for organic impurities, produce a color darker than the standard shall be rejected, unless it is demonstrated that the discoloration is due to small quantities of materials not harmful to the concrete.

4.1.2. *Staining—ASTM C 641*. An aggregate producing a heavy stain index 60 or higher shall be rejected when the deposited stain is found upon chemical analysis to contain an iron content, expressed as Fe_2O_3, equal to or greater than 1.5 mg/200 g of sample.

4.1.3. *Loss on Ignition—T 105*. The loss on ignition of lightweight aggregates shall not exceed 5 percent.

Note 2—Some aggregates may contain carbonates or water of hydration that contribute to loss on ignition, but may not affect the quality of the product. Therefore, when evaluating an aggregate, consideration should be given to the material characteristics that cause the ignition loss.

5. PHYSICAL PROPERTIES

5.1. Lightweight aggregate under test shall meet the following requirements:

5.1.1. *Clay Lumps and Friable Particles*—The total amount of clay lumps and friable particles shall not exceed 2 percent by dry mass.

5.1.2. *Grading*—The grading shall conform to the requirements shown in Table 1.

Table 1—Grading Requirements for Lightweight Aggregates for Structural Concrete

	Percentages (Mass) Passing Sieves Having Square Openings								
Nominal Size Designation	25.0 mm (1 in.)	19.0 mm ($^{3}/_{4}$ in.)	12.5 mm ($^{1}/_{2}$ in.)	9.5 mm ($^{3}/_{8}$ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No. 50)	150 µm (No. 100)
Fine aggregate:									
4.75 mm to 0	—	—	—	100	85–100	—	40–80	10–35	5–25
Coarse aggregate:									
25.0 to 4.75 mm	95–100	—	25–60	—	0–10	—	—	—	—
19.0 to 4.75 mm	100	90–100	—	10–50	0–15	—	—	—	—
12.5 to 4.75 mm	—	100	90–100	40–80	0–20	0–10	—	—	—
9.5 to 2.36 mm	—	—	100	80–100	5–40	0–20	0–10	—	—
Combined fine and coarse aggregate:									
12.5 mm to 0	—	100	95–100	—	50–80	—	—	5–20	2–15
9.5 mm to 0	—	—	100	90–100	65–90	35–65	—	10–25	5–15

Note 3—The surfaces of pyro-processed lightweight aggregate particles finer than 75-µm (No. 200) sieves are not deleterious and may be moderately pozzolanic.

5.1.3. *Uniformity of Grading*—To ensure reasonable uniformity in the grading of successive shipments of lightweight aggregate, fineness modulus shall be determined on samples taken from shipments at intervals stipulated by the purchaser. If the fineness modulus of the aggregate in any shipment differs by more than 7 percent from that of the sample submitted for acceptance tests, the aggregate in the shipment shall be rejected, unless the supplier demonstrates that it will produce concrete of the required characteristics.

5.1.4. *Bulk Density (Dry Loose)*—The dry loose bulk density of the lightweight aggregates shall conform to the requirements shown in Table 2.

Table 2—Maximum Dry Loose Bulk Density Requirements of Lightweight Aggregates for Structural Concrete

Size Designation	Maximum Dry Loose Bulk Density, kg/m^3 (lb/ft^3)
Fine aggregate	1120 (70)
Coarse aggregate	880 (55)
Combined fine and coarse aggregate	1040 (65)

5.1.5. *Uniformity of Bulk Density (Dry Loose)*—The dry loose bulk density of lightweight aggregate shipments, sampled and tested, shall not differ by more than 10 percent from that of the sample submitted for acceptance tests, but the dry loose bulk density shall not exceed the limits in Table 2.

5.1.6. *Density Factor*—When specified, the density factor shall be determined in accordance with Section 8.9.

5.2. Concrete specimens containing lightweight aggregate under test shall meet the following requirements:

5.2.1. *Compressive Strength—T 22, Density—ASTM C 567, and Splitting Tensile Strength—T 198*. Compressive strength and density shall be an average of three specimens and the splitting tensile strength shall be the average of eight specimens. It shall be possible to produce structural concrete using the lightweight aggregates under test, so that from the same batch of concrete one or more of the compressive strength requirements and splitting tensile strength requirements in the Table 3 will be satisfied without exceeding the corresponding maximum bulk density values.

Table 3—Compressive and Tensile Strength Requirements

Calculated Equilibrium Density, max kg/m^3 (lb/ft^3)	Average 28-day Splitting Tensile Strength, min MPa (psi)	Average 28-day Compressive Strength, min MPa (psi)
	All Lightweight Aggregate	
1760 (110)	2.2 (320)	28 (4000)
1680 (105)	2.1 (300)	21 (3000)
1600 (100)	2.0 (290)	17 (2500)
	Sand/Lightweight Aggregate	
1840 (115)	2.3 (330)	28 (4000)
1760 (110)	2.1 (310)	21 (3000)
1680 (105)	2.1 (300)	17 (2500)

Note 4—Intermediate values for strength and corresponding density values shall be established by interpolation. Materials that do not meet the minimum average splitting tensile strength requirement may be used provided the design is modified to compensate for the lower value.

5.2.2. *Natural Aggregates*—Natural aggregates, when used to replace part or all of the lightweight-aggregate fines, shall comply with the applicable requirements of M 6. The test report shall record the proportion of all ingredients and the characteristics of the natural aggregates to ensure compliance with these minimum requirements.

5.2.3. *Drying Shrinkage*—The drying shrinkage of concrete specimens prepared, cured, and tested in accordance with Section 8.4 shall not exceed 0.07 percent.

5.2.4. *Popouts*—Concrete specimens prepared as described in the method for preparation of sample for shrinkage of concrete and tested in accordance with T 107 shall show no surface popouts.

5.2.5. *Resistance to Freezing and Thawing*—When required, the aggregate supplier shall demonstrate by test or proven field performance that the lightweight aggregate when used in concrete, had the necessary resistance to freezing and thawing to perform satisfactorily in its intended use.

6. SAMPLING

6.1. Sample lightweight aggregates in accordance with T 2.

6.2. Reduce sample to test size in accordance with T 248.

7. NUMBER OF TESTS

7.1. *Tests on Aggregate*—One representative sample is required for each test for organic impurities, staining, loss on ignition, grading, bulk density, and clay lumps.

7.2. *Tests on Concrete*—At least three specimens are required for each of the following tests of concrete: compressive strength, shrinkage, density, resistance to freezing and thawing, and presence of popout materials. At least eight concrete specimens are required for splitting tensile strength tests.

8. TEST METHODS

8.1. *Compressive Strength—T 22*. Make test specimens in accordance with R 39. Unless otherwise specified, cure specimens in accordance with R 39 until the time of test. When specified, an alternative curing method is allowed. The alternative method shall be in accordance with R 39 for the first seven days, after which the specimens shall be removed from the moist curing and stored at 23 ± 2ºC (73.5 ± 3.5ºF) with a relative humidity of 50 ± 5 percent until the time of test.

8.2. *Splitting Tensile Strength*—Make 152 by 305 mm (6 by 12 in.) cylindrical test specimens in accordance with R 39, cure, and test in accordance with T 198.

8.3. *Density of Concrete—ASTM C 567*. Follow the procedures in ASTM C 567.

8.4. *Shrinkage of Concrete—T 160*. Follow the procedures of T 160 with the following exceptions:

8.4.1. Prepare the concrete mixture using 335 kilograms of cement per cubic meter (564 pounds of cement per cubic yard), admixture (if any), and with an air content of 6 ± 1 percent. Adjust the water content so as to produce a slump of 50 to 100 mm (2 to 4 in.). Thoroughly consolidate the concrete in steel molds not smaller than 50 by 50 mm (2 by 2 in.) nor larger than 100 by 100 mm (4 by 4 in.) in cross section, and long enough to provide a 250-mm (10-in.) gauge length. The surface of the concrete shall be steel troweled.

8.4.2. *Curing*—To prevent evaporation of water from the unhardened concrete, cover the specimen with a nonabsorptive, nonreactive plate or sheet of tough, durable, impervious plastic or wet burlap. When wet burlap is used for covering, the burlap must be kept wet until the specimens are removed from the molds. (See Note 5.) Remove specimens from the molds not less than 20 nor more than 48 hours after casting and store in a moist room maintained at 23 ± 2ºC (73.5 ± 3.5ºF) with a relative humidity of not less than 95 percent. At the age of seven days, remove the specimens from the moist room, measure for length, and store in a curing cabinet maintained at 37.8 ± 1.1ºC (100 ± 2ºF) with a relative humidity of 32 ± 2 percent.

Note 5—Placing a sheet of plastic over the burlap will facilitate keeping it wet.

Note 6—The air immediately above a saturated solution of magnesium chloride ($MgCl_2$) at 37.8ºC (100ºF) is approximately 32 percent relative humidity.

8.4.3. *Report*—After storage in the cabinet for 28 days, determine the change in length of each specimen to the nearest 0.01 percent of the effective gauge length. Report the change in length as the drying shrinkage of the specimen; report the average drying shrinkage of the specimens as the drying shrinkage of the concrete.

8.5. *Test for Popout Materials*—Prepare concrete specimens for the test for popout materials as described in method for preparation of samples for shrinkage of concrete. Cure and autoclave the specimens in accordance with T 107. Visually inspect the autoclaved specimens for the number of popouts that have developed on the surface. Report the average number of popouts per specimen.

8.6. *Test for Freezing and Thawing*—Make freezing and thawing tests of concrete, when required, in accordance with T 161, with the following modification to the section on Test Specimens and on Procedure. Unless otherwise specified, remove the lightweight aggregate concrete specimens from moist curing at an age of 14 days and allow to air dry for another 14 days exposed to a relative humidity of 50 ± 5 percent and a temperature of 23 ± 2ºC (73.5 ± 3.5ºF). Then submerge the specimens in water for 24 hours, prior to the freezing and thawing test.

Table 4—Mass of Sieve Test Sample for Fine Lightweight Aggregates

Nominal Bulk Density (Loose) of Aggregate		Mass of Test Sample, g
kg/m^3	lb/ft^3	
80–240	5–15	50
240–400	15–25	100
400–560	25–35	150
560–720	35–45	200
720–880	45–55	250
880–1040	55–65	300
1040–1120	65–70	350

8.7. *Bulk Density (Loose)—T 19M/T 19.* The aggregate shall be tested in an oven dry condition utilizing the shoveling procedure.

8.8. *Clay Lumps and Friable Particles in Aggregates*—Shall be in accordance with T 112.

8.9. *Density Factor*—Determine the Density (“Specific Gravity”) Factor in accordance with ACI 211.2.

9. REJECTION

9.1. Material that fails to conform to the requirements of this specification shall be subject to rejection. Rejection shall be reported to the producer or supplier promptly and in writing.

10. CERTIFICATION

10.1. When specified in the purchase order or contract, a producer’s or supplier’s certification shall be furnished to the purchaser that the material was manufactured, sampled, and tested in accordance with this specification and has been found to meet the requirements. When specified in the purchase order or contract, a report of the test results shall be furnished.

Standard Specification for

Processing Additions for Use in the Manufacture of Hydraulic Cements

AASHTO Designation: M 327-09
ASTM Designation: C 465-99 (2005)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Processing Additions for Use in the Manufacture of Hydraulic Cements

AASHTO Designation: M 327-09
ASTM Designation: C 465-99 (2005)

1. SCOPE

1.1. This specification pertains to the criteria and tests to be used for determining whether an organic or inorganic processing addition, when used in the recommended amount at the option of the cement producer in the manufacture of hydraulic cements, meets the requirements as prescribed by definition in M 85 and M 240 as well as ASTM C 1157 and C 845. The materials listed in the following former AASHTO and ASTM specifications shall be considered as meeting the organic processing additions requirements of this specification:

- M 85-57 I, for Portland Cement
- ASTM C 205-58 T, for Portland Blast-Furnace Slag Cement
- ASTM C 340-58 T, for Portland-Pozzolan Cement
- ASTM C 358-58, for Slag Cement

1.2. *The following safety hazards caveat pertains only to the test methods described in this specification. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 85-57 I, for Portland Cement
- M 240, Blended Hydraulic Cements
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 97, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- T 98, Fineness of Portland Cement by the Turbidimeter
- T 105, Chemical Analysis of Hydraulic Cement
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 107, Autoclave Expansion of Hydraulic Cement
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

- T 129, Normal Consistency of Hydraulic Cement
- T 131, Time of Setting of Hydraulic Cement by Vicat Needle
- T 133, Density of Hydraulic Cement
- T 137, Air Content of Hydraulic Cement Mortar
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 153, Fineness of Hydraulic Cement by Air Permeability Apparatus
- T 177, Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
- T 231, Capping Cylindrical Concrete Specimens

2.2. *ASTM Standards:*

- C 205-58 T, Specification for Portland Blast-Furnace Slag Cement
- C 226, Standard Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Hydraulic Cement
- C 340-58 T, Specification for Portland-Pozzolan Cement
- C 358-58, Specification for Slag Cement
- C 596, Standard Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement
- C 845, Standard Specification for Expansive Hydraulic Cement
- C 1157, Standard Performance Specification for Hydraulic Cement
- D 891, Standard Test Methods for Specific Gravity, Apparent, of Liquid Industrial Chemicals
- E 203, Standard Test Method for Water Using Volumetric Karl Fischer Titration

3. MATERIALS

3.1. *Cements:*

3.1.1. In cases where it is desired that the proposed organic processing addition be accepted for general use in portland cement, tests shall be made on cements prepared from at least five different clinkers. As a minimum, these clinkers shall represent two Type I cements containing not less than 9.0 percent C_3A, one Type II cement, and two Type III cements, all conforming to M 85.

3.1.2. In cases where it is also desired that the proposed organic processing addition be used in blended cements, the test and test procedures shall be as specified with a control and an addition for cement conforming to the appropriate M 240 or ASTM C 1157.

3.1.3. Organic processing additions that have been shown to meet the requirements of this specification may also be used in cements conforming to ASTM C 845. Testing of the addition with these special cements, where desired, shall be done using the tests and test procedures as specified with a control cement and a cement containing the addition, both conforming to ASTM C 845.

3.1.4. In cases where it is desired that the proposed organic processing addition be limited in use to specific types of cement less in number than required in 3.1.1, the tests and test procedures shall be as specified, and at least two pairs of cements shall be prepared from two clinkers from different plants for each type under specific consideration.

3.1.5. For inorganic processing additions, or in cases where it is desired that the proposed organic processing addition be limited in use to a single plant, the tests and test procedures shall be as specified and at least two pairs of cements shall be prepared from clinkers representing each type under specific consideration.

3.1.6. The two companion cements to be made from any one clinker shall be ground to the same fineness within 7 m^2/kg when tested in accordance with T 98 or within 13 m^2/kg when tested in accordance with T 153, and the SO_3 content, expressed as a percentage of the cement mass and reported to the nearest 0.01 percent, shall differ by not more than 0.3, so as to afford comparable samples for indicating the effect of the addition on the cement. Each control cement shall comply with all requirements in the specification applicable to that type of cement, and shall not contain the proposed addition when tested by the method furnished by the producer or seller of the addition.

3.1.7. The percentage of each of the following shall be determined for each lot of cement tested: silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), sulfur trioxide (SO_3), ignition loss, insoluble residue, sodium oxide (Na_2O), and potassium oxide (K_2O). There shall also be calculated the potential percentages of the following compounds: tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite. Determinations for the percentage of the addition shall be made, both on the control cements and on those with which the addition was interground, using the method proposed therefore by the sponsor.

3.2. *Aggregates*—The fine and coarse aggregates shall comply with M 6 and M 80; the coarse aggregate shall comply with the grading requirements for Size No. 57 or Size No. 67. A sufficient quantity from a single lot of coarse aggregate and from a single lot of fine aggregate shall be provided to complete all tests. To prevent the segregation of particle sizes in the fine aggregate, a single lot of sand sufficient for all tests shall either (1) be separated on the 4.75-mm (No. 4), 1.18-mm (No. 16), 300-µm (No. 50), and 150-µm (No. 100) sieves and then be recombined in the required quantity for each batch; or (2) be blended while in a damp condition, and maintained in that condition for the duration of the tests. Under option (2), lots of appropriate size for single mortar and concrete batches shall be carefully split or quartered from the entire batch.

4. GENERAL REQUIREMENTS

4.1. Processing additions shall conform to the respective requirements in this specification.

4.2. The trade name, source, character of the material, and means for the quantitative determination of the addition in the finished cement shall be furnished by the sponsor, manufacturer, or supplier of the addition, and the information shall form a part of the record of tests of the addition. If the processing addition is a liquid, the specific gravity and percent water content shall also be part of the record. If the processing addition is an inorganic solid, the allowable ranges of chemical analysis and specific gravity of the addition shall also be part of the record.

4.2.1. The specific gravity, run in accordance with Section 7.1.1 shall be within ±0.05 units of the value reported in Section 4.2.

4.2.2. The chemical analysis in Section 7.2.1 and specific gravity in Section 7.2.2 shall be within the ranges given in Section 4.2.

4.3. Processing additions shall be evaluated by comparing cements containing the addition to otherwise identical cements from the same source without the addition, or containing one processing addition that has been shown to comply with this specification using control cements without any additions, hereinafter designated the “control” cement.

4.4. The amount of the processing addition to be interground with the cement for evaluation purposes shall be determined by the sponsor of the addition.

4.4.1. The amount of the addition in the cement containing the addition and showing compliance with the requirements of this specification shall be determined quantitatively by means of the quantitative determination required by Section 4.2.

4.4.2. The amount of addition, so determined, shall be used to state the amount of addition that shows compliance with this specification.

4.4.3. When tests on cements containing the addition show compliance with the requirements of this specification, the addition in cement may be used in any amount up to the maximum amount showing compliance.

4.5. The cement produced for evaluation purposes with the processing addition shall comply with the appropriate specifications M 85 or M 240 and ASTM C 845 or C 1157, except that it contains the addition under test. The effect of the addition on the properties of the cement shall also be within the following limits:

4.5.1. The percentage of water by mass of cement required for normal consistency of cement containing the addition shall not exceed that required by the corresponding control cement by more than 1.0 percent. For those cements not limited to a fixed water requirement, the percentage of water by mass of cement required for standard consistency of the mortar used for strength determinations as described in Section 4.5.4 shall not be increased by more than 2.0 percent by the addition over that required for the control cement.

4.5.2. The time of setting of cement containing the addition shall not vary from the time of setting of the corresponding control cement by more than 1 h or 50 percent, whichever is the lesser.

4.5.3. The autoclave expansion of cement containing the addition, expressed as a percentage change in length, shall not be more than 0.10 percent greater than that of the corresponding control cement.

4.5.4. The compressive strength of mortar cubes made with cement containing the addition, in accordance with T 106M/T 106, and tested at 1, 3, 7, and 28 days for all types, shall be compared with strengths obtained with the control cement at similar ages. The grand average of these individual strength percentages shall not be less than 95 percent of the control cement values. It is required that cubes for companion cements be made and tested on the same days, with storage of specimens side by side in the same section of the moist cabinet during the 24-h curing period. Retesting of companion cements on the same, or a following, day is required in order to provide six, rather than three, test specimens for each cement and age of test.

4.5.5. The ultimate drying shrinkage of mortar made with cement containing the addition shall not be more than 0.025 percent greater than that of similar mortar made with the corresponding control cement when tested in accordance with ASTM C 596.

4.5.6. The compressive strength of the concrete made with cement containing the addition shall be compared with strengths obtained with the control cement at similar ages. The grand average of these individual strength percentages shall not be less than 90 percent of the values for the control cement.

4.5.7. The flexural strength of concrete made with cement containing the addition shall be compared with strengths obtained with the control cement at similar ages. The grand average of these individual strength percentages shall not be less than 90 percent of the values for the control cement.

4.5.8. The amount of air-entraining addition required to produce 19 ± 3 percent air in the mortar test made in accordance with T 137, with the cement containing the addition under test, shall not be greater than 120 percent of the amount required to produce, within ±1 percent, the air content obtained with the control cement. The air-entraining addition used shall meet the requirements of ASTM C 226.

4.6. Processing additions that provide maximum effects as grinding aids or pack set inhibitors may increase cement flowability to a point where mill retention time is reduced sufficiently to affect significantly the particle size distribution of the resulting cement and its physical-chemical properties. Mill retention times are controllable by mechanical means in full-scale grinding mills. Hence, the true physical-chemical effects of the test additive may be determined for acceptance purposes by making supplementary laboratory or pilot-mill grinds in instances where full-scale tests have shown mill retention time reductions to have significant effects on the properties of the resulting cement.

4.7. In the event that the effect of the addition on the properties of cement are determined on the basis of laboratory or pilot mill grinds, this fact shall be entered in the report specified in Section 13, and the specific tests shall be indicated.

5. SAMPLING CEMENT

5.1. Samples of the plant-ground cement shall be taken from the product stream during grinding. Prior to the start of sampling a given lot of cement, the mill shall have run for 4 h or long enough to have reached equilibrium under the general conditions that are to govern during the sampling period.

Note 1—Records should be kept as to the rate and continuity of feed of the addition, the form in which the addition is used, strength of solution (if applicable), magnitude of circulating loads, mill discharge temperature, and feed rate of clinker and gypsum. Product fineness should be determined during the grinding immediately subsequent to sampling.

5.2. As the cement samples are taken, they shall be placed in sealable containers that shall be sealed immediately at the end of the sampling period. Prior to use, the samples of a given lot of cement shall be thoroughly blended to form a uniform, representative composite.

6. TEST METHODS

6.1. Determine the properties enumerated in this specification in accordance with the test methods prescribed in Sections 7–12.

7. TESTS ON PROCESSING ADDITIONS

7.1. Test the liquid, organic processing addition, in the form normally marketed, in accordance with the following test methods:

7.1.1. *Specific Gravity*—Use ASTM D 891, Test Method A or B.

7.1.2. *Water Content*—Use ASTM E 203.

7.2. Conduct the following tests on solid, inorganic processing addition in accordance with the following test methods:

7.2.1. *Chemical Analysis*—Use T 105 to determine silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), sulfur trioxide (SO_3), ignition loss, insoluble residue, sodium oxide (Na_2O), and potassium oxide (K_2O).

7.2.2. *Specific Gravity*—Use T 133 except use the inorganic processing addition instead of hydraulic cement.

8. TESTS ON CEMENT

8.1. Test cement in accordance with the following standards:

8.1.1. *Chemical Analysis of Cement*—T 105.

8.1.2. *Compound Composition*—M 85.

8.1.3. *Fineness of Cement*—T 98 or T 153.

8.1.4. *Normal Consistency*—T 129.

8.1.5. *Time of Setting (Vicat)*—T 131.

8.1.6. *Autoclave Expansion*—T 107.

8.1.7. *Air Content of Mortar*—T 137.

8.1.8. *Compressive Strength of Mortar*—T 106M/T 106.

8.1.9. *Drying Shrinkage of Mortar*—ASTM C 596.

9. CONCRETE MIXTURES

9.1. *Preparation and Weighing*—Prepare all materials used in making the concrete mixtures and make all weighings as prescribed in R 39. Report the amount of mixing water used in each batch on the basis of saturated, surface-dry aggregates.

9.2. *Proportions*—Design one basic concrete mixture having an actual cement content of 307 ± 3 kg/m^3 (517 ± 5 lb/yd^3), and use in all concrete tests herein specified. Adjust the water content of mixtures to provide concrete having a consistency equal to a 64 ± 13-mm ($2^1/_2 \pm {}^1/_2$-in.) slump in each case. Adjust the ratio of fine to coarse aggregate to the optimum for concrete to be consolidated by hand rodding. Recommended trial values for the percentage of fine aggregate in the total aggregate, by absolute volume, are as follows:

Coarse Aggregate, Max 25.0 mm (1 in.)	Concrete Without Entrained Air
Angular	45
Rounded	40

9.3. *Mixing of Concrete*—Mix the concrete in accordance with R 39 except as follows:

9.3.1. Hand mixing will not be permitted.

9.3.2. The rated capacity of the machine mixer shall not be more than twice the size of the batch used.

10. TESTS ON FRESHLY MIXED CONCRETE

10.1. Test samples of the freshly mixed concrete for slump in accordance with T 119; unit weight in accordance with T 121M/T 121; and air content in accordance with T 121M/T 121, T 152, or T 196M/T 196.

11. TEST SPECIMENS OF HARDENED CONCRETE

11.1. *Number of Specimens*—At least three specimens shall be made for each test condition. For each cement containing an addition and its companion control cement, make three rounds of concrete mixed on different days. One round of mixes on a given day shall include both the cement containing the addition and its companion control cement. From each round, make at least one test specimen for each test condition. To obtain enough concrete for all test specimens to be made in any one round, it may be necessary to make more than one concrete batch for each round.

11.2. *Types of Specimens:*

11.2.1. *Compressive Strength*—Compressive strength test specimens shall be cylinders made and cured as prescribed in R 39. Cylinders shall be capped as prescribed in T 231.

11.2.2. *Flexural Strength*—Flexural strength test specimens shall be beams made and cured as prescribed in R 39.

12. TESTS ON HARDENED CONCRETE

12.1. Test the specimens on hardened concrete, as specified in Section 11, in accordance with the following methods and at the specified ages:

12.1.1. *Compressive Strength*—Test specimens in accordance with T 22 at ages 3, 7, and 28 days, except also test Type III cement at 24 h.

12.1.2. Flexural Strength—Test specimens in accordance with T 177 or T 97, ages at 3, 7, and 28 days, except also test Type III cement at 24 h. By either method of test, turn the specimen on its side with respect to its position as molded and center it on the bearing blocks.

13. REPORT

13.1. The report covering the results of the evaluation of a material proposed for use as a processing addition in the manufacture of portland cement under this specification shall include the following information:

13.1.1. Trade name, source and character of the material, and the amount recommended for use, together with the means used for determining the amount of the proposed addition in the finished cement, all as furnished by the sponsor, manufacturer, or seller of the addition;

13.1.2. If the proposed processing addition is an organic liquid, the specific gravity and percent water content by mass;

13.1.3. If the proposed processing addition is an inorganic solid, report chemical analysis and specific gravity;

13.1.4. Detailed results of all analyses and tests prescribed by this specification, and the amount of the addition used, as well as other pertinent information required;

13.1.5. Comparison of test results to determine compliance with the requirements prescribed in Section 4.4;

13.1.6. Name and location of the laboratory or laboratories that made the tests covered by the report;

13.1.7. Include, as an appendix to the report, letters of certification from the various cement manufacturers stating the name of the addition, the amount used, and the type of cement in which it is used; and

13.1.8. The highest amount of addition that has demonstrated compliance with the specification in a particular type of cement (see Section 4.4.3).

14. MANUFACTURER’S CERTIFICATION PROCESSING ADDITIONS

14.1. *Organic Processing Additions*—Upon request of the purchaser in the contract or order, a manufacturer's report shall be furnished at the time of shipment stating the water content and specific gravity of the samples of the material taken during production or transfer and certifying that the specific gravity value is within the specified limits of the originally qualified product and that the product meets the requirements of this specification.

14.2. *Inorganic Processing Additions*—Upon request of the purchaser in the contract or order, a manufacturer’s report shall be furnished at time of shipment stating the chemical analysis and specific gravity of the samples of the material taken during production or transfer and certifying that they are within the specified limits of the originally qualified product and that the product meets the requirements of this specification.

15. KEYWORDS

15.1. Additions; hydraulic cements; processing.

Standard Specification for

Cutback Asphalt (Rapid-Curing Type)

AASHTO Designation: M 81-92 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Cutback Asphalt (Rapid-Curing Type)

AASHTO Designation: M 81-92 (2008)

1. SCOPE

1.1 This specification covers liquid petroleum products, produced by fluxing an asphalt base with suitable petroleum distillates, to be used in the treatment of road surfaces.

1.2 The values stated in SI units are to be regarded as the standard.

2. GENERAL REQUIREMENTS

2.1 The cutback asphalt shall show no separation or curdling prior to use and shall not foam when heated to the application temperature.

3. PROPERTIES

3.1 Cutback asphalt of the grade designated shall conform to the requirements shown in Table 1.

4. METHODS OF SAMPLING AND TESTING

4.1 Sampling and testing cutback asphalt (rapid-curing type) shall be in accordance with the following AASHTO standards:

- T 40, Sampling Bituminous Materials
- T 44, Solubility of Bituminous Materials
- T 49, Penetration of Bituminous Materials
- T 51, Ductility of Asphalt Materials
- T 55, Water in Petroleum Products and Bituminous Materials by Distillation
- T 72, Saybolt Viscosity
- T 78, Distillation of Cutback Asphaltic (Bituminous) Products
- T 79, Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93.3ºC (200ºF)
- T 102, Spot Test of Asphaltic Materials
- T 201, Kinematic Viscosity of Asphalts (Bitumens)
- T 202, Viscosity of Asphalts by Vacuum Capillary Viscometer

Table 1—Minimum and Maximum Cutback Asphalt Grade Requirements

	RC-70		RC-250		RC-800		RC-3000	
	Min	Max	Min	Max	Min	Max	Min	Max
Kinematic viscosity at 60˚C (140˚F),								
mm^2/s[a]	70	140	250	500	800	1600	3000	6000
Flash point (tag open-cup), degrees °C (°F)	—	—	27 (80)	—	27 (80)	—	27(80)	—
Water, percent	—	0.2	—	0.2	—	0.2	—	0.2
Distillation test:								
Distillation, percentage by volume of total								
distillate to 360˚C (680˚F)								
to 190˚C (374˚F)	10	—	—	—	—	—	—	—
to 225˚C (437˚F)	50	—	35	—	15	—	—	—
to 260˚C (500˚F)	70	—	60	—	45	—	25	—
to 315˚C (600˚F)	85	—	80	—	75	—	70	—
Residue from distillation to 360˚C (680˚F),				—				
volume percentage of sample by difference	55	—	65	—	75	—	80	—
Tests on residue from distillation:								
Absolute viscosity at 60˚C (140˚F),	60	240	60	240	60	240	60	240
Pa·s (P)[b]	(600)	(2400)	(600)	(2400)	(600)	(2400)	(600)	(2400)
Ductility, 5 cm/min at 25˚C (77˚F), cm	100	—	100	—	100	—	100	—
Solubility in Trichloroethylene, percent	99.0	—	99.0	—	99.0	—	99.0	—
Spot test[c] with:								
Standard naphtha	Negative for all grades							
Naphtha-xylene solvent, percent xylene	Negative for all grades							
Heptane-xylene solvent, percent xylene	Negative for all grades							

[a] As an alternate, Saybolt-Furol viscosities may be specified as follows:
Grade RC-70–Furol viscosity at 50˚C (122˚F)—60 to 120 s.
Grade RC-250–Furol viscosity at 60˚C (140˚F)—125 to 250 s.
Grade RC-800–Furol viscosity at 82.2˚C (180˚F)—100 to 200 s.
Grade RC-3000–Furol viscosity at 82.2˚C (180˚F)—300 to 600 s.

[b] In lieu of viscosity of the residue, the specifying agency, at its option, can specify penetration at 100 g, 5 s at 25˚C (77˚F) of 80 to 120 for Grades RC-70, RC-250, RC-800, and RC-3000. However, in no case will both viscosity and penetration be required.

[c] The use of the spot test is optional. When specified, indicate whether the standard naphtha solvent, naphtha-xylene solvent, or heptane-xylene solvent will be used in determining compliance with the requirement, and also, in the case of the xylene solvents, the percentage of xylene to be used.

Standard Specification for

Cutback Asphalt (Medium-Curing Type)

AASHTO Designation: M 82-75 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Cutback Asphalt (Medium-Curing Type)

AASHTO Designation: M 82-75 (2008)

1. SCOPE

1.1 This specification covers liquid petroleum products, produced by fluxing an asphaltic base with suitable petroleum distillates, to be used in the treatment of road surfaces.

1.2 The values stated in SI units are to be regarded as the standard.

2. GENERAL REQUIREMENTS

2.1 The cutback asphalt shall show no separation or curdling prior to use and shall not foam when heated to the application temperature.

3. PROPERTIES

3.1 Cutback asphalt of the grade designated shall conform to the requirements shown in Table 1.

4. METHODS OF SAMPLING AND TESTING

4.1 Sampling and testing cutback asphalt (medium-curing type) shall be in accordance with the following standard methods of the AASHTO standards:

- T 40, Sampling Bituminous Materials
- T 44, Solubility of Bituminous Materials
- T 49, Penetration of Bituminous Materials
- T 51, Ductility of Asphalt Materials
- T 55, Water in Petroleum Products and Bituminous Materials by Distillation
- T 72, Saybolt Viscosity
- T 78, Distillation of Cutback Asphaltic (Bituminous) Products
- T 79, Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93.3°C (200°F)
- T 102, Spot Test of Asphaltic Materials
- T 201, Kinematic Viscosity of Asphalts (Bitumens)
- T 202, Viscosity of Asphalts by Vacuum Capillary Viscometer

Table 1—Minimum and Maximum Cutback Asphalt Grade Requirements

	MC-30		MC-70		MC-250		MC-800		MC-3000	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Kinematic viscosity at 60˚C (140˚F)										
mm^2/s^a	30	60	70	140	250	500	800	1600	3000	6000
Flash point (tag open-cup),	38	—	38	—	66	—	66	—	66	—
°C (°F)	(100)		(100)		(150)		(150)		(150)	
Water, percent	—	0.2	—	0.2	—	0.2	—	0.2	—	0.2
Distillation test:										
Distillation, percentage by volume of total distillate to 360˚C (680˚F)										
to 225˚C (437˚F)	—	25	0	20	0	10	—	—	—	—
to 260˚C (500˚F)	40	70	20	60	15	55	0	35	0	15
to 315˚C (600˚F)	75	93	65	90	60	87	45	80	15	75
Residue from distillation to 360˚C (680˚F),										
volume percentage of sample by difference	50	—	55	—	67	—	75	—	80	—
Tests on residue from distillation:										
Absolute viscosity at 60˚C (140˚F) Pa·s (P)[b]	30	120	30	120	30	120	30	120	30	120
	(300)	(1200)	(300)	(1200)	(300)	(1200)	(300)	(1200)	(300)	(1200)
Ductility, 5 cm/min, cm[c]	100	—	100	—	100	—	100	—	100	—
Solubility in trichloroethylene, percent	99.0	—	99.0	—	99.0	—	99.0	—	99.0	—
Spot test[d] with:										
Standard naphtha	Negative for all grades									
Naphtha-xylene solvent, percent xylene	Negative for all grades									
Heptane-xylene solvent, percent xylene	Negative for all grades									

[a] As an alternate, Saybolt-Furol viscosities may be specified as follows:
Grade MC-30–Furol viscosity at 25°C (77°F)—75 to 150 s.
Grade MC-70–Furol viscosity at 50˚C (122˚F)—60 to 120 s.
Grade MC-250–Furol viscosity at 60˚C (140˚F)—125 to 250 s.
Grade MC-800–Furol viscosity at 82.2˚C (180˚F)—100 to 200 s.
Grade MC-3000–Furol viscosity at 82.2˚C (180˚F)—300 to 600 s.

[b] In lieu of viscosity of the residue, the specifying agency, at its option, can specify penetration at 100 g, 5 s at 25˚C (77˚F) of 120 to 250 for Grades MC-30, MC-70, MC-250, MC-800, and MC-3000. However, in no case will both viscosity and penetration be required.

[c] If the ductility at 25˚C (77˚F) is less than 100, the material will be acceptable if its ductility at 15.5˚C (60˚F) is more than 100.

[d] The use of the spot test is optional. When specified, indicate whether the standard naphtha solvent, naphtha-xylene solvent, or heptane-xylene solvent will be used in determining compliance with the requirement, and also, in the case of the xylene solvents, the percentage of xylene to be used.

Standard Specification for

Emulsified Asphalt

AASHTO Designation: M 140-08
ASTM Designation: D 977-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Emulsified Asphalt

AASHTO Designation: M 140-08
ASTM Designation: D 977-05

AASHTO M 140-08 is identical to ASTM D 977-05 except for the following provisions:

1. All references to the ASTM standards listed in the following table shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO
D 140	T 40
D 244	T 59

2. Add the following to Section 2:

   2.2 *AASHTO Standard*:

   R 5, Selection and Use of Emulsified Asphalts

3. Replace Section 3.1 with the following:

   3.1 Within 30 days after delivery and provided separation has not been caused by freezing, the emulsified asphalt shall be homogeneous after thorough mixing.

4. Add the following footnotes at the bottom of Table 1:

   [b] *Demulsibility*—The demulsibility test shall be performed within 30 days from the date of shipment.

   [c] *Sieve Test*—A maximum percentage of 0.30 is acceptable for samples taken at the point of use.

   [d] Refer to R 5 for typical applications.

Standard Specification for

Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures

AASHTO Designation: M 156-97 (2009)
ASTM Designation: D 995-95b (2002)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures

AASHTO Designation: M 156-97 (2009)
ASTM Designation: D 995-95b (2002)

AASHTO M 156-97 (2009) is identical to ASTM D 995-95b (2002) except for the following provisions:

1. All references to the ASTM standards listed in the following table shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO
C 136	T 27
D 140	T 40

2. Replace Section 4.2.4 with the following:

   A sampling tap and valve shall be provided in the asphalt binder storage tank or in the feedline between the pump and the return line discharge. The sampling valve shall be readily accessible and free from obstructions. An acceptable sample valve detail is shown in T 40.

3. Add the following sentence to Section 4.3:

   Baghouse fines recirculated into the mix shall be considered as a mineral filler.

4. Add the following sentence to Section 4.5:

   Leave no visible unburned oil or carbon residue on the aggregate when discharged from the dryer.

5. Change the first sentence of Section 4.8.1 to read as follows:

   Plants located in areas regulated by emission standards shall have a dust collection system.

6. Change Section 4.9 to the following:

   4.9 Surge and Storage Bins or Silos

   4.9.1 Bins or silos may be provided for surge or storage capacity of mixtures.

   4.9.2 Bins or silos used for surge capacity during mixing and delivery periods shall be such that the mixture discharged into delivery units meets the requirements of the applicable specifications. The surge bin or silo shall be emptied at the cessation of each mixing and delivery period.

7. Add the following sentence to Section 9.1.3:

   Baghouse fines recirculated into the mix shall be considered as a mineral filler.

8. Add the following sentence to Section 10.2.4:

   Baghouse fines recirculated into the mix shall be considered as a mineral filler.

9. Add the following to Section 10.4:

   10.4.1 The plant shall be equipped with approved recording thermometers, pyrometers, or other approved recording thermometric instruments at the discharge chute of the drum mixer.

10.4.2 The plant shall have means of diverting mixes at startup and shutdowns or when mixing is not complete or uniform.

10. Add the following requirements:

12. STORAGE OF MIXTURES

12.1 *Conditions of Use*:

12.1.1 A plant may be permitted to store hot mix asphalt in a silo after prior evaluation and approval by the engineer. Use will be in conformance with all limitations on retention time, type of mixture, heater operation, silo atmosphere, mix level, or other characteristics set forth in the applicable specifications. Affixed to each silo and visible to the loading operator shall be an indicating device, which will be activated when the material drops below the top of the sloped portion of the silo.

12.2 *Approval Procedure*:

12.2.1 An evaluation of a unit will determine the degree of mix composition uniformity, temperature characteristics, and degree of asphalt binder hardening of mixture processed through the unit. Approval will be granted for operation that consistently results in mixtures having gradation and temperature properties of no less quality than specified mixtures discharged directly from the plant's mixing operation. Storage times beyond those listed in Table 1 require demonstration that the properties of the asphalt binder are not changed and the asphalt binder does not undergo additional hardening compared to samples stored under Table 1 conditions. Mixtures which the engineer determines visually to be segregated will be rejected.

12.3 *Limits for Storage of Asphalt Mix*:

12.3.1 Dense-graded asphalt mix will not exceed 18 hours in storage.

Open-graded asphalt mix will not exceed 2 hours in storage.

The indicated storage times may be reduced by the engineer if it is determined that asphalt absorption is a concern. Storage of open-graded mixtures will not be allowed if it is determined that migration of asphalt during the storage period is excessive.

12.3.2 Samples for asphalt binder tests shall be taken from trucks loaded from the storage unit or mixing operation, chilled immediately, and maintained at a temperature below 0ºC (32ºF) until tested.

12.4 *Changes in System*:

12.4.1 In the event that an approved storage unit is changed or altered, the engineer shall be notified of the modifications. Any departure from the approved unit will necessitate reevaluation.

12.5 *Temporary Use of Unapproved Silos*:

12.5.1 In the event that a unit is permitted to be used prior to evaluation and approval, the maximum storage times to be used are shown in the following table:

Table 1—Maximum Storage Times (h)

	Fine-Graded Mix, Nominal-Maximum Aggregate Size of 12.5 mm ($^1/_2$ in.)	Coarse-Graded Mix, Nominal-Maximum Aggregate Size of 38 mm (1$^1/_2$ in.)
Untreated asphalt binder, air in silo	8	4
Treated asphalt binder (Note 1), air in silo	12	6
Untreated asphalt binder, inert gas in silo	12	6
Treated asphalt binder (Note 1), inert gas in silo	12	12

Note 1—Treated with Dow Corning Fluid DC-200 at a rate of approximately 30 mL (1 oz) per 18.9 kL (5000 gal) of asphalt binder.

Standard Specification for

Cationic Emulsified Asphalt

AASHTO Designation: M 208-01 (2009)
ASTM Designation: D 2397-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Cationic Emulsified Asphalt

AASHTO Designation: M 208-01 (2009)
ASTM Designation: D 2397-02

1. SCOPE

1.1 This specification covers seven grades of cationic emulsified asphalt for use in pavement construction in the manner designated.

Note 1—See M 140 for emulsions other than cationic.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:
- M 140, Emulsified Asphalt
- R 5, Selection and Use of Emulsified Asphalts
- T 40, Sampling Bituminous Materials
- T 59, Emulsified Asphalts

3. REQUIREMENTS

3.1 Within 14 days after delivery, and provided separation has not been caused by freezing, the emulsified asphalt shall be homogeneous after thorough mixing.

3.2 Emulsified asphalt shall conform to the requirements in Table 1.

Table 1—Requirements and Typical Applications for Cationic Emulsified Asphalt[a]

Type	Rapid-Setting				Medium-Setting				Slow-Setting				Quick-Setting	
Grade	CRS -1		CRS-2		CMS-2		CMS-2 h		CSS-1		CSS-1 h		CQS-1 h	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Test on emulsions:														
Viscosity, Saybolt Furol at 25°C (77°F), s									20	100	20	100	20	100
Viscosity, Saybolt Furol at 50°C (122°F), s	20	100	100	400	50	450	50	450						
Storage stability test, 24 h, percent[b]		1		1		1		1		1		1		
Demulsibility, 35 mL, 0.8 percent														
Sodium dioctyl sulfosucinate, percent	40		40											
Coating, ability and water resistance:														
Coating, dry aggregate					Good		good							
Coating, after spraying					Fair		fair							
Coating, wet aggregate					Fair		fair							
Coating, after spraying					Fair		fair							
Particle charge test	positive		positive		positive		positive		positive		positive		positive	
Sieve test, percent[b]		0.10		0.10		0.10		0.10		0.10		0.10		0.10
Cement mixing test, percent										2.0		2.0		
Distillation:														
Oil distillate, by volume of emulsion, percent		3		3		12		12						
Residue, percent	60		65		65		65		57		57		57	
Tests on residue from distillation test:														
Penetration, 25°C (77°F), 100 g, 5 s	100	250	100	250	100	250	40	90	100	250	40	90	40	90
Ductility, 25°C (77°F), 5 cm/min, cm	40		40		40		40		40		40		40	
Solubility in trichloroethylene, percent	97.5		97.5		97.5		97.5		97.5		97.5		97.5	

[a] Refer to R 5 for typical applications.

[b] This test requirement on representative samples may be waived if successful application of the material has been achieved in the field.

4. SAMPLING

4.1 Samples of emulsified asphalt shall be taken in accordance with T 40.

4.2 Samples shall be stored in clean, airtight sealed containers at a temperature of not less than 4ºC (39ºF) until tested.

5. METHODS OF TEST

5.1 The properties of the emulsified asphalts given in Table 1 shall be determined in accordance with T 59, with the following exception:

5.1.1 *Sieve Test*—Use distilled water in all wetting and washing operations in place of sodium oleate solution (2 percent).

Standard Specification for

Viscosity-Graded Asphalt Cement

AASHTO Designation: M 226-80 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Viscosity-Graded Asphalt Cement

AASHTO Designation: M 226-80 (2008)

1. SCOPE

1.1. This specification covers asphalt binders graded by viscosity at 60°C (140°F) for use in pavement construction. Three sets of limits are offered in this specification. The purchaser shall specify the applicable table of limits. In the event the purchaser does not specify limits, Table 1 shall apply.

1.2. The values stated in SI units are to be regarded as the standard.

2. MANUFACTURE

2.1. The asphalt binder shall be prepared for crude petroleum by suitable methods.

3. REQUIREMENTS

3.1. The asphalt binder shall be homogeneous, free from water, and shall not foam when heated to 175ºC (347ºF).

3.2. The asphalt binders shall conform to the requirements given in Tables 1, 2, or 3, as specified by the purchaser.

Table 1—Requirements for Asphalt Binder Graded by Viscosity at 60ºC (140ºF) (Grading Based on Original Asphalt)

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 60°C (140°F), Pa·s (Poises)	25 ± 5 (250 ± 50)	50 ± 10 (500 ± 100)	100 ± 20 (1000 ± 200)	200 ± 40 (2000 ± 400)	400 ± 80 (4000 ± 800)
Viscosity, 135°C (275°F), mm^2/s—min	80	100	150	210	300
Penetration, 25°C (77°F), 100 g, 5 s—min	200	120	70	40	20
Flash point, COC, °C (°F)—min	163 (325)	177 (350)	219 (425)	232 (450)	232 (450)
Solubility in trichloroethylene, percent—min	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 60°C (140°F), Pa·s (Poises), max	100 (1000)	200 (2000)	400 (4000)	800 (8000)	1600 (16000)
Ductility, 25°C (77°F), 5 cm/min, cm—min	100[a]	100	50	20	10
Spot test (when and as specified)[b] with:					
Standard naphtha solvent	Negative for all grades				
Naphtha-xylene solvent, percent xylene	Negative for all grades				
Heptane-xylene solvent, percent xylene	Negative for all grades				

[a] If ductility is less than 100 cm, material will be accepted if ductility at 15.6°C (60°F) is 100 cm minimum.

[b] The use of the spot test is optional. When it is specified, the engineer shall indicate whether the standard naphtha solvent, the naphtha-xylene solvent, or the heptane-xylene solvent will be used in determining compliance with the requirement, and also, in the case of xylene solvents, the percentage of xylene to be used.

Table 2—Requirements for Asphalt Binder Graded by Viscosity at 60ºC (140ºF) (Grading Based on Original Asphalt)

Test	Viscosity Grade					
	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40
Viscosity, 60°C (140°F), Pa·s (Poises)	25 ± 5 (250 ± 50)	50 ± 10 (500 ± 100)	100 ± 20 (1000 ± 200)	200 ± 40 (2000 ± 400)	300 ± 60 (3000 ± 600)	400 ± 80 (4000 ± 800)
Viscosity, 135°C (275°F), mm^2/s—min	125	175	250	300	350	400
Penetration, 25°C (77°F), 100 g, 5 s—min	220	140	80	60	50	40
Flash point, COC, °C (°F)—min	163 (325)	177 (350)	219 (425)	232 (450)	232 (450)	232 (450)
Solubility in trichloroethylene, percent—min	99.0	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:						
Loss on heating percent—max[a]	—	1.0	0.5	0.5	0.5	0.5
Viscosity, 60°C (140°F), Pa·s (Poises)—max	100 (1000)	200 (2000)	400 (4000)	800 (8000)	1200 (12000)	1600 (16000)
Ductility, 25°C (77°F), 5 cm/min, cm—min	100[b]	100	75	50	40	25
Spot test (when and as specified)[c] with:						
Standard naphtha solvent	Negative for all grades					
Naphtha-xylene solvent, percent xylene	Negative for all grades					
Heptane-xylene solvent, percent xylene	Negative for all grades					

[a] The use of loss on heating requirement is optional.

[b] If ductility is less than 100 cm, material will be accepted if ductility at 15.6°C (60°F) is 100 cm minimum.

[c] The use of the spot test is optional. When it is specified, the engineer shall indicate whether the standard naphtha solvent, the naphtha-xylene solvent, or the heptane-xylene solvent will be used in determining compliance with the requirement, and also, in the case of xylene solvents, the percentage of xylene to be used.

Table 3—Requirements for Asphalt Binder Graded by Viscosity at 60ºC (140ºF) (Grading Based on Residue from Rolling Thin-Film Oven Test)

Tests on Residue from AASHTO Test Method T 240[a]	Viscosity Grade				
	AR-10	AR-20	AR-40	AR-80	AR-160
Viscosity, 60°C (140°F), Pa·s (Poises)	100 ± 25 (1000 ± 250)	200 ± 50 (2000 ± 500)	400 ± 100 (4000 ± 1000)	800 ± 200 (8000 ± 2000)	1600 ± 400 (16000 ± 4000)
Viscosity, 135°C (275°F), mm^2/s—min	140	200	275	400	550
Penetration, 25°C (77°F), 100 g, 5 s—min	65	40	25	20	20
Percent of original penetration, 25°C (77°F)—min	—	40	45	50	52
Ductility, 25°C (77°F), 5 cm/min, cm—min	100[b]	100[b]	75	75	75
Tests on original asphalt:					
Flash point, COC, °C (°F)—min	205 (400)	219 (425)	227 (440)	232 (450)	238 (460)
Solubility in trichloroethylene, percent—min	99.0	99.0	99.0	99.0	99.0

[a] AASHTO T 179 (Rolling Thin-Film Oven Test) may be used, but AASHTO T 240 shall be the referee method.

[b] If ductility is less than 100 cm, material will be accepted if ductility at 15.6°C (60°F) is 100 cm minimum.

4. METHODS OF SAMPLING AND TESTING

4.1. Sampling and testing of asphalt binders shall be in accordance with the following standard methods of the American Association of State Highway and Transportation Officials:

- T 40, Sampling
- T 44, Solubility in Bituminous Materials
- T 48, Flash Point (COC)
- T 49, Penetration
- T 51, Ductility
- T 55, Water
- T 102, Spot Test
- T 179, Thin-Film Oven Test
- T 201, Viscosity at 135°C (275°F)
- T 202, Viscosity at 60°C (140°F)
- T 240, Rolling Thin-Film Oven Test

Standard Specification for

Lime for Asphalt Mixtures

AASHTO Designation: M 303-89 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Lime for Asphalt Mixtures

AASHTO Designation: M 303-89 (2006)

1. SCOPE

1.1. This specification covers two types of lime to be used for reducing water susceptibility in asphalt mixtures.

1.1.1. *Type I*—High calcium-hydrated lime containing maximum magnesium content, calculated as magnesium oxide, of 4 percent by mass. Compliance with chemical composition requirements shall be determined by use of T 219. (Note 1)

1.1.2. *Type II*—Magnesium or dolomitic lime containing magnesium, calculated as magnesium oxide, greater than 4 but no more than 36 percent by mass. Compliance with chemical composition requirements shall be determined by use of ASTM C 25. (Note 2)

1.2. The values stated in SI units are to be regarded as the standard.

Note 1—Magnesium oxide content may be determined by ASTM C 25.

Note 2—Except that Section 2, "Samples for Analysis," is excluded.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 165, Effect of Water on Cohesion of Compacted Bituminous Mixtures (Discontinued)
- T 218, Sampling Hydrated Lime
- T 219, Testing Lime for Chemical Constituents and Particle Sizes
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

2.2. *ASTM Standard*:

- C 25, Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime

3. CHEMICAL LIMITS

3.1. Types I and II lime, when sampled and tested by procedures prescribed herein, shall conform to the following requirements. (See Tables 1 and 2.)

3.2. Type II lime, when tested in accordance with ASTM C 25, shall conform to the requirements listed in Table 2.

Table 1—Types I and II Requirements

Min total active lime content, percent by mass (Percent by mass $Ca(OH)_2$ + percent by mass Ca(O)[a])	90
Max unhydrated lime content, percent by mass CaO	7
Max "Free Water" content, percent by mass H_2O	3

[a] No more than 7 percent by mass calcium oxide (unhydrated lime) will be allowed in determining total active lime content.

Table 2—Type II Requirements (when tested by ASTM C 25)

Calcium and magnesium oxide content of ignition residue, min, percent[a]	96
Carbon dioxide (as received basis), max, percent	4
Unhydrated calcium oxide (as received basis), max, percent	7

[a] Ignition to constant mass shall be performed utilizing an electric muffle furnace operating at 1000–1100°C [1800–2000°F].

4. PHYSICAL REQUIREMENTS

4.1. Types I and II lime shall conform to the following particle size requirements when tested according to T 219:

Maximum residue retained on a 600-µm (No. 30) sieve, percent by mass	3
Maximum residue retained on a 75-µm (No. 200) sieve, percent by mass	20

5. PACKAGING AND MARKING

5.1. When the lime is delivered in bags, the name and brand of the manufacturer and type shall be plainly identified thereon. A bag shall contain a nominal mass of 25 kg (50 lb) and all bags shall be in good condition at the time of inspection. When lime is delivered in bulk, information regarding type and manufacturer shall be contained in the invoice accompanying the shipment.

6. INSPECTION

6.1. Every facility shall be provided the purchaser for careful sampling and inspection of the lime at either the plant or at the site of the work as may be specified by the purchaser.

7. REJECTION

7.1. The lime shall be rejected if it fails to meet any of the requirements of this specification.

7.2. In the case of bag lime, bags varying more than 5 percent from the specified mass may be rejected. If the average mass of bags in any shipment as shown by weighing 50 bags taken at random is less than that specified, the entire shipment may be rejected.

8. METHODS OF SAMPLING AND TESTING

8.1. The sampling and testing of lime shall be in accordance with the following standard methods of AASHTO or ASTM:

- *Sampling*—T 218
- *Chemical Analysis for Type I*—T 219
- *Chemical Analysis for Type II Lime*—ASTM C 25
- *Physical Requirements*—Quantity of lime required to correct water susceptibility can be determined from test results obtained in accordance with T 165 or T 283.

Standard Specification for

Polymer-Modified Cationic Emulsified Asphalt

AASHTO Designation: M 316-99 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Polymer-Modified Cationic Emulsified Asphalt

AASHTO Designation: M 316-99 (2007)

1. SCOPE

1.1. This specification covers grades of polymer-modified cationic emulsified asphalt for use in pavement construction. The modifier may be either a solid or latex polymer. The modifier may be added either to the asphalt binder or during the emulsification process.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 40, Sampling Bituminous Materials
- T 59, Emulsified Asphalts

3. DEFINITIONS

3.1. *CRS-2P*—A cationic emulsion made with base asphalt binder typically modified with styrene-butadiene or styrene-butadiene styrene block copolymers.

3.2. *CRS-2L*—A cationic emulsion made with base asphalt binder typically modified with styrene-butadiene rubber latex or polychloroprene latex.

4. REQUIREMENTS

4.1. Within 30 days after delivery and provided separation has not been caused by freezing, the emulsified asphalt shall be homogeneous after thorough mixing.

4.2. The emulsified asphalt shall conform to the requirements in Table 1.

Table 1—Requirements for Polymer-Modified Cationic Emulsified Asphalt

Type, Grade		Rapid-Setting			
		CRS-2P		CRS-2L	
		Min	Max	Min	Max
Test on emulsions:					
Viscosity, Saybolt Furol at 50˚C (122˚F)	s	100	400	100	400
Storage stability test, 24-h	%		1		1
Demulsibility, 35 mL of 0.8 % dioctyl sodium sulfosucinate	%	40		40	
Particle charge test		positive		positive	
Sieve test	%		0.10		0.10
Evaporation residue	%	65		65	
Test on residue from evaporation test:					
Penetration, 25˚C (77˚F), 100 g, 5 s	0.1 mm	100	175	100	175
Ductility, 4˚C (39˚F), 5 cm/min	cm	30		30	
Ductility, 25˚C (77˚F), 5 cm/min	cm	125		125	
Force ratio	(f_2/f_1)	0.3		NA	
Elastic recovery	%	50		NA	
Polymer solids content	%	2.5		2.5	
Solubility in trichloroethylene	%	97.5[a]		97.5[a]	

[a] If the solubility of the residue is less than 97.5 percent, the base asphalt binder for the emulsion shall be tested. The solubility of the base asphalt binder shall be greater than 99 percent.

5. SAMPLING

5.1. Samples of emulsified asphalt shall be taken in accordance with T 40.

5.2. Samples shall be stored in clean, airtight, plastic containers at a temperature of not less than 4.5ºC (40ºF) until tested.

6. METHOD OF TEST

6.1. The properties of the emulsified asphalt given in Table 1 shall be determined in accordance with T 59, with the following exception:

6.1.1. *Sieve Test*—Use distilled water in all wetting and washing operations rather than a sodium oleate solution (2 percent).

Standard Specification for

Performance-Graded Asphalt Binder

AASHTO Designation: M 320-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Performance-Graded Asphalt Binder

AASHTO Designation: M 320-10

1. SCOPE

1.1. This specification covers asphalt binders graded by performance. Grading designations are related to the average seven-day maximum pavement design and minimum pavement design temperatures. This specification contains Table 1 and Table 2. If no table is specified, the default is Table 1.

1.2. Table 2 incorporates R 49 for determining the critical low cracking temperature using a combination of T 313 and T 314 test procedures.

Note 1—For asphalt cements graded by viscosity at 60°C, see M 226.

Note 2—R 29 provides information for determining the performance grade of an asphalt binder.

Note 3—For specifying performance-graded asphalt binder using Multiple Stress Creep Recovery (MSCR), see MP 19.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 226, Viscosity-Graded Asphalt Cement
- M 323, Superpave Volumetric Mix Design
- MP 19, Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- R 49, Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders
- T 40, Sampling Bituminous Materials
- T 44, Solubility of Bituminous Materials
- T 48, Flash and Fire Points by Cleveland Open Cup
- T 55, Water in Petroleum Products and Bituminous Materials by Distillation
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.2. *ASTM Standards*:

- D 8, Standard Terminology Relating to Materials for Roads and Pavements
- D 5546, Standard Test Method for Solubility of Asphalt Binders in Toluene by Centrifuge

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. Definitions for many terms common to asphalt binder are found in ASTM D 8.

3.1.2. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

4. ORDERING INFORMATION

4.1. When ordering under this specification, include in the purchase order the performance grade (PG) of asphalt binder required and the table used (e.g., (1) M 320, PG 52-16, Table 1, or (2) M 320, PG 64-34, Table 2). If no table is specified, the default is Table 1.

4.2. Asphalt binder grades may be selected by following the procedures described in M 323 and R 35.

5. MATERIALS AND MANUFACTURE

5.1. Asphalt binder shall be prepared by the refining of crude petroleum by suitable methods, with or without the addition of modifiers.

5.2. Modifiers may be any organic material of suitable manufacture that is used in virgin or recycled condition and that is dissolved, dispersed, or reacted in asphalt binder to enhance its performance.

5.3. The asphalt binder shall be homogeneous, free from water and deleterious materials, and shall not foam when heated to 175°C.

5.4. The asphalt binder shall be at least 99.0 percent soluble as determined by T 44 or ASTM D 5546.

5.5. This specification is not applicable for asphalt binders in which fibers or other discrete particles are larger than 250 μm in size.

5.6. The grades of asphalt binder shall conform to the requirements given in Table 1 or Table 2.

6. SAMPLING

6.1. The material shall be sampled in accordance with T 40.

7. TEST METHODS

7.1. The properties outlined in Sections 5.3, 5.4, and 5.6 shall be determined in accordance with R 28, T 44 or ASTM D 5546, T 48, T 55, T 240, T 313, T 314, T 315, and T 316.

8. INSPECTION AND CERTIFICATION

8.1. Inspection and certification of the material shall be agreed upon between the purchaser and the seller. Specific requirements shall be made part of the purchase contract. The seller shall provide material handling and storage procedures to the purchaser for each asphalt binder grade certified.

9. REJECTION AND RETESTING

9.1. If the results of any test do not conform to the requirements of this specification, retesting to determine conformity is performed as indicated in the purchase order or as otherwise agreed upon between the purchaser and the seller.

10. KEYWORDS

10.1. Asphalt binder; asphalt cement; direct tension; flash point; modifier; performance specifications; pressure aging; rheology.

Table 1—Performance-Graded Asphalt Binder Specification

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day max pavement design temp, °C[a]	<46			<52							<58					<64					
Min pavement design temperature, °C[a]	>– 34	>– 40	>– 46	>– 10	>– 16	>– 22	>– 28	>– 34	>– 40	>– 46	>– 16	> 22	>– 28	>– 34	>– 40	>– 10	>– 16	>– 22	>– 28	>– 34	>– 40
Original Binder																					
Flash point temp, T 48, min °C	230																				
Viscosity, T 316:[b] max 3 Pa·s, test temp, °C	135																				
Dynamic shear, T 315:[c] G*/sinδ,[d] min 1.00 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue (T 240)																					
Mass change,[e] max, percent	1.00																				
Dynamic shear, T 315: G*/sinδ,[d] min 2.20 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Pressurized Aging Vessel Residue (R 28)																					
PAV aging temperature, °C[f]	90			90							100					100					
Dynamic shear, T 315: G* sinδ,[d] max 5000 kPa test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Creep stiffness, T 313:[g] S, max 300 MPa *m*-value, min 0.300 test temp @ 60 s, °C	–24	–30	–36	0	–6	–12	–18	–24	–30	–36	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	–30
Direct tension, T 314:[g] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	–24	–30	–36	0	–6	–12	–18	–24	–30	–36	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	–30

[a] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

[b] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[c] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[d] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[e] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[f] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[g] If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

Table 1—Performance-Graded Asphalt Binder Specification *(Continued)*

Performance Grade	PG 70						PG 76					PG 82				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temperature, °C[a]	<70						<76					<82				
Min pavement design temperature, °C[a]	>– 10	>– 16	>– 22	>– 28	>– 34	>– 40	>– 10	>– 16	>– 22	>– 28	>– 34	>– 10	>– 16	>– 22	>– 28	>– 34
Original Binder																
Flash point temp, T 48, min °C	230															
Viscosity, T 316:[b] max 3 Pa·s, test temp, °C	135															
Dynamic shear, T 315:[c] G*/sin δ,[d] min 1.00 kPa test temp @ 10 rad/s, °C	70						76					82				
Rolling Thin-Film Oven Residue (T 240)																
Mass change,[e] max, percent	1.00															
Dynamic shear, T 315: G*/sin δ,[d] min 2.20 kPa test temp @ 10 rad/s, °C	70						76					82				
Pressurized Aging Vessel Residue (R 28)																
PAV aging temperature, °C[f]	100 (110)						100 (110)					100 (110)				
Dynamic shear, T 315: G* sin δ,[d] max 5000 kPa test temp @ 10 rad/s, °C	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Creep stiffness, T 313:[g] S, max 300 MPa *m*-value, min 0.300 test temp @ 60 s, °C	0	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	0	–6	–12	–18	–24
Direct tension, T 314:[g] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	0	–6	–12	–18	–24

[a] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

[b] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[c] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[d] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[e] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[f] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[g] If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The *m*-value requirement must be satisfied in both cases.

Table 2—Performance-Graded Asphalt Binder Specification

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day max pavement design temperature, °C[a]	<46			<52							<58					<64					
Min pavement design temperature, °C[a]	>–34	>–40	>–46	>–10	>–16	>–22	>–28	>–34	>–40	>–46	>–16	>–22	>–28	>–34	>–40	>–10	>–16	>–22	>–28	>–34	>–40
Original Binder																					
Flash point temp, T 48, min °C	230																				
Viscosity, T 316:[b] max 3 Pa·s, test temp, °C	135																				
Dynamic shear, T 315:[c] G*/sinδ[d], min 1.00 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue (T 240)																					
Mass change,[e] max, percent	1.00																				
Dynamic shear, T 315: G*/sinδ[d], min 2.20 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Pressurized Aging Vessel Residue (R 28)																					
PAV aging temperature, °C[f]	90			90							100					100					
Dynamic shear, T 315: G* sinδ[d], max 5000 kPa test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Critical low cracking temp, R 49:[g] Critical cracking temp determined by R 49, test temp, °C	–24	–30	–36	0	–6	–12	–18	–24	–30	–36	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	–30

[a] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

[b] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[c] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[d] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[e] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[f] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[g] For verification of grade, at a minimum perform T 313 at the test temperature and at the test temperature minus 6°C and T 314 at the test temperature. Testing at additional temperatures for T 313 may be necessary if 300 MPa is not bracketed at the initial two test temperatures. Compare the failure stress from T 314 to the calculated induced thermal stress as per R 49. If the failure stress exceeds the induced thermal stress, the asphalt binder is deemed a "PASS" at the specification temperature.

Table 2—Performance-Graded Asphalt Binder Specification *(Continued)*

Performance Grade	PG 70						PG 76					PG 82				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temperature, °C[a]	<70						<76					<82				
Min pavement design temperature, °C[a]	>–10	>–16	>–22	>–28	>–34	>–40	>–10	>–16	>–22	>–28	>–34	>–10	>–16	>–22	>–28	>–34
Original Binder																
Flash point temp, T 48, min °C	230															
Viscosity, T 316:[b] max 3 Pa·s, test temp, °C	135															
Dynamic shear, T 315:[c] G*/sinδ[d], min 1.00 kPa test temp @ 10 rad/s, °C	70						76					82				
Rolling Thin-Film Oven Residue (T 240)																
Mass change,[e] max, percent	1.00															
Dynamic shear, T 315: G*/sinδ[d], min 2.20 kPa test temp @ 10 rad/s, °C	70						76					82				
Pressurized Aging Vessel Residue (R 28)																
PAV aging temperature, °C[f]	100 (110)						100 (110)					100 (110)				
Dynamic shear, T 315: G* sinδ[d], max 5000 kPa test temp @ 10 rad/s, °C	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Critical low cracking temp, R 49:[g] Critical cracking temp determined by R 49, test temp, °C	0	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	0	–6	–12	–18	–24

[a] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35.

[b] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[c] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[d] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[e] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[f] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[g] For verification of grade, at a minimum perform T 313 at the test temperature and at the test temperature minus 6°C and T 314 at the test temperature. Testing at additional temperatures for T 313 may be necessary if 300 MPa is not bracketed at the initial two test temperatures. Compare the failure stress from T 314 to the calculated induced thermal stress as per R 49. If the failure stress exceeds the induced thermal stress, the asphalt binder is deemed a "PASS" at the specification temperature.

Standard Specification for

Superpave Volumetric Mix Design

AASHTO Designation: M 323-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Superpave Volumetric Mix Design

AASHTO Designation: M 323-07

1. SCOPE

1.1. This specification for Superpave volumetric mix design uses aggregate and mixture properties to produce a hot mix asphalt (HMA) job-mix formula.

1.2. This standard specifies minimum quality requirements for binder, aggregate, and HMA for Superpave volumetric mix designs.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 170, Recovery of Asphalt Binder from Solution by Abson Method
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
- T 304, Uncompacted Void Content of Fine Aggregate
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 319, Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

2.2. *ASTM Standards*:

- D 4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- D 5821, Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate

2.3. *Asphalt Institute Publication*:

- MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*

2.4. *National Asphalt Pavement Association Publication*:

- IS 128, HMA Pavement Mix Type Selection Guide

2.5. *Other References*:

- *LTPP Seasonal Asphalt Concrete Pavement Temperature Models*. LTPPBind 3.1 http://www.ltppbind.com
- *NCHRP Report 452: Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Technician's Manual*. National Cooperative Highway Research Program Project D9-12, Transportation Research Board, Washington, DC, 2001.

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3. TERMINOLOGY

3.1. *HMA*—hot mix asphalt.

3.2. *design ESALs*—design equivalent (80 kN) single-axle loads.

3.2.1. *Discussion*—Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. For pavements designed for more or less than 20 years, determine the design ESALs for 20 years when using this standard.

3.3. *air voids* (V_a)—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1).

Note 1—Term defined in Asphalt Institute Manual MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*.

3.4. *voids in the mineral aggregate (VMA)*—the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.5. *voids filled with asphalt (VFA)*—the percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.6. *dust-to-binder ratio* ($P_{0.075}/P_{be}$)—by mass, the ratio between the percent of aggregate passing the 75-µm (No. 200) sieve ($P_{0.075}$) and the effective binder content (P_{be}).

3.7. *nominal maximum aggregate size*—one size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.8. *maximum aggregate size*—one size larger than the nominal maximum aggregate size (Note 2).

Note 2—The definitions given in Sections 3.7 and 3.8 apply to Superpave mixes only and differ from the definitions published in other AASHTO standards.

3.9. *reclaimed asphalt pavement (RAP)*—removed and/or processed pavement materials containing asphalt binder and aggregate.

3.10. *primary control sieve (PCS)*—the sieve defining the break point between fine- and coarse-graded mixtures for each nominal maximum aggregate size.

4. SIGNIFICANCE AND USE

4.1. This standard may be used to select and evaluate materials for Superpave volumetric mix designs.

5. BINDER REQUIREMENTS

5.1. The binder shall be a performance-graded (PG) binder, meeting the requirements of M 320, which is appropriate for the climate and traffic-loading conditions at the site of the paving project or as specified by the contract documents.

5.1.1. Determine the mean and the standard deviation of the yearly, 7-day-average, maximum pavement temperature, measured 20 mm below the pavement surface, and the mean and the standard deviation of the yearly, 1-day-minimum pavement temperature, measured at the pavement surface, at the site of the paving project. These temperatures can be determined by use of the LTPPBind 3.1 software or can be supplied by the specifying agency. If the LTPPBind software is used, the LTPP high- and low-temperature models should be selected in the software when determining the binder grade. Often, actual site data are not available, and representative data from the nearest weather station will have to be used.

5.1.2. Select the design reliability for the high- and low-temperature performance desired. The design reliability required is established by agency policy.

Note 3—The selection of design reliability may be influenced by the initial cost of the materials and the subsequent maintenance costs.

5.1.3. Using the pavement temperature data determined, select the minimum required PG binder that satisfies the required design reliability.

5.2. If traffic speed or the design ESALs warrant, increase the high-temperature grade by the number of grade equivalents indicated in Table 1 to account for the anticipated traffic conditions at the project site.

Table 1—Binder Selection on the Basis of Traffic Speed and Traffic Level

	Adjustment to the High-Temperature Grade of the Binder[a]		
	Traffic Load Rate		
Design ESALs[b] (Million)	Standing[c]	Slow[d]	Standard[e]
<0.3	—[f]	—	—
0.3 to <3	2	1	—
3 to <10	2	1	—
10 to <30	2	1	—[f]
≥30	2	1	1

[a] Increase the high-temperature grade by the number of grade equivalents indicated (one grade is equivalent to 6˚C). Use the low-temperature grade as determined in Section 5.

[b] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[c] *Standing Traffic*—where the average traffic speed is less than 20 km/h.

[d] *Slow Traffic*—where the average traffic speed ranges from 20 to 70 km/h.

[e] *Standard Traffic*—where the average traffic speed is greater than 70 km/h.

[f] Consideration should be given to increasing the high-temperature grade by one grade equivalent.

Note 4—Practically, PG binders stiffer than PG 82-xx should be avoided. In cases where the required adjustment to the high-temperature binder grade would result in a grade higher than a PG 82, consideration should be given to specifying a PG 82-xx and increasing the design ESALs by one level (e.g., 10 to <30 million increased to ≥30 million).

5.3. If RAP is to be used in the mixture, adjust the binder grade selected in Sections 5.1.3 and 5.2 according to Table 2 to account for the amount and stiffness of the RAP binder. Procedures for developing a blending chart are included in the appendix.

Note 5—Research conducted as part of NCHRP Project 9-12 indicated that the high stiffness RAP (PG 88-4 after recovery) used in the study had a greater effect on the low-temperature properties of the blended asphalt binder than the medium and low stiffness RAP (PG 82-16 and PG 82-22, respectively). These data suggests that the limiting RAP values in Table 2 may be modified depending on the low-temperature stiffness of the recovered RAP binder. Refer to NCHRP Report 452 for more details.

Table 2—Binder Selection Guidelines for Reclaimed Asphalt Pavement (RAP) Mixtures

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	<15
Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used)	15 to 25
Follow recommendations from blending charts	>25

6. COMBINED AGGREGATE REQUIREMENTS

6.1. *Size Requirements:*

6.1.1. *Nominal Maximum Size*—The combined aggregate shall have a nominal maximum aggregate size of 4.75 to 19.0 mm for HMA surface courses and no larger than 37.5 mm for HMA subsurface courses.

Note 6—Additional guidance on selection of the appropriate nominal maximum size mixture can be found in the National Asphalt Pavement Association's IS 128.

6.1.2. *Gradation Control Points*—The combined aggregate shall conform to the gradation requirements specified in Table 3 when tested according to T 11 and T 27.

Table 3—Aggregate Gradation Control Points

Sieve Size	Nominal Maximum Aggregate Size—Control Points (Percent Passing)											
	37.5 mm		25.0 mm		19.0 mm		12.5 mm		9.5 mm		4.75 mm	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
50.0 mm	100	—	—	—	—	—	—	—	—	—	—	—
37.5 mm	90	100	100	—	—	—	—	—	—	—	—	—
25.0 mm	—	90	90	100	100	—	—	—	—	—	—	—
19.0 mm	—	—	—	90	90	100	100	—	—	—	—	—
12.5 mm	—	—	—	—	—	90	90	100	100	—	100	—
9.5 mm	—	—	—	—	—	—	—	90	90	100	95	100
4.75 mm	—	—	—	—	—	—	—	—	—	90	90	100
2.36 mm	15	41	19	45	23	49	28	58	32	67	—	—
1.18 mm	—	—	—	—	—	—	—	—	—	—	30	60
0.075 mm	0	6	1	7	2	8	2	10	2	10	6	12

6.1.3. *Gradation Classification*—The combined aggregate gradation shall be classified as coarse-graded when it passes below the Primary Control Sieve (PCS) control point as defined in Table 4. All other gradations shall be classified as fine-graded.

Table 4—Gradation Classification

PCS Control Point for Mixture Nominal Maximum Aggregate Size (% Passing)					
Nominal Maximum Aggregate Size	37.5 mm	25.0 mm	19.0 mm	12.5 mm	9.5 mm
Primary Control Sieve	9.5 mm	4.75 mm	4.75 mm	2.36 mm	2.36 mm
PCS Control Point (% Passing)	47	40	47	39	47

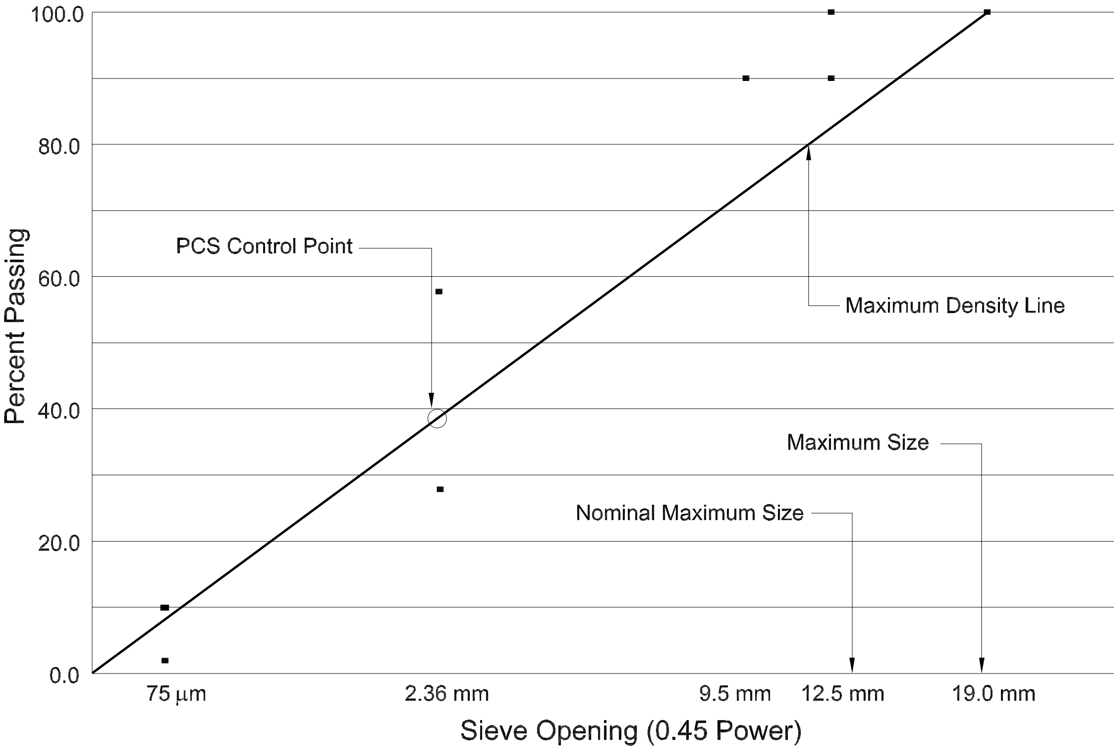

Figure 1—Superpave Gradation Control Points for a 12.5-mm Nominal Maximum Size Aggregate Gradation

6.2. *Coarse Aggregate Angularity Requirements*—The aggregate shall meet the percentage of fractured faces requirements, specified in Table 5, measured according to D 5821.

6.3. *Fine Aggregate Angularity Requirements*—The aggregate shall meet the uncompacted void content of fine aggregate requirements, specified in Table 5, measured according to T 304, Method A.

6.4. *Sand Equivalent Requirements*—The aggregate shall meet the sand equivalent (clay content) requirements, specified in Table 5, measured according to T 176.

6.5. *Flat-and-Elongated Requirements*—The aggregate shall meet the flat-and-elongated requirements, specified in Table 5, measured according to D 4791, with the exception that the material passing the 9.5-mm sieve and retained on the 4.75-mm sieve shall be included. The aggregate shall be measured using the ratio of 5:1, comparing the length (longest dimension) to the thickness (smallest dimension) of the aggregate particles.

6.6. When RAP is used in the mixture, the RAP aggregate shall be extracted from the RAP using a solvent extraction (T 164) or ignition oven (T 308) as specified by the agency. The RAP aggregate shall be included in determinations of gradation, coarse aggregate angularity, fine aggregate angularity, and flat-and-elongated requirements. The sand equivalent requirements shall be waived for the RAP aggregate but shall apply to the remainder of the aggregate blend.

Table 5—Superpave Aggregate Consensus Property Requirements

	Fractured Faces, Coarse Aggregate,[c] Percent Minimum		Uncompacted Void Content of Fine Aggregate, Percent Minimum		Sand Equivalent, Percent Minimum	Flat and Elongated,[c] Percent Maximum
	Depth from Surface		Depth from Surface			
Design ESALs[a] (Million)	≤100 mm	>100 mm	≤100 mm	>100 mm		
<0.3	55/—	—/—	—	—	40	—
0.3 to <3	75/—	50/—	40	40	40	10
3 to <10	85/80[b]	60/—	45	40	45	10
10 to <30	95/90	80/75	45	40	45	10
≥30	100/100	100/100	45	45	50	10

[a] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[b] 85/80 denotes that 85 percent of the coarse aggregate has one fractured face and 80 percent has two or more fractured faces.

[c] This criterion does not apply to 4.75-mm nominal maximum size mixtures.

Note 7—If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.

7. HMA DESIGN REQUIREMENTS

7.1. The binder and aggregate in the HMA shall conform to the requirements of Sections 5 and 6.

7.2. The HMA design, when compacted in accordance with T 312, shall meet the relative density, VMA, VFA, and dust-to-binder ratio requirements specified in Table 6. The initial, design, and maximum number of gyrations are specified in R 35.

Table 6—Superpave HMA Design Requirements

	Required Relative Density, Percent of Theoretical Maximum Specific Gravity			Voids in the Mineral Aggregate (VMA), Percent Minimum						Voids Filled with Asphalt (VFA) Range,[b] Percent	Dust-to-Binder Ratio Range[c]
				Nominal Maximum Aggregate Size, mm							
Design ESALs[a] (Million)	N_{initial}	N_{design}	N_{max}	37.5	25.0	19.0	12.5	9.5	4.75		
<0.3	≤91.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	70–80[d]	0.6–1.2
0.3 to <3	≤90.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–78	0.6–1.2
3 to <10	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–75[e]	0.6–1.2
10 to <30	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–75[e]	0.6–1.2
≥30	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–75[e]	0.6–1.2

[a] Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[b] For 37.5-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 64 percent for all design traffic levels.

[c] For 4.75-mm nominal maximum size mixtures, the dust-to-binder ratio shall be 0.9 to 2.0.

[d] For 25.0-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 67 percent for design traffic levels <0.3 million ESALs.

[e] For design traffic levels >3 million ESALs, 9.5-mm nominal maximum size mixtures, the specified VFA range shall be 73 to 76 percent and for 4.75-mm nominal maximum size mixtures shall be 75 to 78 percent.

Note 8—If the aggregate gradation passes beneath the PCS Control Point specified in Table 4, the dust-to-binder ratio range may be increased from 0.6–1.2 to 0.8–1.6 at the agency's discretion.

Note 9—Mixtures with VMA exceeding the minimum value by more than 2 percent may be prone to flushing and rutting. Unless satisfactory experience with high VMA mixtures is available, mixtures with VMA greater than 2 percent above the minimum should be avoided.

7.3. The HMA design, when compacted according to T 312 at 7.0 ± 0.5 percent air voids and tested in accordance with T 283, shall have a minimum tensile strength ratio of 0.80.

APPENDIX

(Nonmandatory Information)

X1. PROCEDURES FOR DEVELOPING A BLENDING CHART

X1.1. Blending of RAP binders can be accomplished by knowing the desired final grade (critical temperature) of the blended binder, the physical properties (and critical temperatures) of the recovered RAP binder, and either the physical properties (and critical temperatures) of the virgin asphalt binder or the desired percentage of RAP in the mixture.

X1.2. *Determine the physical properties and critical temperatures of the RAP binder.*

X1.2.1. Recover the RAP binder using T 319 (Note 10) with an appropriate solvent. At least 50 g of recovered RAP binder are needed for testing. Perform binder classification testing using the tests in M 320. Rotational viscosity, flash point, and mass loss tests are not required.

Note X1—While T 319 is the preferred method, at the discretion of the agency, T 170 may be used. Research conducted under NCHRP 9-12 indicated that T 170 might affect recovered binder properties.

X1.2.2. Perform original dynamic shear rheometer (DSR) testing on the recovered RAP binder to determine the critical high temperature, $T_c(High)$, based on original DSR values where $G^*/\sin\delta = 1.00$ kPa. Calculate the critical high temperature as follows:

X1.2.2.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta\log(G^*/\sin\delta)/\Delta T \qquad (X1.1)$$

X1.2.2.2. Determine T_c (*High*) to the nearest 0.1°C using the following equation:

$$T_c\ (High) = \left(\frac{Log(1.00) - Log(G_1)}{a}\right) + T_1 \qquad (X1.2)$$

where:

G_1 = the $G^*/\sin\delta$ value at a specific temperature T_1, and

a = the slope as described in Equation X1.1.

Note X2—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the $G^*/\sin\delta$ value closest to the criterion (1.00 kPa) to minimize extrapolation errors.

X1.2.3. Perform rolling thin-film oven (RTFO) aging on the remaining binder.

X1.2.4. Perform RTFO DSR testing on the RTFO-aged recovered binder to determine the critical high temperature (based on RTFO DSR). Calculate the critical high temperature (RTFO DSR).

X1.2.4.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(G^*/\sin \delta)/\Delta T \qquad (X1.3)$$

X1.2.4.2. Determine $T_c(High)$ based on RTFO DSR, to the nearest 0.1°C using the following equation:

$$T_c(High) = \left(\frac{Log(2.20) - Log(G_1)}{a} \right) + T_1 \qquad (X1.4)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1, and

a = the slope as described in Equation X1.3.

Note X3—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (2.20 kPa) to minimize extrapolation errors.

X1.2.5. Determine the critical high temperature of the recovered RAP binder as the lowest of the original DSR and RTFO DSR critical temperatures. Determine the high temperature performance grade (PG) of the recovered RAP binder based on this single critical high temperature.

X1.2.6. Perform intermediate temperature DSR testing on the RTFO-aged recovered RAP binder to determine the critical intermediate temperature $T_c\,(Int)$, as if the RAP binder were pressure aging vessel (PAV) aged.

X1.2.6.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(G^*/\sin \delta)/\Delta T \qquad (X1.5)$$

X1.2.6.2. Determine $T_c\,(Int)$ to the nearest 0.1°C using the following equation:

$$T_c(Int) = \left(\frac{Log(5000) - Log(G_1)}{a} \right) + T_1 \qquad (X1.6)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1, and

a = the slope as described in Equation X1.5.

Note X4—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (5000 kPa) to minimize extrapolation errors.

X1.2.7. Perform BBR testing on the RTFO-aged recovered RAP binder to determine the critical low temperature, $T_c\,(S)$ or $T_c\,(m)$, based on bending beam rheometer (BBR) Stiffness or *m*-value.

X1.2.7.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(S)/\Delta T \qquad (X1.7)$$

X1.2.7.2. Determine $T_c(S)$ to the nearest 0.1°C using the following equation:

$$T_c(S) = \left(\frac{Log(300) - Log(S_1)}{a} \right) + T_1 \qquad (X1.8)$$

where:

S_1 = the *S*-value at a specific temperature T_1, and

a = the slope as described in Equation X1.7.

Note X5—Although any temperature (T_1) and the corresponding stiffness (S_1) can be selected, it is advisable to use the *S*-value closest to the criterion (300 MPa) to minimize extrapolation errors.

X1.2.7.3. Determine the slope of the *m*-value-Temperature curve as follows:

$$a = \Delta m\text{-value}/\Delta T \qquad (X1.9)$$

X1.2.7.4. Determine $T_c(m)$ to the nearest 0.1°C using the following equation:

$$T_c(m) = \left(\frac{0.300 - m_1}{a} \right) + T_1 \qquad (X1.10)$$

where:

m_1 = the *m*-value at a specific temperature T_1, and

a = the slope as described in Equation X1.9.

Note X6—Although any temperature (T_1) and the corresponding *m*-value (m_1) can be selected, it is advisable to use the *m*-value closest to the criterion (0.300) to minimize extrapolation errors.

X1.2.7.5. Select the higher of the two low critical temperatures, $T_c(S)$ or $T_c(m)$, to represent the low critical temperature for the recovered asphalt binder, $T_c(Low)$. Determine the low temperature PG of the recovered RAP binder based on this single critical low temperature.

X1.2.8. Once the physical properties and critical temperatures of the recovered RAP binder are known, proceed with blending at a known RAP percentage or with a known virgin binder grade.

X1.3. *Blending at a known RAP percentage.*

X1.3.1. If the desired final blended binder grade, the desired percentage of RAP, and the recovered RAP binder properties are known, then the required properties of an appropriate virgin binder grade can be determined.

X1.3.1.1. Determine the critical temperatures of the virgin asphalt binder at high, intermediate, and low properties using the following equation:

$$T_{Virgin} = \frac{T_{Blend} - (\%\text{RAP} \times T_{RAP})}{(1 - \%\text{RAP})} \qquad (X1.11)$$

where:

T_{Virgin} = critical temperature of virgin asphalt binder (high, intermediate, or low);

T_{Blend} = critical temperature of blended asphalt binder (final desired) (high, intermediate, or low);

%RAP = percentage of RAP expressed as a decimal; and

T_{RAP} = critical temperature of recovered RAP binder (high, intermediate, or low).

X1.3.1.2. Using Equation X1.11 for the high, intermediate, and low critical temperatures respectively, the properties of the virgin asphalt binder needed can be determined.

X1.4. *Blending with a known virgin binder*.

X1.4.1. If the final blended binder grade, virgin asphalt binder grade, and recovered RAP properties are known, then the allowable RAP percentage can be determined.

X1.4.1.1. Determine the allowable RAP percentage using the following equation:

$$\%RAP = \frac{T_{Blend} - T_{Virgin}}{T_{RAP} - T_{Virgin}} \tag{X1.12}$$

where:

T_{Virgin} = critical temperature of virgin asphalt binder (high, intermediate, or low);

T_{Blend} = critical temperature of blended asphalt binder (high, intermediate, or low); and

T_{RAP} = critical temperature of recovered RAP binder (high, intermediate, or low).

X1.4.1.2. Using Equation X1.12 for the high, intermediate, and low critical temperatures, respectively, the allowable RAP percentage that will satisfy all temperatures can be determined.

Standard Specification for

Stone Matrix Asphalt (SMA)

AASHTO Designation: M 325-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Stone Matrix Asphalt (SMA)

AASHTO Designation: M 325-08

1. SCOPE

1.1. This specification covers the design of Stone Matrix Asphalt (SMA) using the Superpave Gyratory Compactor (SGC). The SMA design is based on the volumetric properties of the SMA in terms of air voids (V_a), the voids in mineral aggregate (VMA), and the presence of stone-on-stone contact.

1.2. This standard specifies minimum quality requirements for asphalt binder, aggregate, mineral filler, and stabilizing additives for SMA mixture designs.

1.3. The values stated in SI units are to be regarded as the standard. The U.S. Customary units in parentheses are for information only.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- R 46, Designing Stone Matrix Asphalt (SMA)
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
- T 305, Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2. *ASTM Standards*:

- D 4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- D 5821, Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate

2.3. *Asphalt Institute Publication*:

- MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*

2.4. *National Asphalt Pavement Association Publication*:

- IS 127, *Evaluation of Baghouse Fines for Hot Mix Asphalt*

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3. TERMINOLOGY

3.1. *stone matrix asphalt* (SMA)—a hot mix asphalt (HMA) consisting of two parts, a coarse aggregate skeleton and a rich asphalt binder mortar. The mixture must have an aggregate skeleton with coarse aggregate-on-coarse aggregate contact (generally referred to as stone-on-stone contact). The coarse aggregate is generally considered to be that fraction of the aggregate retained on the 4.75-mm (No. 4) sieve but may be designated as other sizes.

3.2. *air voids* (V_a)—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1).

Note 1—Term defined in the Asphalt Institute Publication MS-2.

3.3. *voids in the mineral aggregate (VMA)*—the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.4. *voids in the coarse aggregate (VCA)*—the volume between the coarse aggregate particles. This volume includes filler, fine aggregate, air voids, asphalt binder, and stabilizing additive (if used).

3.5. *SMA mortar*—a mixture of asphalt binder, filler [material passing the 0.075-mm (No. 200) sieve], and stabilizing additive.

3.6. *stabilizing additive*—either cellulose or mineral fiber.

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4. SIGNIFICANCE AND USE

4.1. This standard may be used for designing and evaluating material and mixture properties for SMA.

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5. ASPHALT BINDER REQUIREMENTS

5.1. The asphalt binder shall be a performance grade meeting the requirements of M 320, which is appropriate for the climate and traffic-loading conditions at the site of the paving project. Guidance for the selection of the appropriate asphalt binder is provided in M 323.

6. AGGREGATE REQUIREMENTS

6.1. Aggregates used in SMA shall conform to the requirements listed below.

6.1.1. *Coarse Aggregate*—Coarse aggregates shall be 100 percent crushed and conform to the quality requirements of Table 1.

6.1.2. *Fine Aggregate*—Fine aggregates shall be 100 percent crushed and conform to the quality requirements of Table 2.

Table 1—Coarse Aggregate Quality Requirements

Test		Method	Minimum	Maximum
Los Angeles (L.A.) Abrasion, percent loss		T 96	—	30[a]
Flat and Elongated, percent[b]	3 to 1	D 4791	—	20
	5 to 1	D 4791	—	5
Absorption, percent		T 85	—	2.0
Soundness (5 Cycles), percent[c]		T 104		
Sodium sulfate or			—	15
Magnesium sulfate			—	20
Crushed Content, percent		D 5821		
One Face			100	—
Two Face			90	—

[a] Aggregates with higher L.A. Abrasion values have been used successfully to produce SMA mixes. However, when the L. A. Abrasion exceeds 30, excessive breakdown may occur in the laboratory compaction process or during in-place compaction.

[b] Flat and Elongated criteria apply to the design aggregate blend.

[c] Sodium sulfate or magnesium sulfate may be used. It is not a requirement to perform both methods.

Table 2—Fine Aggregate Quality Requirements

Test	Method	Minimum	Maximum
Soundness (5 Cycles), percent[a]	T 104		
Sodium sulfate or		—	15
Magnesium sulfate		—	20
Liquid Limit, percent	T 89	—	25
Plasticity Index, percent	T 90	Non-plastic	

[a] Sodium sulfate or magnesium sulfate may be used. It is not a requirement to perform both methods.

7. MINERAL FILLER

7.1. Mineral filler shall consist of finely divided mineral matter such as crusher fines and fly ash. At the time of use, it should be sufficiently dry to flow freely and essentially free from agglomerations. Filler shall be free from organic impurities and have a plasticity index not greater than four.

Note 2—It is recommended that mineral fillers with modified Rigden voids (IS 127) higher than 50 percent not be used in SMA. Experience has shown that fillers exceeding 50 percent excessively stiffen the SMA mortar.

8. STABILIZING ADDITIVE

8.1. A stabilizer such as cellulose or mineral fiber will be added to the mixture. The dosage rate for cellulose shall be approximately 0.3 percent or more by total mixture mass and sufficient to prevent draindown. For mineral fibers, the dosage rate shall be approximately 0.4 percent by total mixture mass and sufficient to prevent draindown. The maximum draindown will be 0.3 percent by weight of the mix when held at the plant temperature for 1 hour.

Note 3—If the draindown from the plant-produced samples exceeds the draindown from laboratory-prepared samples, the quantity of the stabilizer should be increased. To maximize durability (through binder volume), fibers also can be added regardless of draindown.

9. SMA DESIGN REQUIREMENTS

9.1. The combined aggregates shall conform to the gradation requirements of Table 3. When the bulk specific gravities of the different stockpiles to be used in the mixture vary by more than 0.2, the trial blend gradations shall be based on the volumetric percentage.

Table 3—SMA Gradation Specification Bands

Sieve, mm (in.)	Nominal-Maximum Aggregate Size					
	19 mm ($^3/_4$ in.)		12.5 mm ($^1/_2$ in.)		9.5 mm ($^3/_8$ in.)	
	Lower	Upper	Lower	Upper	Lower	Upper
25.0 mm (1 in.)	100					
19.0 mm ($^3/_4$ in.)	90	100	100			
12.5 mm ($^1/_2$ in.)	50	88	90	100	100	
9.5 mm ($^3/_8$ in.)	25	60	50	80	70	95
4.75 mm (No. 4)	20	28	20	35	30	50
2.36 mm (No. 8)	16	24	16	24	20	30
1.18 mm (No. 16)	—	—	—	—	—	21
0.60 mm (No. 30)	—	—	—	—	—	18
0.30 mm (No. 50)	—	—	—	—	—	15
0.075 mm (No. 200)	8.0	11.0	8.0	11.0	8.0	12.0

9.2. The designed SMA mixture shall meet the requirements of Table 4.

Table 4—SMA Mixture Specifications for Superpave Gyratory Compactor[a]

Property	Requirement
Air Voids, %	4.0 (Note 4)
VMA, %	17.0 min
VCA_{MIX}, %	Less than VCA_{DRC} (Note 6)
TSR	0.80 min
Draindown at Production Temperature, %	0.3 max
Asphalt Binder Content, %	6.0 min (Note 7)

[a] SMA Mixture Specifications refer to specimens compacted in accordance with T 312 at 100 gyrations (Note 5).

Note 4—For low-traffic-volume roadways or colder climates, target air void contents less than 4.0 percent can be used, but should not be less than 3.0 percent.

Note 5—When aggregates have a Los Angeles Abrasion loss value greater than 30 percent, the desirable number of SGC design gyrations is 75.

Note 6—See R 46 for instructions on calculating VCA_{MIX} and VCA_{DRC}.

Note 7—Experience has shown that binder contents should be from 6.0 to 7.0 percent. Lowering the binder content below 6.0 percent can detrimentally affect the durability of the SMA. When an SMA mix cannot be designed within the minimum binder content requirements of Table 4 using the available aggregates, refer to the guidance given on this issue in R 46.

9.3. The tensile strength ratio (TSR) of the SMA shall be at least 0.80, at 6.0 ± 1.0 percent air voids, when tested in accordance with T 283.

9.4. Draindown sensitivity shall be determined on the SMA mixture in accordance with T 305 at the anticipated plant-production temperature and shall not exceed 0.3 percent.

Standard Practice for

Selection and Use of Emulsified Asphalts

AASHTO Designation: R 5-08
ASTM Designation: D 3628-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Selection and Use of Emulsified Asphalts

AASHTO Designation: R 5-08
ASTM Designation: D 3628-06

AASHTO R 5-08 is identical to ASTM D 3628-06 except that all references to the ASTM standards listed in the following table shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO
D 977	M 140
D 2397	M 208

Standard Practice for

Classifying Hot Mix Recycling Agents

AASHTO Designation: R 14-88 (2007)
ASTM Designation: D 4552-92 (2004)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Practice for

Classifying Hot Mix Recycling Agents

AASHTO Designation: R 14-88 (2007)
ASTM Designation: D 4552-92 (2004)

AASHTO R 14-88 (2007) is identical to ASTM D 4552-92 (2004) except for the following provisions:

1. All references to the ASTM standards listed in the following table shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO	ASTM	AASHTO
D 70	T 228	D 2170	T 201
D 92	T 48	D 2171	T 202
D 140	T 40	D 2872	T 240
D 1298	T 227	D 3381	M 226
D 1754	T 179		

2. Replace Table 1 with the following table:

Table 1—Physical Properties of Hot Mix Recycling Agents

Test	Test Method	RA 1		RA 5		RA 25		RA 75		RA 250		RA 500	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity at 140°F, cSt[a]	T 201 or T 202	50	150	200	800	1000	4000	5000	10000	15000	35000	40000	60000
Flash point, COC, °F	T 48	425	—	425	—	425	—	425	—	425	—	425	—
Saturates, weight, %[b]	D 2007	—	25	—	25	—	25	—	25	—	25	—	25
Tests on residue from RTF or TF oven, 325°F	T 240 or T 179												
Viscosity ratio[c]		—	3	—	3	—	3	—	3	—	3	—	3
Weight change, ±, %		—	4	—	4	—	3	—	3	—	3	—	3
Specific gravity	T 228 or T 227	Report		Report		Report		Report		Report		Report	

[a] A recycling agent having a viscosity value outside the specified range is acceptable providing it meets all the above criteria, except viscosity, and has a minimum-to-maximum viscosity range comparable to the nearest RA grade.

[b] A recycling agent having a "Saturates weight percent" above 25 and below 30 is acceptable providing it meets all the above criteria except "Saturates weight percent."

[c]
$$\text{Viscosity Ratio} = \frac{\text{Viscosity of Residue from RTF or TF Oven Test at 140°F, cSt}}{\text{Original Viscosity at 140°F, cSt}}$$

Note: Compliance requires the asphalt be extracted from the pavement to be recycled and combined with the recycling agent being tested. This combination should be in accordance with the ratio of recycling agent to recovered asphalt used in the mix. The resulting mixture must meet all specifications for the appropriate grade from M 20 or M 226.

Standard Practice for

Asphalt Additives and Modifiers

AASHTO Designation: R 15-00 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Asphalt Additives and Modifiers

AASHTO Designation: R 15-00 (2008)

1. SCOPE

1.1. This standard practice covers the laboratory testing required to evaluate asphalt additives and modifiers in both neat asphalt and in asphalt-aggregate hot mixtures. The terms “additive” and “modifier” are used interchangeably and are broadly interpreted to include any materials added to asphalt binder in minor amounts, other than mineral fillers, sand, and aggregates, whose purported effect is to improve the performance and service life of pavements or maintenance materials by improving the properties of the asphalt binder or hot mix asphalt, or both.

1.2. Following is a list of the common purposes for which an additive/modifier may be added:

1.2.1. *Anti-Rutting* (permanent deformation).

1.2.2. *Anti-Cracking*.

1.2.2.1. Thermal Cracking (low-temperature cracking, thermal-fatigue cracking).

1.2.2.2. Load-Associated Fatigue Cracking.

1.2.3. *Anti-Stripping*—Moisture susceptibility of the asphalt-aggregate bond.

1.2.4. *Antioxidants*.

1.2.5. *Recycling* (not included).

Recycling is omitted from this standard practice. It is felt that consideration of the various characteristics of the material from the pavement to be recycled and formulation of the recycle mix are so involved as to make inclusion of recycling in this standard practice cumbersome and impractical.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

2.1.1. *Asphalt Binders*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- T 40, Sampling Bituminous Materials

- T 44, Solubility of Bituminous Materials
- T 48, Flash and Fire Points by Cleveland Open Cup
- T 55, Water in Petroleum Products and Bituminous Materials by Distillation
- T 228, Specific Gravity of Semi-Solid Asphalt Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.1.2. *Aggregates*:

- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 37, Sieve Analysis of Mineral Filler for Hot Mix Asphalt
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 133, Density of Hydraulic Cement
- T 248, Reducing Samples of Aggregate to Testing Size

2.1.3. *Mixtures*:

- M 323, Superpave Volumetric Mix Design
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 275, Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 320, Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)
- TP 31, Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension[1]

2.2. *ASTM Standards*:

2.2.1. *Binders*:

- D 3407, Standard Test Methods for Joint Sealants, Hot-Poured, for Concrete and Asphalt Pavements (Withdrawn 1996)

- D 3570, Test Method for Viscosity of Bituminous Materials with a Sliding Plate Microviscometer (Withdrawn 1986)

2.2.2. *Mixtures*:

- D 3497-79 (1995), Standard Test Method for Dynamic Modulus of Asphalt Mixtures
- D 4123, Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures (Withdrawn 2003)

2.3. *Other Methods*:

- NCHRP Report 274, Use of Anti-Stripping Additives in Asphaltic Concrete Mixtures—Laboratory Phase, Transportation Research Board, Washington, DC, December 1984
- FHWA/RD-87/001, Investigation of Asphalt Additives, FHWA, McLean, VA, June 1987
- FHWA/TX-85/347/1, Asphalt-Rubber Binder Laboratory Performance, Texas State Department of Highways and Public Transportation, Austin, TX, August 1985
- NCHRP Report 268, Influence of Asphalt Temperature Susceptibility on Pavement Construction and Performance, Transportation Research Board, Washington, DC, December 1983

3. SUMMARY OF METHOD

3.1. The testing is divided into two phases. Phase I tests the modified binder (with tests of appropriate unmodified controls), while Phase II tests the modified hot mix asphalt. The purpose of dividing the testing into two phases is to use the faster and easier tests of Phase I as a screening method. If an asphalt additive or modifier shows no promise in Phase I, there may be no need to continue to Phase II. This, of course, would not apply if the additive/modifier interacts specifically with the aggregate, e.g., in the case of anti-stripping agents.

4. SIGNIFICANCE AND USE

4.1. This standard practice details the tests and procedure for evaluating asphalt modifiers to be used for paving. The modified asphalt binder is compared, as is appropriate, either with the same asphalt binder unmodified or with asphalt binder from the same base crude refined to a specification grade mimicking the specification-defining properties of the modified asphalt binder as closely as possible.

In most respects the evaluation procedures are those desirable for an unmodified asphalt binder. Both modified asphalt binder and hot mix asphalt using modified asphalt binders are evaluated. Performance-based testing is emphasized.

The procedures go beyond those that would be desirable for unmodified asphalt binder in that unmodified control asphalt binders are used and tested specifically for those properties to be enhanced by the modifier.

If testing (at appropriate additive levels) indicates that the functional purpose of the additive is not fulfilled, testing of the additive may be terminated.

If any of the other important performance properties of the modified asphalt binder are either unsatisfactory or significantly degraded, and cannot be remedied by, e.g., further modification, evaluation of the modifier may likewise be terminated.

If the results of evaluation according to this standard practice are positive, small-scale field trials and economic cost-benefit analysis may be warranted.

If the additive/modifier is being promoted by a supplier to a customer or evaluating laboratory, e.g., a governmental agency, a suggested list of information to be provided by the supplier to such a customer/evaluator is provided in Appendix X1.

5. CHOICE OF CONTROL SAMPLES

5.1. Control samples may be chosen for three purposes. Type A control samples are used for the most general evaluation of additive/modifiers. Type B is used when the supplier believes that his additive/modifier is useful under rather specific circumstances. Type C is used in evaluating an additive/modifier for a specific paving project. A minimum of three samples, i.e., three hot mix asphalt and their corresponding neat asphalt binders, which are commonly used as paving materials, must be chosen.

A. Hot mix asphalt and their corresponding neat asphalt binders spanning the range of those typically used throughout the United States may be chosen. It is recommended that the additive manufacturer obtain representative hot mix asphalt designs and constituent materials currently being produced for and approved by three State highway administrations. Depending upon the purpose of the additive, the manufacturer should obtain the hot mix asphalt and materials from states having experienced that type of asphalt pavement problem.

B. Hot mix asphalt and the corresponding neat asphalt binders recommended by the additive/modifier supplier as particularly appropriate to demonstrate the additive’s enhancement properties may be chosen, or

C. Specific hot mix asphalt and their corresponding neat asphalt binders considered for use in a particular modified asphalt project or in particular States or regions may be chosen.

6. EVALUATION TESTING

Note 1—It is suggested that the testing be done by a laboratory inspected for the appropriate tests by the AASHTO Materials Reference Laboratory (AMRL) and enrolled in the appropriate reference sample program by the AMRL.

6.1. *Relationship of Modified Asphalt Testing to Tests in Standard AASHTO Asphalt Specification*:

6.1.1. A modified asphalt binder, in the first instance, is compared to, and, in general, has to meet the applicable specifications for unmodified asphalt binders. These tests are found in M 320.

6.2. *Order of Performing Tests*:

6.2.1. The testing order should be based on what the asphalt additive is designed to accomplish. The most crucial tests (“go” or “no-go” tests) should be performed first. For example, if the proposed additive is purported to alleviate stripping as its only benefit, it is most appropriate to run Section 6.4.5, Moisture Damage Test, first. Should this test show that the additive provides no anti-stripping properties, there would likely be no reason to run any further tests. If the neat asphalt binder/asphalt binder-aggregate mixture responds favorably to this initial test (or tests), the remaining tests should be performed in order to make sure that the modifier does not have an unfavorable impact on any of the properties of the material.

6.3. *Phase I Testing—Asphalt Binders*:

6.3.1. Pressurized Aging Vessel (PAV) Aging—R 28;

6.3.2. Grading or Verifying the Performance Grade of an Asphalt Binder—R 29;

6.3.3. Bending Beam Rheometer (BBR) Test—T 313;

6.3.4. Direct Tension Test (DTT)—T 314;

6.3.5. Dynamic Shear Rheometer (DSR) Test—T 315;

6.3.6. Viscosity Using Rotational Viscometer—T 316;

6.3.7. Sampling—T 40;

6.3.8. Solubility—T 44;

6.3.9. Flash Point by Cleveland Open Cup—T 48;

6.3.10. Water in Petroleum Products and Bituminous Materials—T 55;

6.3.11. Specific Gravity of Semi-Solid Bituminous Materials—T 228;

6.3.12. Rolling Thin-Film Oven Test—T 240;

Note 2—The following tests need at least verification and often basic development. Hence, the references given are often indicative rather than definitive.

6.3.13. Limiting Stiffness Method for Predicting Cracking Temperature—FHWA/RD-87/001;

6.3.14. Critical Stress Method for Predicting Temperature—FHWA/RD-87/001;

6.3.15. Force-Ductility—FHWA/TX85/347/1;

6.3.16. Dynamic Mechanical Analysis (DMA)—Including Aging Index—FHWA/RD-87/001;

6.3.17. Time-Temperature Degradation Profile of Additive/Modifier—FHWA/RD-87/001;

6.3.18. Aging as Measured by Infrared Spectroscopy (IR)—FHWA/RD-87/001; and

6.3.19. Homogeneity Test (Compatibility Between Modifier and Asphalt)—FHWA/RD-87/001.

6.4. *Phase II Hot Mix Asphalt*:

6.4.1. Short- and Long-Term Aging of Hot Mix Asphalt (HMA)—R 30;

6.4.2. Superpave Volumetric Design for Hot Mix Asphalt (HMA)—R 35 and M 323;

6.4.3. Hot Mix Asphalt (HMA) Specimens by Means of the SHRP Gyratory Compactor—T 312;

6.4.4. Volumetric Analysis (Air Voids and VMA);

6.4.4.1. Theoretical Maximum Specific Gravity—T 209;

6.4.4.2. Bulk Specific Gravity—T 166 or T 275;

6.4.4.3. Percent Air Voids Calculation—T 269;

6.4.4.4. Specific Gravities and Absorption of Aggregate—T 84, T 85, and T 133;

Note 3—The bulk specific gravity of the aggregate is needed to calculate VMA.

6.4.5. Moisture Damage Test—T 283 or NCHRP-274;

Note 4—When testing anti-stripping additives, it is recommended that the retained ratio from these tests for the untreated mixture be less than 70 percent.

6.4.6. Permanent Deformation and Fatigue Cracking Characteristics of Hot Mix Asphalt (HMA) Using the Simple Shear Test (SST) Device—T 320; and

6.4.7. Resilient Modulus by Indirect Tension (IDT)—TP 31.[1]

7. REPORT

7.1. Description of asphalt binders;

7.2. Description of Aggregates;

7.3. Mix Design Properties; and

7.4. Results of Tests Performed.

APPENDIX

(Nonmandatory Information)

X1. INFORMATION FROM ADDITIVE/MODIFIER SUPPLIER:

X1.1. What is the material (trade name, generic name, and specific chemical identity)?

X1.2. Who is the manufacturer (company name, street address, mailing address, zip code, telephone number, fax number, contact person)? Who supplied it for testing (company name, street address, mailing address, zip code, telephone number, fax number, contact person)?

X1.3. Physical properties?

X1.4. Material Safety Data Sheet (MSDS).

Is the material a Resource Conservation and Recovery Act of 1976 (RCRA) hazardous waste?

X1.5. What properties does the Additive/Modifier improve?

X1.5.1. In asphalt binder.

X1.5.1.1. What tests demonstrate this? Give details or references.

X1.5.2. In hot mix asphalt.

X1.5.2.1. What tests demonstrate this? Give details or references.

X1.6. Instructions for Use.

X1.6.1. Percent.

X1.6.2. Method of addition.

X1.6.3. Restrictions on use.

X1.7. Qualitative and Quantitative Analysis of Additive/Modifier.

X1.7.1. Neat.

X1.7.2. In asphalt binder.

X1.7.3. In hot mix asphalt.

X1.8. What asphalt binder, aggregate, and mix design should be used with the additive/modifier? Answer with reference to Section X1.5.

X1.9. Marketing Data.

X1.9.1. Availability.

X1.9.2. Approximate cost.

X1.9.3. Sample availability (optional).

X1.9.4. Which public agencies have used this material?

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[1] TP 31 was last published in the May 2002 Edition of the AASHTO Provisional Standards.

Standard Practice for

Certifying Suppliers of Performance-Graded Asphalt Binders

AASHTO Designation: R 26-01 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Certifying Suppliers of Performance-Graded Asphalt Binders

AASHTO Designation: R 26-01 (2009)

1. SCOPE

1.1. This standard specifies requirements and procedures for a certification system that shall be applicable to all suppliers of performance-graded asphalt binder (PGAB). The requirements and procedures shall apply to materials that meet the requirements of M 320, Section 5, Materials and Manufacture, and which are manufactured at refineries, mixed at terminals, in-line blended, or modified at the hot mix asphalt (HMA) plant.

1.2. *This standard may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with this use. The user of this standard shall be responsible for appropriate safety and health practices.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- T 40, Sampling Bituminous Materials

2.2. *ASTM Standards*:

- D 8, Standard Terminology Relating to Materials for Roads and Pavements
- D 3665, Standard Practice for Random Sampling of Construction Materials

3. TERMINOLOGY

3.1. *AAP*—AASHTO accreditation program.

3.2. *agency*—agency shall be defined as a state highway agency or other agency responsible for the final acceptance of the PGAB.

3.3. *AS*—approved supplier.

3.4. *ASC*—approved supplier certification.

3.5. *asphalt binder*—an asphalt based cement that is produced from petroleum residue either with or without the addition of nonparticulate organic modifiers.

3.6. *PGAB*—performance-graded asphalt binder.

3.7. *quality control testing*—the quality control testing shall be described in the supplier's quality control plan. The supplier's quality control plan shall be approved by the agency.

3.8. *specification compliance testing*—complete testing in accordance with the M 320 specification requirements. The procedure for verification of PGAB as described in R 29 shall be followed.

3.9. *supplier*—a *supplier* shall be defined as one who produces the final product or who makes the blend or modification that alters the properties of the PGAB specified in M 320. A supplier shall be a refinery, a terminal, or an HMA producer. If no modification is made to the PGAB after its initial production at the refinery, the refinery shall be the supplier and must provide the certification. If any modifications are made to the PGAB at the terminal, the terminal shall be the supplier and must provide certification. If any modification, blending, or blending of PGAB from different sources is made at the HMA plant, the HMA producer shall be the supplier and must provide the certification.

Note 1—Various refining techniques can produce equivalent PGAB; however, these asphalts may be incompatible with each other. Users shall consider compatibility before combining asphalts from different sources.

Note 2—Definitions for many terms common to asphalt binder are found in ASTM D 8.

4. SIGNIFICANCE AND USE

4.1. This standard specifies procedures for minimizing disruption of PGAB shipments. This is accomplished by a certification system which evaluates quality control and specification compliance tests performed by the supplier on samples obtained prior to shipment.

4.2. The number of PGAB available under M 320 may require construction of additional storage facilities if the procedure of "sample and hold while testing" is followed exclusively. The addition of new storage capacity at a facility may be infeasible at some locations. Standardization of procedures that allow shipment under an approved supplier certification provides the flexibility needed to use existing facilities and to limit the shipment disruptions.

4.3. This standard provides information on the following activities:

4.3.1. General requirements that the supplier shall satisfy to be given approved-supplier status;

4.3.2. Minimum requirements that shall be included in a supplier's quality control plan;

4.3.3. General requirements that the agency shall satisfy before certification;

4.3.4. Procedure for shipping PGAB under an ASC system;

4.3.5. Procedure for agency monitoring of an ASC system at the shipping facility; and

4.3.6. Procedure for field sampling and testing of PGAB shipped under an ASC system.

5. HAZARDS

5.1. The safety requirements of the field and/or laboratory organization and/or OSHA shall be observed.

6. SAMPLING

6.1. All test samples required by this standard shall be obtained in accordance with T 40 and ASTM D 3665. The use of a random sampling procedure is mandatory to the establishment of a valid certification program.

7. TESTING REQUIREMENTS

7.1. Testing required for this standard shall be performed by a laboratory currently accredited by the AAP. Any satellite laboratory of a supplier that performs required testing under this standard shall be identified in the AS quality control plan (Section 9) and shall be approved by the agency.

Note 3—Cost of this inspection shall be borne by the source of data. Satellite laboratories may be inspected by the source's primary AMRL inspected laboratory staff. A copy of the report of the satellite laboratory inspection shall be provided with the test report, if requested.

8. SUPPLIER REQUIREMENTS

8.1. The supplier shall submit a written request to the agency for authorization to ship PGAB under the ASC system and shall list the PGAB to which the request applies.

8.2. The supplier shall allow the agency to visit the production and/or shipping site to observe the supplier's quality control activities, to inspect the facilities, and to obtain samples for test.

8.3. The supplier shall submit to the agency for approval a complete quality control plan, which complies with the requirements of Section 9.

8.4. The supplier shall follow the procedures described in the approved quality control plan.

8.5. The supplier shall establish a continuing test record for each test required on each PGAB included in the written request prepared to satisfy the requirements of Section 8.1.

8.6. The supplier shall forward to the agency the initial series of test data for each performance grade included in the written request prepared to satisfy the requirements of Section 8.1. The supplier shall also obtain and provide a split sample for the agency if requested.

8.7. The supplier shall submit to the agency all reports required by this standard in a form approved by the agency. A sample of an acceptable worksheet and standard report form is shown in Figures 1 and 2.

SAMPLE ID: ____________

Rotational Viscosity:

Test Temperature: 135°C___ C Spindle #: ____________ Speed: 20 RPM

Three Readings/1-minute intervals: ____________, ____________, ____________

Average: ________ cP X 0.001 = Pa•s

Note: 1cP = 0.001 Pa•s

Rolling Thin-Film Oven Residue:

Time in oven: ________ (+85 minutes) Time out of Oven: ____________

Bottle number				
Weight of bottle and asphalt:		G		g
Weight of bottle:		G		g
Weight of asphalt before heating:		G		g
Asphalt and bottle after heating:		G		g
Mass loss (–) or gain (+):		G		g
Percent loss (–) or gain (+):		%		%

Average percent loss or gain ☐ %

Pressure Aging Vessel Residue:

Time In: ____________ (+20 hours) Time Out: ____________

Aging Test Temperature, nearest 0.1°C: ____________

Maximum and Minimum aging temperature recorded, nearest 0.1°C:

Max: ____________

Min: ____________

Total time during aging that temperature was outside the specified range nearest 0.1 minute: N/A

Total aging time, hours and minutes: ____________

Bending Beam Rheometer:

Sample ID:					
Time Poured:					
Time Trimmed:					
Time in Bath:					
Time Tested:					

Direct Tension Time:

Sample ID:					
Time Poured:					
Time Trimmed:					
Time in Chamber:					
Time Tested:					

Figure 1—Sample Worksheet

Project:		Supplier:	
Sample:		Comments/Requests:	
Tech:			
Date:		Performance Grade:	

Original Binder

Flash Point Temp (T 48):

Min 230°C		°C

Rotational Viscosity (T 316):

Max 3 Pa•s @ 135°C		Pa•s

Dynamic Sheer (T 315):

G*/sin (delta), Min 1.00 kPa:		kPa
Test Temp @ 10 rad/s, °C:		°C

RTFO Residue

Percent Change, (1.00% Max loss):		%

Dynamic Sheer (T 315):

G*/sin (delta), Min 2.20 kPa:		kPa
Test Temp @ 10 rad/s, °C:		°C

PAV Residue

R 28, 20 hours @ 2.07 MPa

Dynamic Sheer (T 315):

G*/sin (delta), Max 5000 kPa:		kPa
Test Temp @ 10 rad/s, °C:		°C

Creep Stiffness (T 313):

S, Max 300 Mpa		MPa
Test Temp @ 60 s, °C		°C
m-value, Min 0.300		

Direct Tension

Failure Strain, Min 1.0%:		%
Test Temp @ 1.0 mm/min, °C		°C

Figure 2—Performance-Graded Binder Test Results According to M 320

8.8. The supplier shall have a satisfactory record of compliance with governing specifications. Judgments by the agency concerning this requirement shall be based on the test results furnished by the supplier and satisfactory results when the monitoring and field tests are compared with supplier tests.

9. SUPPLIER QUALITY CONTROL PLAN—MINIMUM REQUIREMENTS

9.1. The supplier's quality control plan shall identify the following:

9.1.1. Facility type (refinery, terminal, in-line blending or HMA plant);

9.1.2. Facility location;

9.1.3. Name and telephone number of the person responsible for quality control at the facility;

9.1.4. The quality control tests to be performed on each PGAB; and

9.1.5. Name and location of the laboratory performing quality control tests on the PGAB that is shipped.

9.2. The supplier's quality control plan shall include a declaration stating that if a test result indicates that a shipment of PGAB is not in compliance with the purchase specifications, the supplier shall (1) immediately notify the agency of the shipment in question; (2) identify the material; (3) cease shipment until material complies with the specification; (4) notify the agency prior to resuming shipment; and (5) implement any mutually agreed upon procedures for the disposition of the material. In the event a mutual agreement is not obtained, the specifying agency shall have final authority in the decision on specification compliance.

9.3. The supplier's quality control plan shall describe method and frequency for initial testing, quality control testing, and specification compliance testing.

9.3.1. *Initial Testing*—For each grade of PGAB to be supplied, specification compliance testing (complete M 320 testing) shall be performed for at least three consecutive lots. A lot may be a fixed batch of material or a specified quantity in a continuous operation (see Note 4). The supplier and the agency shall agree on a lot size. The agency must approve any change to a lot size.

Note 4—If a batch operation is used to manufacture the PGAB, a tank may be defined as a lot. Lot size would be the amount of material batched into the tank. If a continuous process (in-line blending or a shipment from "live" tanks) is used to manufacture the PGAB, lot size may be obtained at random during the production for continuous operations. Lot size shall depend on the production method used and the quantity of the PGAB produced.

9.3.2. *Reduced Frequency of Testing for Specification Compliance*—If approved by the agency, the frequency of testing for specification compliance may be decreased if the individual M 320 test result for every sample of the initial testing is within specification by at least the tolerance of the test method for each of the required test methods. With the approval of the agency, the frequency of testing may be further reduced as long as the individual test results continue to meet the tolerance criterion. If the tolerance criterion is not met, every lot will continue to be tested for the individual M 320 property until three consecutive lots comply with the tolerance criterion.

9.3.3. *Minimum Frequency*—Specification compliance testing shall be run at the minimum frequency required by the agency for each PGAB that is supplied.

9.3.4. *Quality Control Testing for Guiding Manufacturer*—At least two M 320 tests shall be used for monitoring high and low temperature properties of the PGAB. Non-M 320 tests may be used for guiding manufacturer, if approved by the agency. The use of non-M 320 tests does not preclude the need to meet M 320 specifications or to run complete M 320 tests according to the guidelines in Section 9.3.

9.4. The supplier's quality control plan shall include a statement that the supplier will prepare monthly summary reports for all quality control and specification compliance tests performed during that period and will submit them to the agency on request.

9.5. The supplier quality control plan shall provide an outline of the procedure to be followed for checking transport vehicles before loading to prevent contamination of shipments. The outline shall include a statement that the transport vehicle inspection report, signed by the responsible inspector, shall be maintained in the supplier's records, and will be made available to the agency on request.

9.6. The supplier shall submit a written request to the agency for authorization to use in-line blending of additives that meet Section 5 of M 320 at the HMA plant to produce PGAB. With the request, the supplier shall submit (1) a sample of the additives; (2) a sample of the base binder materials; (3) a notice of the proportions that will be used; and (4) the M 320 test results for the base binder material and for the blended binder material determined under the requirements of Section 8.

9.6.1. The supplier, if an HMA producer, shall submit a detailed plan for QC at the HMA plant. The QC plan shall conform to the procedure established in Section 9.3 with the following modifications: (1) the initial testing shall be conducted on the modified binder that is sampled beyond the in-line blending point, and (2) the supplier shall keep a record of the proportions, based on mass or other indicators. The supplier and agency shall agree on the frequency for recording the proportions. (See Section 3.6.)

Note 5—For additives that do **not** meet the requirements of Section 5, M 320, the supplier may submit a written request to the agency for authorization to use solid additives that are to be added directly to the mix at the asphalt batch plant or the drum mix plant. With the request, the supplier shall submit (1) a sample of the additives; (2) a sample of the base binder materials; (3) a notice of the proportions that will be used; and (4) the M 320 test results for the base binder material and for the blended binder material, as applicable under M 320, determined under the requirements of Section 8.

M 320 and the test procedures may not be applicable for some of the solid additives because of their size range after blending with the base binder or other characteristics of the modifier. If the binder fails to meet any of the criteria under Section 5 of M 320, acceptance of the binder shall be at the discretion of the agency. Supplier and agency shall therefore agree on the test methods to be used. The agency may allow the use of M 320 tests or may require testing of the resultant HMA using selected test procedures to assure the level of performance expected.

The supplier shall submit a detailed plan for QC at the HMA plant. The QC plan shall conform to the procedure established in Section 9.3 with the following modifications: (1) initial testing shall be conducted on a laboratory blend of the solid additive and the binder to be added at the HMA plant; (2) the supplier shall keep a record of the proportions, based on mass or other indicators; and (3) the supplier and agency shall agree on the frequency for recording the proportions.

Note 6—*Reclaimed Asphalt Pavement* (RAP)—The HMA producer may submit a written request to the agency for authorization to add RAP to the mix at the HMA plant to meet the PGAB specified. With the request, the HMA producer shall submit (1) a sample of the RAP; (2) a sample of the base binder materials; (3) a notice of the proportions that will be used; and (4) the M 320 test results for the base binder material and for the blended binder material determined under the requirements of Section 8.

The HMA producer shall submit a detailed plan for QC at the HMA plant. The QC plan shall conform to the procedure established in Section 9.3 with the following modifications: (1) initial testing shall be conducted on a laboratory blend of the asphalt cement extracted from the RAP sample, any addition of additive, and the binder material that is to be added at the HMA plant; (2) the HMA producer shall keep a record of the proportions, based on mass or other indicators; and (3) the HMA producer and agency shall agree on the frequency for recording the proportions.

The agency may waive the requirement for testing the laboratory-blended binder and may use other guidelines for selecting the performance grade of the new binder relative to the amount of RAP used.

10. AGENCY REQUIREMENTS

10.1. The agency shall verify that the supplier's quality control plan is adequate. The agency may visit the shipping site when required.

10.2. The agency shall notify the supplier that the supplier's application for AS status has been granted. The notification shall include a list of the PGAB covered.

10.3. The agency shall verify that the supplier's primary testing laboratory is currently AASHTO accredited.

10.4. The agency may perform split sample testing in accordance with Section 12.

10.5. The agency may perform quality assurance sampling and testing in accordance with Section 13.

10.6. The agency shall authorize shipment of each listed PGAB under the ASC system only after all ASC system requirements have been satisfied.

10.7. The agency shall inspect the operations of the supplier's facility related to the PGAB shipments when required.

10.8. The agency shall notify the supplier when split sample data versus supplier sample data do not compare within the limits established in Sections 12 and 13.

Note 7—The supplier and/or the HMA producer may take a split sample for comparison purposes. If a split sample is taken, a third sample shall be taken as a referee. The referee sample shall be retained either by the agency or by the HMA producer until the test results are available. If the test results are disputed, the agency and supplier shall agree upon a test procedure for the referee sample.

11. REQUIREMENTS FOR SHIPPING PGAB BY AN APPROVED SUPPLIER

11.1. The supplier's quality control plan as approved by the agency shall be implemented. (See Section 9.)

11.2. The supplier shall make PGAB shipments covered by the certification as dictated by shipping schedules.

11.3. Each shipment shall be accompanied by two copies of the bill of lading, which shall include (1) the name and location of the supplier; (2) the performance grade of material; (3) the quantity of material shipped; (4) the date of shipment; (5) a statement certifying the material meets specification requirements; and (6) a statement certifying that the transport vehicle was inspected before loading and was found acceptable for the material shipped.

Note 8—On any invoice or Bill of Lading, it is recommended that metric tons be used as the primary unit of measurement.

11.4. If the specification compliance test results do not conform to PGAB specifications, the supplier shall remove the noncompliant material from the shipping queue as outlined in Section 9.2.

11.5. Based on the agency's split sample testing on the referee sample (see Note 7), price adjustment may be made for material that does not comply with the specified PGAB requirements. The price adjustment shall be determined by the agency. If problems with the PGAB recur at the HMA plant, the agency may suspend use of the PGAB until the cause for noncompliance with specifications can be identified and corrected.

12. SPLIT SAMPLE TESTING

12.1. The agency may test split samples that are obtained at random from the supplier's facility.

Note 9—Split samples will be obtained from the same general points in the supplier's shipping process from which the supplier's samples are taken, for example, from a storage tank at the refinery, from a holding tank at a terminal, or from a loading line downstream from the blending operation of an in-line blending process.

12.2. The agency shall determine the frequency of split sample testing.

12.3. If the split sample data and the supplier test data are not within the test tolerance specified (see Section 15), an immediate investigation shall be conducted to determine the reason for the difference between the data. Unless available facts indicate otherwise, the investigation shall include a review of sampling and testing procedures of both supplier and agency.

13. FIELD SAMPLING

13.1. The agency or HMA producer may design the field-sampling plan to accomplish the intended purpose.

Note 10—Field samples may be taken for several different purposes: to determine the type and magnitude of any changes in the properties of the PGAB during transportation and storage; to determine that the material received in the field is the material ordered; or to verify that the quality control/quality assurance system is performing as intended.

13.2. The agency may obtain samples from the field facility on a random basis for the purpose of quality assurance.

13.3. The agency shall determine a minimum frequency of field sampling that shall be adequate to satisfy the purpose for which the field samples are taken.

13.4. If the field test data are not within tolerance, the agency shall immediately notify the approved supplier and HMA producer. Unless available facts indicate otherwise, an investigation shall be conducted that shall include a review of quality control and sampling and testing procedures for field sampling and split sampling. When the differences are not readily resolved, all facts available to identify the problem shall be used to decide on an appropriate course of corrective action.

13.5. If the PGAB fails to comply with the specification, the supplier or HMA producer shall immediately investigate the possibility of contamination in transport vehicles, field storage tanks, pumps, lines, and at handling facilities. If the cause is determined, correction shall be made promptly. If field test data show a serious departure from the specifications, the supplier or HMA producer shall delay the project work pending corrective action.

14. REPORT AND DATA SHEETS

14.1. *Supplier Reports*—The supplier shall prepare the reports described in Sections 8.1, 8.3, 8.6, 8.7, 9.2, 9.4, 9.5, 11.2, and 11.3.

14.2. *Agency Reports*—The supplier may request copies of the split sample test results and field test data.

15. KEYWORDS

15.1. Approved Supplier (AS); Approved Supplier Certification (ASC); certification system; certified shipments; Performance-Graded Asphalt Binder (PGAB) Certification.

Standard Practice for

Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)

AASHTO Designation: R 28-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)

AASHTO Designation: R 28-09

1. SCOPE

1.1. This standard practice covers the accelerated aging (oxidation) of asphalt binders by means of pressurized air and elevated temperature. The practice is intended to simulate in-service oxidative aging of asphalt binders and is intended for use with residue from T 240 (RTFOT).

1.2. The aging of asphalt binders during service is affected by mixture-associated variables such as the volumetric proportions of the mix, permeability of the mix, properties of the aggregates, and possibly other factors. This practice is intended to provide an evaluation of the relative resistance of different asphalt binders to oxidative aging at selected temperatures and cannot account for mixture variables.

1.3. *This standard practice may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- M 320, Performance-Graded Asphalt Binder
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)

2.2. *ASTM Standard*:

- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques

2.3. *Deutche Industrie Norm (DIN) Standard*:

- 43760, Standard for Calibrating Thermocouples

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

3.1.2. *in-service*—refers to aging of the asphalt binder that occurs in the pavement as a result of the combined effects of time, traffic, and the environment.

4. SUMMARY OF PRACTICE

4.1. Asphalt binder is first aged using T 240 (RTFOT). A specified thickness of residue, from the RTFOT, is then placed in stainless steel pans and aged at the specified aging temperature for 20 hours in a vessel pressurized with air to 2.10 MPa. The aging temperature is selected according to the grade of the asphalt binder. At the completion of the PAV process, the asphalt binder residue is then vacuum degassed.

5. SIGNIFICANCE AND USE

5.1. This practice is designed to simulate the in-service oxidative aging that occurs in asphalt binders during pavement service. Residue from this practice may be used to estimate the physical or chemical properties of asphalt binders after 5 to 10 years of in-service aging in the field.

5.2. Asphalt binders aged using R 28 are used to determine specification properties in accordance with M 320. The asphalt binder is aged with the RTFO test prior to this conditioning step. Tank asphalt binders, as well as RTFOT and residue from this practice, are used to determine specification properties in accordance with M 320.

5.3. For asphalt binders of different grades or from different sources, there is no unique correlation between the aging time and temperature in this practice and in-service pavement age and temperature. Therefore, for a given set of in-service climatic conditions, it is not possible to select a single PAV aging time and temperature that will predict the properties of all asphalt binders after a specific set of in-service exposure conditions.

5.4. The relative degree of hardening of different asphalt binders varies at different aging temperatures in the PAV. Therefore, two asphalt binders may age similarly at one temperature, but age differently at another temperature.

6. APPARATUS

6.1. A test system consists of a pressure vessel, pressure controlling devices, temperature controlling devices, pressure and temperature measuring devices, and a temperature-recording device (Figure 1).

6.1.1. *Pressure Vessel*—A stainless steel pressure vessel designed to operate at 2.1 ± 0.1 MPa between 90 and 110°C with interior dimensions adequate to hold ten stainless steel pans and a pan holder. The pressure vessel shall contain a pan holder capable of holding ten stainless steel pans in a horizontal (level) position such that the asphalt binder film thickness in the bottom of the pans does not vary by more than 0.5 mm across any diameter of the pan. The holder shall be designed for easy insertion and removal from the vessel when the holder, pans, and asphalt binder are at the test temperature. A schematic showing the vessel, pan holder and pans, and specifying the dimensional requirements is shown in Figure 2.

Note 1—The vessel may be a separate unit to be placed in a forced draft oven for conditioning the asphalt binders or an integral part of the temperature control system (for example, by direct heating of the vessel or by surrounding the vessel with a permanently affixed heating unit, forced air oven, or liquid bath).

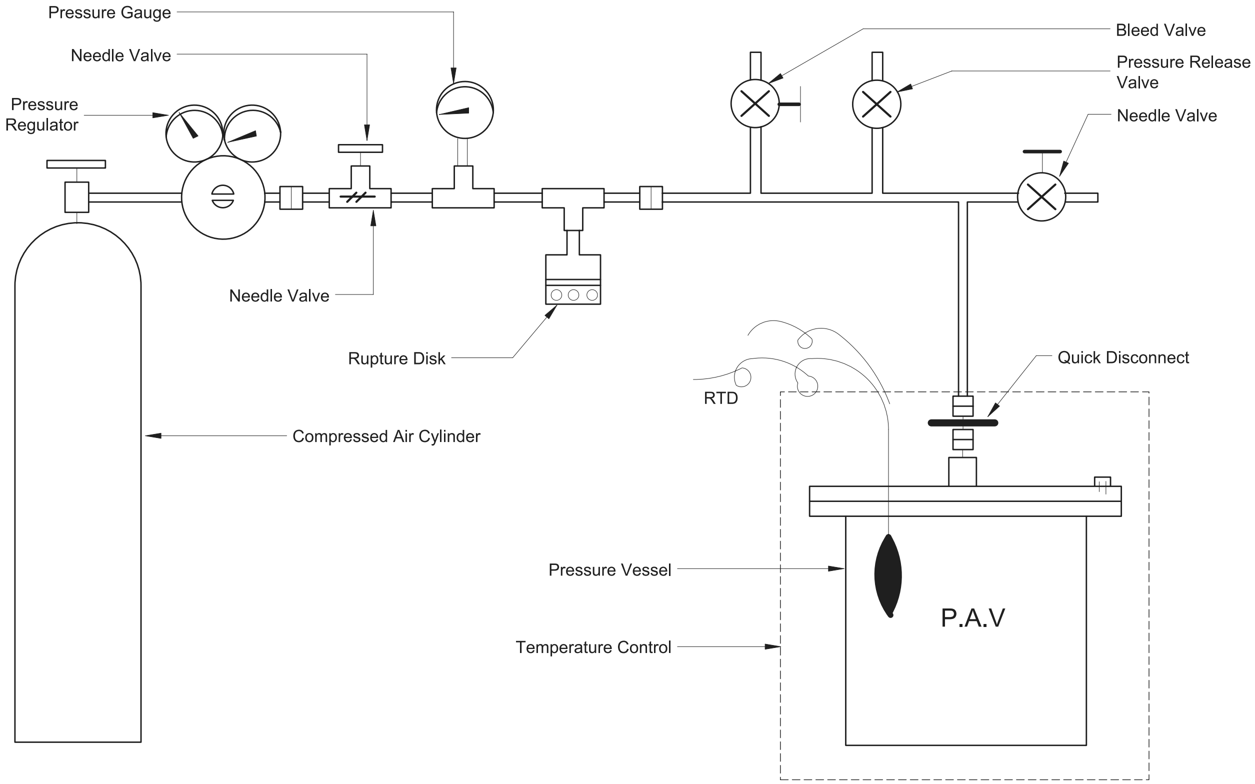
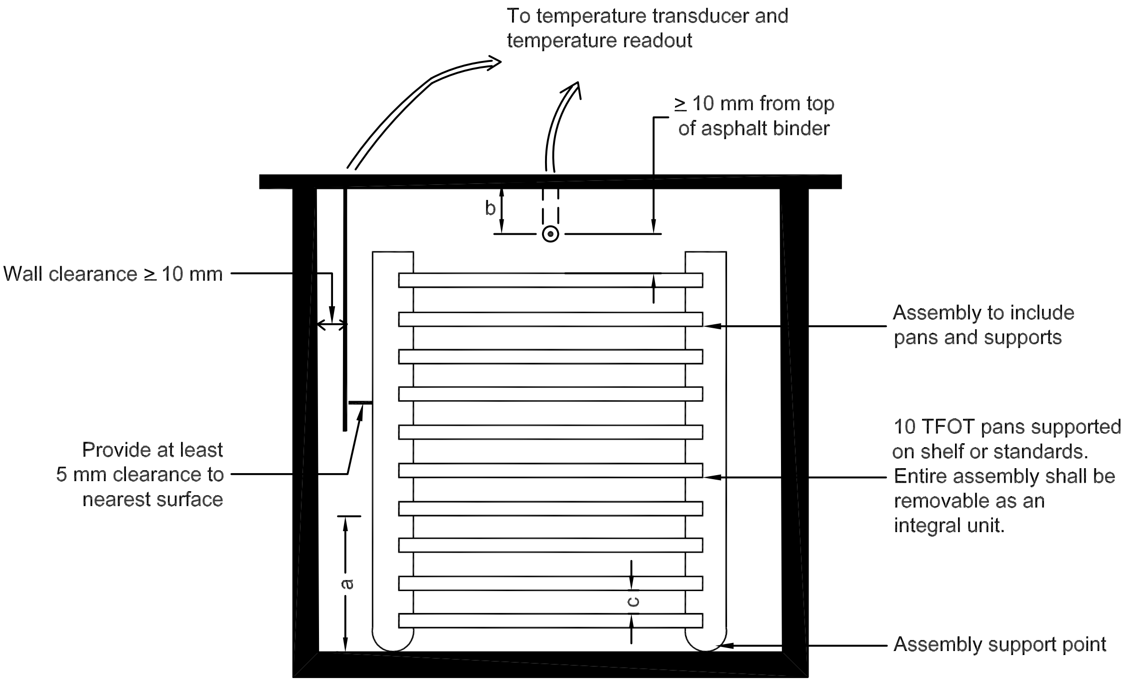


Figure 1—Schematic of Typical PAV Test System



Notes:
1. Distance "a" controls the levelness of the pans. The assembly shall be supported at three or more support points. The distance "a", measured from each assembly support point to the bottom of the pan (top of shelf or pan support point), shall be controlled to ±0.05 mm. Provisions shall be made to ensure that the bottom of the vessel is leveled so that the thickness of the binder in the pan varies by no more than ±0.05 mm across the diameter of any pan.
2. Distance "b" shall be such that any active portion of the temperature transducer is ≥10 mm from the top surface of the vessel.
3. Distance "c" shall be ≥12 mm.

Figure 2—Schematic Showing Location of Pans and RTD within Representative PAV

6.1.2. *Pressure Controlling Devices*:

6.1.2.1. A pressure release valve that prevents pressure in the vessel from exceeding 2.2 MPa during the aging procedure.

6.1.2.2. A pressure regulator capable of controlling the pressure within the vessel to ±1 percent, and with a capacity adequate to reduce the pressure from the source of compressed air so that the pressure within the loaded pressure vessel is maintained at 2.1 ± 0.1 MPa during the practice.

6.1.2.3. A slow release bleed valve that allows the pressure in the vessel at the completion of the conditioning procedure to be reduced at an approximately linear rate from 2.1 MPa to local atmospheric pressure within 9 ± 1 minutes.

6.1.3. *Temperature Controlling Devices*—A temperature control device as described in Section 6.1.3.1 or Section 6.1.3.2 for maintaining the temperature during the aging procedure at all points within the pressure vessel at the aging temperature ±0.5°C and a digital proportional controller for maintaining the specified temperature control.

6.1.3.1. A forced-draft oven or fluid bath capable of (1) bringing the loaded unpressurized vessel to the desired conditioning temperature ±0.5°C, as recorded by the Resistance Thermal Detector (RTD) inside the vessel within 2 hours, and (2) maintaining the temperature at all points within the pressure vessel at the aging temperature ±0.5°C. The oven shall have sufficiently large interior dimensions to allow forced air to freely circulate within the oven and around the pressure vessel when the vessel is placed in the oven. The oven shall contain a stand or shelf which supports the loaded pressure vessel in a level position above the lower surface of the oven (i.e., maintains the film thickness in the aging pans within the specified tolerance).

6.1.3.2. A pressure vessel with integral temperature control system that is capable of (1) bringing the loaded pressure vessel to the desired conditioning temperature ±0.5°C within 2 hours, as recorded by the RTD inside the loaded pressure vessel, and (2) maintaining the temperature at all points within the pressure vessel at the aging temperature ±0.5°C.

6.1.4. *Temperature and Pressure Measuring Devices*:

6.1.4.1. A platinum RTD accurate to the nearest 0.1°C and meeting DIN Standard 43760 (Class A), or equal, for measuring temperature inside the pressure vessel. The RTD shall be calibrated as an integral unit with its respective meter or electronic circuitry.

Note 2—The RTD or thermistor and its meter may be calibrated by the manufacturer or a commercial vendor. Verification can be obtained by comparing the output from the RTD with an NIST traceable ASTM 94C mercury in glass thermometer in accordance with ASTM E 220. A stirred fluid bath is suitable for calibrating the thermal detector. Select a partial immersion mercury-in-glass thermometer with an appropriate range and place the thermal detector and the thermometer in the stirred water bath. Fasten the detector to the glass thermometer with a rubber band or rubber O-ring. Allow the bath, detector, and thermometer to come to thermal equilibrium and record the temperature of the glass thermometer and the readout from the thermal detector. The temperature in the bath shall not change by more than 0.1°C per minute during the calibration process.

6.1.4.2. *Temperature-Recording Device*—A strip chart recorder or other data acquisition system capable of recording temperature throughout the test to 0.1°C. As an alternative, an electronic device capable of reporting maximum and minimum temperatures (accurate to ±0.1°C) may be used.

6.1.4.3. A pressure gauge capable of measuring the pressure in the pressure vessel to within ±1 percent during the test.

6.2. *Stainless Steel Pans*—Ten standard stainless steel pans with an inside diameter of 140 mm ($5^1/_2$ in.) and 9.5 mm ($^3/_8$ in.) deep with a flat bottom. Pans shall be made of stainless steel and should have a metal thickness of approximately 0.635 mm ($^1/_4$ in.).

6.3. *Balance*—A balance conforming to the requirements of M 231, Class G 2.

6.4. *Vacuum Oven*—A vacuum oven capable of maintaining a temperature up to 180°C with an accuracy of ±5.0°C and a vacuum of 1.0 kPa absolute.

6.5. *Vacuum System*—A vacuum system capable of generating and maintaining pressures below 15 kPa absolute. Suitable vacuum systems include a vacuum pump, air aspirator, or house vacuum system.

7. MATERIALS

7.1. Commercial bottled air or equivalent.

8. HAZARDS

8.1. Use standard laboratory safety procedures in handling the hot asphalt binder when preparing test specimens and removing the residue from the pressure vessel. Use special precaution when lifting the pressure vessel.

9. CALIBRATION AND STANDARDIZATION

9.1. *Temperature Detector*—Verify the calibration of the RTD to 0.1°C at least every 6 months using a calibrated thermometer.

9.2. *Pressure Gauge*—Standardize the pressure gauge to an accuracy of 1 percent at least every 6 months.

Note 3—The pressure gauge is usually calibrated by the manufacturer or a commercial calibration service. Verification of the continued stability of the pressure gauge within the specified requirements should be done periodically by checking against another certified pressure measurement device.

9.3. To determine the optimum temperature at which to apply pressure to the pressure vessel, several tests should be made. With the vessel loaded with pan rack and empty pans, increase the temperature to aging temperature. When the temperature inside the pressure vessel is within 10°C of the aging temperature, apply an air pressure of 2.1 ± 0.1 MPa. Record the temperature increase when the pressure is applied. Perform the procedure at least three times and use the average temperature increase to establish the temperature at which to apply pressure to the vessel for performing the aging procedure.

10. PROCEDURE

10.1. Condition the asphalt binder and determine the mass change during conditioning in accordance with T 240 (RTFOT).

10.2. Combine the hot residue from the RTFOT into a single container and stir it to blend. Transfer the residue into (or leave it in) stainless steel pans for PAV conditioning or allow the hot residue in the container to cool to room temperature and cover and store at room temperature for PAV conditioning at a later date. If conditioned asphalt binder is allowed to cool to room temperature, heat it until it is sufficiently fluid to pour and stir it before pouring it into the stainless steel pans.

10.3. Place the pan holder inside the pressure vessel. If an oven is used, place the pressure vessel inside the oven. If an integrated temperature control pressure vessel is used, turn on the heater. Select an aging temperature and preheat the pressure vessel to the aging temperature selected.

Note 4—If conditioning asphalt binders for conformance to M 320, select the appropriate aging temperature from Table 1 of M 320.

Note 5—Preheating the vessel 10 to 15°C above the conditioning temperature can be used to reduce the drop in PAV temperature during the loading process and minimize the time required to stabilize the system, after loading, to attain the required temperature.

Note 6—Aging temperature in the PAV is selected to account for different climatic regions. Temperatures in excess of approximately 115°C can change the chemistry of asphalt binders aged in accelerated tests and should be avoided.

10.4. Place the stainless steel pan on a balance and add 50 ± 0.5 g of asphalt binder to the pan. This amount will yield approximately a 3.2-mm-thick film of asphalt binder.

Note 7—The mass change is not measured as part of this procedure. Mass change is not meaningful because the asphalt binder absorbs air as a result of pressurization. Any gain in mass as a result of oxidation is masked by air absorbed by the asphalt binder as a result of the pressurization.

10.5. If the vessel is preheated to other than the desired aging temperature, reset the temperature control on the heating device to the aging temperature.

10.6. Place the filled pans in the pan holder. (Pans containing asphalt binders from different sources and grades may be placed in the pressure vessel during a single test.) Place the pan holder with filled pans inside the pressure vessel, and close the pressure vessel.

10.7. If an oven is used, place the loaded and closed pressure vessel in the oven.

10.8. Connect the temperature transducer line and the air pressure supply line to the loaded pressure vessel's external connections.

10.9. Perform the operations described in Sections 10.5 to 10.8 as quickly as possible to avoid cooling of the vessel and pan holder.

10.10. Wait until the temperature inside the pressure vessel is within 20°C of the aging temperature, apply an air pressure of 2.1 ± 0.1 MPa, and then start timing the test. If the temperature inside the vessel has not reached the desired temperature for applying pressure within 2 hours of loading the pan holders and pans, discontinue the procedure and discard the asphalt samples.

Note 8—Pressures in excess of 2.1 MPa do not substantially increase the rate of aging. Therefore, higher pressures are not warranted.

Note 9—Once pressurized, the temperature inside the pressure vessel will equilibrate rapidly. The time under pressure, not to include any preheating time at ambient pressure, is the aging time. Relatively little aging occurs at ambient pressure during the time that the vessel is being reheated to the test temperature, given that asphalt binder residue under test has been exposed to 163°C in the RTFOT.

10.11. Maintain the temperature and air pressure inside the pressure vessel for 20 h ± 10 min.

10.12. At the end of the 20-hour test period, slowly begin reducing the internal pressure of the PAV, using the air pressure bleed valve. Adjust the bleed valve to an opening that requires 9 ± 1 min to equalize the internal and external pressures on the PAV, thus avoiding excessive bubbling and foaming of the asphalt binder. During this process it may be necessary to adjust the setting of the needle valve as the pressure drops in order to maintain an approximate linear rate of pressure decrease. Do not include the pressure release and equalization time as part of the 20-hour aging period.

10.13. If the temperature indicated by the temperature-recording device falls above or below the target aging temperature ±0.5°C for more than 60 minutes during the 20-hour aging period, declare the test invalid and discard the material.

10.14. Remove the pan holder and pans from the PAV, and place the stainless steel pans in an oven set at a minimum temperature for a minimum time until sufficiently fluid to pour. Stir it gently to assist in the removal of air bubbles.

Note 10—A temperature of 163°C has been found to be suitable for many binder grades.

10.15. Preheat the vacuum oven until it stabilizes at 170 ± 5°C. Select a container of dimensions such that the depth of the residue in the container is between 15 and 40 mm. If tests to determine the properties of the PAV residue are not performed immediately, it is permissible to divide the contents of the container into individual tins and to cover and store them at room temperature for future testing.

10.16. Remove the pans from the oven, and pour the hot residue from the pans into a single container. After the last pan is scraped, transfer the container to the vacuum oven within one minute and maintain the temperature in the vacuum oven at 170 ± 5°C for 10 ± 1 min, without a vacuum applied. After the 10 minutes of equilibration, open the vacuum valve as rapidly as possible to reduce the pressure in the oven to 15 ± 2.5 kPa absolute. Maintain the absolute pressure in the oven at 15 ± 2.5 kPa for 30 ± 1 min. At the end of the 30 minutes, release the vacuum, and remove the container. If any bubbles are visible on the surface of the residue, remove them by flashing the surface of the residue with a torch or hot knife.

Note 11—A pressure of 15 ± 2.5 kPa absolute is equal to a standard vacuum gauge reading of 25 to $26^1/_2$ in. Hg. Consult the manufacturer for adjusting the pressure for local barometric pressure conditions.

Note 12—If the material foams over the lip of the container during the de-gassing, slowly and temporarily reduce the vacuum until the foaming ceases.

11. REPORT

11.1. *Report the following information*:

11.1.1. Sample identification;

11.1.2. Aging test temperature, nearest 0.5°C;

11.1.3. Maximum and minimum aging temperature recorded, nearest 0.1°C;

11.1.4. Total time during aging that temperature was outside the specified range, nearest minute;

11.1.5. Total aging time, hours and minutes; and

11.1.6. Report the heating temperature and heating time if temperatures greater than 163°C are required at any time during the handling of the material.

12. PRECISION AND BIAS

12.1. *Precision*—The research required to develop precision estimates for tests performed on PAV residue has not been conducted.

12.2. *Bias*—The research required to establish the bias of tests performed on PAV residue has not been conducted.

13. KEYWORDS

13.1. Accelerated aging; elevated temperature; in-service aging; PAV; pressure aging; pressure aging vessel.

Standard Practice for

Grading or Verifying the Performance Grade (PG) of an Asphalt Binder

AASHTO Designation: R 29-08

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Practice for

Grading or Verifying the Performance Grade (PG) of an Asphalt Binder

AASHTO Designation: R 29-08

1. SCOPE

1.1. This standard practice describes the testing required to determine the performance grade (PG) of an asphalt binder according to M 320, Table 1. It presents two approaches. In the first, the PG of an unknown asphalt binder is determined. In the second, the nominal PG of an asphalt binder is verified. It also provides an estimate of the time required to complete a single test sequence.

1.2. *This standard practice may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- T 48, Flash and Fire Points by Cleveland Open Cup
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

3. SUMMARY OF THE PRACTICE

3.1. The tank (as-received) sample of asphalt binder is tested to determine the flash point (T 48), viscosity at 135°C (T 316), and shear modulus (G^*) and phase angle (δ) (T 315).

3.2. The asphalt binder is aged in the rolling thin-film oven (T 240), and the residue is tested to determine the mass change (T 240) and the shear modulus (G^*) and phase angle (δ) (T 315).

3.3. The residue from the rolling thin-film oven (RTFO) is aged in the pressurized aging vessel (R 28), and this residue is tested to determine the shear modulus (G^*) and phase angle (δ) (T 315), creep stiffness (S) and slope, *m*, of the log creep stiffness versus log time relationship at 60 seconds (T 313), and the failure strain in direct tension (T 314), as necessary.

3.4. Based on these test results, the asphalt binder is graded according to M 320, Table 1.

4. SIGNIFICANCE AND USE

4.1. This practice describes the testing required for grading or verifying the PG of an asphalt binder according to M 320, Table 1.

5. ESTIMATED TIME NECESSARY FOR TESTING

5.1. For both grading and verification, if the analysis is started at the beginning of a morning work shift, all testing and analysis should be completed during the afternoon of the next day. This schedule provides the 20 hours needed for PAV conditioning. Of course, samples can be aged and analyzed in parallel, and the productivity of the laboratory thus increased. However, for the purpose of this document, analysis of a single asphalt binder will be discussed.

6. TEST PROCEDURE FOR GRADING AN UNKNOWN ASPHALT BINDER

6.1. Prepare samples and test specimens using the procedures specified in the applicable test methods. In the case where the grade of the asphalt binder is unknown, approximately 400 g of unaged asphalt binder is required to complete the tests with the necessary replicates.

6.2. Begin conditioning asphalt binder in the RTFO. Condition a sufficient amount of asphalt binder depending on the type and number of tests to be performed.

Note 1—Two BBR beams requiring PAV aged material are needed at each test temperature. In addition, at least six direct tension (DT) specimens requiring PAV aged material may also be needed at each test temperature. A minimum of two test temperatures will be required. This testing will utilize approximately 200 g of RTFO residue.

6.3. Perform the DSR test (T 315) on the original asphalt binder beginning at 58°C, and increase or decrease the test temperature at 6.0°C increments until a value for $G^*/\sin\delta \leq 1.00$ kPa is obtained. The highest test temperature where the value for $G^*/\sin\delta \geq 1.00$ kPa determines the starting PG grade.

Note 2—For example, if $G^*/\sin\delta$ is 0.60 kPa at 64°C and 1.20 kPa at 58°C, the starting asphalt binder grade is PG 58-xx.

6.4. Determine the flash point on a sample of original binder using T 48. The flash point must be greater than 230°C to meet the requirements of M 320.

6.5. Determine the viscosity of the original asphalt binder at 135°C using T 316. The viscosity must not exceed 3 Pa·s to meet the requirements of M 320.

6.6. After the RTFO conditioning (T 240) is complete, determine the mass change of the original asphalt binder. The mass change must be ≤1.00 percent to meet the requirements of M 320.

6.7. If the original asphalt binder does not meet M 320 requirements for the tests in Sections 6.4, 6.5, or 6.6, the asphalt binder will not satisfy the specification for any PG, and no further testing is required.

6.8. Perform the DSR test (T 315) on the RTFO residue at the test temperature used to determine the starting PG grade (Section 6.3) to confirm the high temperature grade of the asphalt binder (e.g. PG 46-xx, 52-xx, 58-xx, etc.). The value for $G^*/\sin\delta$ of the RTFO residue must be ≥2.20 kPa. Choose the lower performance grade in cases where the test values in Sections 6.3 and 6.8 give conflicting grades.

6.9. Age a sufficient quantity of RTFO residue in the PAV (R 28) (Note 1). Use an aging temperature of 90°C for starting grades PG 46-xx or 52-xx and 100°C for starting grades PG 58-xx and higher. A PAV temperature of 110°C is used in simulating desert environments.

Note 3—Complete Sections 6.1 through 6.9 during the first day of testing. This schedule will allow further testing to begin on the second day after PAV aging is complete.

6.10. At the conclusion of the PAV aging procedure (R 28), including aging, combining, and degassing the binder, prepare two BBR specimens for each test temperature according to T 313. Retain sufficient residue to prepare at least six DT specimens for each test temperature, if required.

6.11. Perform the DSR test (T 315) on the PAV residue beginning at a test temperature of 16 and 19°C, respectively, for starting grades PG 52-xx and 58-xx, 22°C for starting grade PG 64-xx, and 28°C for starting grade PG 70-xx, unless there is other information to suggest the temperature at which $G^*\sin\delta \leq 5000$ kPa. Decrease or increase the test temperature at 3.0°C increments until the value for $G^*\sin\delta > 5000$ kPa.

6.12. Determine the beginning test temperature for the BBR test (T 313) on the PAV residue from Table 1 of M 320 using the starting PG grade determined in Section 6.3 and the lowest temperature from Section 6.11 where the value for $G^*\sin\delta \leq 5000$ kPa, unless there is other information to suggest the temperature at which the creep stiffness (S) ≤300 MPa and the slope (m) ≥0.300.

6.13. Test pairs of BBR specimens according to T 313 beginning at the test temperature selected in Section 6.12 and increasing at 6.0°C increments, until a creep stiffness (S) and slope (m) meeting the requirements of M 320, Table 1 are obtained. Test fresh BBR specimens at each temperature.

6.14. Certain asphalt binders may satisfy the M 320, Table 1 slope requirement at substantially lower temperatures than they satisfy the creep stiffness (S) requirement. If the creep stiffness is between 300 and 600 MPa at a test temperature at which the slope, m, ≥0.300, it may be possible to satisfy the DT (T 314) failure strain requirement in lieu of the creep stiffness requirement. Test DT specimens according to T 314 at the test temperature at which $m \geq 0.300$, and determine if the failure strain ≥1.0 percent. Test a sufficient number of specimens so that a minimum of six valid test results are obtained.

6.15. If the failure strain <1.0 percent, test additional sets of DT specimens, increasing the test temperature in 6.0°C increments, until a failure strain ≥1.0 percent is obtained.

6.16. Using the results of Sections 6.11 through 6.15, determine the final grade of the asphalt binder.

7. TEST PROCEDURE FOR VERIFYING THE NOMINAL GRADE OF AN ASPHALT BINDER

7.1. Prepare samples and test specimens using the procedures specified in the applicable test methods. In the case where the grade of the asphalt binder is being verified, approximately 250 g of unaged asphalt binder are required to complete the tests with the necessary replicates.

7.2. Begin conditioning asphalt binder in the RTFO. Condition a sufficient amount of asphalt binder depending on the type and number of tests to be performed.

Note 4—Two BBR beams requiring PAV aged material are needed. In addition, at least six DT specimens requiring PAV aged material may also be required. Only one test temperature will be required. This testing will utilize approximately 100 g of RTFO residue.

7.3. Perform the DSR test (T 315) on the original asphalt binder at the test temperature indicated by the high temperature grading designation. For example, test a PG 70-16 asphalt binder at 70°C. The value for $G^*/\sin\delta$ must be ≥ 1.0 kPa to meet the requirements of M 320.

Note 5—This step verifies the starting PG grade. For example, if a PG 58-22 is tested at 58°C and $G^*/\sin\delta \geq 1.00$ kPa, the high temperature grading designation for the asphalt binder is verified to be PG 58-xx.

Note 6—If the asphalt binder fails to meet the requirements of M 320, Table 1 for the grade designated, it may be treated as a binder of unknown grade and tested according to Section 6, or the testing may be stopped because the grade was not verified.

7.4. Determine the flash point on a sample of original binder using T 48. The flash point must be greater than 230°C to meet the requirements of M 320.

7.5. Determine the viscosity of the original asphalt binder at 135°C using T 316. The viscosity must not exceed 3 Pa·s to meet the requirements of M 320.

7.6. After the RTFO conditioning (T 240) is complete, determine the mass change of the original asphalt binder. The mass change must be ≤ 1.00 percent to meet the requirements of M 320.

7.7. If the original asphalt binder does not meet M 320, Table 1 requirements for any of the tests performed in Sections 7.4, 7.5, or 7.6, the asphalt binder will not satisfy the specification for any PG, and no further testing is required.

7.8. To verify the high temperature properties of the binder, perform the DSR test (T 315) on the RTFO residue at the test temperature indicated by the high temperature grading designation. For example, test a PG 70-16 asphalt binder at 70°C. The value for $G^*/\sin\delta$ of the RTFO residue must be ≥ 2.20 kPa to meet the requirements of M 320, Table 1 (Note 6).

7.9. Age a sufficient quantity of RTFO residue in the PAV (R 28). Use an aging temperature of 90°C for binders having a high temperature grading designation of PG 46-xx or PG 52-xx and 100°C for binders having high temperature grading designations of PG 58-xx and higher. A PAV temperature of 110°C is used in simulating desert environments.

Note 7—Two BBR beams (requiring PAV-aged material) are required. In addition, six DT samples may also be needed requiring about 60 g of PAV-aged asphalt binder.

Note 8—Complete Sections 7.1 through 7.9 during the first day of testing. This schedule will allow further testing to begin on the second day after PAV aging is complete.

7.10. At the conclusion of the PAV aging procedure (R 28), including aging, combining, and degassing the binder, prepare two BBR specimens according to T 313. Retain sufficient residue to prepare at least six DT specimens if required.

7.11. Perform the DSR test (T 315) on the PAV residue at the test temperature specified in Table 1 of M 320 for the high temperature and low temperature grading designation of the binder being verified. For example, test a PG 64-40 asphalt binder at 16°C. The value for G*sin δ must not exceed 5000 kPa to meet the requirements of M 320 (Note 6).

7.12. Test two BBR specimens according to T 313 at the test temperature specified in Table 1 of M 320 for the high temperature and low temperature grading designation of the binder being verified. For example, test a PG 58-28 asphalt binder at –18°C. The value of the slope, *m*, must be ≥0.300 to meet the requirements of M 320, Table 1. The value of the creep stiffness (S) must be ≤300 MPa to meet the requirements of M 320, Table 1. Certain asphalt binders may satisfy the BBR slope requirement at substantially lower temperatures than they satisfy the BBR stiffness requirement (Note 6).

7.13. If the creep stiffness (S) is between 300 and 600 MPa and the slope (*m*) ≥0.300 at the test temperature, it may be possible to satisfy the DT (T 314) failure strain requirement in lieu of the creep stiffness (S) requirement. Test DT samples according to T 314 at the same test temperature used to test the BBR specimens. Test a sufficient number of specimens so that a minimum of six valid test results are obtained. The failure strain must be ≥1.0 percent to meet the requirements of M 320, Table 1 (Note 6).

8. REPORT

8.1. If the grade of the asphalt binder tested is determined, report the results of all tests performed and the high temperature grading designation determined followed by the low temperature designation (e.g., PG 52-34).

8.2. If the grade of an asphalt binder is verified, report the results of all tests performed and if the binder meets the requirements of M 320, Table 1.

9. KEYWORDS

9.1. Asphalt binder; performance grading.

Standard Practice for

Mixture Conditioning of Hot Mix Asphalt (HMA)

AASHTO Designation: R 30-02 (2006)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Mixture Conditioning of Hot Mix Asphalt (HMA)

AASHTO Designation: R 30-02 (2006)[1]

1. SCOPE

1.1. This standard practice describes procedures for mixture conditioning of compacted and uncompacted hot mix asphalt (HMA). Three types of conditioning are described: (1) mixture conditioning for volumetric mixture design; (2) short-term conditioning for mixture mechanical property testing (both of which simulate the precompaction phase of the construction process); and (3) long-term conditioning for mixture mechanical property testing to simulate the aging that occurs over the service life of a pavement. The procedures for long-term conditioning for mixture mechanical property testing are preceded by the procedure for short-term conditioning for mixture mechanical property testing.

1.2. *This standard practice may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- PP 3, Preparing Hot Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor[2]
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

3. SUMMARY OF PRACTICE

For mixture conditioning for volumetric mixture design, a mixture of aggregate and binder is conditioned in a forced-draft oven for 2 hours at the mixture's specified compaction temperature. For short-term mixture conditioning for mechanical property testing, a mixture of aggregate and binder is conditioned in a forced-draft oven for 4 hours at 135°C. For long-term mixture conditioning for mechanical property testing, a compacted mixture of aggregate and binder is conditioned in a forced-draft oven for 5 days at 85°C.

4. SIGNIFICANCE AND USE

The properties and performance of HMA can be more accurately predicted by using conditioned test samples. The mixture conditioning for the volumetric mixture design procedure is designed to allow for binder absorption during the mixture design. The short-term mixture conditioning for the mechanical property testing procedure is designed to simulate the plant-mixing and construction effects on the mixture. The long-term mixture conditioning for the mechanical property testing procedure is designed to simulate the aging the compacted mixture will undergo during 7 to 10 years of service.

5. APPARATUS

5.1. *Oven*—A forced-draft oven, thermostatically controlled, capable of maintaining any desired temperature setting from room temperature to 176°C within ±3°C.

5.2. *Thermometers*—Thermometers having a range from 50 to 260°C and readable to 1°C.

5.3. *Miscellaneous*—A metal pan for heating aggregates, a shallow metal pan for heating uncompacted HMA, a metal spatula or spoon, timer, and gloves for handling hot equipment.

6. HAZARDS

6.1. This standard involves the handling of hot binder, aggregate, and HMA, which can cause severe burns if allowed to contact skin. Follow standard safety precautions to avoid burns.

7. MIXTURE CONDITIONING PROCEDURES

7.1. *Mixture Conditioning for Volumetric Mixture Design*:

7.1.1. The mixture conditioning for the volumetric mixture design procedure applies to laboratory-prepared, loose mixture only. No mixture conditioning is required when conducting quality control or quality assurance testing on plant-produced mixture.

Note 1—The Agency may identify the need to condition plant-produced mixture to be more representative of field conditions, particularly where absorptive aggregates are used.

7.1.2. Place the mixture in a pan, and spread it to an even thickness ranging between 25 and 50 mm. Place the mixture and pan in a forced-draft oven for 2 h ± 5 min at a temperature equal to the mixture's compaction temperature ±3°C. The compaction temperature range of a HMA mixture is defined as the range of temperatures where the unaged binder has a kinematic viscosity of 280 ± 30 mm^2/s (approximately 0.28 ± 0.03 Pa·s) measured in accordance with T 316 (Note 2). The target compaction temperature is generally the midpoint of this range.

Note 2—Modified binders may not adhere to the equi-viscosity requirements noted. The agency should consider the manufacturer's recommendations when establishing the mixing and compaction temperatures for modified binders. Practically, the mixing temperature should not exceed 165°C and the compaction temperature should not be lower than 115°C.

7.1.3. Stir the mixture after 60 ± 5 min to maintain uniform conditioning.

7.1.4. After 2 h ± 5 min, remove the mixture from the forced-draft oven. The conditioned mixture is now ready for compaction or testing.

7.2. *Short-Term Conditioning for Mixture Mechanical Property Testing*:

7.2.1. The short-term conditioning for the mixture mechanical property testing procedure applies to laboratory-prepared, loose mix only.

7.2.2. Place the mixture in a pan, and spread it to an even thickness ranging between 25 and 50 mm. Place the mixture and pan in the conditioning oven for 4 h ± 5 min at a temperature of 135 ± 3°C.

7.2.3. Stir the mixture every 60 ± 5 min to maintain uniform conditioning.

7.2.4. After 4 h ± 5 min, remove the mixture from the forced-draft oven. The conditioned mixture is now ready for further conditioning or testing as required.

7.3. *Long-Term Conditioning for Mixture Mechanical Property Testing*:

7.3.1. The long-term conditioning for the mixture mechanical property testing procedure applies to laboratory-prepared mixtures that have been subjected to the short-term conditioning for the mixture mechanical property testing procedure described in Section 7.2, plant-mixed HMA, and compacted roadway specimens.

7.3.2. *Preparing Specimens from Loose HMA*:

7.3.2.1. Specimens Compacted Using the Superpave Gyratory Compactor:

7.3.2.1.1. Compact the specimens in accordance with T 312. Cool the test specimen at room temperature for 16 ± 1 h.

Note 3—Extrude the specimen from the compaction mold after cooling for 2 to 3 h.

Note 4—Specimen cooling is usually scheduled as an overnight step. Cooling may be accelerated by placing the specimen in front of a fan.

7.3.2.2. Specimens Compacted Using the Rolling Wheel Compactor:

7.3.2.2.1. Compact the specimens in accordance with PP 3.

7.3.2.2.2. Cool the test specimen at room temperature for 16 ± 1 h.

7.3.2.2.3. Remove the slab from the mold, and saw or core the required specimens from the slab.

7.3.3. *Preparing Compacted Roadway Specimens*:

7.3.3.1. Cool test specimens at room temperature for 16 ± 1 h.

7.3.4. *Long-Term Conditioning of Prepared Test Specimens*—Place the compacted test specimens in the conditioning oven for 120 ± 0.5 h at a temperature of 85 ± 3°C.

7.3.5. After 120 ± 0.5 h, turn the oven off; open the doors, and allow the test specimen to cool to room temperature. Do not touch or remove the specimen until it has cooled to room temperature.

Note 5—Cooling to room temperature will take approximately 16 h.

7.3.6. After cooling to room temperature, remove the test specimen from the oven. The long-term-conditioned specimen is now ready for testing as required.

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8. REPORT

8.1. Report the binder grade, binder content (nearest 0.1 percent), and the aggregate type and gradation, if applicable.

8.2. Report the following mixture conditioning information for the volumetric mixture design conditions, if applicable:

8.2.1. Mixture conditioning temperature in laboratory (compaction temperature, nearest 1°C);

8.2.2. Mixture conditioning duration in laboratory (nearest minute); and

8.2.3. Laboratory compaction temperature (nearest 1°C).

8.3. Report the following short-term conditioning information for the mixture mechanical property testing conditions, if applicable:

8.3.1. Short-term mixture conditioning temperature in laboratory (nearest 1°C);

8.3.2. Short-term mixture conditioning duration in laboratory (nearest minute); and

8.3.3. Laboratory compaction temperature (nearest 1°C).

8.4. Report the following long-term conditioning information for the mixture mechanical property testing conditions, if applicable:

8.4.1. Laboratory compaction temperature (nearest 1°C);

8.4.2. Long-term mixture conditioning temperature in laboratory (nearest 1°C); and

8.4.3. Long-term mixture conditioning duration in laboratory (nearest 5 minutes).

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9. KEYWORDS

9.1. Conditioning; hot mix asphalt; long-term conditioning; short-term conditioning.

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[1] This standard is based on SHRP Product 1031.

[2] PP 3-94 was last printed in the May 2002 Edition of the *AASHTO Provisional Standards*.

Standard Practice for

Superpave Volumetric Design for Hot Mix Asphalt (HMA)

AASHTO Designation: R 35-09

American Association of State Highway and Transportation Officials
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Standard Practice for

Superpave Volumetric Design for Hot Mix Asphalt (HMA)

AASHTO Designation: R 35-09

1. SCOPE

1.1. This standard practice for mix design evaluation uses aggregate and mixture properties to produce a hot mix asphalt (HMA) job-mix formula. The mix design is based on the volumetric properties of the HMA in terms of the air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

1.2. This standard practice may also be used to provide a preliminary selection of mix parameters as a starting point for mix analysis and performance prediction analyses that primarily use T 320 and T 322.

1.3. *This standard practice may involve hazardous materials, operations, and equipment. This standard practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 100, Specific Gravity of Soils
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 228, Specific Gravity of Semi-Solid Asphalt Materials
- T 248, Reducing Samples of Aggregate to Testing Size
- T 275, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 320, Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)
- T 322, Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device

2.2. *Asphalt Institute Standard*:

- SP-2, Superpave Mix Design

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3. TERMINOLOGY

3.1. *HMA*—hot mix asphalt.

3.2. *design ESALs*—design equivalent (80 kN) single-axle loads.

3.2.1. *Discussion*—Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. For pavements designed for more or less than 20 years, determine the design ESALs for 20 years when using this standard practice.

3.3. *air voids* (V_a)—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1).

Note 1—Term defined in Asphalt Institute Manual SP-2, Superpave Mix Design.

3.4. *voids in the mineral aggregate (VMA)*—the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.5. *absorbed binder volume* (V_{ba})—the volume of binder absorbed into the aggregate (equal to the difference in aggregate volume when calculated with the bulk specific gravity and effective specific gravity).

3.6. *binder content* (P_b)—the percent by mass of binder in the total mixture including binder and aggregate.

3.7. *effective binder volume* (V_{be})—the volume of binder which is not absorbed into the aggregate.

3.8. *voids filled with asphalt (VFA)*—the percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.9. *dust-to-binder ratio* ($P_{0.075}/P_{be}$)—by mass, the ratio between the percent passing the 75-µm (No. 200) sieve ($P_{0.075}$) and the effective binder content (P_{be}).

3.10. *nominal maximum aggregate size*—one size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.11. *maximum aggregate size*—one size larger than the nominal maximum aggregate size (Note 2).

Note 2—The definitions given in Sections 3.10 and 3.11 apply to Superpave mixes only and differ from the definitions published in other AASHTO standards.

3.12. *reclaimed asphalt pavement (RAP)*—removed and/or processed pavement materials containing asphalt binder and aggregate.

3.13. *primary control sieve (PCS)*—the sieve defining the break point between fine and coarse-graded mixtures for each nominal maximum aggregate size.

4. SUMMARY OF THE PRACTICE

4.1. *Materials Selection*—Binder, aggregate and RAP stockpiles are selected that meet the environmental and traffic requirements applicable to the paving project. The bulk specific gravity of all aggregates proposed for blending and the specific gravity of the binder are determined.

Note 3—If RAP is used, the bulk specific gravity of the RAP aggregate may be estimated by determining the theoretical maximum specific gravity (G_{mm}) of the RAP mixture and using an assumed asphalt absorption for the RAP aggregate to back-calculate the RAP aggregate bulk specific gravity, if the absorption can be estimated with confidence. The RAP aggregate effective specific gravity may be used in lieu of the bulk specific gravity at the discretion of the Agency. The use of the effective specific gravity may introduce an error into the combined aggregate bulk specific gravity and subsequent VMA calculations. The Agency may choose to specify adjustments to the VMA requirements to account for this error based on experience with local aggregates.

4.2. *Design Aggregate Structure*—It is recommended at least three trial aggregate blend gradations from selected aggregate stockpiles are blended. For each trial gradation, an initial trial binder content is determined, and at least two specimens are compacted in accordance with T 312. A design aggregate structure and an estimated design binder content are selected on the basis of satisfactory conformance of a trial gradation meeting the requirements given in M 323 for V_a, VMA, VFA, dust-to-binder ratio at N_{design}, and relative density at N_{initial}.

Note 4—Previous Superpave mix design experience with specific aggregate blends may eliminate the need for three trial blends.

4.3. *Design Binder Content Selection*—Replicate specimens are compacted in accordance with T 312 at the estimated design binder content and at the estimated design binder content ±0.5 percent and +1.0 percent. The design binder content is selected on the basis of satisfactory conformance with the requirements of M 323 for V_a, VMA, VFA, and dust-to-binder ratio at N_{design}, and the relative density at N_{initial} and N_{max}.

4.4. *Evaluating Moisture Susceptibility*—The moisture susceptibility of the design aggregate structure is evaluated at the design binder content: the mixture is conditioned according to the mixture conditioning for the volumetric mixture design procedure in R 30, compacted to 7.0 ± 0.5 percent air voids in accordance with T 312, and evaluated according to T 283. The design shall meet the tensile strength ratio requirement of M 323.

5. SIGNIFICANCE AND USE

5.1. The procedure described in this standard practice is used to produce HMA which satisfies Superpave HMA volumetric mix design requirements.

6. PREPARING AGGREGATE TRIAL BLEND GRADATIONS

6.1. Select a binder in accordance with the requirements of M 323.

6.2. Determine the specific gravity of the binder according to T 228.

6.3. Obtain samples of aggregates proposed to be used for the project from the aggregate stockpiles in accordance with T 2.

Note 5—Each stockpile usually contains a given size of an aggregate fraction. Most projects employ three to five stockpiles to generate a combined gradation conforming to the job-mix formula and M 323.

6.4. Reduce the samples of aggregate fractions according to T 248 to samples of the size specified in T 27.

6.5. Wash and grade each aggregate sample according to T 11 and T 27.

6.6. Determine the bulk and apparent specific gravity for each coarse and fine aggregate fraction in accordance with T 85 and T 84, respectively, and determine the specific gravity of the mineral filler in accordance with T 100.

6.7. Blend the aggregate fractions using Equation 1:

$$P = Aa + Bb + Cc, \text{ etc.} \qquad (1)$$

where:

P = Percentage of material passing a given sieve for the combined aggregates A, B, C, etc.;

A, B, C, etc. = Percentage of material passing a given sieve for aggregates A, B, C, etc.; and

a, b, c, etc. = Proportions of aggregates A, B, C, etc., used in the combination, and where the total = 1.00.

6.8. Prepare a minimum of three trial aggregate blend gradations; plot the gradation of each trial blend on a 0.45-power gradation analysis chart, and confirm that each trial blend meets M 323 gradation controls (see Table 3 of M 323). Gradation control is based on four control sieve sizes: the sieve for the maximum aggregate size, the sieve for the nominal maximum aggregate size, the 4.75- or 2.36-mm sieve, and the 0.075-mm sieve. An example of three acceptable trial blends in the form of a gradation plot is given in Figure 1.

6.9. Obtain a test specimen from each of the trial blends according to T 248, and conduct the quality tests specified in Section 6 of M 323 to confirm that the aggregate in the trial blends meets the minimum quality requirements specified in M 323.

Note 6—The designer has an option of performing the quality tests on each stockpile instead of the trial aggregate blend. The test results from each stockpile can be used to estimate the results for a given combination of materials.

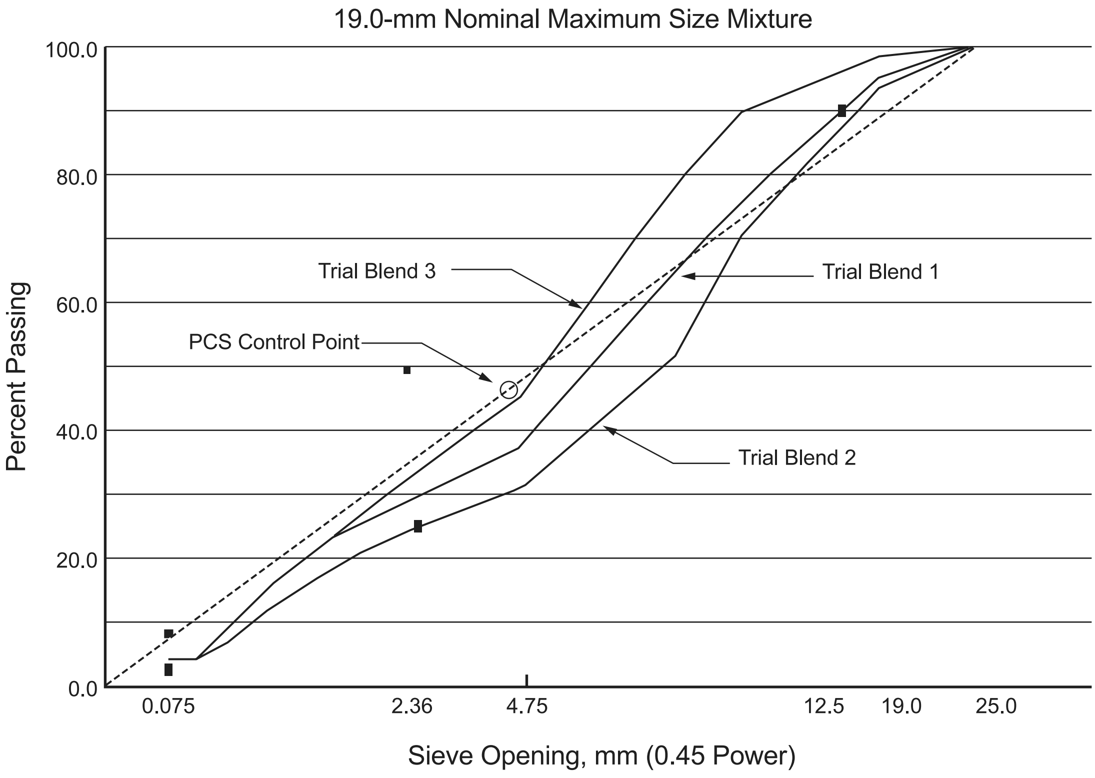


Figure 1—Evaluation of the Gradations of Three Trial Blends (Example)

7. DETERMINING AN INITIAL TRIAL BINDER CONTENT FOR EACH TRIAL AGGREGATE GRADATION

7.1. Designers can either use their experience with the materials or the procedure given in Appendix A1 to determine an initial trial binder content for each trial aggregate blend gradation.

Note 7—When using RAP, the initial trial asphalt content should be reduced by an amount equal to that provided by the RAP.

8. COMPACTING SPECIMENS OF EACH TRIAL GRADATION

8.1. Prepare replicate mixtures (Note 8) at the initial trial binder content for each of the chosen trial aggregate trial blend gradations. From Table 1, determine the number of gyrations based on the design ESALs for the project.

Note 8—At least two replicate specimens are required, but three or more may be prepared if desired. Generally, 4500 to 4700 g of aggregate is sufficient for each compacted specimen with a height of 110 to 120 mm for aggregates with combined bulk specific gravities of 2.55 to 2.70, respectively.

8.2. Condition the mixtures according to R 30, and compact the specimens to N_{design} gyrations in accordance with T 312. Record the specimen height to the nearest 0.1 mm after each revolution.

8.3. Determine the bulk specific gravity (G_{mb}) of each of the compacted specimens in accordance with T 166 or T 275 as appropriate.

Table 1—Superpave Gyratory Compaction Effort

Design ESALs[a] (million)	Compaction Parameters			Typical Roadway Application[b]
	N_{initial}	N_{design}	$N_{\max}$	
<0.3	6	50	75	Applications include roadways with very light traffic volumes such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature, not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas may also be applicable to this level.
0.3 to <3	7	75	115	Applications include many collector roads or access streets. Medium-trafficked city streets and the majority of county roadways may be applicable to this level.
3 to <30	8	100	160	Applications include many two-lane, multilane, divided, and partially or completely controlled access roadways. Among these are medium to highly trafficked city streets, many state routes, U.S. highways, and some rural Interstates.
≥30	9	125	205	Applications include the vast majority of the U.S. Interstate system, both rural and urban in nature. Special applications such as truck-weighing stations or truck-climbing lanes on two-lane roadways may also be applicable to this level.

[a] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[b] As defined by *A Policy on Geometric Design of Highways and Streets*, 2004, AASHTO.

Note 9—When specified by the Agency and the top of the design layer is ≥100 mm from the pavement surface and the estimated design traffic level is ≥0.3 million ESALs, decrease the estimated design traffic level by one, unless the mixture will be exposed to significant mainline construction traffic prior to being overlaid. If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.

Note 10—When the estimated design traffic level is between 3 and <10 million ESALs, the Agency may, at its discretion, specify N_{initial} at 7, N_{design} at 75, and $N_{\max}$ at 115.

8.4. Determine the theoretical maximum specific gravity (G_{mm}) according to T 209 of separate samples representing each of these combinations that have been mixed and conditioned to the same extent as the compacted specimens.

Note 11—The maximum specific gravity for each trial mixture shall be based on the average of at least two tests.

9. EVALUATING COMPACTED TRIAL MIXTURES

9.1. Determine the volumetric requirements for the trial mixtures in accordance with M 323.

9.2. Calculate V_a and VMA at N_{design} for each trial mixture using Equations 2 and 3:

$$V_a = 100 \times \left(1 - \left(\frac{G_{mb}}{G_{mm}}\right)\right) \qquad (2)$$

$$\text{VMA} = 100 \times \left(1 - \frac{G_{mb}P_s}{G_{sb}}\right) \qquad (3)$$

where:

G_{mb} = bulk specific gravity of the extruded specimen;
G_{mm} = theoretical maximum specific gravity of the mixture;
P_s = percent of aggregate in the mix; and
G_{sb} = bulk specific gravity of the combined aggregate.

Note 12—Although the initial trial binder content was estimated for a design air void content of 4.0 percent, the actual air void content of the compacted specimen is unlikely to be exactly 4.0 percent. Therefore, the change in binder content needed to obtain a 4.0 percent air void content, and the change in VMA caused by this change in binder content, is estimated. These calculations permit the evaluation of VMA and VFA of each trial aggregate gradation at the same design air void content, 4.0 percent.

9.3. Estimate the volumetric properties at 4.0 percent air voids for each compacted specimen.

9.3.1. Determine the difference in average air void content at N_{design} (ΔV_a) of each aggregate trial blend from the design level of 4.0 percent using Equation 4:

$$\Delta V_a = 4.0 - V_a \qquad (4)$$

where:

V_a = air void content of the aggregate trial blend at N_{design} gyrations.

9.3.2. Estimate the change in binder content (ΔP_b) needed to change the air void content to 4.0 percent using Equation 5:

$$\Delta P_b = -0.4(\Delta V_a) \qquad (5)$$

9.3.3. Estimate the change in VMA (ΔVMA) caused by the change in the air void content (ΔV_a) determined in Section 9.3.1 for each trial aggregate blend gradation, using Equation 6 or 7.

$$\Delta VMA = 0.2(\Delta V_a) \text{ if } V_a > 4.0 \qquad (6)$$

$$\Delta VMA = -0.1(\Delta V_a) \text{ if } V_a < 4.0 \qquad (7)$$

Note 13—A change in binder content affects the VMA through a change in the bulk specific gravity of the compacted specimen (G_{mb}).

9.3.4. Calculate the VMA for each aggregate trial blend at N_{design} gyrations and 4.0 percent air voids using Equation 8:

$$VMA_{\text{design}} = VMA_{\text{trial}} + \Delta VMA \qquad (8)$$

where:

$\text{VMA}_{\text{design}}$ = VMA estimated at a design air void content of 4.0 percent; and
$\text{VMA}_{\text{trial}}$ = VMA determined at the initial trial binder content.

9.3.5. Using the values of ΔV_a determined in Section 9.3.1 and Equation 9, estimate the relative density of each specimen at N_{initial} when the design air void content is adjusted to 4.0 percent at N_{design}:

$$\%G_{mm_{\text{initial}}} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i}\right) - \Delta V_a \qquad (9)$$

where:

$\%G_{mm_{\text{initial}}}$ = relative density at N_{initial} gyrations at the adjusted design binder content;

h_d = height of the specimen after N_{design} gyrations, from the Superpave gyratory compactor, mm; and

h_i = height of the specimen after N_{initial} gyrations, from the Superpave gyratory compactor, mm.

9.3.6. Calculate the effective specific gravity of the aggregate (G_{se}), the estimated percent of effective binder ($P_{be_{est}}$), and the estimated dust-to-binder ratio ($P_{0.075}/P_{be}$) for each trial blend using Equations 10, 11, and 12:

$$G_{se} = \frac{100 - P_b}{\dfrac{100}{G_{mm}} - \dfrac{P_b}{G_b}} \qquad (10)$$

$$P_{be_{est}} = -\left(P_s \times G_b\right)\frac{\left(G_{se} - G_{sb}\right)}{\left(G_{se} \times G_{sb}\right)} + P_{b_{est}} \qquad (11)$$

where:

$P_{be_{est}}$ = estimated effective binder content;

P_s = aggregate content;

G_b = specific gravity of the binder;

G_{se} = effective specific gravity of the aggregate;

G_{sb} = bulk specific gravity of the combined aggregate; and

$P_{b_{est}}$ = estimated binder content.

$$P_{0.075} \Big/ P_{be} = \frac{P_{0.075}}{P_{be_{est}}} \qquad (12)$$

where:

$P_{0.075}$ = percent passing the 0.075-mm sieve.

9.3.7. Compare the estimated volumetric properties from each trial aggregate blend gradation at the adjusted design binder content with the criteria specified in M 323. Choose the trial aggregate blend gradation that best satisfies the volumetric criteria.

Note 14—Table 2 presents an example of the selection of a design aggregate structure from three trial aggregate blend gradations.

Note 15—Many trial aggregate blend gradations will fail the VMA criterion. Generally, the $\%\,G_{mm_{\text{initial}}}$ criterion will be met if the VMA criterion is satisfied. Section 12.1 gives a procedure for the adjustment of VMA.

Note 16—If the trial aggregate gradations have been chosen to cover the entire range of the gradation controls, then the only remaining solution is to make adjustments to the aggregate production or to introduce aggregates from a new source. The aggregates that fail to meet the required criteria will not produce a quality mix and should not be used. One or more of the aggregate stockpiles should be replaced with another material which produces a stronger structure. For example, a quarry stone can replace a crushed gravel, or crushed fines can replace natural fines.

Table 2—Selection of a Design Aggregate Structure (Example)

Volumetric Property	Trial Mixture (19.0-mm Nominal Maximum Aggregate) 20-Year Project Design ESALs = 5 million			Criteria
	1	2	3	
	At the Initial Trial Binder Content			
P_b (trial)	4.4	4.4	4.4	
% $G_{mm_{\text{initial}}}$ (trial)	88.3	88.0	87.3	
% $G_{mm_{\text{design}}}$ (trial)	95.6	94.9	94.5	
V_a at N_{design}	4.4	5.1	5.5	4.0
$\text{VMA}_{\text{trial}}$	13.0	13.6	14.1	
	Adjustments to Reach Design Binder Content (V_a = 4.0% at N_{design})			
ΔV_a	–0.4	–1.1	–1.5	
ΔP_b	0.2	0.4	0.6	
ΔVMA	–0.1	–0.2	–0.3	
	At the Estimated Design Binder Content (V_a = 4.0 % at N_{design})			
Estimated P_b (design)	4.6	4.8	5.0	
VMA (design)	12.9	13.4	13.8	≥13.0
% $G_{mm_{\text{initial}}}$ (design)	88.7	89.1	88.5	≤89.0

Notes:

1. The top portion of this table presents measured densities and volumetric properties for specimens prepared for each aggregate trial blend at the initial trial binder content.
2. None of the specimens had an air void content of exactly 4.0 percent. Therefore, the procedures described in Section 9 must be applied to: (1) estimate the design binder content at which V_a = 4.0 percent, and (2) obtain adjusted VMA and relative density values at this estimated binder content.
3. The middle portion of this table presents the change in binder content (ΔP_b) and VMA (ΔVMA) that occurs when the air void content (V_a) is adjusted to 4.0 percent for each trial aggregate blend gradation.
4. A comparison of the VMA and densities at the estimated design binder content to the criteria in the last column shows that trial aggregate blend gradation No. 1 does not have sufficient VMA (12.9 percent versus a requirement of ≥13.0 percent). Trial blend No. 2 exceeds the criterion for relative density at N_{initial} gyrations (89.1 percent versus a requirement of ≤89.0 percent). Trial blend No. 3 meets the requirement for relative density and VMA and, in this example, is selected as the design aggregate structure.

10. SELECTING THE DESIGN BINDER CONTENT

10.1. Prepare replicate mixtures (Note 8) containing the selected design aggregate structure at each of the following four binder contents: (1) the estimated design binder content, P_b (design); (2) 0.5 percent below P_b (design); (3) 0.5 percent above P_b (design); and (4) 1.0 percent above P_b (design).

10.1.1. Use the number of gyrations previously determined in Section 8.1.

10.2. Condition the mixtures according to R 30, and compact the specimens to N_{design} gyrations according to T 312. Record the specimen height to the nearest 0.1 mm after each revolution.

10.3. Determine the bulk specific gravity of each of the compacted specimens in accordance with T 166 or T 275 as appropriate.

10.4. Determine the theoretical maximum specific gravity (G_{mm}) according to T 209 of each of the four mixtures using companion samples which have been conditioned to the same extent as the compacted specimens (Note 11).

10.5. Determine the design binder content which produces a target air void content (V_a) of 4.0 percent at N_{design} gyrations using the following steps:

10.5.1. Calculate V_a, VMA, and VFA at N_{design} using Equations 2, 3, and 13:

$$VFA = 100 \times \left[\frac{VMA - V_a}{VMA} \right] \quad (13)$$

10.5.2. Calculate the dust-to-binder ratio using Equation 14.

$$P_{0.075} \Big/ P_{be} = \frac{P_{0.075}}{P_{be}} \quad (14)$$

where:

P_{be} = effective binder content.

10.5.3. For each of the four mixtures, determine the average corrected specimen relative densities at N_{initial} ($\%G_{mm_{\text{initial}}}$), using Equation 15.

$$\%G_{mm_{\text{initial}}} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i} \right) \quad (15)$$

10.5.4. Plot the average V_a, VMA, VFA, and relative density at N_{design} for replicate specimens versus binder content.

Note 17—All plots are generated automatically by the Superpave software. Figure 2 presents a sample data set and the associated plots.

10.5.5. By graphical or mathematical interpolation (Figure 2), determine the binder content to the nearest 0.1 percent at which the target V_a is equal to 4.0 percent. This is the design binder content (P_b) at N_{design}.

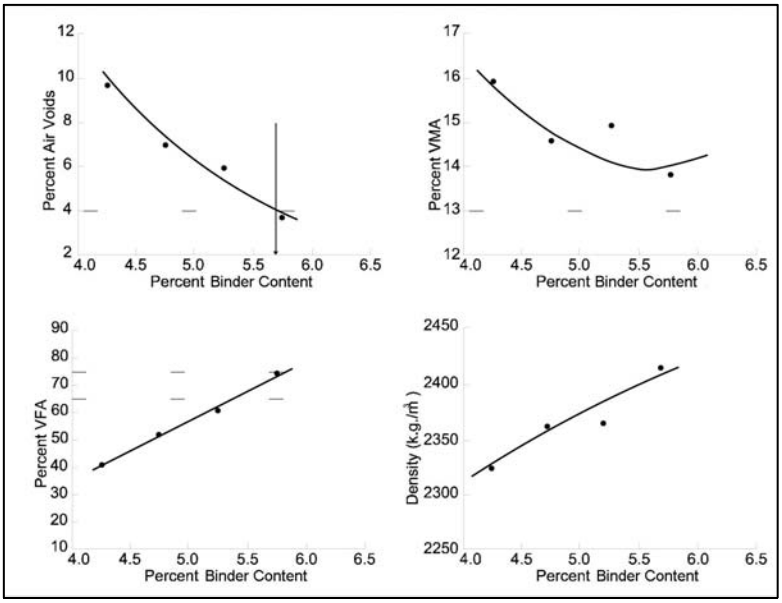
10.5.6. By interpolation (Figure 2), verify that the volumetric requirements specified in M 323 are met at the design binder content.

10.6. Compare the calculated percent of maximum relative density with the design criteria at N_{initial} by interpolation, if necessary. This interpolation can be accomplished by the following procedure.

10.6.1. Prepare a densification curve for each mixture by plotting the measured relative density at X gyrations, $\%G_{mm_x}$, versus the logarithm of the number of gyrations (see Figure 3).

10.6.2. Examine a plot of air void content versus binder content. Determine the difference in air voids between 4.0 percent and the air void content at the nearest, lower binder content. Determine the air void content at the nearest, lower binder content at its data point, not on the line of best fit. Designate the difference in air void content as ΔV_a.

10.6.3. Using Equation 15, determine the average corrected specimen relative densities at N_{initial} ($\%G_{mm_{\text{initial}}}$). Confirm that $\%G_{mm_{\text{initial}}}$ satisfies the design requirements in M 323 at the design binder content.



Average V_a, VMA, VFA, and Relative Density at N_{design}

P_b (%)	V_a (%)	VMA (%)	VFA (%)	Density at N_{design} (kg/m^3)
4.3	9.5	15.9	40.3	2320
4.8	7.0	14.7	52.4	2366
5.3	6.0	14.9	59.5	2372
5.8	3.7	13.9	73.5	2412

Notes:

1. In this example, the estimated design binder content is 4.8 percent; the minimum VMA requirement for the design aggregate structure (19.0-mm nominal maximum size) is 13.0 percent, and the VFA requirement is 65 to 75 percent.
2. Entering the plot of percent air voids versus percent binder content at 4.0 percent air voids, the design binder content is determined as 5.7 percent.
3. Entering the plots of percent VMA versus percent binder content and percent VFA versus percent binder content at 5.7 percent binder content, the mix meets the VMA and VFA requirements.

Figure 2—Sample Volumetric Design Data at N_{design}

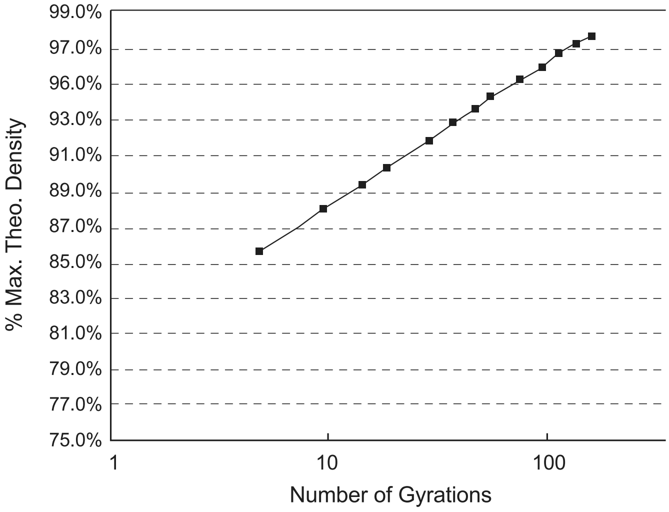


Figure 3—Sample Densification Curve

10.7. Prepare replicate (Note 8) specimens composed of the design aggregate structure at the design binder content to confirm that $\%G_{mm_{\max}}$ satisfies the design requirements in M 323.

10.7.1. Condition the mixtures according to R 30, and compact the specimens according to T 312 to the maximum number of gyrations, $N_{\max}$, from Table 1.

10.7.2. Determine the average specimen relative density at $N_{\max}$, $\%G_{mm_{\max}}$, by using Equation 16, and confirm that $\%G_{mm_{\max}}$ satisfies the volumetric requirement in M 323.

$$\%G_{mm_{\max}} = 100\frac{G_{mb}}{G_{mm}} \qquad (16)$$

where:

$\%G_{mm_{\max}}$ = relative density at $N_{\max}$ gyrations at the design binder content.

11. EVALUATING MOISTURE SUSCEPTIBILITY

11.1. Prepare six mixture specimens (nine are needed if freeze-thaw testing is required) composed of the design aggregate structure at the design binder content. Condition the mixtures in accordance with R 30, and compact the specimens to 7.0 ± 0.5 percent air voids in accordance with T 312.

11.2. Test the specimens and calculate the tensile strength ratio in accordance with T 283.

11.3. If the tensile strength ratio is less than 0.80, as required in M 323, remedial action such as the use of anti-strip agents is required to improve the moisture susceptibility of the mix. When remedial agents are used to modify the binder, retest the mix to assure compliance with the 0.80 minimum requirement.

12. ADJUSTING THE MIXTURE TO MEET PROPERTIES

12.1. *Adjusting VMA*—If a change in the design aggregate skeleton is required to meet the specified VMA, there are three likely options: (1) change the gradation (Note 18); (2) reduce the minus 0.075-mm fraction (Note 19); or (3) change the surface texture and/or shape of one or more of the aggregate fractions (Note 20).

Note 18—Changing gradation may not be an option if the trial aggregate blend gradation analysis includes the full spectrum of the gradation control area.

Note 19—Reducing the percent passing the 0.075-mm sieve of the mix will typically increase the VMA. If the percent passing the 0.075-mm sieve is already low, this is not a viable option.

Note 20—This option will require further processing of existing materials or a change in aggregate sources.

12.2. *Adjusting VFA*—The lower limit of the VFA range should always be met at 4.0 percent air voids if the VMA meets the requirements. If the upper limit of the VFA is exceeded, then the VMA is substantially above the minimum required. If so, redesign the mixture to reduce the VMA. Actions to consider for redesign include: (1) changing to a gradation that is closer to the maximum density line; (2) increasing the minus 0.075-mm fraction, if room is available within the specification control points; or (3) changing the surface texture and shape of the aggregates by incorporating material with better packing characteristics, e.g., less thin, elongated aggregate particles.

12.3. *Adjusting the Tensile Strength Ratio*—The tensile strength ratio can be increased by: (1) adding chemical anti-strip agents to the binder to promote adhesion in the presence of water; or (2) adding hydrated lime to the mix.

13. REPORT

13.1. The report shall include the identification of the project number, traffic level, and mix design number.

13.2. The report shall include information on the design aggregate structure including the source of aggregate, kind of aggregate, required quality characteristics, and gradation.

13.3. The report shall contain information about the design binder including the source of binder and the performance grade.

13.4. The report shall contain information about the HMA including the percent of binder in the mix; the relative density; the number of initial, design, and maximum gyrations; and the VMA, VFA, V_{be}, V_{ba}, V_a, and dust-to-binder ratio.

14. KEYWORDS

14.1. HMA mix design; Superpave; volumetric mix design.

APPENDIX

(Nonmandatory Information)

X1. CALCULATING AN INITIAL TRIAL BINDER CONTENT FOR EACH AGGREGATE TRIAL BLEND

X1.1. Calculate the bulk and apparent specific gravities of the combined aggregate in each trial blend using the specific gravity data for the aggregate fractions obtained in Section 6.6 and Equations X1.1 and X1.2:

$$G_{sb} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}} \qquad (X1.1)$$

$$G_{sa} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}} \qquad (X1.2)$$

where:

G_{sb} = bulk specific gravity for the combined aggregate;
G_{sa} = apparent specific gravity for the combined aggregate;
$P_1, P_2, \ldots P_n$ = percentages by mass of aggregates 1, 2, …*n*; and

$G_1, G_2, \ldots G_n$ = bulk specific gravities (Equation X1.1) or apparent specific gravities (Equation X1.2) of aggregates 1, 2, *n*.

X1.2. Estimate the effective specific gravity of the combined aggregate in the aggregate trial blend using Equation X1.3:

$$G_{se} = G_{sb} + 0.8\left(G_{sa} - G_{sb}\right) \qquad (X1.3)$$

where:

G_{se} = effective specific gravity of the combined aggregate;
G_{sb} = bulk specific gravity of the combined aggregate; and
G_{sa} = apparent specific gravity of the combined aggregate.

Note X1—The multiplier, 0.8, can be changed at the discretion of the designer. Absorptive aggregates may require values closer to 0.6 or 0.5.

Note X2—The Superpave mix design system includes a mixture conditioning step before the compaction of all specimens; this conditioning generally permits binder absorption to proceed to completion. Therefore, the effective specific gravity of Superpave mixtures will tend to be close to the apparent specific gravity in contrast to other design methods where the effective specific gravity generally will lie near the midpoint between the bulk and apparent specific gravities.

X1.3. Estimate the volume of binder absorbed into the aggregate, V_{ba}, using Equations X1.4 and X1.5:

$$V_{ba} = W_s\left(\frac{1}{G_{sb}} - \frac{1}{G_{se}}\right) \qquad (X1.4)$$

where:

W_s, the mass of aggregate in 1 cm^3 of mix, g, is calculated as:

$$W_s = \frac{P_s(1 - V_a)}{\frac{P_b}{G_b} + \frac{P_s}{G_{se}}} \qquad (X1.5)$$

and where:

P_b = mass percent of binder, in decimal equivalent, assumed to be 0.05;
P_s = mass percent of aggregate, in decimal equivalent, assumed to be 0.95;
G_b = specific gravity of the binder; and
V_a = volume of air voids, assumed to be 0.04 cm^3 in 1 cm^3 of mix.

Note X3—This estimate calculates the volume of binder absorbed into the aggregate, V_{ba}, and subsequently, the initial, trial binder content at a target air void content of 4.0 percent.

X1.4. Estimate the volume of effective binder using Equation X1.6:

$$V_{be} = 0.176 - \left[\, 0.0675 \log(S_n)\right] \qquad (X1.6)$$

where:

V_{be} = volume of effective binder, cm^3; and
S_n = nominal maximum sieve size of the largest aggregate in the aggregate trial blend, mm.

Note X4—This regression Equation is derived from an empirical relationship between: (1) VMA and V_{be} when the air void content, V_a, is equal to 4.0 percent: V_{be} = VMA – V_a = VMA – 4.0; and (2) the relationship between VMA and the nominal maximum sieve size of the aggregate in M 323.

X1.5. Calculate the estimated initial trial binder (P_{bi}) content for the aggregate trial blend gradation using Equation X1.7:

$$P_{bi} = 100 \times \left(\frac{G_b(V_{be} + V_{ba})}{(G_b(V_{be} + V_{ba})) + W_s}\right) \qquad (X1.7)$$

where:

P_{bi} = estimated initial trial binder content, percent by weight of total mix.

Standard Practice for

Designing Stone Matrix Asphalt (SMA)

AASHTO Designation: R 46-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Designing Stone Matrix Asphalt (SMA)

AASHTO Designation: R 46-08

1. SCOPE

1.1. This standard practice covers the design of Stone Matrix Asphalt (SMA) using the Superpave Gyratory Compactor™ (SGC). The SMA design is based on the volumetric properties of the SMA in terms of air voids (V_a), voids in the mineral aggregate (VMA), and the presence of stone-on-stone contact.

1.2. The values stated in SI units are to be regarded as the standard. The U.S. Customary units in parentheses are for information only.

1.3. *This standard practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 325, Stone Matrix Asphalt (SMA)
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
- T 305, Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2. *Asphalt Institute Publication*:

- MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*

3. TERMINOLOGY

3.1. *Definitions*:

3.2. *stone matrix asphalt (SMA)*—a hot mix asphalt (HMA) consisting of two parts, a coarse aggregate skeleton and a rich asphalt binder mortar. The mixture must have an aggregate skeleton with coarse aggregate-on-coarse aggregate contact (generally referred to as stone-on-stone contact). The coarse aggregate is generally considered to be that fraction of the aggregate retained on the 4.75-mm (No. 4) sieve but may be designated as other sizes.

3.3. *air voids* (V_a)—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1).

Note 1—Term defined in the Asphalt Institute Publication MS-2.

3.4. *voids in the mineral aggregate (VMA)*—the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.5. *voids in the coarse aggregate (VCA)*—the volume between the coarse aggregate particles. This volume includes filler, fine aggregate, air voids, asphalt binder, and stabilizing additive (if used).

3.6. *SMA mortar*—a mixture of asphalt binder, filler [material passing the 0.075-mm (No. 200) sieve], and stabilizing additive.

3.7. *stabilizing additive*—either cellulose or mineral fiber.

4. SUMMARY OF THE PRACTICE

4.1. *Materials Selection*—Asphalt binder, aggregate, mineral fillers, and stabilizing additives that meet the applicable specification are selected.

4.2. *Selecting Optimum Gradation*—Three recommended trial aggregate gradations from the selected aggregates are blended. The dry-rodded unit weight for the coarse aggregate for each trial gradation is determined in accordance with T 19/T 19M. For each trial gradation, an initial trial asphalt binder content is selected, and at least two specimens are compacted in accordance with T 312. Where no previous history is available, an initial trial asphalt binder content between 6.0 and 6.5 percent is recommended. Gradations of the three blends are selected to ensure that minimum VMA requirements and stone-on-stone contact are achieved.

4.3. *Selecting Design Binder Content* —Replicate specimens are compacted in accordance with T 312 at three binder contents. The design binder content is selected on the basis of satisfactory conformance with the requirements of Section 10 (Note 2).

Note 2—When an SMA mix cannot be designed within the minimum binder content requirements, the guidelines given in Table X2.1 can be used to establish minimum binder content requirements based on the combined-aggregate bulk specific gravity.

4.4. *Evaluating Moisture Susceptibility*—The moisture susceptibility of the mixture, designed and compacted in accordance with T 312 to a V_a content of 6.0 ± 1.0 percent, is evaluated in accordance with T 283.

4.5. *Evaluating Draindown*—The mixture is evaluated for sensitivity to asphalt binder draindown in accordance with T 305. If the mixture fails the moisture susceptibility or draindown tests, it must be modified so that the specification requirements are met.

5. TEST SPECIMENS

5.1. *Number of Samples*—A total of nine samples are initially required; at least three samples at each of the three trial gradations are produced. Each sample is mixed with the trial asphalt binder content, and two of the three samples for each trial gradation are compacted. The remaining sample of each trial gradation is used to determine the theoretical maximum density in accordance with T 209.

5.2. *Preparation of Aggregates*—Dry aggregates to a constant mass at 105°C to 110°C (221°F to 230°F), and separate the aggregates by dry-sieving into the desired size fractions. The following size fractions are recommended:

- 37.5 mm ($1^1/_2$ in.) to 25.0 mm (1 in.);
- 25.0 mm (1 in.) to 19.0 mm ($^3/_4$ in.);
- 19.0 mm ($^3/_4$ in.) to 12.5 mm ($^1/_2$ in.);
- 12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.);
- 9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4);
- 4.75 mm (No. 4) to 2.36 mm (No. 8);
- 2.36 mm (No. 8) to 0.075 mm (No. 200); and
- Passing 0.075 mm (No. 200).

5.3. *Determination of Mixing and Compaction Temperatures*:

5.3.1. The temperature to which the asphalt binder must be heated to produce a viscosity of 170 ± 20 cSt shall be the mixing temperature.

5.3.2. The temperature to which the asphalt binder must be heated to produce a viscosity of 280 ± 30 cSt shall be the compaction temperature.

Note 3—While the temperatures given in Sections 5.3.1 and 5.3.2 are appropriate for neat asphalt binders, the selected temperatures may not be applicable to modified asphalt binders. In those cases, it is recommended that the manufacturer’s guidelines for mixing and compaction temperatures be used.

5.4. *Preparation of Mixtures*:

5.4.1. A mechanical mixing apparatus shall be used.

5.4.2. An initial batch shall be mixed for the purpose of “buttering” the mixing bowl and stirrers. This batch shall be emptied after mixing, and the sides of the bowl and stirrers shall be cleaned of mixture residue by scraping with a small limber spatula but shall not be wiped with a cloth or washed clean with solvent, except when a change is to be made in the asphalt binder or at the end of a design.

5.4.3. Into separate pans for each test specimen, weigh sufficient material to produce compacted samples of the desired volume, approximately 4700 g. Mix the aggregate in each pan. Place the aggregate in an oven and heat to a temperature not exceeding the mixing temperature established in Section 5.3 by more than approximately 28°C (50°F). Heat the asphalt binder to the established mixing temperature. The stabilizing additive is added to the heated aggregate prior to the introduction of the asphalt binder.

Note 4—It is recommended that the stabilizing additive be manually mixed with the heated aggregate. This procedure is needed to ensure an even distribution of the stabilizing additive during the laboratory mixing process. The use of stabilizing additives generally requires slightly longer mixing times.

5.4.4. Form a crater in the dry blended aggregate and stabilizing additive, and weigh the preheated required amount of asphalt binder into the crater. Care must be exercised to prevent loss of the mix during mixing and subsequent handling. At this point, the temperature of the aggregate and asphalt binder shall be within the limits of the mixing temperature established in Section 5.3. Mix the aggregate and asphalt binder rapidly until the aggregate is thoroughly coated.

5.5. *Compaction of Specimens*—The compaction temperature is determined in accordance with Section 5.3. Laboratory samples of SMA are short-term conditioned in accordance with R 30 and then compacted for 100 gyrations.

Note 5—When aggregates have a Los Angeles Abrasion loss value greater than 30 percent, the desirable number of SGC design gyrations is 75.

6. SELECTION OF TRIAL GRADATIONS

6.1. The trial gradations must be selected to be within the desired specification range as defined in M 325. To design an SMA mixture, it is recommended that at least three trial gradations be initially evaluated. It is suggested that one of the trial blends fall along the coarse limits, one along the fine limits, and one in the middle of the gradation bands as defined in M 325. When the bulk specific gravities of the different aggregates to be used in the mixture vary by more than 0.2, the trial blend gradations should be based upon volumetric percentage. An example problem illustrating how to blend aggregates based on volume is given in Appendix X1.1.

7. SELECTION OF TRIAL BINDER CONTENT

7.1. As a starting point, for aggregates with bulk specific gravities approximately equal to 2.75, a binder content of approximately 6.0 percent or greater, by mass, needs to be selected. If the bulk specific gravity of the coarse aggregate exceeds 2.75, the trial binder content can be reduced by approximately 0.1 percent for each specific-gravity increment of 0.05 above 2.75. If the bulk specific gravity of the coarse aggregate is below 2.75, the trial binder content can be increased approximately 0.1 percent for each specific gravity increment of 0.05 below 2.75 (see Table X2.1).

8. DETERMINATION OF VCA IN COARSE-AGGREGATE FRACTION OF MIXTURE

8.1. For best performance, the SMA must have a coarse-aggregate skeleton with stone-on-stone contact. The course-aggregate fraction is that portion of the total aggregate blend retained on the 4.75-mm (No. 4) sieve for 12.5-mm ($^1/_2$-in.) and 19-mm ($^3/_4$-in.) SMA. For the 9.5-mm ($^3/_8$-in.) nominal-maximum aggregate size SMA, the coarse aggregate is that portion of the total aggregate blend retained on the 2.36-mm (No. 8) sieve. The condition of stone-on-stone contact within an SMA is defined as the point at which the VCA of the compacted mixture is less than the VCA of the coarse aggregate in the dry-rodded test.

8.2. The dry-rodded VCA of the coarse-aggregate fraction (VCA_{DRC}) is determined by compacting the stone with the dry-rodded technique in accordance with T 19M/T 19. When the dry-rodded density of the stone fraction has been determined, the VCA_{DRC} can be calculated using Equation 1:

$$VCA_{DRC} = \frac{G_{CA}\gamma_w - \gamma_s}{G_{CA}\gamma_w} \times 100 \qquad (1)$$

where:

G_{CA} = the bulk specific gravity of the coarse aggregate (T 85);

γ_s = the unit weight of the coarse-aggregate fraction in the dry-rodded condition [kg/m^3 (lb/ft^3)] (T 19/T 19M); and

γ_w = the unit weight of water [1000 kg/m^3 (62.4 lb/ft^3)].

9. SELECTION OF DESIRED GRADATION

9.1. After the trial samples have been compacted and allowed to cool, they are removed from the molds and tested to determine their bulk specific gravity in accordance with T 166. The uncompacted samples are used to determine the theoretical maximum density in accordance with T 209. Using the bulk specific gravity and theoretical maximum density, the V_a, VMA, and VCA of the compacted mixture (VCA_{mix}) can be calculated using Equations 2, 3, and 4:

$$\text{VMA} = 100 - \left(G_{mb}/G_{sb}\right)P_s \qquad (2)$$

$$\text{VCA}_{\text{mix}} = 100 - \left(G_{mb}/G_{CA}\right)P_{CA} \qquad (3)$$

$$V_a = 100 \times (1 - (G_{mb}/G_{mm})) \qquad (4)$$

where:

G_{mb} = the bulk specific gravity of the compacted mixture (T 166);

G_{sb} = the bulk specific gravity of the total aggregate;

P_s = the percent of aggregate in the mixture;

G_{CA} = the bulk specific gravity of the coarse-aggregate fraction (T 85);

P_{CA} = the percent of coarse aggregate in the total mixture; and

G_{mm} = the theoretical maximum density of the mixture (T 209).

9.2. Of the three trial gradations evaluated, the one with the lowest percent of coarse aggregate that meets or exceeds the minimum VMA requirement, and has a VCA_{mix} less than VCA_{DRC}, is selected as the desired gradation. The trial gradation selected, based on the above conditions, is referred to as the optimum gradation.

Note 6—If possible, the selected gradation should have a VMA somewhat higher than the minimum criteria to allow for some reduction in VMA during plant production.

10. SELECTION OF OPTIMUM BINDER CONTENT

10.1. Once the optimum gradation of the mixture has been chosen, it may be necessary to raise or lower the binder content to obtain the proper amount of V_a in the mixture. In this case, additional samples are prepared using the selected gradation and varying the binder content. The optimum binder content is chosen to produce the V_a in the mixture specified in M 325.

10.2. Twelve samples are needed for this portion of the procedure. This number provides for three compacted samples and one uncompacted sample (used to determine the theoretical maximum density) at each of the three binder contents. The mixture properties are determined and the optimum binder content is selected to provide the desired V_a level. The SMA selected should have properties meeting the criteria as specified in M 325. If these criteria are not satisfied, the mixture should be modified so that the requirements are satisfied.

11. MOISTURE SUSCEPTIBILITY

11.1. Moisture susceptibility of the selected mixture is determined in accordance with T 283 using samples compacted in accordance with T 312 to a V_a content of 6.0 ± 1.0 percent. The retained tensile strength level of the SMA shall be as specified in MP 8 at 6.0 ± 1.0 percent V_a.

12. DRAINDOWN SENSITIVITY

12.1. Draindown sensitivity of the selected mixture is determined using T 305. Draindown sensitivity is determined at the anticipated plant-production temperature and shall satisfy the requirements of M 325.

13. ADJUSTING MIXTURE TO MEET PROPERTIES

13.1. *V_a Content*—The amount of V_a in the mixture can be controlled by the binder content. However, a problem occurs when low V_a contents exist at binder contents below the minimum values specified. Lowering the binder content below these values to achieve a proper amount of V_a violates the minimum binder-content specification. Instead, the mixture gradation must be modified to increase the VMA.

13.2. *VMA*—The VMA may be raised by increasing the percentage of coarse aggregate. Changing the aggregate source may also be required to increase VMA.

13.3. *VCA_{mix}*—If the $\mathrm{VCA}_{\mathrm{mix}}$ is higher than the $\mathrm{VCA}_{\mathrm{DRC}}$, then the mixture gradation must be modified. This modification is typically accomplished by increasing the percentage of coarse aggregate.

13.4. *Moisture Susceptibility*—If the mixture fails to meet the moisture-susceptibility requirements, anti-strip agents can be used. If these measures prove ineffective, the aggregate source and/or binder source can be changed to obtain better aggregate/binder compatibility.

13.5. *Draindown Sensitivity*—Problems with draindown sensitivity can be remedied by increasing the amount of, or by selecting a different, stabilizing additive.

14. REPORT

14.1. *Report the following information*:

14.1.1. Identification of the project name and project number;

14.1.2. Information on the materials used, including aggregate source, binder source and performance grade, type and amount of stabilizing additive, and material quality characteristics;

14.1.3. Results of the gradation optimization (results of all trial gradations);

14.1.4. Optimum gradation and binder content;

14.1.5. Volumetric properties for each trial blend and at the optimum binder content;

14.1.6. Moisture susceptibility results; and

14.1.7. Draindown sensitivity results.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE OF BLENDING AGGREGATE COMPONENTS TO SATISFY SMA GRADATION BANDS

X1.1. In HMA designs, specified aggregate gradations should be based on aggregate volume and not aggregate mass. However, for most conventional HMA mixtures (dense-graded), the specific gravities of the different aggregate stockpiles are assumed to be sufficiently comparable to make the gradations based on mass percentages similar to those based on volumetric percentages. This assumption is often not true in the aggregate components and, particularly in the mineral fillers used in SMA, where specific gravities vary widely. Therefore, in SMA, the specified gradation bands presented in the mixture design procedure are based on the percent passing by volume. This appendix gives an illustrative example with the objective of providing guidance on blending aggregate components based on volumes to meet the SMA gradation bands. However, if the G_{sb} of the different aggregates to be used within the mixture varies by 0.2 or less, gradations based on mass percentages may be used.

X1.2. The first step is to perform gradation tests based on mass in accordance with T 27 for the various aggregates to be used in SMA. For the example covered in this appendix, a 19.0-mm ($^3/_4$-in.) nominal-maximum aggregate size SMA is to be blended. Table X1.1 provides the results of the gradation tests performed on four aggregates that are to be blended. Also needed to determine aggregate gradations based on volume are the G_{sb} of the different aggregates. Table X1.1 also provides the G_{sb} values for each aggregate. Notice that the G_{sb} values differ by more than 0.2.

X1.3. The second step is to determine the percent, by mass, retained on each sieve for the different aggregates. For a given sieve, this calculation is performed by subtracting the percent passing the given sieve from the percent passing the next larger sieve. For example, using Aggregate C, the percent, by mass, retained on the 4.75-mm (No. 4) sieve would be calculated as follows:

Percent retained on 4.75-mm (No. 4) Sieve = 84.6 – 48.9 = 35.7 percent

where:

84.6 = the percent by mass passing the 9.5-mm ($^3/_8$-in.) sieve (Table X1.1);

48.9 = the percent by mass passing the 4.75-mm (No. 4) sieve (Table X1.1); and

35.7 = the percent by mass retained on the 4.75-mm (No. 4) sieve.

Table X1.1—Results of Gradation and Specific Gravity Tests for Aggregates to Be Used

	Stockpile Designation and Percent Passing Based on Mass			
Sieve	Aggregate A	Aggregate B	Aggregate C	Mineral Filler
19.0 mm ($^3/_4$ in.)	100.0	100.0	100.0	100.0
12.5 mm ($^1/_2$ in.)	66.0	71.0	97.4	100.0
9.5 mm ($^3/_8$ in.)	43.0	46.0	84.6	100.0
4.75 mm (No. 4)	9.0	6.0	48.9	100.0
2.36 mm (No. 8)	5.0	4.0	27.8	100.0
1.18 mm (No. 16)	2.0	4.0	16.6	100.0
0.60 mm (No. 30)	2.0	3.0	10.7	100.0
0.30 mm (No. 50)	2.0	3.0	7.6	100.0
0.075 mm (No. 200)	1.0	1.5	4.6	72.5
G_{sb}	2.616	2.734	2.736	2.401

X1.4. In the third step, assume the mass of each aggregate stockpile is 100 g. Using this assumption allows for the mass that would be retained on each sieve for each aggregate to be determined and shown to be equal to the numbers displayed in Table X1.2.

X1.5. Table X1.2 presents the values for the percent, by mass, retained for all sieves and aggregates. Note that a row has been added to reflect the material finer than the 0.075-mm (No. 200) sieve.

Table X1.2—Percent, by Mass, Retained on Each Sieve

	Stockpile Designation and Percent, by Mass, Retained on Each Sieve			
Sieve	Aggregate A	Aggregate B	Aggregate C	Mineral Filler
19.0 mm ($^3/_4$ in.)	0.0	0.0	0.0	0.0
12.5 mm ($^1/_2$ in.)	34.0	29.0	2.6	0.0
9.5 mm ($^3/_8$ in.)	23.0	25.0	12.8	0.0
4.75 mm (No. 4)	34.0	40.0	35.7	0.0
2.36 mm (No. 8)	4.0	2.0	21.1	0.0
1.18 mm (No. 16)	3.0	0.0	11.2	0.0
0.60 mm (No. 30)	0.0	1.0	5.9	0.0
0.30 mm (No. 50)	0.0	0.0	3.1	0.0
0.075 mm (No. 200)	1.0	1.5	3.0	27.5
–0.075 mm (No. 200)	1.0	1.5	4.6	72.5
Total, Σ	100	100	100	100

X1.6. The fourth step converts the masses determined in Step 3 to volumes per sieve. To make this conversion, the G_{sb} of the individual aggregates is needed. The volume of aggregate retained on each sieve for each aggregate can be determined from Equation X1.1:

$$\text{Volume of aggregate for a given sieve (cm}^3\text{)} = \frac{\text{Mass of aggregate retained, } g}{\text{Specific gravity } x\, \gamma_w} \qquad (X1.1)$$

where:

γ_w = the unit weight of water (1.0 g/cm^3).

X1.7. The following calculation applies for the volume of the aggregate retained on the 4.75-mm (No. 4) sieve of Aggregate C.

$$\text{Volume} = \frac{35.7\text{ g}}{2.736 \times 1\text{ g/cm}^3} = 13.05\text{ cm}^3$$

where:

35.7 g = the mass of Aggregate C retained on the 4.75-mm (No. 4) sieve (Table X1.2);
2.736 = the bulk specific gravity of Aggregate C (Table X1.1);
1.0 g/cm^3 = the unit weight of water; and
13.05 cm^3 = the volume of Aggregate C retained on the 4.75-mm (No. 4) sieve.

X1.8. The volumes retained on all sieves for each of the four aggregates are provided in Table X1.3.

Table X1.3—Volumes of Aggregate Retained on Each Sieve

	Stockpile Designation and Volume of Aggregate Retained on Each Sieve, cm^3			
Sieve	Aggregate A	Aggregate B	Aggregate C	Mineral Filler
19.0 mm ($^3/_4$ in.)	0.00	0.00	0.00	0.00
12.5 mm ($^1/_2$ in.)	13.00	10.61	0.95	0.00
9.5 mm ($^3/_8$ in.)	8.79	9.14	4.68	0.00
4.75 mm (No. 4)	13.00	14.63	13.05	0.00
2.36 mm (No. 8)	1.53	0.73	7.71	0.00
1.18 mm (No. 16)	1.15	0.00	4.09	0.00
0.60 mm (No. 30)	0.00	0.37	2.16	0.00
0.30 mm (No. 50)	0.00	0.00	1.13	0.00
0.075 mm (No. 200)	0.38	0.55	1.10	11.45
–0.075 mm (No. 200)	0.38	0.55	1.68	30.20

X1.9. The values provided in Table X1.3 are used to blend the different aggregates to meet the desired gradation based on volumes. In this procedure, the aggregate is blended by mass; then the final gradation is determined based on volume. As with gradations based on mass, this is a trial-and-error process. To perform the blending, select the estimated percentages, by mass, of the different aggregates to be used. For this example, the percentages in Table X1.4 will be tried first.

Table X1.4—Percentages of the Four Aggregates Used for the First Trial

Stockpile	% of Blend by Mass
Aggregate A	30
Aggregate B	30
Aggregate C	30
Mineral Filler	10

X1.10. Notice that the percentages in Table X1.4 are based on mass. This format indicates that the volume represented by 30 percent of Aggregate A, by mass, will be used in the blending of the aggregates based on volumes.

X1.11. The percent of each aggregate in the blend is multiplied by the volume retained on a given sieve for each aggregate to determine the total volume retained on that sieve. Using the 4.75-mm (No. 4) sieve, the total volume retained on the 4.75-mm (No. 4) sieve is calculated as follows:

$$\text{Total volume retained on the 4.75-mm (No. 4) sieve} = (0.30 \times 13.00) + (0.30 \times 14.63) + (0.30 \times 13.05) + (0.10 \times 0.00) = 12.20\ \text{cm}^3$$

where:

0.30, 0.30, 0.30, and 0.10 = the percentage, by mass, of each aggregate in the blend expressed as a decimal; and

13.00, 14.63, 13.05, and 0.00 = the volume retained on the 4.75-mm (No. 4) sieve for each aggregate (Table X1.3).

X1.12. The calculation in Section X1.11 is performed for each of the sieves in the gradation. Table X1.5 presents the total volume retained for each of the sieves in the gradation.

Table X1.5—Total Volumes Retained for Each Sieve for the First Trial

Sieve	Volume Retained for Each Sieve, cm^3
19.0 mm ($^3/_4$ in.)	0.00
12.5 mm ($^1/_2$ in.)	7.37
9.5 mm ($^3/_8$ in.)	6.78
4.75 mm (No. 4)	12.20
2.36 mm (No. 8)	2.99
1.18 mm (No. 16)	1.57
0.60 mm (No. 30)	0.76
0.30 mm (No. 50)	0.34
0.075 mm (No. 200)	1.75
–0.075 mm (No. 200)	3.80
Total Volume, Σ	37.56

X1.13. Now, based on the total volume retained per sieve and the total volume of the blended aggregates, the percent retained for each sieve, by volume, can be determined for the blend. This calculation is accomplished for a given sieve by dividing the volume retained on that sieve by the total volume of the blend. The following illustrates this calculation for the 4.75-mm (No. 4) sieve.

$$\text{Percent volume retained on the 4.75-mm (No. 4) sieve} = \frac{12.20\ \text{cm}^3}{37.56\ \text{cm}^3} \times 100 = 32.48\ \text{percent}$$

where:

12.20 cm^3 = the volume retained on the 4.75-mm (No. 4) sieve (Table X1.5);

37.56 cm^3 = the total volume of the blend (Table X1.5); and

32.48 = the percent volume of the blend retained on the 4.75-mm (No. 4) sieve.

X1.14. Using the percent retained per sieve based on volume, the percent passing, by volume, for the gradation can be determined similarly to the method used for gradations based on mass. Determine the cumulative percent retained for each sieve, and then subtract that value from 100.

X1.15. Table X1.6 provides the percents retained, based on volumes, for each of the sieves and converts these values to percent passing.

Table X1.6—Percents Passing Based on Volumes for the First Trial

Sieve	Percent Retained on Each Sieve	Cumulative Percent Retained	Percent Passing by Volume
19.0 mm ($^3/_4$ in.)	0.0	0.0	100.0
12.5 mm ($^1/_2$ in.)	19.6	19.6	80.4
9.5 mm ($^3/_8$ in.)	18.0	37.6	62.4
4.75 mm (No. 4)	32.5	70.1	29.9
2.36 mm (No. 8)	8.0	78.1	21.9
1.18 mm (No. 16)	4.2	82.3	17.7
0.60 mm (No. 30)	2.0	84.3	15.7
0.30 mm (No. 50)	0.9	85.2	14.8
0.075 mm (No. 200)	4.7	89.9	10.1
–0.075 mm (No. 200)	10.1	100.0	0.0

X1.16. Now, the blended gradation is compared to the required gradation band (also based on volume). Table X1.7 compares the gradation band for a 19.0-mm ($^3/_4$-in.) nominal-maximum aggregate size SMA from MP 8 to the gradation shown in Table X1.6.

Table X1.7—Comparison of Gradation Blend Based on Volume for the First Trial to Specified Gradation Band

Sieve	Gradation Band	Percent Passing for Blend
19.0 mm ($^3/_4$ in.)	90 to 100	100.0
12.5 mm ($^1/_2$ in.)	50 to 88	80.4
9.5 mm ($^3/_8$ in.)	25 to 60	62.4[a]
4.75 mm (No. 4)	20 to 28	29.9[a]
2.36 mm (No. 8)	16 to 24	21.9
1.18 mm (No. 16)	—	17.7
0.60 mm (No. 30)	—	15.7
0.30 mm (No. 50)	—	14.8
0.075 mm (No. 200)	8.0 to 11.0	10.1

[a] Does not meet the applicable requirements.

X1.17. Based on Table X1.7, the blended gradation did not meet the specified gradation band for a 19.0-mm ($^3/_4$-in.) nominal-maximum aggregate size SMA. Therefore, different blending percentages for the various aggregates are needed. Table X1.8 shows the percentages of the four aggregates used for the second trial.

Table X1.8—Percentages of the Four Aggregates Used for the Second Trial

Stockpile	% of Blend by Mass
Aggregate A	40
Aggregate B	41
Aggregate C	10
Mineral Filler	9

X1.18. Table X1.9 presents the blending of the four aggregates for the second trial. The second trial blend percentages were used along with the values from Table X1.3 to determine the percent passing, by volume, for the blend.

Table X1.9—Percents Passing Based on Volumes for the Second Trial

Sieve	Percent Retained on Each Sieve by Volume	Cumulative Percent Retained by Volume	Percent Passing by Volume	Percent Passing by Mass (for Comparison)	Gradation Band by Volume
19.0 mm ($^3/_4$ in.)	0.0	0.0	100.0	100.0	90 to 100
12.5 mm ($^1/_2$ in.)	25.6	25.6	74.4	74.3	50 to 88
9.5 mm ($^3/_8$ in.)	20.5	46.1	53.9	53.5	25 to 60
4.75 mm (No. 4)	33.2	79.3	20.7	20.0	20 to 28
2.36 mm (No. 8)	4.5	83.8	16.2	15.4	16 to 24
1.18 mm (No. 16)	2.3	86.1	13.9	13.1	—
0.60 mm (No. 30)	1.0	87.1	12.9	12.1	—
0.30 mm (No. 50)	0.3	87.4	12.6	11.8	—
0.075 mm (No. 200)	4.0	91.4	8.6	8.0	8.0 to 11.0
–0.075 mm (No. 200)	8.6	100.0	—	—	—

X1.19. Based on Table X1.9, the following percentages in Table X1.10 produce a gradation, based on volume, which satisfies the 19.0-mm ($^3/_4$-in.) nominal-maximum-aggregate size gradation band for SMA.

Table X1.10—Acceptable Blend of the Four Aggregates

Stockpile	% of Blend by Mass
Aggregate A	40
Aggregate B	41
Aggregate C	10
Mineral Filler	9

X2. ADJUSTMENT OF MINIMUM BINDER CONTENT BASED ON BULK SPECIFIC GRAVITY (G_{SB}) OF THE COMBINED AGGREGATES

Table X2.1—Guide to Adjust Minimum Binder Content Based on Varying G_{sb} of Combined Aggregates

Combined Aggregate, G_{sb}	Minimum Binder Content, %
2.40	6.8
2.45	6.7
2.50	6.6
2.55	6.5
2.60	6.3
2.65	6.2
2.70	6.1
2.75	6.0
2.80	5.9
2.85	5.8
2.90	5.7
2.95	5.6
3.00	5.5

Standard Practice for

Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size

AASHTO Designation: R 47-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size

AASHTO Designation: R 47-08

1. SCOPE

1.1 This standard practice outlines methods for the reduction of large samples of hot mix asphalt (HMA) to the appropriate size for testing, employing techniques that are intended to minimize variations in the measured characteristics between the test samples so selected and the large sample.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard practice may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 168, Sampling Bituminous Paving Mixtures

3. TERMINOLOGY

3.1 *mastic*—a mixture of asphalt binder and fine mineral material.

4. SIGNIFICANCE AND USE

4.1 Specifications for HMA mixtures require sampling portions of the material for testing. Other factors being equal, larger samples will tend to be more representative of the total supply. This method provides procedures for reducing the large sample obtained in the field or produced in the laboratory to a convenient size for conducting a number of tests to describe the material and measure its quality in a manner that the smaller test sample portion is most likely to be a representation of the larger sample, and thus of the total supply. The individual test methods provide the minimum quantity of material necessary.

5. SELECTION OF METHOD

5.1 The selection of a particular method to reduce the large sample to test size depends on the amount of material comprising the large sample. It is recommended that for a large amount of material a mechanical splitter be employed whenever possible, thus lessening the time needed for reduction and minimizing the loss of temperature. To further reduce the sample size, a quartering method can be utilized.

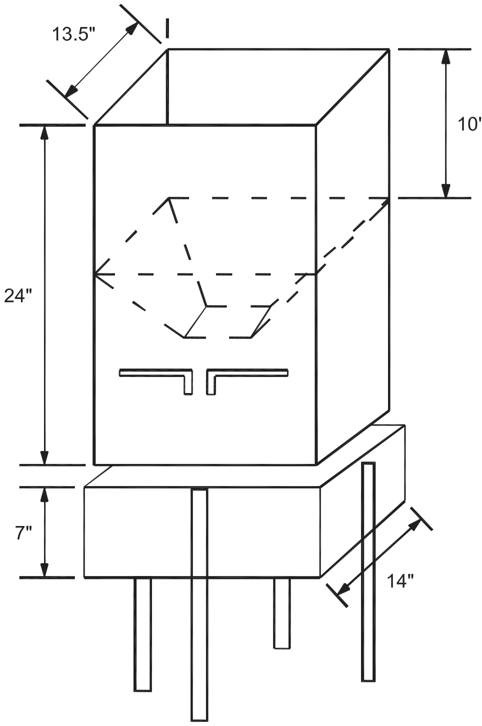
6. SAMPLING

6.1 Obtain samples of HMA according to T 168 or as required by individual test methods. When additional tests are to be conducted, ensure that the initial size of the field sample is adequate to accomplish all intended tests. Use similar procedures for HMA produced in the laboratory.

MECHANICAL SPLITTER METHOD

7. APPARATUS

7.1 *Mechanical Splitter Type A*—The splitter shall have four equal-width chutes that discharge the material into four appropriate size containers. The splitter shall be designed with a receiving hopper that will hold the HMA field sample until a handle releases the material to fall through a divider and distribute it into four equal portions. The splitter shall be designed so that the HMA field sample will flow smoothly and freely through the divider without restriction or the loss of material (see Figures 1 to 3).

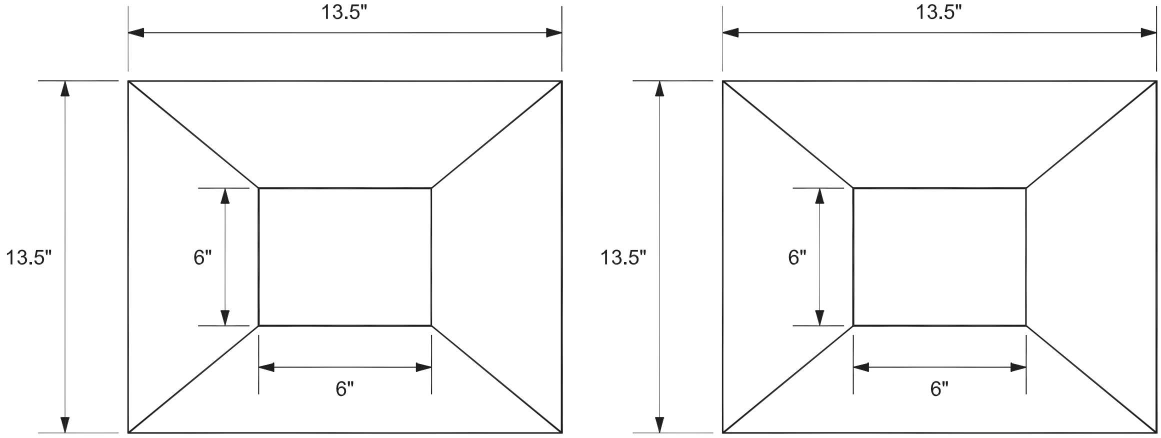


Metric Equivalents

in.	mm
7	178
10	254
13.5	343
14	356
24	610

Note: All dimensions shown in inches unless otherwise noted.

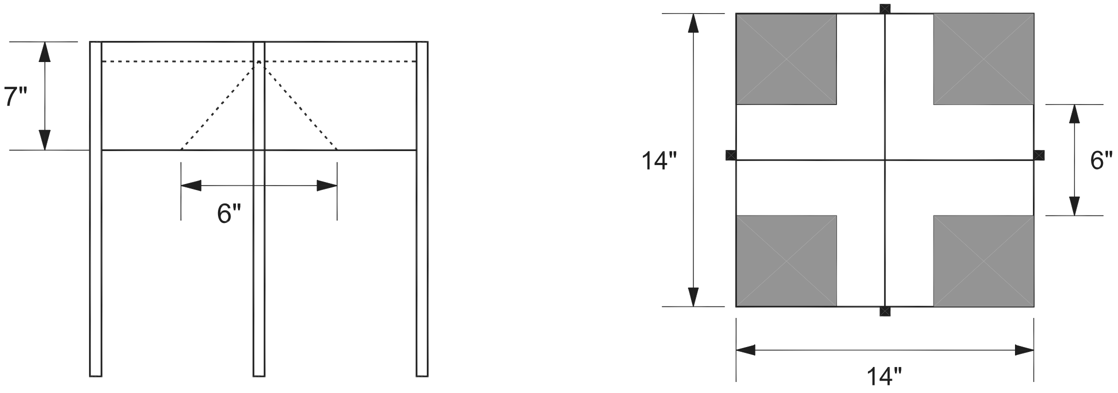
Figure 1—Mechanical Splitter Type A



Metric Equivalents	
in.	mm
6	152
13.5	343

Note: All dimensions shown in inches unless otherwise noted.

Figure 2—Plan View of Splitter



a. Elevation View of Bottom Portion of Splitter

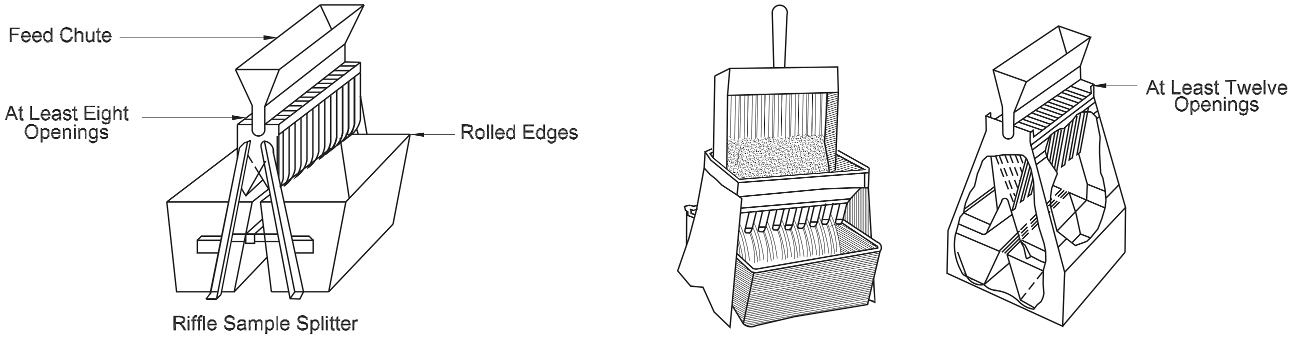
b. Plan View of Bottom Portion of Splitter

Metric Equivalents	
in.	mm
6	152
7	178
14	356

Note: All dimensions shown in inches unless otherwise noted.

Figure 3—Elevation and Plan View of Bottom Portion of Splitter

7.2 *Mechanical Splitter Type B*—This splitter shall have an even number of equal-width chutes (no fewer than a total of eight for a Large Splitter and no fewer than 12 for a Small Splitter) which discharge alternately to each side of the splitter. The minimum width of the individual chutes shall be approximately 50 percent larger than the largest particle to be split. The splitter shall be equipped with two receptacles to catch the two halves of the sample following splitting. It shall also be equipped with a hopper or straightedged pan that has a width equal to or slightly less than the overall width of the assembly of chutes, by which the sample may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the sample will flow smoothly and freely without restriction or the loss of material.



a. Large Splitter for large samples

b. Small Splitters for small samples

Figure 4—Mechanical Splitter Type B

Note 1—Type B Mechanical splitters are commonly available in sizes adequate for HMA having a nominal maximum aggregate size not over 25.4 mm (1 in.). Use closed versions for larger sizes.

7.3 *Non-Contact Temperature Device*

7.4 *Asphalt Release Agent*—Shall not contain any solvents or petroleum-based products that could affect asphalt binder properties.

8. PROCEDURE FOR MECHANICAL SPLITTER METHOD

8.1 Place the splitter on a level surface. The splitter and accessory equipment may be heated, not to exceed 110°C (230°F), as determined by a non-contact temperature device. Surfaces of the mechanical splitter that will come in contact with the HMA may be lightly coated with an approved asphalt release agent to prevent a buildup and loss of asphalt binder and fines. The release agent shall not contain any solvents or petroleum-based products that could affect asphalt binder properties.

8.2 *Mechanical Splitter Type A*—Place the field or laboratory-prepared HMA into the mechanical splitter hopper, and position four sample receptacles to receive the reduced portions of the original sample. Fill the hopper in such a manner as to avoid segregation of the HMA, typically using a continuous or segmented pour from multiple directions around the hopper. Release the handle to drop the HMA through the dividers into the sample receptacles. Reintroduce selected receptacles from opposite corners into the splitter hopper as many times as necessary to further reduce the HMA sample to the size specified for the intended test.

8.3 *Mechanical Splitter Type B*—Place the field or laboratory-prepared HMA into the sample splitter pan or hopper, and uniformly distribute it from edge to edge so that when it is introduced into the chutes, approximately equal amounts will flow through each chute. The rate at which the sample is introduced shall be such as to allow free flow through the chutes into the receptacles below. The entire sample may be mixed by repeated use of the mechanical splitter. Reintroduce the portion of the sample from one of the receptacles into the splitter as many times as necessary to reduce the sample to the size necessary for the intended test. The portion of the material collected in the other receptacle may be reserved for reduction in size for other tests.

QUARTERING METHOD

9. APPARATUS

9.1 *Quartering Template*—A quartering template manufactured from a suitable metal that withstands heat and use without deforming is recommended. The template should be configured in the form of a cross with sides of equal length sufficient to be 1.1 times the diameter of a flattened cone of HMA sample to be quartered. The height of the sides should be sufficient to extend above the thickness of the flattened cone of the HMA sample to be quartered. The sides shall form a 90 degree angle at their juncture (see Figure 5).

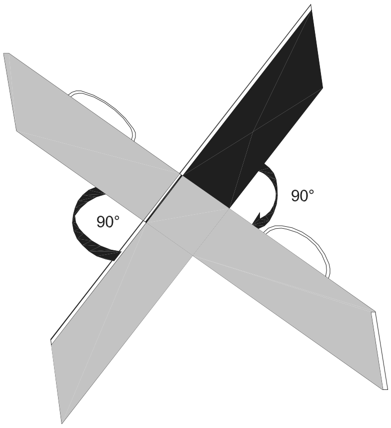


Figure 5—Quartering Device

9.2 *Flat-Bottom Scoop*—A large, straightedged, flat-bottom scoop should be used to sample HMA. A square shovel or trowel will meet this requirement.

9.3 *Straightedge*—Large spatula, trowel, or metal straightedge.

9.4 *Non-stick paper or heat resistant plastic*.

9.5 *Asphalt Release Agent*—Shall not contain any solvents or petroleum-based products that could affect asphalt binder properties.

10. PROCEDURE FOR QUARTERING METHOD

10.1 Place the original sample on a hard, “non-stick”, clean, level surface where there will be neither a loss of material nor the accidental addition of foreign material. The surface can be made non-stick by the application of an approved asphalt release agent, non-stick paper or heat resistant plastic.

10.2 Mix the material thoroughly by turning the entire sample over a minimum of four times with a flat-bottom scoop or by alternately lifting each corner of the paper and pulling it over the sample diagonally toward the opposite corner causing the material to be rolled. Create a conical pile by either depositing each scoop or shovelful of the last turning on top of the preceding one, or lifting both opposite corners. Carefully flatten the conical pile to a uniform thickness and diameter by pressing down the apex with a shovel or large, flat-bottomed, square scoop. The diameter should be approximately four to eight times the thickness. Make a visual observation to ensure that the material is homogeneous.

10.3 Divide the flattened mass into four quarters by inserting the quartering template and pressing down until the template is in complete contact with the surface on which the sample is placed. Straightedges may be used in lieu of the quartering device to completely separate the material into approximately equal quarters.

10.4 Reduce the sample using one of the following procedures:

10.5 Remove two diagonally opposite quarters, including all fine mastic material. Remove the quartering template. Successively mix and quarter the remaining material until the sample is reduced to the desired size.

10.6 Using a straightedge, slice through a quarter of the HMA from the center point to the outer edge of the quarter. Pull or drag the material from the quarter holding one edge of the straightedge in contact with the quartering device. Two straightedges may be used in lieu of the quartering device. Remove an equal portion from the opposite quarter.

INCREMENTAL METHOD

11. APPARATUS

11.1 *Flat-Bottom Scoop*—A large, straightedged, flat-bottom scoop should be used to sample HMA. A square shovel or trowel will meet this requirement.

11.2 *Non-stick heavy paper or heat-resistant plastic*.

11.3 *Large spatulas, trowels, metal straightedge, or 305 mm (12 in.) drywall taping knife*.

11.4 *Miscellaneous Equipment*—Including hot plate, non-asbestos heat-resistant gloves or mittens, pans, buckets, and cans.

12. PROCEDURE FOR INCREMENTAL METHOD

12.1 Place the original sample on a hard, non-stick, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material. The surface shall be covered with a non-stick heavy paper, heat resistant plastic, or other suitable material.

12.2 Mix the material thoroughly by turning the entire sample over a minimum of four times with a flat-bottom scoop or by alternately lifting each corner of the paper and pulling it over the sample diagonally toward the opposite corner causing the material to be rolled. Create a conical pile by either depositing each scoop or shovelful of the last turning on top of the preceding one, or lifting both opposite corners. Make a visual observation to ensure that the material is homogeneous.

12.3 Grasp the paper; roll the material into a cylindrical roll (loaf), and flatten the top.

12.4 Pull the paper so at least $^1/_4$ of the length of the loaf is off the edge of the counter. Allow this material to drop into a container. Alternately, use a straightedge to slice off approximately $^1/_4$ of the length of the loaf and place the material in a sample pan or container. Set the material obtained aside.

12.5 Pull additional material off the edge of the counter and drop the appropriate-size sample into a sample pan or container. Alternately, use a straightedge to slice off an appropriate-size sample from the length of the loaf and place in a sample pan or container.

12.6 Repeat Section 12.5 as necessary until the proper-size sample has been obtained (Note 2). Repeat Sections 12.4 and 12.5 until all the samples for testing have been obtained. At any time while obtaining test samples, it may be necessary to re-roll the material as described in Sections 12.2 and 12.3.

Note 2—When reducing the sample to test size, it is advisable to take several small increments, determining the mass each time until the proper minimum size is achieved. Unless the sample size is grossly in excess of the minimum or exceeds the maximum test size, use the sample as reduced for the test.

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13. KEYWORDS

13.1 Hot mix asphalt (HMA); incremental method; quartering method; sample splitter; sample reduction; sampling.

Standard Practice for

Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders

AASHTO Designation: R 49-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders

AASHTO Designation: R 49-09[1]

1. SCOPE

1.1. This standard practice covers the determination of low-temperature properties of asphalt binders using data from the bending beam rheometer (T 313) and the direct tension tester (T 314). This standard practice can be used on data from unaged material or from material aged using T 240 (RTFOT), R 28 (PAV), or T 240 (RTFOT) and R 28 (PAV). This standard practice can be used on data generated within the temperature range from +6 to –36°C.

1.2. This standard practice is only valid for data on materials that fall within the scope of suitability for both test methods T 313 and T 314.

1.3. This standard practice can be used to determine the following:

1.3.1. *PG Grade Determination of an Asphalt Binder*—The determination of a low-temperature grade or grades that are satisfied by an asphalt binder. The determination of the temperature corresponds to the specification parameter, T_{cr}, the critical cracking temperature.

1.3.2. *Prequalification of an Asphalt Binder*—The procedure required to qualify an asphalt binder for supply.

1.3.3. *Verification of an Asphalt Binder Grade*—The testing required to certify that a binder complies with an existing prequalified binder.

1.4. While this standard practice determines the critical cracking temperature for typical hot mix asphalt (HMA), the intent of this standard practice is grading of asphalt binder according to M 320, not performance prediction for asphalt pavement. This standard practice should not be used in lieu of T 322.

1.5. *This standard practice may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

Note 1—The algorithms contained in this standard require implementation by a person trained in the subject of numerical methods and visco-elasticity. However, due to the complexity of the calculations they must, of necessity, be performed on a computer. Software to perform the calculations may be written or purchased as a spreadsheet or as a stand-alone program.[2]

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- T 322, Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *Arrhenius parameter* (a_1)—this is the constant coefficient in the Arrhenius model for shift factors, $\ln(a_T) = a_1(1/T - 1/T_{\mathrm{ref}})$.

3.1.2. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

3.1.3. *coefficient of linear thermal expansion* (α)—the fractional change in size in one dimension associated with a temperature increase of 1°C.

3.1.4. *conventional unmodified asphalt binders*—asphalt binders for which the following two conditions are satisfied: (1) The difference between the temperature at which $S(60) = 300$ MPa and m-value $(60) = 0.300$ is less than or equal to ±2.0°C. The $S(60)$ and the m-value are determined using the T 313 BBR test; (2) The failure strength determined using T 314 must be within 3.77 ± 0.77 MPa.

3.1.5. *creep compliance* [$D(T,t)$]—the reciprocal of the stiffness of a material, $1/S(T,t)$, at temperature, T, and time, t. Creep compliance may also be expressed using reduced time, ξ, as $D(T_{\mathrm{ref}}, \xi)$.

3.1.6. *critical cracking temperature* (T_{cr})—the temperature, estimated using this standard practice, at which the induced thermal stress in a material exceeds its fracture stress. The critical cracking temperature is a "single event cracking" limit prediction that does not include the effect of low-temperature thermal fatigue.

3.1.7. *failure stress* (σ_f)—the tensile stress value at the point of failure obtained from T 314.

3.1.8. *glassy modulus*—the modulus at which the binder exhibits glass-like behavior, assumed to be 3×10^9 Pa for this procedure.

3.1.9. *induced thermal stress* (σ_{th})—the stress induced in a material by cooling it while it is restrained so that it cannot contract.

3.1.10. *master curve*—a composite curve at a single reference temperature, T_{ref}, which can be constructed by shifting, along the log time or log frequency axis, a series of overlapping modulus data curves at various test temperatures. The modulus data curve at the reference temperature is not shifted. The shifted smooth curve is called the master curve at the reference temperature.

3.1.11. *pavement constant* (*C*)—an empirical, constant factor that serves as a damage transfer function to convert the thermal stresses calculated from laboratory data to the thermal stresses generated in the pavement. The damage transfer function is needed to account for the differences in the strain rates experienced by the distribution of binder films in the pavement and the bulk strain rate used in the T 314 direct tension test (DDT). Critical cracking temperatures of conventional unmodified asphalt binders were used to determine the pavement constant, *C*. The value of the pavement constant, *C*, is the value that minimizes the difference between the critical cracking temperature, T_{cr}, determined using the procedure described in this standard practice and the T 313 bending beam rheometer (BBR) test. The T_{cr} from the BBR test is determined as the higher value between the temperature where *S*(60) is 300 MPa and the temperature where the *m*-value at 60 seconds is 0.3. Using the above procedure, the value of the pavement constant was determined to be 18. The pavement constant of 18 is based on the most current pavement performance data available. Federal Highway Administration (FHWA) and the Transportation Research Board (TRB) Binder Expert Task Group (ETG) continue to collect and analyze field-performance data.

3.1.12. *reduced time* (ξ)—the computed loading time at the reference temperature, T_{ref}, equivalent to actual loading at temperature *T*. The reduced time is determined by dividing actual loading time, *t*, at temperature *T*, by the shift factor, *aT*, $\xi = t/a_T$.

3.1.13. *reference temperature* (T_{ref})—the temperature at which the master curve is constructed in degrees Kelvin.

3.1.14. *relaxation modulus* [$E(T,t)$]—the modulus of a material determined using a strain-controlled (relaxation) experiment at temperature, *T*, and time, *t*. Relaxation modulus may also be expressed using reduced time as $E(T_{\mathrm{ref}}, \xi)$.

3.1.15. *shift factor* (a_T)—the shift in the time or frequency domain associated with a shift from temperature, *T*, to the reference, T_{ref}.

3.1.16. *specification temperature* (T_{spec})—the specified low-temperature grade of the binder being prequalified.

3.1.17. *stiffness modulus* [$S(T,t)$]—the modulus (stress/strain) of a material at temperature, *T*, and time, *t*. Stiffness modulus may also be expressed using reduced time as $S(T_{\mathrm{ref}}, \xi)$.

4. SUMMARY OF THE PRACTICE

4.1. This standard practice describes the procedure used to calculate the relaxation modulus master curve and subsequently the thermally induced stress curve for an asphalt binder from data generated from the bending beam rheometer test.

4.2. The stiffness master curve is calculated from the stiffness versus time data measured in the BBR at two temperatures. The fitting procedure follows the Christensen-Anderson-Marasteanu (CAM) rheological model for asphalt binder. The stiffness master curve is then converted to the creep compliance curve by taking its inverse.

4.3. The creep compliance is converted to relaxation modulus using the Hopkins and Hamming method, which is fitted to the CAM model. The Hopkins and Hamming method is a numerical solution of the convolution integral.

4.4. The thermally induced stress is calculated by numerically solving the convolution integral. The thermal stress calculations are based on Boltzmann's superposition principle for linear viscoelastic materials. The calculated thermally induced stress is then multiplied by the pavement constant to predict the thermal stress produced in the hot mix asphalt pavement. A value of 18 is used for the pavement constant.

4.5. The calculated thermal stress is then compared to the failure stress from the direct tension test to determine the critical cracking temperature of the pavement.

5. SIGNIFICANCE AND USE

5.1. Estimated cracking temperature, as determined by this standard practice, is a criterion for specifying the low-temperature properties of asphalt binder in accordance with M 320.

5.2. This standard practice is designed to identify the temperature region where the induced thermal stress in a typical hot mix asphalt subjected to rapid cooling (1°C/h) exceeds the fracture stress of the HMA.

5.3. For evaluating an asphalt binder for conformance to M 320, the test temperature for the bending beam rheometer (BBR) and direct tension test (DTT) data is selected from Table 2 of M 320 according to the grade of asphalt binder.

Note 2—Other cooling rates and test temperatures may be used to test asphalt binders for experimental purposes.

6. METHODOLOGY AND REQUIRED DATA

6.1. This standard practice uses data from both bending beam rheometer and direct tension measurements on an asphalt binder.

6.1.1. The DTT data required is the stress at failure obtained by testing at a strain rate of 3 percent per minute. For continuous grade and PG determination, DTT results are required at a minimum of two test temperatures. The DT tests shall be conducted at the test temperatures from M 320 at 6°C increments corresponding to the low-temperature binder grade. For prequalification and verification, DTT results are required at a single temperature that is equal to the low-temperature grade plus 10°C.

6.1.2. Two BBR data sets at two different temperatures are required with deflection measurements at 8, 15, 30, 60, 120, and 240 seconds. The BBR test temperatures, T and $T - 6$°C, are selected such that $S(T,60) \leq 300$ MPa and $S(T - 6,60) > 300$ MPa. T shall be the appropriate test temperatures from M 320 at 6°C increments corresponding to the low-temperature binder grade.

Note 3—It is helpful to begin testing at a temperature that is 6°C lower than the critical low cracking temperature for a given grade in Table 2 of M 320. Depending upon the result, perform the next test either at the critical low cracking temperature for a given grade in Table 2 of M 320 or 12°C lower than that temperature. Additional tests may be necessary to bracket 300 MPa.

Using a PG xx-22 as an example, test the first set of BBR beams at a test temperature of –18°C. If *S*(–18°C,60) > 300 MPa, test the next set of BBR beams at a test temperature of –12°C. If *S*(–8°C,60) ≤ 300 MPa, test the next set of BBR beams at a test temperature of –24°C.

7. CALCULATIONS

7.1. *Calculation of the Stiffness Master Curve*:

7.1.1. Calculate the BBR compliance data in accordance with T 313 to obtain the following data:

$D(T,t)$ = compliance at temperature, T, and time, t.

$D(T,8)$, $D(T,15)$, $D(T,30)$, $D(T,60)$, $D(T,120)$,
$D(T,240)$, $D(T-6,8)$, $D(T-6,15)$, $D(T-6,30)$, $D(T-6,60)$,
$D(T-6,120)$, $D(T-6,240)$

7.1.2. Calculate the BBR stiffness data in accordance with T 313 as:

$S(T,t) = 1/D(T,t)$

7.1.3. Determine a_{T-6}, the shift factor for the data at temperature T – 6°C, numerically using the Gordon and Shaw method (Gordon and Shaw, 1994) to produce a master curve. The reference temperature shall be the higher of the two test temperatures. The linear coefficient of thermal expansion, above and below the glass transition temperature, shall be 0.00017 m/m/°C. The glass transition temperature is taken as –20°C.

Note 4—This procedure is described in Gordon and Shaw, *Computer Programs for Rheologists*, Hanser Gardner (1994). The SHIFTT routine, which can be found in Chapter 5 of *Computer Programs for Rheologists*, is to be used. The value of –20°C is used for glass transition but has no effect on the calculation since the linear expansion coefficient is assumed to be the same either side of this temperature. Experimental data have indicated that some binders may have a variation in their glass transition temperature and α value. For research purposes, these values may be determined and the measured values used in the calculations.

7.1.4. From a_{T-6}, calculate the Arrhenius parameter as:

$$\ln\left(a_{T-6}\right) = a_1\left(\frac{1}{T_{\mathrm{ref}}-6} - \frac{1}{T_{\mathrm{ref}}}\right) \qquad (1)$$

where:

$$a_1 = \frac{\ln(a_{T-6})}{\left[\frac{1}{T_{\mathrm{ref}}-6} - \frac{1}{T_{\mathrm{ref}}}\right]} \qquad (2)$$

Note 5—The Gordon/Shaw method uses a shift factor (a_T) in the form of a base 10 log (log10). However, this specification is based on the natural log (ln or loge).

7.1.5. Reduced time, ξ, for data at temperature, T, is determined by integrating the reciprocal of the shift factor with respect to time as:

$$\xi(t) = \int_0^t \frac{dt'}{a_T} \qquad (3)$$

When T is constant with time, this reduces to the equation, as follows:

$$\xi(t) = \frac{t}{a_T} \tag{4}$$

7.1.6. All 12 values for $S(T,t)$ obtained, as described in Section 7.1.1, are converted to $S(T_{\text{ref}},\xi)$ with time being replaced by reduced time.

7.1.7. The values are fitted to the Christensen-Anderson-Marasteanu (CAM) model for asphalt master curves solving three parameters (λ, κ, and β):

$$S(T_{\text{ref}},\xi) = S_{\text{glassy}}[1+(\xi/\lambda)^{\beta}]^{-\kappa/\beta} \tag{5}$$

where:

S_{glassy} is the assumed glassy modulus of the binder: $S_{\text{glassy}} = 3 \times 10^9$ Pa.

7.1.8. Fit the resulting stiffness master curve data to this equation using a non-linear least squares fitting method to achieve a root mean square error, rms(percent), of less than or equal to 1.25 percent. Appendix X1 contains an example calculation of this error criterion. Appendix X2 contains a routine for curve fitting which may be used.

7.2. *Convert Stiffness Master Curve to Relaxation Modulus Master Curve*:

7.2.1. Use the Hopkins and Hamming method to convert creep compliance obtained from the master curve values $D(T_{\text{ref}}, \xi) = 1/S(T_{\text{ref}}, \xi)$ to relaxation modulus $E(T_{\text{ref}}, \xi)$.

Note 6—This procedure is described in Hopkins L. L., and Hamming R. W., “On Creep and Relaxation,” *Journal of Applied Physics*, Vol. 28, No. 8, August 1957, pp. 906-909.

7.2.2. The glassy modulus value of 3×10^9 Pa shall be adopted in the analysis for $S(T_{\text{ref}}, 1 \times 10^8 \text{ s}) = E(T_{\text{ref}}, 1 \times 10^8 \text{ s})$. Calculate relaxation modulus data points using the following iterative formula from $t = 1 \times 10^8$ to $t = 1 \times 10^7$ seconds with intervals of 4 points per decade—1.000, 1.778, 3.162, and 5.623 ($10^{0.0}$, $10^{0.25}$, $10^{0.5}$, $10^{0.75}$ seconds).

$$E(t_{n+\frac{1}{2}}) = \frac{t_{n+1} - \sum_{i=0}^{n-1} E(t_{i+\frac{1}{2}})\left[f(t_{n+1}-t_i) - f(t_{n+1}-t_{i+1})\right]}{f(t_{n+1}-t_n)} \tag{6}$$

where:

$$f(t_{n+1}) = f(t_n) + \frac{1}{2}\left[D(t_{n+1}) + D(t_n)\right]\left[t_{n+1} - t_n\right] \tag{7}$$

Use the same time intervals as above and use $f(t_0) = 0$. A cubic spline has been found to be suitable for interpolation.

7.2.3. Fit the relaxation modulus values to the CAM as described in Sections 7.1.7 and 7.1.8.

7.3. *Calculation of Thermal Stress*:

Note 7—The calculation of thermal stress is performed using three procedures: stress generation, stress relaxation, and stress summation. Stress calculations are based on Boltzmann's superposition principle for linear visco-elastic materials.

7.3.1. *Stress Generation*:

7.3.1.1. Use the following 7 constants:

- Start temperature, 0°C;
- End temperature, –45°C;
- Temperature increment, $\Delta T^N = 0.2°C$;
- Coefficient of linear thermal expansion, $\alpha = 1.7 \times 10^{-4}$ m/m/°C;
- Time per increment, $\Delta t = 720$ s;
- Strain per increment, $\in\ = \Delta T_i \alpha = 3.4 \times 10^{-5}$ m/m; and
- Strain rate = 4.72×10^{-8} m/m/s.

7.3.1.2. For the *N*th increment, the initial temperature shall be $T^N = -0.2(N - 1)$.

7.3.1.3. Divide each increment *N* into sub-steps.

7.3.1.3.1. Use *n* sub-steps where $n = 20 - 0.048(N - 1)$ truncated to an integer. "*n*" varies from 20 sub-steps at 0°C to 9 sub-steps at –45°C.

7.3.1.3.2. Divide the increment logarithmically so that each sub-step is approximately twice the size of the previous one. This defines $n + 1$ points in the increment.

Note 8—For example, with nine sub-steps, the 10 points are t_0, $t_0 + \Delta t/255$, $t_0 + 2\Delta t/255$, $t_0 + 4\Delta t/255$, $t_0 + 8\Delta t/255$, $t_0 + 16\Delta t/255$, $t_0 + 32\Delta t/255$, $t_0 + 64\Delta t/255$, $t_0 + 128\Delta t/255$ and $t_0 + \Delta t$.

7.3.1.3.3. Define the midpoint of each sub-step as the arithmetic midpoint. This defines additional *n* points.

7.3.1.3.4. The endpoints and midpoints of the sub-steps now define $2n + 1$ points in the increment. Define T_i^N and t_i^N for $i = 0$ to $2n$ as the temperature and time, respectively, at each of these points in order.

7.3.1.4. For each increment, calculate the shift factor, a_{Ti}, as follows:

7.3.1.4.1. Calculate the second-order gauss-points as follows:

$$t_{p1} = \Delta t \left(1 - 1/\sqrt{3}\right)/2 \quad (8)$$

$$t_{p2} = \Delta t \left(1 + 1/\sqrt{3}\right)/2 \quad (9)$$

7.3.1.4.2. Denote the temperatures at these points as T_{p1} and T_{p2} where:

$$T_{p1} = T^N + \Delta T\left(1 - 1/\sqrt{3}\right)/2 \qquad (10)$$

$$T_{p2} = T^N + \Delta T\left(1 + 1/\sqrt{3}\right)/2 \qquad (11)$$

7.3.1.4.3. The shift factors at these points are then:

$$a_{Tp1} = e^{\left(a_1\left(\frac{1}{T_{p1}} - \frac{1}{T_{\mathrm{ref}}}\right)\right)} \qquad (12)$$

$$a_{Tp2} = e^{\left(a_1\left(\frac{1}{T_{p2}} - \frac{1}{T_{\mathrm{ref}}}\right)\right)} \qquad (13)$$

7.3.1.4.4. The shift factor for the increment is then approximated by:

$$a_T = b_0 + b_1 t \qquad (14)$$

where:

$$b_1 = \left(a_{Tp2} - a_{Tp1}\right)/\left(t_{p2} - t_{p1}\right) \qquad (15)$$

and

$$b_0 = a_{Tp1} - t_{p1} b_1 \qquad (16)$$

7.3.1.5. The reduced time at time t from the start of the increment is then given by:

$$\xi(t) = \left(\frac{1}{b_1^N}\right)\ln\left(\frac{b_0^N + b_1^N t}{b_0^N}\right) \qquad (17)$$

7.3.1.6. Calculate the average modulus for the increment.

7.3.1.6.1. Calculate t_i^N for $i = 0$ to $2n$ as $t_0^N = 0$; $t_{2i}^N = 2^{(i/N-1)}\Delta t$ and $t_{2i-1}^N = (t_{2i} + t_{2i-2})/2$ for $i = 1$ to n.

7.3.1.6.2. The reduced time at each point is then:

$$\xi\left(t_i^N\right) = \left(\frac{1}{b_1^N}\right)\ln\left(\frac{b_0^N + b_1^N t_i^N}{b_0^N}\right) \qquad (18)$$

7.3.1.6.3. The relaxation modulus at each point is then given by the CAM fitted master curve:

$$E\left(\xi_i^N\right) = E_{\mathrm{glassy}}\left[1 + \left(\xi_i^N/\lambda\right)^{\beta}\right]^{-\kappa/\beta} \qquad (19)$$

7.3.1.6.4. Finally, the average relaxation modulus for the increment is given by the numerical quadrature as follows:

$$\bar{E} = \left(\sum_{i=1}^{n}\left[\left(E_{2i-2} + 4E_{2i-1} + E_{2i}\right)\left(t_{2i} - t_{2i-2}\right)\right]\right)/\left(6\Delta t\right) \qquad (20)$$

7.3.1.7. The generated stress at increment N, σ_{str}^N, is determined as follows:

$$\sigma_{str}^N = \overline{E}^N \times \in = \overline{E}^N \times \Delta T \times \alpha \qquad (21)$$

7.3.1.8. This cycle is repeated for all increments.

7.3.2. *Stress Relaxation*:

7.3.2.1. The stress relaxation of the stress generated in each individual strain increment *N* is modeled.

7.3.2.2. The stress relaxation is approximated by evaluating the equation, as follows:

$$\sigma\left(t\right) = \in E\left[\xi(t) - \tau\right] \quad (22)$$

7.3.2.3. The first operation in the stress relaxation calculation is to obtain the correction term τ in Equation 22.

7.3.2.4. This correction term τ is the difference between $\xi(\Delta t)$, the reduced time at the cessation of increment strain, and ξ_m, the reduced time at which the increment strain multiplied by relaxation modulus, equals the stress generated in the initial time step of the strain increment *N*. This is shown by the following equation:

$$\tau = \xi(\Delta t) - \xi_m \quad (23)$$

7.3.2.5. The value of τ is calculated immediately after the numerical quadrature defined by Equation 20 has been carried out, by storing temporarily the *E* and ξ values needed to estimate the integral. Interpolating in these values for the reduced time ξ_m at which $E\left[\xi_m\right]$ equals the value of the integral yields the amount of reduced time to be carried forward to the relaxation time steps, and accounts for the term τ.

7.3.2.6. The increase in reduced time during each relaxation time step is found using the same linearization of a_T versus *t* as described previously for the stress-generating time step of the strain increment.

Note 9—In order to use Equation 17, the linearization is calculated afresh for each time step, as specified by Equations 8 through 16.

7.3.2.7. The increase of reduced time during a time step is calculated with Equation 17 and added to the reduced time brought forward from the previous time step. The resulting reduced time is substituted in the CAM equation and the modulus obtained is multiplied by the increment strain to obtain the relaxed stress at the end of the time step.

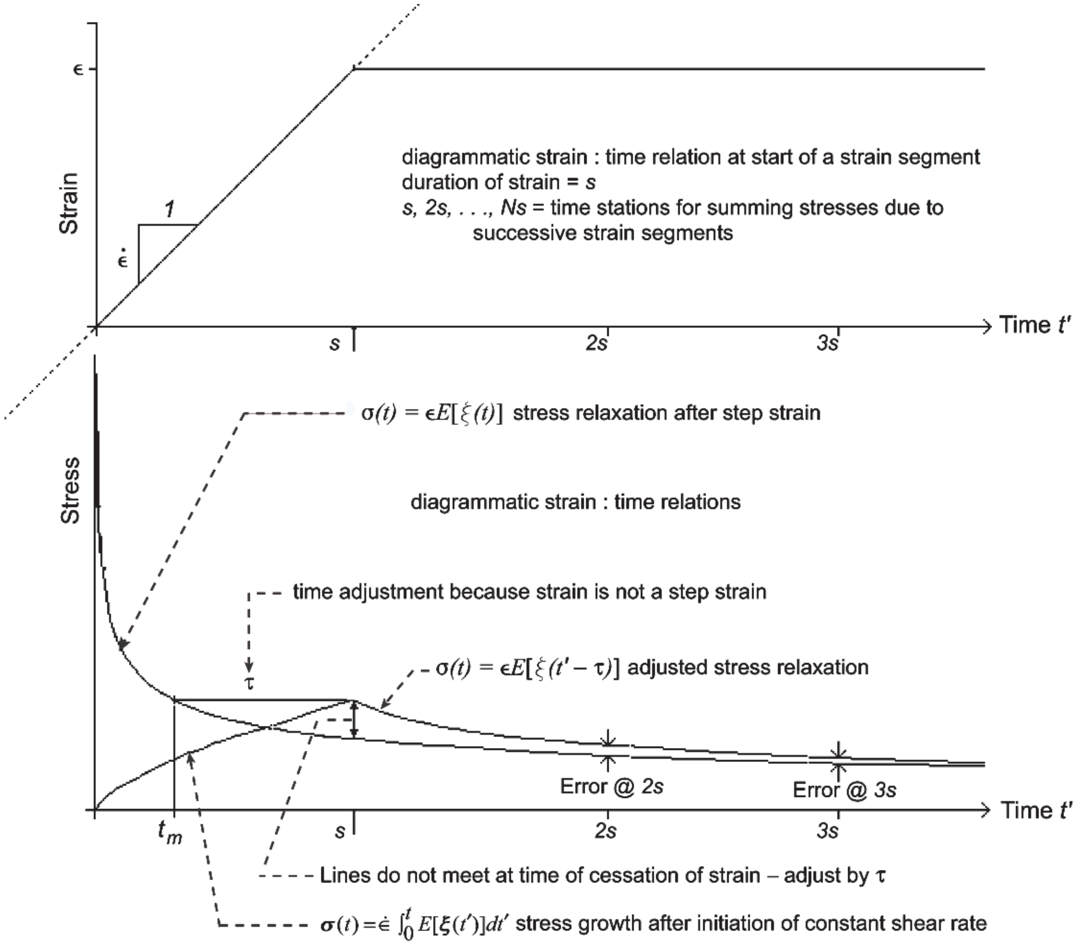

Figure 1—Strain versus Time and Stress versus Time Diagrams

7.3.3. *Stress Summation*:

7.3.3.1. The generated stress for interval *N* is summed with the stress relaxation from all the preceding intervals.

$$\sigma^N = \sigma_{str}^N + \sum_{i=1}^{N-1} \sigma_{rel}^{i,N} \qquad (24)$$

7.3.3.2. These calculations yield the calculated binder thermal stress at temperatures from 0 to –45°C, at 0.2°C increments.

7.3.3.3. The stress resulting from the calculation is multiplied by the pavement constant of 18 to yield the thermally induced stress in the pavement to which all comparisons shall be made in subsequent sections of this procedure. The generated stress in the pavement for interval *N* is summed with the stress relaxation from all the preceding intervals as described in Section 7.3.3.1.

$$(\sigma^n)_{\text{pavement}} = \left(\sigma_{str}^n + \sum_{i=1}^{n-1} \sigma_{rel}^{i,n}\right) \times C \qquad (25)$$

8. PERFORMANCE GRADE LOW-TEMPERATURE GRADE DETERMINATION OF AN ASPHALT BINDER

8.1. Grading of an asphalt binder requires bending beam rheometer data at two test temperatures and direct tension test data at a minimum of two test temperatures.

Note 10—The temperatures to be selected for the DTT may not be consistent with the BBR test temperatures as defined in Section 6.1.2, and additional tests may be required. The example given in Appendix X2 required that one of the DTT temperatures be lower than that used for the BBR tests.

8.2. Using a linear relationship between the DTT results, determine the intercept with the thermally induced stress curve using linear interpolation. The intercept, rounded to the nearest 0.1 degree, shall be reported as the estimated critical cracking temperature, T_{cr}.

8.3. In the case of no intercept being determined, additional direct tension tests shall be performed until an intercept is determined as described in Section 8.2.

Note 11—It may be necessary to conduct direct tension tests at additional test temperatures.

8.4. The grades that the low-temperature grade meets are evaluated by comparing the T_{cr} value to the 6°C temperature grade intervals given in M 320. The grades met are those which have a higher temperature than T_{cr}.

Note 12—For example, if a binder has a T_{cr} value of –24.5°C, it meets the specification at –22, –16, and –10.

9. VERIFICATION OF A PERFORMANCE GRADE OF AN ASPHALT BINDER

9.1. This section describes the testing and analysis required for verification of an already known Performance Grade of an asphalt binder at a specified low-temperature grade, T_{spec}.

9.2. Verification of an asphalt binder grade requires bending beam rheometer data at two test temperatures and direct tension test data at one test temperature.

9.3. To pass verification, the failure stress shall be equal to or greater than the thermal stress at the specification temperature of the binder. The thermal stress at the specification temperature shall be determined as follows.

9.3.1. Execute the procedure given in Section 7 using BBR data at both test temperatures.

9.3.2. Determine the failure stress using the DTT at a test temperature that is 10°C higher than the specification temperature, $T_{\mathrm{spec+10°C}}$.

9.3.3. Compare the failure stress from the DTT to the calculated thermally induced stress at the specification temperature, T_{spec}. If the failure stress exceeds the thermally induced stress, the asphalt binder shall be deemed a “Pass” at the specification temperature. If the failure stress does not exceed the thermally induced stress, the asphalt binder shall be deemed a “Fail” at the specification temperature.

10. REPORT

10.1. *Report the following information*:

10.1.1. Sample identification;

10.1.2. Identifying information for the BBR and DTT data sets used;

10.1.3. Date and time of calculations;

10.1.4. rms(percent) error as defined in Appendix X1;

10.1.5. Low-temperature grade being verified;

10.1.6. Estimated thermal stress at this temperature;

10.1.7. DTT failure stress to the nearest 0.01 MPa;

10.1.8. Whether the comparison of these two values results in a "Pass" or a "Fail" (This reporting item only applies to low-temperature binder grade verification, not to determination.); and

10.1.9. If determined, the estimated critical cracking temperature to the nearest 0.1°C.

11. PRECISION AND BIAS

11.1. *Precision and Bias*—The precision or bias associated with this standard practice is being determined.

12. KEYWORDS

12.1. Asphalt binder; bending beam rheometer; critical cracking temperature; direct tension; failure; failure stress; fracture; thermal cracking; thermally induced stress.

13. REFERENCES

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13.2. Box, G. E. P., "Fitting Empirical Data," *Annals of the New York Academy of Sciences*, Vol. 86, New York, NY, 1960, pp. 792-816.

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13.6. Marasteanu, M. O., and Anderson, D. A., “Improved Model for Bitumen Rheological Characterization,” *Eurobitume Workshop on Performance-Related Properties for Bituminous Binders,* Paper No. 133, Luxembourg, May 1999.

13.7. Rowe, G. M., Sharrock, M. J., Bouldin, M. G., and Dongre, R., “Advanced Techniques to Develop Master Curves from the Bending Beam Rheometer,” *The Asphalt Yearbook 2000*, Institute of Asphalt Technology, Stanwell, Middlesex, England, 2000, pp. 21-26.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF RMS CALCULATION

X1.1. In this example, a binder is being evaluated for a PG xx-34 grade. Two BBR data sets are collected according to the prescribed method. The data stiffness data collected in MPa are as follows:

t, s	*T* = –24°C	*T* = –30°C
8	456	760
15	390	670
30	321	581
60	262	493
120	211	412
240	168	338

X1.2. At *t* = 60 seconds, the stiffness conforms to the 300 MPa criteria specified in Section 6.1.2. The data are shifted to obtain a master curve in accordance with Section 7. The results are as follows:

S(*t*) Master Curve Points Determined by Non-Linear Fit		
t, s	*S*(*t*), MPa	CAM fit *S*(*t*)
0.746762829	777.956079	780.1128634
1.400180304	685.8297012	686.7969332
2.800360608	594.7269499	590.3342984
5.600721215	504.6478249	501.4979943
11.20144243	421.7340849	420.9415568
22.40288486	345.9857299	349.0372177
8	456	458.9964638
15	390	389.5836724
30	321	321.3666772
60	262	261.8456021
120	211	210.7390985
240	168	167.5525635

X1.3. In the above example, the fit was obtained using computer software. The CAM fit parameters, for this example, are as follows:

CAM fit to S(ξ) master curve	
λ	35.04887058
β	0.176793727
κ	0.581197694

X1.4. The relative error for each reduced time ξ is determined by the following:

$$Error = \frac{\left(S(\xi) - S(\xi)_{fitted}\right)}{S(\xi)}$$

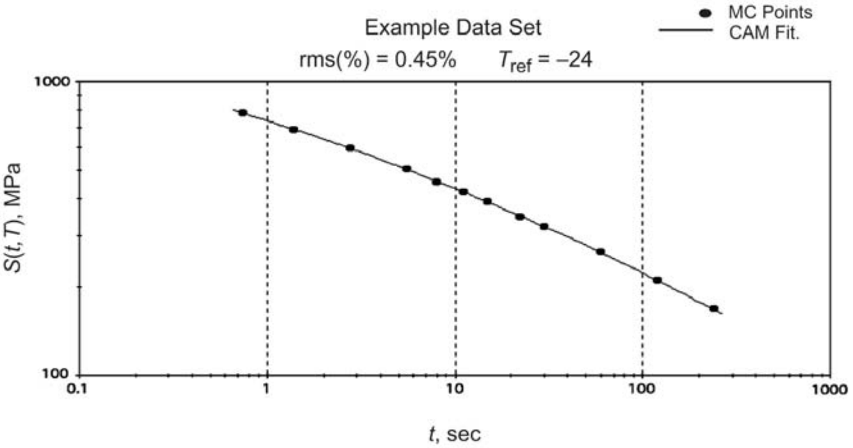
X1.5. The square of the relative error is determined. These values for this data set are given below.

Relative Error of S(ξ)	Square of Relative Error
–0.002772373	7.68605E-06
–0.001410309	1.98897E-06
0.007385997	5.4553E-05
0.006241641	3.89581E-05
0.001879213	3.53144E-06
–0.008819693	7.7787E-05
–0.006571192	4.31806E-05
0.001067507	1.13957E-06
–0.001142296	1.30484E-06
0.000589305	3.4728E-07
0.0012365	1.52893E-06
0.002663312	7.09323E-06

X1.6. The sum of the square of the relative error (SSRE) is computed and from this, the rms(percent) is determined as follows:

$$\mathrm{rms}(\%) = 100\sqrt{\frac{\mathrm{SSRE}}{12}}$$

X1.7. For the data in this example, the computed rms(percent) is 0.45 percent. This fit of the master curve is illustrated below.



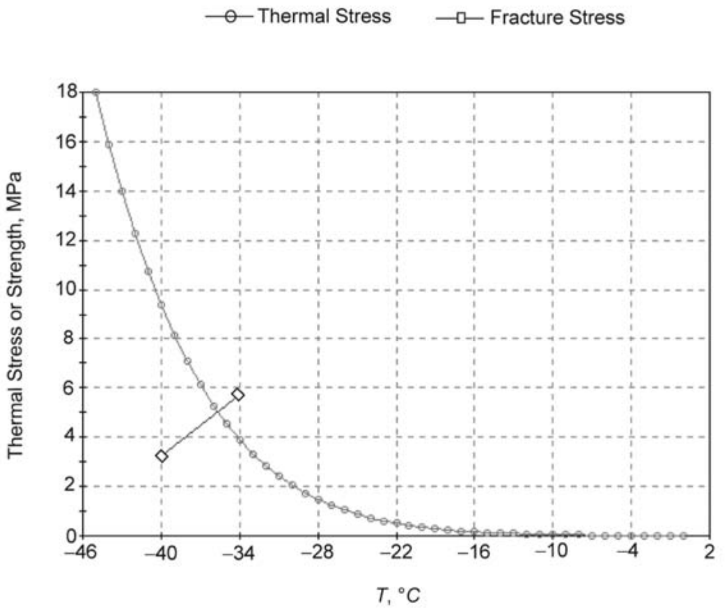
X1.8. The rms(percent) shall be less than or equal to 1.25 percent for the data set to be deemed acceptable.

X2. EXAMPLE OF RESULTS FOR THE EXAMPLE DATA NBS SET

X2.1. In addition to BBR data sets, the DTT testing was performed at two temperatures. These data are as follows:

Temperature, °C	DTT Failure Stress, Mpa
–24	5.713
–30	3.238

X2.2. The graph obtained from the stress calculation is plotted below with the DTT test points. Using linear interpolation, the intersection is determined to be –35.7°C.



Fracture Strength and Thermal Stress, MPa
Critical Temperature –35.7°C

X2.3. At –34°C (the grade for which this binder would be evaluated), report:

1. The sample ID;
2. The BBR and DTT data sets as given above;
3. The date and time of the calculations;
4. The rms(%) error as 0.45 percent;
5. The grade being verified as PG xx-34;
6. The estimated stress at –34°C as 3.88 MPa;
7. The DTT failure stress at –34°C as 5.71 MPa;
8. The result is a PASS;
9. The critical cracking temperature is –35.7°C.

X3. FORTRAN 77 SOURCE CODE USED FOR CAM FIT ROUTINE COMPILED USING COMPAQ VISUAL FORTRAN PROFESSIONAL

Note X1—This code is provided as a suggested procedure. It has not been thoroughly tested. However, preliminary use of this code has resulted in satisfactory and stable results.

```
   INTEGER*4 FUNCTION CAMFIT(Vars1)
   !DEC$ATTRIBUTES ALIAS:'CAMFIT' :: CAMFIT
   !DEC$ATTRIBUTES DLLEXPORT :: CAMFIT
   !DEC$ATTRIBUTES REFERENCE :: Vars1
   USE IMSL
   IMPLICIT NONE
   EXTERNAL CAMFUNC,CAMJACOB
C
```

```
C*** IDENTIFY INPUT AND OUTPUT VARIABLES STRUCTURE
C     TYPE Vars
        REAL(8) GlassStif
        REAL(8) ReducedTimes(12)
        REAL(8) Stifs(12)
        REAL(8) Tolerance
        REAL(8) Lamda
        REAL(8) Beta
        REAL(8) Kappa
      END TYPE Vars
      TYPE (Vars) :: Vars1

      INTEGER LDFJAC,M,N,I
      PARAMETER (LDFJAC=12,M=12,N=3)

      INTEGER IPARAM(6)
      REAL*8 RPARAM(7)

      INTEGER IBTYPE
      REAL*8 FJAC(LDFJAC,N),FVEC(M),X(N),XGUESS(N),FSCALE(M),
        XSCALE(N)
      REAL*8 XLB(N),XUB(N)
      REAL*8 STIFS(12),REDTIME(12)
      REAL*8 GLAS
      COMMON /INPTS/ GLAS,STIFS,REDTIME

      DATA FSCALE/12*1.D0/
      DATA XSCALE/3*1.D0/
C
C*** DEFINE LOWER AND UPPER BOUNDS FOR LN(LAMDA), BETA, AND KAPPA
C    LN(LAMDA) CAN RANGE FROM 3 TO 8.5
C    LAMDA CAN THEREFORE RANGE FROM 20 TO 4915
C    BETA CAN RANGE FROM 0.05 TO 0.5
C    KAPPA CAN RANGE FROM 0.2 TO 1.5
C
      DATA XLB/3.D0,0.050,0.2D0/,XUB/8.5D0,0.5D0,1.5D0/
C
C*** DEFINE SEED VALUES FOR LN(LAMDA),BETA, AND KAPPA
C      LAMDA=1000 (LN(LAMDA)=6.908), BETA=0.2, KAPPA=0.7
C
      DATA XGUESS/6.908D0,0.2D0,0.7D0/

      IPARAM(1) = 0
C
C*** TRANSFORM VALUES BEFORE PERFORMING CURVE-FIT
C
```

```
      GLAS = DLOG(Vars1%GlassStif)
      DO I = 1, 12
        STIFS(I) = DLOG(Vars1%Stifs(I))
        REDTIME(I) = DLOG(Vars1%ReducedTimes(I))
      ENDDO
      IBTYPE = 0

C
C*** CALL IMSL CURVE-FIT ROUTINE
C
      CALL DBCLSJ(CAMFUNC,CAMJACOB,M,N,XGUESS,IBTYPE,XLB,
 XUB,XSCALE, FSCALE,IPARAM,RPARAM,X,FVEC,FJAC,LDFJAC)
C
C*** TRANSFORM LN(LAMDA) BACK TO LAMDA, AND COPY RESULTS BACK
C    INTO OUTPUT STRUCTURE
C
      Vars1%Lamda = DEXP(X(1))
      Vars1%Beta = X(2)
      Vars1%Kappa = X(3)
C
C*** EXIT WITHOUT ERROR
C
      CAMFIT = 1
      END
C
C
      SUBROUTINE CAMFUNC(M, N, X, F)
C****************************************************************
C*** THIS SUBROUTINE DEFINES THE (TRANSFORMED) CAM FUNCTION
C    THE TRANSFORMATION ALLOWS FOR THE CURVE-FIT TO BE DONE OVER
C    A MORE LINEAR REGION, WHICH RESULTS IN A SIGNIFICANTLY
C    REDUCED ERROR
C****************************************************************
      IMPLICIT NONE
      INTEGER M,N,I
      REAL*8 X(N),F(M)
      REAL*8 STIFS(12),REDTIME(12)
      REAL*8 GLAS

      COMMON /INPTS/ GLAS,STIFS,REDTIME

      DO I = 1, 12
        F(I) = GLAS - (X(3)/X(2)) * DLOG(1.D0 + DEXP(X(2) *
         (REDTIME(I)-X(1)))) - STIFS(I)
      ENDDO
```

```
      RETURN
      END
C
C
      SUBROUTINE CAMJACOB(M, N, X, FJAC, LDFJAC)
C****************************************************************
C*** THIS SUBROUTINE DEFINES THE JACOBIANS (PARTIAL-DERIVATIVES)
C   OF THE (TRANSFORMED) CAM FUNCTION
C     FJAC(X,1) IS d(LN(STIF))/d(LN(LAMDA))
C     FJAC(X,2) IS d(LN(STIF))/d(BETA)
C     FJAC(X,3) IS d(LN(STIF))/d(KAPPA)
C****************************************************************
      IMPLICIT NONE
      INTEGER M,N,I,LDFJAC
      REAL*8 X(N),FJAC(LDFJAC,N)
      REAL*8 STIFS(12),REDTIME(12)
      REAL*8 GLAS

      COMMON /INPTS/ GLAS,STIFS,REDTIME

      DO I = 1, 12
         FJAC(I,1) = X(3) * DEXP(X(2) * (REDTIME(I)-X(1))) /
     &    (1.D0 + DEXP(X(2) * (REDTIME(I)-X(1))))
         FJAC(I,2) = X(3) / (X(2) ** 2.D0) *
     &    DLOG(1.D0 + DEXP(X(2) * (REDTIME(I)-X(1)))) -
     &    X(3) / X(2) * (REDTIME(I)-X(1)) *
     &    DEXP(X(2) * (REDTIME(I)-X(1))) /
     &    (1.D0 + DEXP(X(2) * (REDTIME(I)-X(1))))
          FJAC(I,3) = -1.D0 / X(2) *
     &    DLOG(1.D0 + DEXP(X(2) * (REDTIME(I)-X(1))))
      ENDDO

      RETURN
      END
```

---

[1] This standard is based on NCHRP Project Study 9-10. Approved for publication in 2001 as PP 42.

[2] The software TSAR™ obtainable from Abatech Inc. (http://www.abatech.com) has been found suitable for performing the calculations.

Standard Specification for

Corrugated Steel Pipe, Metallic-Coated, for Sewers and Drains

AASHTO Designation: M 36-03 (2007)[1]
ASTM Designation: A 760/A 760M-01a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

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1. SCOPE

1.1. This specification covers corrugated steel pipe (CSP) intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses. Pipe covered by this specification is not normally used for the conveyance of sanitary or industrial wastes. The steel sheet used in fabrication of the pipe has a protective metallic coating of zinc (galvanizing), aluminum Type 2, 55 percent aluminum-zinc alloy, zinc-5 percent aluminum-mischmetal alloy, or aluminum Type 1.

1.1.1. Steel sheet with zinc and aramid fiber composite coating may be specified for fabrication of pipe. Pipe made from sheet with this composite coating is always furnished with an asphalt coating. Therefore, the requirements in this specification should be considered as applying to a semi-finished pipe; the finished pipe must include provisions of M 190.

Note 1—Pipe fabricated with zinc and aramid fiber composite coated sheet and asphalt post-coating may be used for sanitary sewers and industrial applications. Petroleum products or similar materials in the sewer effluent may affect the performance of the asphalt coating.

1.2. The several different metallic coatings may not provide equal protection of the base metal against corrosion or abrasion, or both, in all environments. Some environments may be so severe that none of the metallic coatings included in this specification will provide adequate protection. Additional protection for CSP can be provided by use of coatings applied after fabrication of the pipe as described in M 190, or by use of polymer-precoated CSP as described in M 245.

1.3. This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and sheet thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of sheet thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The installation procedure is described in *AASHTO LRFD Bridge Construction Specifications*, Section 26.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 190, Bituminous-Coated Corrugated Metal Culvert Pipe and Pipe Arches
- M 218, Steel Sheet, Zinc-Coated (Galvanized), for Corrugated Steel Pipe
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 245, Corrugated Steel Pipe, Polymer-Precoated, for Sewers and Drains
- M 274, Steel Sheet, Aluminum-Coated (Type 2), for Corrugated Steel Pipe
- M 289, Aluminum-Zinc Alloy Coated Sheet Steel for Corrugated Steel Pipe

- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- M 315M, Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets [Metric]
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 213M/T 213, Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles
- T 241, Helical Continuously Welded Seam Corrugated Steel Pipe
- T 249, Helical Lock Seam Corrugated Pipe
- *AASHTO LRFD Bridge Construction Specifications*
- *AASHTO LRFD Bridge Design Specifications*

2.2. *ASTM Standards*:

- A 780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- A 796/A 796M, Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications
- A 885, Standard Specification for Steel Sheet, Zinc and Aramid Fiber Composite Coated for Corrugated Steel Sewer, Culvert, and Underdrain Pipe
- A 929/A 929M, Standard Specification for Steel Sheet, Metallic-Coated by the Hot-Dip Process for Corrugated Steel Pipe
- B 633, Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
- D 1056, Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber
- F 568M, Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners (Metric)

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *fabricator*—the producer of the pipe.

3.1.2. *manufacturer*—the producer of the sheet.

3.1.3. *minimized coating structure*—a coating characterized by a finer metallurgical coating structure obtained by a treatment designed to restrict the formation of the normal coarse-grain structure formed during solidification of the Zn-5 Al-MM alloy coating.

3.1.4. *purchaser*—the purchaser of the finished product.

3.1.5. *regular coating structure*—the normal coating structure resulting from unrestricted grain growth during normal solidification of the Zn-5 A1-MM alloy coating.

3.2. *Abbreviations*:

3.2.1. *55 Al-Zn*—55 percent aluminum-zinc,

3.2.2. *MM*—mischmetal,

3.2.3. *Zn-5 Al-MM*—zinc-5 percent aluminum-mischmetal,

3.2.4. *AlT2*—aluminum-coated Type 2, and

3.2.5. *AlT1*—aluminum-coated Type 1.

4. PIPE CLASSIFICATION

4.1. The CSP covered by this specification is classified as follows:

4.1.1. *Type I*—This pipe shall have a full circular cross section, with a single thickness of corrugated sheet, fabricated with annular (circumferential) or helical corrugations.

4.1.2. *Type IA*—This pipe shall have a full circular cross section, with an outer shell of corrugated sheet and an inner liner of smooth (uncorrugated) sheet, fabricated with helical corrugations and lock seams.

4.1.3. *Type IR*—This pipe shall have a full circular cross section with a single thickness of smooth sheet, fabricated with helical ribs projecting outwardly.

4.1.4. *Type II*—This pipe shall be a Type I pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.5. *Type IIA*—This pipe shall be a Type IA pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.6. *Type IIR*—This pipe shall be a Type IR pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.7. *Type III*—This pipe, intended for use as underdrains or for underground disposal of water, shall be a Type I pipe that has been perforated to permit the inflow or outflow of water.

4.1.8. *Type IIIA*—This pipe, intended for use as underdrains, shall consist of a semicircular cross section having a smooth (uncorrugated) bottom with a corrugated top shield.

4.2. Perforations in Type III pipe are included in three classes as described in Section 8.3.2.

4.3. Zn-5 Al-MM alloy-coated material is available in two coating classes, or structures, as follow:

4.3.1. *Class A*—Minimized coating structure.

4.3.2. *Class B*—Regular coating structure.

5. ORDERING INFORMATION

5.1. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product:

5.1.1. Name of material (corrugated steel pipe);

5.1.2. Type of metallic coating (zinc, aluminum-coated Type 2, aluminum-coated Type 1, 55 Al-Zn alloy, Zn-5 Al-MM alloy, or zinc and aramid fiber composite coating) (Section 6.1);

5.1.2.1. For Zn-5 Al-MM alloy, class of coating structure (Class A, minimized, etc.) (Section 4.3);

5.1.3. AASHTO designation and date of issue (M 36-____);

5.1.4. Type of pipe (Section 4.1);

5.1.5. Diameter of circular pipe (Table 6), or span and rise of pipe-arch section (Tables 8, 9, 10, or 11);

5.1.6. Length, either total length or length of each piece and number of pieces;

5.1.7. Description of corrugations (Section 7.2);

5.1.8. Sheet thickness (Section 8.1.2);

5.1.9. For Type I and Type II pipe, the pipe fabrication method, whether with annular corrugations or helical corrugations (Section 7.1.1) (Note 2);

Note 2—Pipe with annular corrugations with spot welded or riveted seams is designed by different criteria than pipe with helical corrugations. Pipe with annular corrugations must consider seam strength. Therefore, consideration of the method of fabrication is important when pipe is installed under certain conditions of loading.

5.1.10. When zinc and aramid fiber composite coated sheet is used for fabrication of pipe, the type of asphalt coating (Sections 1.1.1 and 8.5);

Note 3—See M 190 for additional information appropriate to bituminous post-coatings on pipe.

5.1.11. Joining systems, including the type of joint from Section 9.1 and gasket, if required (If no joining system is specified, the fabricator shall select the system.);

5.1.12. For Type III pipe, class of perforations, if other than Class 1 (Section 8.3.2);

5.1.13. Certification, if required (Section 14.1); and

5.1.14. Special requirements.

6. MATERIALS

6.1. *Steel Sheet for Pipe*—All pipe fabricated under this specification shall be formed from zinc-coated sheet conforming to M 218, or aluminum-coated Type 2 sheet conforming to M 274M, 55 percent aluminum-zinc alloy-coated sheet conforming to M 289, or zinc-5 percent aluminum-mischmetal alloy-coated sheet conforming to ASTM A 929/A 929M, or aluminum-coated Type 1 conforming to ASTM A 929/A 929M. If the type of metallic coating is not stated in the order, zinc-coated sheet conforming to M 218 shall be used. All pipe furnished on the order shall have the same metallic coating, unless otherwise specified.

6.2. *Steel Sheet for Coupling Bands*—The sheet used in fabricating coupling bands shall have the same coating and shall conform to the same specification listed in Section 6.1 as that used for fabrication of the pipe furnished under the order.

6.3. *Rivets*—The rivets used in riveted pipe shall be of the same material as the base metal specified for the corrugated sheets. They shall be thoroughly galvanized or sherardized. If bolts and nuts are substituted for rivets (Section 7.3.1), they shall meet the following requirements:

Bolts	Nuts
F 568	M 291M
Class 8.8	Class 12

6.4. The bolts and nuts shall be hot-dip galvanized in conformance with M 232M/M 232 mechanically galvanized in conformance with M 298, Class 40.

6.5. *Hardware for Joining Systems*—Bolts and nuts for coupling bands shall conform to the following requirements:

Bolts	Nuts
F 568	M 291M
Class 4.6	Class 5

6.6. Bolts, nuts, and other threaded items used with joining systems shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 8; or mechanical process as provided in M 298, Class 8. Other hardware items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 25; or mechanical process as provided in M 298, Class 25.

6.7. *Gaskets*—If gaskets are used in joining systems, they shall be a band of expanded rubber meeting the requirements of ASTM D 1056 for the “RE’’ closed cell grades, or O-rings meeting the requirements of M 315M.

7. FABRICATION

7.1. *General Requirements*—Pipe shall be fabricated in full circular cross section except for Type IIIA, which is described in Section 8.4.

7.1.1. Type I pipe shall have annular corrugations with lap joints fastened with rivets or resistance spot welds, or shall have helical corrugations with a continuous lock seam or welded seam extending from end to end of each length of pipe. The type of fabrication used shall be the option of the fabricator unless otherwise specified, except that the pipe fabricated from zinc and aramid fiber composite coated sheet shall be fabricated by riveted or lock seam fabrication only.

7.1.2. Type IA pipe shall be fabricated with a smooth liner and helically corrugated shell integrally attached at helical lock seams extending from end to end of each length of pipe. The shell shall have corrugations of nominal 68- or 75-mm pitch. Zinc and aramid fiber composite coated sheet shall not be used for fabrication of Type IA pipe.

7.1.3. Type IR pipe shall be fabricated with helical ribs projecting outward with a continuous lock seam extending from end to end of each length of pipe.

7.2. *Corrugations*—The corrugations shall be either annular or helical as provided in Section 7.1. The direction of the crests and valleys of helical corrugations shall not be less than 60 degrees from the axis of the pipe for pipe diameters larger than 525 mm, and not less than 45 degrees from the axis for pipe diameters of 525 mm and smaller.

7.2.1. For Type I and IA pipe, corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 1 for the size indicated in the order, except if the depth measurement of one or more corrugations is less than the minimum depth in Table 1, the depth of all corrugations between adjacent seams shall be measured and the values of Table 2 for minimum average depth and minimum corrugation depth shall apply.

Table 1—Corrugation Requirements for Type I, IA, II, IIA, and III Pipe

			Inside Radius[c]	
Nominal Size, mm	Maximum Pitch,[a] mm	Minimum Depth,[b] mm	Nominal, mm	Minimum, mm
38 by 6.5[d]	48	6.0	7	6.5
68 by 13	73	12	17	12
75 by 25	83	24	14	12
125 by 25	135	24	40	36

[a] Pitch is measured from crest to crest of corrugation, at 90 degrees to the direction of corrugation.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe to the bottom of the intervening valley. If the depth measurement of one or more corrugations is less than the value indicated herein, the depth of all corrugations between seams shall be measured, and the requirements of Table 2 shall be applied. (See Section 7.2.1.)

[c] Minimum inside radius requirement does not apply to a corrugation containing a helical lock seam.

[d] The corrugation size of 38 by 6.5 mm is available only in helically corrugated pipe.

Table 2—Referee Requirements for Corrugation Depth[a]

Nominal Size, mm	Diameter, mm	Minimum Average Depth, mm	Minimum Corrugation Depth, mm
38 by 6.5	All	6.1	5
68 by 13	300 through 525	12.1	10
68 by 13	Greater than 525	12.4	11
75 by 25	All	24.9	23
125 by 25	All	24.9	23

[a] See Section 7.2.1 for application of Table 2.

Note 4—Inspection frequently consists of measurement of the depth of one or a few corrugations. If such measurement indicates insufficient depth, application of the requirements in Table 2 provides for acceptance in cases in which greater depth of some corrugations compensates for lack of depth of others. These measurements would normally be made at one location between seams on a length of pipe.

7.2.2. For Type IR pipe, the corrugations shall be essentially rectangular ribs projecting outward from the pipe wall. The dimensions and spacing of the ribs shall be in accordance with Table 3 for the size indicated on the order. For the 292-mm rib spacing, if the sheet between the ribs does not include a lock seam, a stiffener shall be included midway between the ribs. This stiffener shall have a nominal radius of 6.4 mm and a minimum height of 5.1 mm toward the outside of the pipe.

Table 3—Rib Requirements for Types IR and IIR Pipe

Nominal Size, mm	Rib Width,[a] Min, mm	 Depth,[b] Min, mm	 Spacing,[c] Min, mm	Bottom Outside Radius, Min, mm	Bottom Outside Radius,[d] Max Avg, mm	Top Outside Radius, Min, mm	Top Outside Radius,[d] Max Avg, mm
19 by 19 by 190	17	19	197	2.5	6.0	2.5 + *t*	6.0 + *t*
19 by 25 by 216	17	24	222	2.5	6.0	2.5 + *t*	6.0 + *t*
19 by 25 by 292	17	24	298	2.5	6.0	2.5 + *t*	6.0 + *t*

[a] Width is a dimension of the inside of the rib, but is measured on the outside of the pipe (outside of the rib) and shall meet or exceed the stated minimum width plus two times the wall thicknesses, that is, 2*t* + 17 mm.

[b] Depth is an average of three ribs within one sheet width.

[c] Spacing is an average of three adjacent rib spacings for 19 by 19 by 190 pipe and two adjacent rib spacings for 19 by 25 by 292 pipe measured center-to-center of the ribs, at 90 degrees to the direction of the ribs.

[d] The average of the two top rib radii and of the two bottom rib radii shall be within the minimum and maximum tolerances. The term "outside" refers to the outside surface of the pipe.

Note 5—The nominal dimensions and properties for smooth corrugations and for ribs are given in *AASHTO LRFD Bridge Design Specifications*, Section 12, and in ASTM A 796.

7.3. *Riveted Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any rivet. Pipe to be reformed into pipe-arch shape shall have seams meeting the longitudinal seam requirement of Section 8.2.2. (See also Note 6.)

Note 6—Fabrication of pipe without longitudinal seams in 120 degrees of arc, so that the pipe may be installed without longitudinal seams in the invert, is subject to negotiation between the purchaser and fabricator.

7.3.1. The size of rivets, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 4, depending on sheet thickness, corrugation size, and diameter of pipe. For pipe with 25-mm deep corrugations, M12-diameter bolts and nuts may be used in lieu of rivets on a one-for-one replacement ratio. Circumferential seams shall be riveted using rivets of the same size as for longitudinal seams and shall have a maximum rivet spacing of 150 mm, measured on centers, except that six rivets will be sufficient in 300-mm diameter pipe.

Table 4—Riveted and Spot Welded Longitudinal Seams

Specified Sheet Thickness, mm	68 by 13 mm[a,b]	75 by 25 mm[c,d]	125 by 25 mm[d,e]
	Rivet or Spot Weld Diameters, Min, mm		
1.32	8.0	—	—
1.63	8.0	9.5	9.5
2.01	8.0	9.5	9.5
2.77	9.5	11.0	11.0
3.51	9.5	11.0	11.0
4.27	9.5	11.0	11.0

[a] One rivet or spot weld each valley for pipe diameters 900 mm and smaller. Two rivets or spot welds each valley for pipe diameters 1050 mm and larger.

[b] Minimum width of lap: 38 mm for pipe diameters 900 mm and smaller, and 75 mm for pipe diameters 1050 mm and larger.

[c] Two rivets or spot welds each valley for all pipe diameters.

[d] Minimum width of lap: 75 mm for pipe of all diameters.

[e] Two rivets or spot welds each crest and valley for all pipe diameters.

7.3.2. All rivets shall be driven cold in such a manner that the sheets shall be drawn tightly together throughout the entire lap. The center of a rivet shall be no closer than twice its diameter from the edge of the sheet. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the purchaser, shall be driven without bending, and shall completely fill the hole.

7.4. *Resistance Spot Welded Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any spot weld. Pipe to be reformed into pipe-arch shape shall also meet the longitudinal seam requirement of Section 8.2.2 (Note 6).

7.4.1. The size of spot welds, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 4, depending on sheet thickness, corrugation size, and diameter of pipe. Circumferential seams shall be welded using spot welds of the same size as for longitudinal seams and shall have a maximum weld spacing of 150 mm, except that six welds will be sufficient in 300-mm diameter pipe.

7.4.2. All spot welds shall be made in such a manner that the sheets will be drawn tightly together throughout the lap. The outside edge of each spot weld shall be at least 6.5 mm from the edge of the sheet. The welding shall be performed in such a manner that the exterior surfaces of 90 percent or more of the spot welds on a length of pipe shall show no evidence of melting or burning of the base metal, and the base metal shall not be exposed when the area adjacent to the electrode contact surface area is wire brushed. Discoloration of the spot weld surfaces will not be cause for rejection.

7.4.3. Welding equipment shall be qualified before use, and the qualification shall be verified before each work shift and when changing sheet thickness, all as described in Appendix A1. If use of the equipment at the approved machine settings fails to produce satisfactory welds, fabrication shall be stopped until adjustments are made and the equipment is requalified.

7.5. *Helical Lock Seams*—The lock seam for Type I pipe shall be formed in the tangent element of the corrugation profile with its center near the neutral axis of the corrugation profile. The lock seam for Type IA pipe shall be in the valley of the corrugation, shall be spaced not more than 760 mm apart, and shall be formed from both the liner and the shell in the same general manner as Type I helical lock seam pipe. The lock seam for Type IR pipe shall be formed in the flat zone of the pipe wall, midway between two ribs.

7.5.1. The edges of the sheets within the cross section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of –10 percent of lap width allowable. The lapped surfaces shall be in tight contact. The profile of the sheet shall include a retaining offset adjacent to the 180-degree fold (as described in T 249M) of one sheet thickness on one side of the lock seam, or one-half sheet thickness on both sides of the lock seam, at the fabricator's option. There shall be no visible cracks in the metal, loss of metal-to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam.

7.5.2. Specimens cut from production pipe normal to and across the lock seam shall develop the tensile strength as provided in Table 5, when tested according to T 249. For Type IA pipe, the lock seam strength shall be as tabulated based on the thickness of the corrugated shell.

Table 5—Lock Seam Tensile Strength

Specified Sheet Thickness,[a] mm	Lock Seam Tensile Strength, per Unit Width, Min, kN/m
1.02	30
1.32	42
1.63	60
2.01	91
2.77	122
3.50	154
4.27	210

[a] For Type IA pipe, the thickness shall be that of the corrugated shell.

7.5.3. When the ends of helically corrugated lock seam pipe have been rerolled to form annular corrugations, either with or without a flanged end finish, the lock seam in the rerolled end shall not contain any visible cracks in the base metal and the tensile strength of the lock seam shall be not less than 60 percent of that required in Section 7.5.2.

7.6. *Helical Continuous Welded Seams*—The seam shall be parallel to the corrugations and shall have a continuous weld extending from end to end of each length of pipe. Welding shall be done utilizing ultra-high frequency resistance equipment. Seams shall be welded in such a manner that they will develop the full strength of the pipe and not affect shape or nominal diameter of the pipe. Welded seams shall be controlled such that the combined width of weld and adjacent coating burned by welding does not exceed three times the metal thickness. Damage outside this width shall be repaired as required in Section 11. The fabricator shall certify that the welds have been tested and found satisfactory.

7.6.1. Continuous welded seams shall be tested in accordance with the cup test procedure (Section 3) of T 241. The welded seam shall be acceptable if the sum of the length of cracks or other defects on either side of the cup does not exceed 6.5 mm, basing the result on the second test if the first shows greater defects. The provisions of the referee test method of Section 4 of T 241 shall be applicable in the event of disagreement between the purchaser and the fabricator.

7.6.1.1. Tests of continuous welded seams shall be made as follows:

7.6.1.2. Pipe lengths of 7.3 m or less shall be tested on one end of each length, normally the trailing end.

7.6.1.3. If a length of pipe having a diameter greater than 1200 mm and length of 7.3 m or less is rejected, the following length of pipe produced shall be tested on both ends. If the test on either end fails, this entire length shall also be rejected.

7.6.1.4. Pipe lengths greater than 7.3 m shall be tested on each end of each length of pipe. If either end fails, the entire length shall be rejected.

7.6.2. The requirement for conducting quality control tests in accordance with Section 7.6.1 shall not apply for pipe in which the ends have been rerolled to form annular corrugations. The manufacturer shall maintain visual evaluation of the quality of the weld after rerolling and any indication of weld or base metal failure will be cause for rejection of the pipe.

7.6.3. Any indication of cracks, skips, or deficient welds found through visual inspection will be cause for rejection unless repaired. It is the option of the fabricator to remove the defective portion of the length of pipe or to manually repair defects in the automatically welded seam. Altered or repaired pipe shall meet the applicable requirements of Section 7.6. Where a manual repair occurs within 400 mm of the end of the length of pipe, a test shall be conducted on both the manually repaired section and on the immediately adjacent automatically welded section. If either test results in failure under the criterion of Section 7.6.1, the length of pipe shall be rejected.

7.7. *End Finish*:

7.7.1. To facilitate field jointing, the ends of the individual pipe sections with helical corrugations or ribs may be rerolled to form annular corrugations extending at least two corrugations from the pipe end, or to form an upturned flange meeting the requirements in Section 7.7.2, or both. The diameter of ends shall not exceed that of the pipe barrel by more than the depth of the corrugation. All types of pipe ends, whether rerolled or not, shall be matched in a joint such that the maximum difference in the diameter of abutting pipe ends is 13 mm.

7.7.1.1. When pipe with any size helical corrugation or rib is rerolled to form annular corrugations in the ends, the usual size of the annular corrugation is 68 by 13 mm.

7.7.2. If a flanged finish is used on the ends of individual pipe sections to facilitate field jointing, the flange shall be uniform in width, not less than 13 mm wide, and square to the longitudinal axis of the pipe.

7.7.3. The ends of all pipe that will form the inlet and outlet of culverts, fabricated of sheets having nominal thicknesses of 2.01 mm and less, shall be reinforced in a manner approved by the purchaser, when specified.

8. PIPE REQUIREMENTS

8.1. *Type I, Type IA, and Type IR Pipe*:

8.1.1. *Pipe Dimensions*—The nominal diameter of the pipe shall be as stated in the order, selected from the size listed in Table 6. The sizes of corrugations that are standard for each size of pipe are also shown in Table 6. The average inside diameter of circular pipe and pipe to be reformed into pipe-arches shall not vary more than 1 percent or 13 mm, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugations for Type I pipe, or the inside liner or surface for Type IA or Type IR pipe, respectively. Alternately, for pipe having annular corrugations, conformance with the inside diameter requirement may be determined by measuring the outside circumference, for which minimum values are given in Table 6.

Note 7—The outside circumference of helically corrugated pipe is influenced by the corrugation size and the angle of the corrugation, affecting the number of corrugations crossed; therefore, no minimum measurement can be specified.

8.1.2. *Sheet Thickness*—Sheet thickness shall be specified by the purchaser from the specified sheet thicknesses listed in Table 7 (Notes 8 and 9). For Type IA pipe, the thickness of both the shell and the liner shall be given; the thickness of the corrugated shell shall not be less than 60 percent of the thickness of the equivalent Type I pipe; the liner shall have a nominal thickness of at least 1.02 mm; and the sum of the specified thicknesses of shell and liner shall equal or exceed the specified thickness of an equivalent pipe of identical corrugations as the shell according to the design criteria in *AASHTO LFRD Bridge Design Specifications*.

Table 6—Pipe Sizes

Nominal Inside Diameter, mm	Corrugation Sizes[a]				Ribbed Pipe			Minimum Outside Circumference,[c] mm
	38 by 6.5 mm	68 by 13 mm	75 by 25 mm	125 by 25 mm	19 by 19 by 190 mm[b]	19 by 25 by 292 mm	19 by 25 by 216 mm	
100	X							264
150	X							441
200	X							598
250	X							755
300	X	X						912
375	X	X						1148
450	X	X			X	X	X	1383
500		X			X	X	X	1620
600		X			X	X	X	1854
675		X			X	X	X	2091
750		X			X	X	X	2483
825		X		X	X	X	X	2561
900		X	X	X	X	X	X	2797
1050		X	X	X	X	X	X	3269
1200		X	X	X	X	X	X	3739
1350		X	X	X	X	X	X	4209
1500		X	X	X	X	X	X	4675
1650		X	X	X	X	X	X	5142
1800		X	X	X	X	X	X	5609
1950		X	X	X	X	X	X	6075
2100		X	X	X	X	X	X	6542
2250			X	X	X	X	X	7008
2400			X	X	X	X	X	7475
2550			X	X	X	X	X	7941
2700			X	X	X	X	X	8408
2850			X	X	X		X	8874
3000			X	X	X		X	9341
3150			X	X			X	9807
3300			X	X			X	10274
3450			X	X			X	10740
3600			X	X			X	11207

[a] An “X” indicates standard corrugation sizes for each nominal diameter of pipe.

[b] Rib sizes 19 by 19 by 190 mm and 19 by 25 by 292 mm.

[c] Measured in valley of annular corrugations. Not applicable to helically corrugated pipe.

Table 7—Thicknesses of Metallic-Coated Steel Sheet[a]

	Specification Designation					
Specified Thickness, mm	M 218, Zinc Coated	M 274 AlT2, Aluminum Coated	M 289, 55 Percent Aluminum-Zinc Alloy Coated	A 885, Zinc and Aramid Fiber Coated	A 929M Zn-5 Al-MM, Alloy Coated	A 929M AlT1, Aluminum Coated
1.02	X		X		X	
1.32	X	X	X		X	X
1.63	X	X	X	X	X	X
2.01	X	X	X	X	X	X
2.77	X	X	X	X	X	X
3.51	X	X	X	X	X	X
4.27	X			X	X	

[a] An “X” indicates sheet thickness included in the applicable specification for coating types listed.

Note 8—The sheet thicknesses indicated in Table 7 are the thicknesses listed as available in M 218, M 274, M 289, ASTM A 885, and ASTM A 929M for zinc and aramid fiber composite coated sheet.

Note 9—The purchaser should determine the required thickness for each of the types of pipe described in Section 4.1.1 through Section 4.1.6 according to the design criteria in *AASHTO LRFD Bridge Design*, Section 12, or other appropriate guidelines.

8.1.3. When specified by the purchaser, the finished pipe shall be factory elongated to the extent specified. The elongation shall be accomplished by the use of a mechanical apparatus that will produce a uniform deformation throughout the length of the section.

8.2. *Type II, IIA, and IIR Pipe*:

8.2.1. *Pipe-Arch Dimensions*—Pipe furnished as Type II, IIA, or IIR shall be made from Type I, IA, or IR pipe respectively, and shall be reformed to provide a pipe-arch shape. All applicable requirements for Types I, IA, and IR pipe shall be met by finished Types II, IIA, and IIR pipe, respectively. Pipe-arches shall conform to the dimensional requirements of Tables 8, 9, 10, or 11. All dimensions shall be measured from the inside crests of corrugations for Type II pipe or from the inside liner or surface for Types IIA or IIR, respectively.

8.2.2. *Longitudinal Seams*—Longitudinal seams of riveted or spot welded pipe-arches shall not be placed in the corner radius.

8.2.3. Reforming Type IR into Type IIR pipe shall be done in a manner that avoids damage to the external ribs.

8.3. *Type III Pipe*:

8.3.1. Type III pipe shall have a full circular cross-section and shall conform to the requirements for Type I pipe and, in addition, shall contain perforations conforming to one of the classes described in Section 8.3.2.

Table 8—(M 36) Pipe-Arch Requirements 68 by 13 mm Corrugations

Pipe Arch Size, mm	Equivalent Dia, mm	Span,[a] mm	Rise,[a] mm	Minimum Corner Radius, mm	Maximum B,[b] mm
430 by 330	375	430	330	75	135
530 by 380	450	530	380	75	155
610 by 460	525	610	460	75	185
710 by 510	600	710	510	75	205
780 by 560	675	780	560	75	225
885 by 610	750	870	610	75	240
970 by 690	825	970	690	75	255
1060 by 740	900	1060	740	90	265
1240 by 840	1050	1240	840	100	290
1440 by 970	1200	1440	970	130	345
1620 by 1100	1350	1620	1100	155	380
1800 by 1200	1500	1800	1200	180	420
1950 by 1320	1650	1950	1320	205	460
2100 by 1450	1800	2100	1450	230	510

[a] A tolerance of 25 mm or 2 percent of equivalent diameter, whichever is greater, will be permissible in span and rise.

[b] B is defined as the vertical dimension from a horizontal line across the widest portion of the arch to the lowest portion of the base.

Table 9—(M 36) Pipe-Arch Requirements 75 by 25 mm or 125 by 25 mm Corrugations

Pipe Arch Size, mm	Equivalent Dia, mm	Span,[a] mm	Rise,[a] mm	Minimum Corner Radius, mm
1010 by 790	900	1010 – 45	790 + 45	130
1160 by 920	1050	1160 – 55	920 + 55	155
1340 by 1050	1200	1340 – 60	1050 + 60	180
1520 by 1350	1350	1520 – 70	1170 + 70	205
1670 by 1300	1500	1670 – 75	1300 + 75	230
1850 by 1400	1650	1850 – 85	1400 + 85	305
2050 by 1500	1800	2050 – 95	1500 + 95	355
2200 by 1620	1950	2200 – 110	1620 + 110	355
2400 by 1720	2100	2400 – 120	1720 + 120	410
2600 by 1820	2250	2600 – 130	1820 + 130	410
2840 by 1920	2400	2840 – 145	1920 + 145	460
2970 by 2020	2550	2970 – 150	2020 + 150	480
3240 by 2120	2700	3240 – 165	2120 + 165	480
3470 by 2220	2850	3470 – 175	2220 + 175	480
3600 by 2320	3000	3600 – 180	2320 + 180	480

[a] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances; no tolerance in opposite direction.

Table 10—Pipe-Arch Requirements, 19 by 19 by 190 mm Rib Corrugations

Pipe Arch Size, mm	Equivalent Diameter, mm	Span,[a] mm	Rise,[a] mm	Minimum Corner Radius, mm
500 by 410	450	500 – 25	410 + 25	130
580 by 490	525	550 – 25	490 + 25	130
680 by 540	600	680 – 40	540 + 40	130
750 by 620	675	750 – 40	620 + 40	130
830 by 670	750	830 – 40	670 + 40	130
900 by 750	825	900 – 45	750 + 45	130
1010 by 790	900	1010 – 45	790 + 45	130
1160 by 920	1050	1160 – 55	920 + 55	155
1340 by 1050	1200	1340 – 60	1050 + 60	180
1520 by 1170	1350	1520 – 70	1170 + 70	205
1670 by 1300	1500	1670 – 75	1300 + 75	230
1850 by 1400	1650	1850 – 85	1400 + 85	305
2050 by 1500	1800	2050 – 95	1500 + 95	355
2200 by 1620	1950	2200 – 100	1620 + 100	355
2400 by 1720	2100	2400 – 105	1720 + 105	410
2600 by 1820	2250	2600 – 115	1820 + 115	410
2840 by 1920	2400	2840 – 120	1850 + 120	450
2920 by 1980	2550	2920 – 130	1980 + 130	450

[a] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances; no tolerance in opposite direction.

Table 11—Pipe Arch Requirements, 19 by 25 by 292 mm Rib Corrugation

Pipe Arch Size, mm	Equivalent Diameter, mm	Span,[a] mm	Rise,[a] mm	Minimum Corner Radius, mm
500 by 410	450	500 – 25	410 + 25	130
580 by 490	525	550 – 25	490 + 25	130
680 by 540	600	680 – 40	540 + 40	130
750 by 620	675	750 – 40	620 + 40	130
830 by 670	750	830 – 40	670 + 40	130
900 by 750	825	900 – 45	750 + 45	130
1010 by 790	900	1010 – 45	790 + 45	130
1160 by 920	1050	1160 – 55	920 + 55	155
1340 by 1050	1200	1340 – 60	1050 + 60	180
1520 by 1170	1350	1520 – 70	1170 + 70	205
1670 by 1300	1500	1670 – 75	1300 + 75	230
1850 by 1400	1650	1850 – 85	1400 + 85	305
2050 by 1500	1800	2050 – 95	1500 + 95	355

[a] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances; no tolerance in opposite direction.

8.3.2. *Perforations*—The perforations shall conform to the requirements for Class 1, unless otherwise specified in the order. Class 1 perforations are for pipe intended to be used for subsurface drainage. Class 2 and 3 perforations are for pipe intended to be used for subsurface disposal of water, but pipe containing Class 2 and 3 perforations may also be used for subsurface drainage.

8.3.2.1. *Class 1 Perforations*—The perforations shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm nor greater than 9.5 mm; and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests or along the neutral axis of the corrugations, with one perforation in each row for each corrugation. Pipe connected by couplings or bands may be unperforated within 100 mm of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the centerlines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the centerlines of the uppermost rows above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 12.

Note 10—Pipe with Class 1 perforations is generally available in diameters from 100 to 525 mm inclusive, although perforated pipe in larger sizes may be obtained.

8.3.2.2. *Class 2 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm, or slots with nominal widths of 4.8 to 8.0 mm and not to exceed 13 mm in length. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 230 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

Note 11—323 perforations, 9.5-mm diameter, per square meter satisfies this requirement.

8.3.2.3. *Class 3 Perforations*—The perforations shall be slots with a width of 2.5 ± 1.0 mm and length of 25 ± 6.5 mm, spaced 45 to 65 mm on centers around the circumference and staggered on the outside crests of the corrugations of the pipe. No metal shall be removed in making the slot. Slots shall be made from the inside of the pipe.

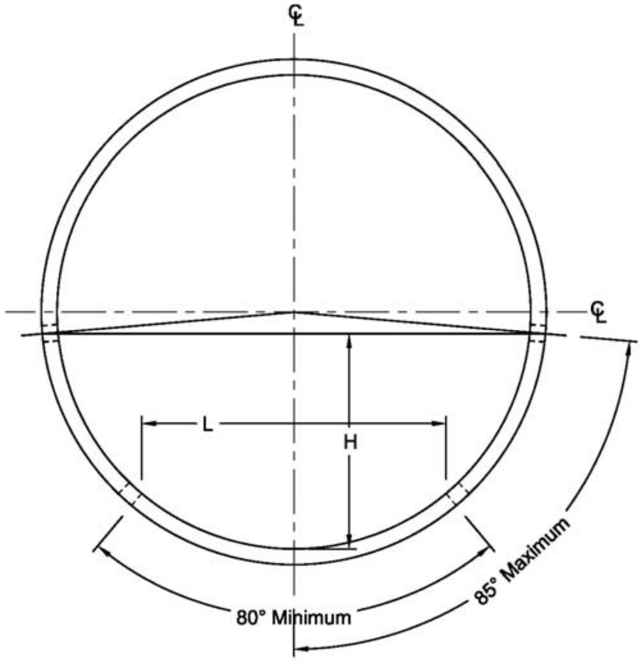

Figure 1—Requirements for Perforations

Table 12—Rows of Perforations, Height *H* of the Centerline of the Uppermost Rows Above the Invert, and Chord Length *L* of Unperforated Segment, for Class 1 Perforations

Internal Diameter of Pipe, mm	Rows of Perforations[a]	*H*, Max,[b] mm	*L*, Min,[b] mm
100	2	46	64
150	4	69	96
200	4	92	128
250	4	115	160
300	6[c]	138	192
375	6[c]	172	240
450	6[c]	207	288
525	6	241	336
600 and larger	8	[d]	[d]

[a] Minimum numbers of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and fabricator. Note that the number of perforations per unit length in each row (and inlet area) is dependent on the corrugation pitch.

[b] See Figure 1 for location of dimensions *H* and *L*.

[c] Minimum of four rows permitted in pipe with 38 by 6.5 mm corrugations.

[d] $H(\max) = 0.46D$; $L(\min) = 0.64D$, where D = internal diameter of pipe, mm or in. as appropriate.

8.4. *Type IIIA Pipe*:

8.4.1. Type IIIA pipe shall be fabricated of an unperforated semicircular bottom section with a top shield of corrugated steel, both of nominal 1.32-mm thickness or greater. The smooth semicircular bottom section shall be approximately 120 mm in diameter and shall have a continuous lip extending outward along each side; the corrugated top shield shall be approximately 160 mm wide including a 19-mm sloping overhang on each side and shall be secured to the lip of the bottom section by integral tabs spaced at about 90 mm center-to-center. The top shield shall have corrugations approximately 22 mm center-to-center and approximately 8.0-mm depth.

8.5. *Pipe Fabricated from Zinc and Aramid Fiber Composite Coated Sheet*—Pipe that has been fabricated from zinc and aramid fiber composite coated sheet shall be coated with asphalt as described in M 190, Type A, Fully Bituminous Coated. If full or partial smooth lining is desired, it shall be specified by the purchaser. (See Section 1.1.1 and M 190.)

9. JOINING SYSTEMS

9.1. *Types of Joining Systems*—Joining systems shall be of the following types, depending upon the configuration of the steel band joining the pipe together. If required, the joining system shall incorporate a flat, O-ring, or profile gasket. The corrugations at the ends of pipe sections being joined shall conform to one of the corrugations detailed in ASTM A 796/A 796M.

Note 12—Bands are classified according to their ability to resist shear, moment, and tensile forces as described in AASHTO *LRFD Bridge Construction Specifications, Section 26* and identified as “standard joints” and “special joints.” The first five types of bands listed in Section 9.1 and meeting the requirements of Section 9.2 are expected to meet the requirements for “standard joints.” Some may also be able to meet the requirements for “special joints,” but such capability should be determined by analysis or test.

9.1.1. *Corrugated Bands*—Bands with either annular or helical corrugations. The band corrugation shall match that of the pipe sections being joined or the annular rerolled ends of those pipe sections.

9.1.2. *Partially Corrugated Bands*—Flat bands with a minimum of one corrugation formed along each circumferential edge of the band. These bands are intended for use with helically corrugated pipe with its ends rerolled to a 68 mm by 13 mm corrugation.

9.1.3. *Bands with Projections*—Flat bands with projections, such as dimples, are used to join pipe with either helical or annular corrugations. The bands shall be formed with the projections in annular rows with one projection for each corrugation of helical pipe engaged by the band. Bands 265 or 300 mm wide shall have two annular rows of projections, and bands 415 or 560 mm wide shall have four annular rows of projections.

9.1.4. *Channel Bands*—Channel bands that incorporate a connector formed into a channel (hat) shape shall be used only with pipe having upturned flanges on the pipe ends. Channel bands shall conform with the requirements of Section 9.3.3.

9.1.5. *Flat Bands*—When specified by the purchaser, flat bands shall be used on pipe with helically corrugated ends, annular corrugated pipe, or helical pipe on which the ends have been rerolled to form annular corrugations.

9.1.6. *Sleeve Couplers*—When specified by the purchaser, the joining system shall incorporate a push-on type coupler designed to properly interface with the pipes being joined. Sleeve couplers generally do not have any external device for tightening around the pipe. Sleeve couplers shall provide a centering device so the coupler laps equally on both pipes being joined. Sleeve couplers for pipe diameters less than 300 mm shall have a minimum stab depth of 75 mm. The minimum stab depth for 300-mm through 1050-mm diameters shall be 150 mm. When sleeve couplers are used with pipes other than Type III or Type IIIA, pipe with annular corrugations or rerolled ends shall be used. Sleeve couplers are not intended for pipe diameters larger than 1050 mm.

9.1.7. *Bell and Spigot*—Bell and spigot configurations incorporate an integral bell that is permanently installed at the factory to one end of the pipe, while the other end of the pipe serves as a spigot. The bell shall be affixed to the pipe by welding or with mechanical fasteners. The steel in the bell shall meet the thickness requirements of Section 9.3.1. The bell and spigot configuration shall be classified in accordance with Section 9.2. The spigot end of the pipe shall be re-rolled or provide annular corrugations to allow placement of a gasket if required. The bell shall provide a minimum stab depth of 150 mm, or 8 percent of the pipe diameter, whichever is greater.

9.1.8. *Special Design*—Other joining systems that meet the requirements of Sections 9.3, 9.4 (if required), and 9.5 (if required), and are specified by the purchaser, shall be used on the project for which they are specified.

9.2. *Joining Systems, Significance and Use*—Joining systems are classified as standard or gasketed, based on the ability of the system to control infiltration and/or exfiltration. These classifications of standard and gasketed systems are covered in Sections 9.2.1 and 9.2.2. When site conditions near the pipe are such that movement or differential settlement is possible at the joint, the joining system shall have structural requirements that conform with Section 9.4.

9.2.1. *Standard Systems*:

9.2.1.1. Standard joining systems for CSP are intended to control the infiltration of soil into the pipe. Standard joining systems are used in the majority of CSP installations. The gradation and plasticity of the backfill materials around the pipe are important factors in the selection of a joining system. The greater the concentration of very fine particles, such as silts which pass the 75-µm sieve, the greater the possibility of soil infiltration. Additionally, when the water table is above the pipe or where the backfill is otherwise saturated and the flow level in the pipe varies rapidly, soil infiltration is more likely to occur.

9.2.1.2. External bands conforming with Sections 9.1.1 through 9.1.3, or 9.1.5, when used with annular pipe or with helical pipe with rerolled ends, generally provide adequate control of infiltration of soil particles. Properly installed, these bands provide continuous metal-to-metal contact with the periphery of the annular portion of the pipe. Where these bands do not provide adequate soil infiltration control, a geotextile wrap around the exterior of the joining system and the adjacent pipe will inhibit the movement of silt and larger soil particles into the pipe.

9.2.2. *Gasketed Systems*:

9.2.2.1. Gasketed joining systems are used to limit the flow of water from the pipe interior to the backfill, to limit the flow of groundwater into the pipe, and, where necessary, to provide further control of soil particle infiltration. Joining systems such as those described in Sections 9.1.4, 9.1.6, and 9.1.7 require gaskets to adequately control soil particle infiltration, except where the pipe is used in underdrain applications. Gaskets used in all joining systems shall conform to the requirements of Sections 6.7 and 9.5.

9.2.2.2. Sites where excessive water infiltration is expected or where the pipe will carry hazardous pollutants require a gasketed joining system. In these cases, the joining system shall be tested to establish a leakage rate not to exceed 18.5 L per millimeter of diameter per kilometer per day with no pressure applied to the pipe or joining system. The joining system shall be tested at the pipe fabricator’s plant or a laboratory, with the pipe in straight alignment. The test shall be witnessed and certified by an approved laboratory.

9.3. *Requirements*—Joining systems shall be fabricated in a manner that ensures that the band or coupler extends over each pipe section an equal length. The joining system shall be fabricated in such a way that proper installation will result in performance conforming with Sections 9.2.1 or 9.2.2 as required for the project.

9.3.1. *Band, Sleeve, or Bell Thickness and Width*—The band, sleeve coupler, or bell portion of the joining system shall be sufficiently strong to resist the forces to which it is subjected. Table 13 provides minimum steel thickness requirements for bands, sleeves, or bells based on the steel thickness of the pipes being connected. Table 13 does not apply to channel (hat) bands, which are covered under Section 9.3.3. The width of coupling bands (Sections 9.1.1–9.1.3 and 9.1.5) shall be equal to or greater than the minimum widths shown in Tables 14 and 15.

9.3.2. *Band Connectors*—The bands shall be connected in a manner approved by the purchaser with hardware that has been suitably galvanized to provide durability. This hardware includes angles and integrally or separately formed and attached flanges that will be connected together with galvanized or cadmium-plated bolts, bars and straps, wedge locks, and straps or lugs. Bands shall be connected with the bolts in accordance with Table 16.

9.3.3. *Channel Bands*—Pipe sections provided with flanges on the ends will be connected by interlocking the flanges of two pipes with a channel (hat) band or other band incorporating an interlocking channel, not less than 19 mm in width. The depth of the channel shall be not less than 13 mm. The channel band shall have a minimum thickness of 1.62 mm.

9.3.4. *Sleeve Couplers*—Sleeve couplers for pipes smaller than 300 mm in diameter shall be made from steel with a minimum thickness of 1.02 mm. The steel thickness for larger sizes shall conform to Table 13. Alternatively the coupler shall be a plastic sleeve with adequate strength to maintain the in-service pipe alignment and meet the requirements of Section 9.2.1.

9.4. *Structural Properties*—Joining systems that are subject to forces created by differential soil movement or settlement require certain structural properties to withstand the applied forces. Minimum values for these structural properties are shown in Table 17. These values for a joining system are determined by either a rational analysis or a suitable physical test.

9.4.1. *Shear Strength*—The shear strength required of the joining system is expressed as a percentage of the calculated shear strength of the pipe at a typical cross section at a location other than a rerolled end.

9.4.2. *Moment Strength*—The moment strength required of a joining system is expressed as a percent of the calculated moment strength of the pipe at a typical cross section at a location other than a rerolled end.

9.4.3. *Tensile Strength*—Where pull-apart (tensile) strength is required to control disjointing in slope drains and similar applications, corrugated, partially corrugated, or channel bands shall be specified. When special requirements exist, joining systems shall provide tensile strength levels of 22 kN for 1050 mm and smaller sizes and 46 kN for larger sizes.

9.5. *Gaskets*—Where infiltration or exfiltration is a concern, as defined in Section 9.2.2, the joining system shall incorporate gaskets. Rubber gaskets shall meet the requirements of Section 6.7 and shall be flat, O-ring, or have a profile shape. Flat gaskets shall be continuous or have a lap joint and be approximately 18 mm wide and approximately 9.5 mm thick. O-ring gaskets shall be 20 mm or 22 mm in diameter for pipe diameters of 900 mm and smaller, or 22-mm diameter for larger diameters of pipe fabricated with a 13-mm deep corrugation. O-ring gaskets shall be 35 mm in diameter when used on pipes having a 25-mm or deeper corrugation. Other types of gaskets may be used, including profile gaskets that meet the specific requirements of the joining system.

Table 13—Band, Sleeve, or Bell Thickness[a,b]

Nominal Pipe Thickness, mm	Nominal Coupling Band Thickness, Min, mm
2.77 and thinner	1.32
3.51	1.63
4.27	2.01

[a] For annular corrugated pipe or helically corrugated pipe with 68 by 13 mm annular rerolled ends.

[b] Applies to joining systems covered by Sections 9.1.1 through 9.1.3, 9.1.5, 9.1.7, and 9.1.6, when the coupler is 300 mm or larger and made from steel.

Note 13—Riveted and spot welded pipe is not watertight, having small openings at the intersection of longitudinal and circumferential seams. Therefore, these types of fabrication should not be used where watertightness is a concern unless the pipe is bituminous coated or lined prior to installation.

Table 14—Band Width Requirements for Pipe with Annular Corrugated Ends[a,b]

Nominal Pipe Diameter, mm	Minimum Band Width, mm
300 to 900	175
1050 to 3600	265

[a] For annular pipe or helical pipe with 68 by 13 mm rerolled ends.

[b] Applies to joining systems covered by Sections 9.1.1 through 9.1.3 and 9.1.5.

Table 15—Band Width Requirements for Helically Corrugated Pipe

Nominal Corrugation, mm	Nominal Pipe Diameter, mm	Minimum Band Width, mm
38 by 6.5	100 to 450	175
68 by 13	300 to 2100	300
75 by 25	900 to 3600	350
125 by 25	900 to 3600	550

Note 1—Corrugation of band shall match that pipe.

Note 2—Band shall be centered on pipes being joined.

Note 3—Applies to joining systems covered by Sections 9.1.1 through 9.1.3 and 9.1.5.

Table 16—Band Connector Bolt Size

Pipe Diameter, mm	Bolt Diameter, mm
450	M10
525	M12
Type III and IIIA	M8

Table 17—Structural Properties of Joining System

	Minimum Value
Shear strength (% of barrel strength)	2
Moment strength (% of barrel strength)	5
Tensile (pull-apart) strength	none

9.6. Other types of coupling bands or fastening devices that are equally effective as those described, and which comply with the joint performance criteria of *AASHTO LRFD Bridge Construction Specifications*, Section 26 may be used when approved by purchaser.

10. WORKMANSHIP

10.1. The complete pipe shall show careful, finished workmanship in all particulars. Pipe that has been damaged, either during fabrication or in shipping, may be rejected unless repairs are made that are satisfactory to the purchaser. Among others, the following defects shall be considered as constituting poor workmanship:

- Variation from a straight centerline;
- Elliptical shape in pipe intended to be round;
- Dents or bends in the metal;
- Metallic coating that has been bruised, broken, or otherwise damaged;
- Lack of rigidity;
- Illegible markings on the steel sheet;
- Ragged or diagonal sheared edges;
- Uneven laps in riveted or spot welded pipe;
- Loose, unevenly lined, or unevenly spaced rivets;
- Defective spot welds or continuous welds; and
- Loosely formed lock seams.

11. REPAIR OF DAMAGED COATINGS

11.1. Pipe on which the metallic coating has been burned by welding beyond the limits provided in Sections 7.4.2 and 7.6, or has been otherwise damaged in fabricating or handling, shall be repaired. The repair shall be done so that the completed pipe shall show careful finished workmanship in all particulars. Pipe which, in the opinion of the purchaser, has not been cleaned or coated satisfactorily may be rejected. If the purchaser so elects, the repair shall be done in his presence.

11.2. The damaged area shall be repaired in conformance with ASTM A 780 (Note 14), except as described herein. The damaged area shall be cleaned to bright metal by blast cleaning, power disk sanding, or wire brushing. The cleaned area shall extend at least 13 mm into the undamaged section of the coating. The cleaned area shall be coated within 24 hours and before any rusting or soiling.

Note 14—While ASTM A 780 specifically refers to repair of damaged zinc coatings, the same procedures are applicable to repair of other metallic coatings except as described in this section.

11.3. *Zinc-Rich Paint Coating*—Zinc-rich paint, as described in the Materials section of ASTM A 780, shall be applied to a dry film thickness of at least 0.13 mm over the damaged section and surrounding cleaned area. Zinc-rich paint shall be used for repair of damage to all types of metallic coating—zinc, aluminum, and aluminum-zinc alloy.

11.4. *Metallizing Coating*—The damaged area shall be cleaned as described in Section 11.2, except it shall be cleaned to the near-white condition. The repair coating applied to the cleaned section shall have a thickness of not less than 0.13 mm over the damaged section and shall taper off to zero thickness at the edges of the cleaned undamaged section.

11.4.1. Where zinc coating is to be metallized, it shall be done with zinc wire containing not less than 99.98 percent zinc.

11.4.2. Where aluminum coating is to be metallized, it shall be done with aluminum wire containing not less than 99 percent aluminum.

11.4.3. Where 55 percent aluminum-zinc alloy coating is to be metallized, it shall be done by using the materials described in Section 11.4.1 or Section 11.4.2, or by using an alloy wire of 55 percent aluminum and 45 percent zinc by mass.

11.4.4. When Zn-5 Al-MM alloy coating is to be metallized, it shall be done using the materials described in Section 11.4.1 or by using an alloy wire of 85 percent zinc and 15 percent aluminum by weight.

11.5. Pipe on which zinc and aramid fiber composite coating is damaged by welding during fabrication of fittings, or otherwise damaged during handling or shipping, shall be repaired as described in Sections 11.2 through 11.4.

12. INSPECTION

12.1. The purchaser or his representative shall have free access to the fabricating plant for inspection, and every facility shall be extended to him for this purpose. This inspection shall include an examination of the pipe for the items in Section 10.1 and the specific requirements of this specification applicable to the type of pipe and method of fabrication.

12.2. On a random basis, samples may be taken for chemical analysis and metallic coating measurements for check purposes. These samples will be secured from fabricated pipe or from sheets or coils of the material used in fabrication of the pipe. The mass of metallic coating shall be determined in accordance with T 65M/T 65 for zinc, 55 Al-Zn alloy, and Zn-5 Al-MM alloy, and T 213M/T 213 for aluminum.

13. REJECTION

13.1. Pipe that fails to conform to the specific requirements of this specification, or that shows poor workmanship, may be rejected. This requirement applies not only to the individual pipe, but to any shipment as a whole in which a substantial number of pipe are defective. If the average deficiency in length of any shipment of pipe is greater than 1 percent, the shipment may be rejected.

14. CERTIFICATION

14.1. When specified in the purchase order or contract, a manufacturer's or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the order, a report of the test results shall be furnished.

ANNEX

(Mandatory Information)

A1. QUALIFICATION OF RESISTANCE SPOT WELDING EQUIPMENT

A1.1. *General*—Welding equipment shall be of sufficient capacity, of such design, and in such condition as to make possible the production of first-class welds. Before being permitted to perform welding on CSP, resistance spot welding machines and operations shall be qualified by means of the test prescribed in Section A1.2. Tests shall be performed by the fabricator's shop or by a recognized independent laboratory at no expense to the purchaser. Qualification tests performed by the fabricator's shop shall be made in the presence of the representative of the purchaser.

A1.2. *Qualification*—Perform three tension shear tests representing each thickness of sheet to be used in the fabrication of the pipe. Prepare specimens by lapping two strips of corrugated steel sheet 38 mm minimum width by 125 mm minimum length and joining them together by a single spot weld duplicating the size to be used in production. The length of lap shall be 38 mm. The longer axis of specimen shall be parallel to the direction of rolling. Test the specimens in tension to destruction in a standard calibrated testing machine. The minimum shear strength in kilonewtons as determined by this test shall be not less than that shown in Table A1.1 for nominal thickness of sheet used in the test.

Table A1.1—Shear Strength of Spot Welds

Specified Sheet Thickness, mm	Minimum Shear Strength, kN
1.63	18.2
2.01	23.1
2.77	31.1
3.51	37.8
4.27	44.5

A1.3. *Verification*—After a machine and operator have been qualified by the foregoing procedure, to ensure that qualification is maintained, make three tension shear tests at the start of each work shift, and make three tension shear tests for each change in sheet thickness.

A1.4. *Machine Setting*—One copy of the approved machine setting shall be posted on the machine for use by the machine operator. No settings shall be varied, except weld phase shift and pressure, which may be varied by ±10 percent.

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[1] This specification is technically identical to ASTM A 760/A 760M-01a.

Standard Specification for

Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe

AASHTO Designation: M 86M/M 86-09[1]
ASTM Designation: C 14M-07 and C 14-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe

AASHTO Designation: M 86M/M 86-09[1]
ASTM Designation: C 14M-07 and C 14-07

1. SCOPE

1.1 This specification covers nonreinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, storm water, and for the construction of culverts.

1.2 This specification is applicable for orders in either SI units (M 86M) or in inch-pound units (M 86). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 86.

Note 1—This specification is a manufacturing and purchasing specification only and does not include requirements for bedding, backfill, or the relationship between field load conditions and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, and care that the installation conforms to the construction specifications. The owner is cautioned that he must correlate the field requirements with the class of pipe specified and provide for or require inspection at the construction site.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- M 315, Joints for Concrete Pipe and Manholes, Using Rubber Gaskets
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standard*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Pipe manufactured according to this specification shall be of three classes identified as “Class 1 Nonreinforced Concrete Pipe,” “Class 2 Nonreinforced Concrete Pipe,” and “Class 3 Nonreinforced Concrete Pipe.” The corresponding strength requirements are prescribed in Table 1.

Table 1— Physical and Dimensional Requirements for Nonreinforced Concrete Pipe[a]

		Class 1				Class 2				Class 3			
Internal Designated Diameter		Minimum Thickness of Wall		Minimum Strength, Three-Edge Bearing		Minimum Thickness of Wall		Minimum Strength, Three-Edge Bearing		Minimum Thickness of Wall		Minimum Strength, Three-Edge Bearing	
mm	[in.]	mm	[in.]	kN/ Linear m	[lbf/ Linear ft.]	mm	[in.]	kN/ Linear m	[lbf/ Linear ft.]	mm	[in.]	kN/ Linear m	[lbf/ Linear ft.]
100	4	16	$^{5}/_{8}$	22.0	1500	19	$^{3}/_{4}$	29.0	2000	19	$^{3}/_{4}$	35.0	2400
150	6	16	$^{5}/_{8}$	22.0	1500	19	$^{3}/_{4}$	29.0	2000	22	$^{7}/_{8}$	35.0	2400
200	8	19	$^{3}/_{4}$	22.0	1500	22	$^{7}/_{8}$	29.0	2000	29	$1^{1}/_{8}$	35.0	2400
250	10	22	$^{7}/_{8}$	23.5	1600	25	1	29.0	2000	32	$1^{1}/_{4}$	35.0	2400
300	12	25	1	26.5	1800	35	$1^{3}/_{8}$	33.0	2250	44	$1^{3}/_{4}$	38.0	2600
375	15	32	$1^{1}/_{4}$	29.0	2000	41	$1^{5}/_{8}$	38.0	2600	47	$1^{7}/_{8}$	42.0	2900
450	18	38	$1^{1}/_{2}$	32.0	2200	50	2	44.0	3000	57	$2^{1}/_{4}$	48.0	3300
525	21	44	$1^{3}/_{4}$	35.0	2400	57	$2^{1}/_{4}$	48.0	3300	69	$2^{3}/_{4}$	56.0	3850
600	24	54	$2^{1}/_{8}$	38.0	2600	75	3	52.5	3600	85	$3^{3}/_{8}$	64.0	4400
675	27	82	$3^{1}/_{4}$	41.0	2800	94	$3^{3}/_{4}$	57.5	3950	94	$3^{3}/_{4}$	67.0	4600
750	30	88	$3^{1}/_{2}$	44.0	3000	107	$4^{1}/_{4}$	63.0	4300	107	$4^{1}/_{4}$	69.5	4750
825	33	94	$3^{3}/_{4}$	46.0	3150	113	$4^{1}/_{2}$	64.0	4400	113	$4^{1}/_{2}$	71.0	4875
900	36	100	4	48.0	3300	119	$4^{3}/_{4}$	65.5	4500	119	$4^{3}/_{4}$	73.0	5000

[a] Subject to tolerance in Section 11.

5. BASIS OF ACCEPTANCE

5.1 The acceptability of the pipe shall be determined by the results of the test prescribed in this section, when required, and by inspection to determine whether the pipe conforms to this specification as to design and freedom from defects.

5.2 *Acceptance as to Strength Properties*—Pipe shall be acceptable under the strength tests when they have met the requirements as prescribed in Section 10.3.

5.3 *Acceptance as to Absorption Properties*—Pipe shall be acceptable under the absorption test when they have met the requirements as prescribed in Section 10.4.

5.4 *Acceptance as to Permeability Properties*—Pipe shall be acceptable under the permeability test when they have met the requirements as prescribed in Section 10.5.

Note 2—Prior to purchase the owner has the option to specify the hydrostatic test prescribed in Section 10.6 instead of the permeability test.

5.5 *Acceptance as to Hydrostatic Properties*—Pipe shall be acceptable under the hydrostatic test when they have met the requirements as prescribed in Section 10.6.

6. MATERIALS

6.1 *Concrete*—The concrete shall consist of cementitious materials, mineral aggregates, and water.

6.2 *Cementitious Materials*:

6.2.1 *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or slag modified portland cement, or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.2.2 *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of Specification C 989.

6.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1 Portland cement only,

6.2.4.2 Portland blast-furnace slag cement only,

6.2.4.3 Slag modified portland cement only,

6.2.4.4 Portland-pozzolan cement only, or

6.2.4.5 A combination of portland cement and fly ash.

6.2.4.6 A combination of portland cement and ground granulated blast-furnace slag, or

6.2.4.7 A combination of portland cement, fly ash (not to exceed 25 percent of the total cementitious weight) and ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight).

6.3 *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—Admixtures and blends shall only be used with the approval of the owner.

6.5 *Synthetic Fibers*—Polypropylene fibers are permitted, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM Specification C 1116 shall be accepted.

7. DESIGN

7.1 *Design Tables*—Design requirements shall be in accordance with Table 1. Wall thickness used shall be not less than the value shown, except as affected by the tolerance herein specified and by the provision for modified design.

7.2 *Modified or Special Design*—Manufacturers shall submit to the owner for approval, prior to manufacture, wall thicknesses other than those shown in Table 1. Such pipe shall meet all of the physical requirements listed in Section 10 that are specified by the owner.

8. JOINTS

8.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 11.

9. MANUFACTURE

9.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 [470 lb/yd^3] unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

9.2 *Curing*—Pipe shall be subjected to any one of the methods of curing described in Sections 9.2.1 through 9.2.4 or to any other method or combination of methods approved by the owner that will give satisfactory results. The pipe shall be adequately cured to obtain the strength properties as described in Section 5.2.

9.2.1 *Steam Curing*—Pipe shall be placed in a curing chamber, free from outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

9.2.2 *Water Curing*—Concrete pipe shall be water cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

9.2.3 The manufacturer is not prohibited from combining the methods described in Sections 9.2.1 and 9.2.2 provided the specified strength is attained.

9.2.4 *Membrane Curing*—A sealing membrane conforming to the requirements of M 148 is not prohibited from being applied and left intact until the specified strength requirements are met. The concrete at the time of application shall be within 6ºC [10ºF] of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

9.3 *Specials*:

9.3.1 *General Requirements*—Special shapes or fittings such as wyes, tees, bends, and adapters for use with concrete pipe conforming to this specification shall conform to the applicable requirements for concrete pipe of corresponding class and internal diameter. Joints shall be compatible with those used in adjoining concrete pipes.

9.3.2 *Fabricated Branches*—Fabricated branches for wyes and tees shall be securely attached to the wall of the pipe in such a manner as not to restrict or otherwise interfere with the flow characteristics of the pipe.

10. PHYSICAL REQUIREMENTS

10.1 *Test Specimen*—The specified number of pipe required for the tests shall be furnished by the manufacturer and shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order. The test pipe shall first be freed from all visible moisture. When dry, each pipe shall be measured and inspected. The results of these observations shall be recorded.

10.2 *Number and Type of Test Specimens Required*—The manufacturer shall furnish pipe for crushing and absorption tests, up to 0.5 percent of the number of pipe of each size included in the order except that in no case shall fewer than two pipes be furnished. For the permeability test, 2 percent of the number of pipe of each size included in the order, but in no case fewer than two pipes shall be furnished. For the hydrostatic test, 0.5 percent of the number of pipe of each size included in the order, but in no case fewer than two pipes shall be furnished.

10.3 *External Load Crushing Requirement*—The crushing strength of nonreinforced concrete pipe shall conform to the requirements prescribed in Table 1. The individual results of the various tests for each size of pipe and for each shipment and plant shall be tabulated separately. The crushing strength shall ordinarily be applied to not less than 75 percent of the pipe received for purpose of test. All tests shall be made in accordance with T 280. Pipe shall be acceptable when all test pipe conform to the specified requirement. Should any of the test pipe provided in Section 10.2 fail to meet the strength requirement, the manufacturer will be allowed to test two pipes for each pipe that failed, and the pipe shall be acceptable only when all of these additional test pipe meet the strength requirement.

10.4 *Absorption Requirement*—When required by the owner, absorption shall be determined by the boiling absorption test and shall not exceed 9 percent. The individual results of the various tests for each size of pipe for each shipment and plant shall be tabulated separately. All tests shall be made in accordance with T 280. The number of absorption test specimens shall be equal to the number of pipe provided for crushing strength testing. These specimens shall be obtained from pipe that are acceptable as to strength, and shall be taken from pipe used in making the strength test after the test is made. These specimens shall be marked with the number or identification mark of the pipe from which they were taken. Each specimen shall have an area of 77 [12] to 129 cm^2 [20 $in.^2$], as measured on one surface of the pipe, and a thickness equal to the pipe wall, and shall be free of visible cracks. Pipe shall be acceptable when all test pipe conform to the specified absorption requirement.

10.5 *Permeability Requirement*—When subjected to the permeability test as specified in T 280, the outer pipe surface of not less than 80 percent of the pipe tested shall show no moist or damp spots at the end of the test period due to water passing through the walls of the pipe.

10.6 *Hydrostatic Requirement*—When subjected to the hydrostatic test as described in T 280, the pipe shall show no leakage during 10 minutes at 70 kPa [10 psi]. Moisture appearing on the surface of the pipe in the form of patches or beads adhering to the surface shall not be considered leakage. The test pipe shall be filled with water and held under 70 kPa [10 psi] pressure for 24 hours prior to the test, except that the manufacturer is not prohibited from reducing, this presoak time or pressure, or both. The manufacturer is not prohibited from continuing this test up to 24 hours, and the pipe will be considered to have passed when, during any 10-minute period, no leakage is observed. When the hydrostatic requirement is used for acceptance of the pipe joint as specified in Section 10 of M 198, it is not prohibited to use the same joint test runs as the basis of acceptance for pipe hydrostatic requirements in accordance with Sections 5.5 and 10.6 of this specification.

10.7 *Retest*—Should more than 20 percent of the samples fail to meet the specified requirements for the permeability or not more than 20 percent of the samples fail to meet the specified requirement for absorption or hydrostatic requirements of this section, it is not prohibited for the manufacturer to cull his stock and eliminate any quantity of pipe and must so mark those pipe that will not be shipped. The required tests shall be made on the balance of the order and they are acceptable if they conform to the specified requirements. If the second sample fails to meet the specified requirements, the whole lot is subject to rejection.

11. DIMENSIONS AND PERMISSIBLE VARIATIONS

11.1 *Sizes and Dimensions*—Pipe shall be furnished of the sizes, internal diameters, and dimensions prescribed in Table 1.

11.2 *Permissible Variations in Dimensions*—Permissible variations in dimensions shall be limited to the following:

11.2.1 *Internal Diameter*—Permissible variations are as prescribed in Table 2.

Table 2—Permissible Variation in Internal Diameter

Designated Diameter of Pipe		Permissible Variation Internal Diameter of Pipe			
		Minimum		Maximum	
mm	[in.]	mm	[in.]	mm	[in.]
100	4	95	$3^{13}/_{16}$	105	$4^{3}/_{16}$
150	6	145	$5^{13}/_{16}$	155	$6^{3}/_{16}$
200	8	195	$7^{13}/_{16}$	205	$8^{3}/_{16}$
250	10	245	$9^{13}/_{16}$	255	$10^{3}/_{16}$
300	12	295	$11^{13}/_{16}$	305	$12^{3}/_{16}$
375	15	368	$14^{3}/_{4}$	382	$15^{1}/_{4}$
450	18	443	$17^{3}/_{4}$	457	$18^{1}/_{4}$
525	21	517	$20^{11}/_{16}$	533	$21^{5}/_{16}$
600	24	590	$23^{5}/_{8}$	610	$24^{3}/_{8}$
675	27	665	$26^{5}/_{8}$	685	$27^{3}/_{8}$
750	30	740	$29^{5}/_{8}$	760	$30^{3}/_{8}$
825	33	815	$32^{5}/_{8}$	835	$33^{3}/_{8}$
900	36	890	$35^{5}/_{8}$	910	$36^{3}/_{8}$

11.2.2 *Thickness of Wall*—The wall thickness shall be not less than the values shown in Table 1 or the manufacturer's designated thickness if greater than shown in Table 1 by more than 2 mm [$^1/_{16}$ in.] for pipe 250 mm [10 in.] or less in diameter; by more than 3 mm [$^1/_8$ in.] for pipe 300 [12 in.] to 600 mm [24 in.] in diameter; and by more than 5 mm [$^3/_{16}$ in.] for pipe more than 600 mm [24 in.] in diameter; or by more than 5 percent of the tabulated or designated wall thickness, whichever is greater. Localized variations in wall thickness exceeding those specified above shall be accepted if the physical test requirements specified herein are met.

11.2.3 *Length*—The length of any section of pipe shall vary not more than minus 13 mm [$^1/_2$ in.] from a specified or designated design length.

11.2.4 *Length of Two Opposite Sides*—The length of two opposite sides of any section of pipe shall vary not more than 6 mm [$^1/_4$ in.] or 2 percent of the designated diameter, whichever is larger.

11.2.5 *Straightness*—Pipe intended to be straight shall not vary in alignment more than 10 mm/m [$^1/_8$ in./ft] of length.

12. REPAIRS

12.1 Pipe repaired because of imperfections in manufacturing or damage during handling are acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

13. INSPECTION

13.1 The quality of all materials and the finished pipe shall be subject to inspection and approval by the owner. Such inspection shall be performed either at the point of manufacture or delivery, or both. The method of marking as to acceptance or rejection of pipe shall be agreed upon, prior to inspection, between the owner and the manufacturer. Rejected pipe shall be replaced by the manufacturer with pipe that meets the requirements of this specification.

14. REJECTION

14.1 Pipe shall be subject to rejection if it fails to conform to any of the specification requirements. This specification is a manufacturing and purchasing specification only. Therefore, damage to pipe during installation or caused by field loading in the installed condition shall not be cause for rejection on the basis of not meeting this specification. Individual sections of pipe are subject to rejection because of any of the following:

14.1.1 Fractures or cracks passing through the wall or joints, except that a single crack not exceeding 50 mm [2 in.] in length at either end of a pipe or a single fracture or spall in the joints not exceeding 75 mm [3 in.] around the circumference of the pipe nor 50 mm [2 in.] in length into joint shall not be considered cause for rejection unless these defects exist in more than 5 percent of the entire shipment or delivery.

14.1.2 The planes of the ends of the pipe are not perpendicular to the longitudinal axis, subject to the limits of variation as shown in Section 11.2.4.

14.1.3 Defects that indicates mixing and molding not in accordance with Section 9.1.

14.1.4 Cracks sufficient to impair the strength, durability, or serviceability of the pipe.

15. PRODUCT MARKING

15.1 The following information shall be legibly marked on each pipe:

15.1.1 The pipe class and specification designation,

15.1.2 The date of manufacture,

15.1.3 The name or trademark of the manufacturer, and

15.1.4 Identification of the plant.

15.2 Marking shall be indented on the pipe section or painted thereon with waterproof paint.

16. KEYWORDS

16.1 Concrete sewer; culvert; nonreinforced; pipe; storm drain.

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[1] Agrees with ASTM C 14M-07 and C 14-07 except for limiting absorption testing to the 5-hour boil method, the use of fibers in Section 6.5 is at the owners option, and the manufacturer is not afforded the option to supply inch-pound sized pipe when the order is placed in SI units.

Standard Specification for

Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe-Arches, and Arches

AASHTO Designation: M 167M/M 167-09
ASTM Designation: A 761/A 761M-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe-Arches, and Arches

AASHTO Designation: M 167M/M 167-09
ASTM Designation: A 761/A 761M-04

1. SCOPE

1.1. This specification covers corrugated steel structural plate, zinc-coated, used in the construction of pipe, pipe-arches, arches, underpasses, and special shapes for field assembly. Appropriate fasteners and accessory materials are also described. The pipe, arches, and other shapes are generally used for drainage purposes, pedestrian and vehicular underpasses, and utility tunnels.

1.2. This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and plate thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of plate thickness, type of bedding and backfill, manufacture in the plant, and care in the installation. The purchaser must correlate the above factors and also the corrosion and abrasion requirements of the field installation with the plate thickness. The structural design of corrugated steel structural plate pipe and the proper installation procedures are described in *AASHTO LRFD Bridge Design Specifications*, Section 12 and *AASHTO LRFD Bridge Construction Specifications*, Section 26, respectively.

1.3. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 111M/M 111, Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
- M 120, Zinc
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 291, Carbon and Alloy Steel Nuts
- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 244, Mechanical Testing of Steel Products
- *AASHTO LRFD Bridge Design Specifications*
- *AASHTO LRFD Bridge Construction Specifications*

2.2. *ASTM Standards*:

- A 36/A 36M, Standard Specification for Carbon Structural Steel

- A 307, Standard Specification for Carbon Steel Bolts and Studs, 60 000 psi Tensile Strength
- A 449, Standard Specification for Hex Cap Screws, Bolts and Studs, Steel, Heat Treated, 120/105/90 ksi Minimum Tensile Strength, General Use
- A 751, Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
- A 754/A 754M, Standard Test Method for Coating Weight (Mass) of Metallic Coatings on Steel by X-Ray Fluorescence
- A 780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods
- F 568M, Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners

2.3. *American National Standards*:

- B18.2.1, Square and Hex Bolts and Screws, Inch Series
- B18.2.2, Square and Hex Nuts
- B18.2.3.6M, Bolts, Metric Heavy Hex
- B18.2.4.6M, Hex Nuts, Heavy, Metric

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1. *arch*—a partial circle shape spanning an open invert between the footings on which it rests.

3.2. *box culvert*—a rectangular box with a long-radius crown and either short-radius corners or welded corners. It can be with full invert or with footings.

3.3. *fabricator*—the producer of the components for the finished product.

3.4. *flat plate*—sheet or plate used to fabricate structural plate.

3.5. *manufacturer*—the producer of the flat plate and accessories.

3.6. *pipe*—a conduit having full circular shape; also, in a general context, all structural shapes covered by this specification.

3.7. *pipe-arch*—an arch shape with an approximate semicircular crown, small-radius corners, and large-radius invert.

3.8. *pipe, horizontal ellipse*—an elliptically shaped pipe with the horizontal diameter approximately 25 percent greater than the nominal diameter.

3.9. *pipe, vertically elongated*—an elliptically shaped pipe with the vertical diameter up to 10 percent greater than the nominal diameter.

3.10. *purchaser*—the purchaser of the finished product.

3.11. *special shape*—a shape, other than described elsewhere in this section, suitable for fabrication with structural plate.

3.12. *structural plate*—a corrugated and curved plate that is field assembled with other structural plates to form the required structure.

3.13. *vehicular underpass*—a high arch shape with an approximate semicircular crown, large-radius sides, small-radius corners between sides and invert, and large-radius invert.

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4. ORDERING INFORMATION

4.1. Orders for material under this specification shall include the following information, as necessary, to adequately describe the desired product:

4.1.1. Name of material (corrugated steel structural plate and accessories);

4.1.2. Description of structure (Section 3);

4.1.3. Number of structures;

4.1.4. AASHTO designation and year of issue;

4.1.5. Dimensions of structure (diameter or span and rise, and length, etc.) (Section 8.2 and Note 7);

4.1.6. Thickness of plate (Section 8.1), and for the 150 × 50 mm [6 × 2 in.] corrugation, the type of steel in accordance with 5.1.3. and Table 2;

4.1.7. Description of corrugations (Section 6.2);

4.1.8. End treatment (bevel, skew, grade or slope corrections, or other special provision if required by the project plans or specifications);

4.1.9. Seam bolt size and number per corrugation, if different from the minimums indicated by Tables 3 and 5 (Section 6.3);

4.1.10. Special requirements (including reinforcement locations, shapes, and thicknesses), if required; and

4.1.11. Certification, if required (Section 12.1).

Note 1—A typical ordering description is as follows: (1) Structural plates and fasteners for two corrugated steel plate pipe-arch, per M 167-____, 180-in. diameter, 0.168-in. plate thickness, 6 × 2-in. corrugations, 140-ft. nominal centerline length with square ends, longitudinal seams with four M20 bolts per corrugation. (2) Structural plates and fasteners for two corrugated steel plate pipe-arch, per M 167M-____, 3860-mm span by 2460-mm rise, 5.54-mm plate thickness, 150 × 50-mm corrugations, 27.0-m nominal centerline length with square ends, longitudinal seams with four M20 bolts per corrugation.

5. MATERIALS

5.1. *Flat Plate*:

5.1.1. *Manufacture*—The base steel shall be made by any of the following processes: open-hearth, basic-oxygen, or electric-furnace.

5.1.2. *Chemical Composition*—The base metal cast or heat (formerly ladle) analysis shall conform to the chemical requirements of Table 1. The requirements of this specification shall be met in continuous mass production during which the manufacturer has made analysis of individual heats to ensure that material is controlled within the specified limits.

5.1.3. *Mechanical Requirements*—The mechanical properties of the flat plate material prior to corrugating shall conform to the requirements in Table 2. For the 150 × 50 mm [6 × 2 in.] corrugation, either Type 33 or Type 38 must be specified.

Note 2—The properties enumerated in Table 2 for the flat plate normally provide the minimum yield strength of 230 MPa [33 ksi] for Type 33 material and 265 MPa [38 ksi] for Type 38 material (used in structural design for pipe with 150 × 50 mm [6 × 2 in.] corrugations), or 300 MPa [44 ksi] (used in structural design for pipes with 380 × 140 mm [15 × 5$^1/_2$ in.] and 400 × 150 mm [16 × 6 in.] corrugations) after the plate is corrugated.

Table 1—Chemical Composition by Cast Analysis

Corrugations, mm [in.]		Composition, percent	Tolerance Over the Maximum Limit by Product Analysis, percent
150 × 50 [6 × 2]	Sulfur, max	0.05	+0.01
	Sum of carbon, manganese, phosphorus, silicon, and sulfur, max	0.70	+0.04
380 × 140 [15 × 5 $^1/_2$] and 400 × 150 [16 × 6]	Sulfur, max	0.04	+0.01
	Sum of carbon, manganese, phosphorus, silicon, and sulfur, max	1.86	+0.13

Table 2—Mechanical Requirements for Flat Plate[a]

	Yield Point,[b] Min, MPa [ksi]	Tensile Strength,[b] Min, MPa, [ksi]	Elongation in 50 mm [2 in.],[c] Min, percent
150 × 50 [6 × 2]			
Type 33	190 [28.0]	290 [42.0]	25
Type 38	225 [33.0]	310 [45.0]	25
380 × 140 [15 × 5 $^1/_2$] and 400 × 150 [16 × 6]	275 [40.0]	380 [55.0]	25

[a] To determine conformance with this specification, each value for tensile strength and for yield point shall be rounded to the nearest 1 MPa [0.1 ksi] and each value for elongation to the nearest 1 percent, both in accordance with the rounding-off method of ASTM E 29.

[b] Yield point and tensile strength are based on thickness of the base metal. If tests are made after coating, determine the base metal thickness after stripping the coating from the ends of the specimen contacting the grips of the tension testing machine.

[c] Elongation requirement does not apply to material tested after corrugating.

5.2. *Bearings for Arches*—When specified, metal bearings for arches may be cold-formed channels made from flat plate material conforming to Section 5.1, and not less than 4.78 mm [0.188 in.] in specified thickness.

5.3. *Members for Structural Reinforcement*—Steel members for circumferential or longitudinal stiffeners, or secondary structural components, shall be fabricated from rolled shapes conforming to A 36/A 36M, or from flat plate material conforming to Section 5.1.

Note 3—Steel transverse structural reinforcing members, when used, are part of long span or box corrugated steel structural plate structures. The structural reinforcement for either of these types of structures can be designed using *AASHTO LRFD Bridge Design Specifications*. The structural design of long span structures is given in *AASHTO LRFD Bridge Design Specification,* Section 12.

5.4. *Assembly Fasteners*—Except as provided elsewhere in this section, bolts and nuts shall conform to the requirements specified in Table 3. The bearing surface of both bolts and nuts for use with 150 × 50 mm [6 × 2 in.] and 400 × 150 mm [16 × 6 in.] corrugations shall be shaped to a 25-mm [1-in.] radius spherical surface. In lieu of bolts and nuts with the special bearing surface, standard type bolts and nuts with special washers providing comparable bearing surface may be used. Bolts and nuts with standard bearing surfaces shall be used with 380 × 140 mm [15 × 5 $^1/_2$ in.] corrugations. The number of bolts and nuts of each size and length furnished shall be 2 percent in excess of the theoretical number required to field erect the structure or structures. Bolt lengths shall be such as to result in at least “full nut” engagement when tightened in place.

5.5. *Head Wall and Bearing Anchorage*—Bolts and nuts for head wall anchorage and for anchoring arch bearings to foundations shall be fabricated as shown on the plans and shall conform to the requirements specified in Table 3.

Table 3—Bolt and Nut Requirements

	Bolts[a]	Nuts
General Dimensions[b]	ANSI B18.2.3.6M Heavy Hex	ANSI B18.2.4.6M Heavy Hex
Seam bolts and nuts[c]	F 568 Class 8.8	M 291 Class 12
Anchorage bolts and nuts	F 568 Class 4.6	M 291 Class 5
Zinc coating	M 232M/M 232	M 232M/M 232
Nominal diameter, min, metric size[d]	M 20	M 20

[a] Bolts with special hemispherical base under the head are only available in inch sizes. They are also intended for use with metric plate.

[b] See Section 5.4 for permissible modifications to bearing surface.

[c] Bolts and nuts also used for connecting arch plates to bearing and structural reinforcement to structural plates.

[d] Bolt size of M 22, M 24, or M 27 may be required with thicker plates, especially with 380 × 140 mm corrugation, and shall be furnished when specified in the order.

6. FABRICATION

6.1. *Structural Plates*—Structural plates shall be fabricated from flat sheets or plates, corrugated in accordance with Section 6.2, punched for bolted lap seams in accordance with Section 6.3, and curved to the required radius.

6.2. *Corrugations*—Corrugations shall form smooth continuous curves and tangents. Corrugations shall form annular rings (complete or partial) about the axis of the structure. The dimensions of the corrugations shall be in accordance with Table 4 for the size specified in the order.

Table 4—Corrugation Requirements

Nominal Size	Maximum Pitch[a]	Minimum Depth[b]	Minimum Inside Radius
		M 167M (mm)	
150 × 50	158	48	25
380 × 140	394	133	68
400 × 150	413	144	74
		M 167 (in.)	
6 × 2	6.25	—	1.0
15 × 5$^1/_2$	15.5	5.23	2.7
16 × 6	16.3	5.67	2.9

[a] Pitch is measured from crest to crest of corrugation, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe to the bottom of the intervening valley.

6.3. *Bolt Holes*—The bolt holes shall be punched so that all plates having like dimensions, curvature, and same size and number of bolts per meter [foot] of seam shall be interchangeable. Except as otherwise specified, the location and number of seam bolt holes shall conform to the requirements of Table 5 for the size of bolts indicated in Table 3 (Note 4). For 150 × 50 mm [6 × 2 in.] corrugations, the diameter of bolt holes in the longitudinal seams shall not exceed the bolt diameter by more than 3 mm [$^1/_8$ in.] except those in plate corners. Bolt holes in circumferential seams, including plate corners, shall not exceed the bolt diameter by more than 6 mm [$^1/_4$ in.] or may be slotted with a width equal to the bolt diameter plus 3 mm [$^1/_8$ in.] and a length equal to the bolt diameter plus 10 mm [$^3/_8$ in.]. For 380 × 140 mm [15 × 5 $^1/_2$ in.] corrugations, the diameter of bolt holes in the longitudinal and circumferential seams shall not exceed the bolt diameter by more than 6 mm [$^1/_4$ in.]. Bolt holes for the attachment of circumferential reinforcing, where required, shall be slotted with a width not greater than the bolt diameter plus 6 mm [$^1/_4$ in.] and a length not greater than the bolt diameter plus 12 mm [$^1/_2$ in.]. For 400 × 150 mm [16 × 6 in.] corrugations, the diameter of bolt holes in the longitudinal seams shall not exceed the bolt diameter by more than 6 mm [$^1/_4$ in.] except those in the plate corners and two other locations (aligned with the center hole of the group of three corner holes, and in adjacent corrugations), which will be the same as the circumferential holes. The bolt holes in circumferential seams shall be slotted holes with a width not greater than the bolt diameter plus 5 mm [$^3/_{16}$ in.] and a length not greater than the bolt diameter plus 10 mm [$^3/_8$ in.].

6.4. Holes shall be provided as required for connecting headwall anchors, structural reinforcement, and miscellaneous attachments.

Note 4—Determine the appropriate bolt size and number of bolts per corrugation for longitudinal seams according to the design criteria in *AASHTO LRFD Bridge Design Specifications*, Section 12, or other appropriate guidelines.

Table 5—Bolt Hole Patterns in Structural Plate[a]

	Corrugation Size, mm [in.]		
	150 × 50 [6 × 2]	380 × 140 [15 × 5$^1/_2$]	400 × 150 [16 × 6]
Longitudinal Seams:			
Number of rows	2	3	3
Holes per corrugation, each row, min:			
For plates thinner than 7.87 mm [0.310 in.]	1[b]	2[c]	2
For 7.87 mm [0.310 in.] and thicker plates	2	2[c]	2
Spacing between rows, min, mm [in.]	50 [2]	75 [3]	100 [4]
Circumferential Seams:			
Number of rows	1	1	1
Spacing in rows, max, mm [in.]	250 [10]	400 [16]	425 [16.75]
Arch Anchorage Seams:			
Number of rows	1	1	1
Spacing in rows, nominal max, mm [in.]	600 [24]	380 [15]	400 [16]

[a] All bolt holes shall be located 1.75 × bolt diameter minimum, center of the hole to edge of sheet.

[b] For minimum of one hole per corrugation, holes shall be staggered with holes in one row in valleys and holes in the other row in crests of corrugation.

[c] One hole each crest and valley of all corrugations for each row.

6.4.1. *Bolt Holes in Bearings for Arches*—Bolt holes for anchoring bearings to foundation shall be punched as shown on the plans, with spacing at not more than 600 mm [24 in.] on centers. Bolt holes shall be punched in the vertical leg of bearings to match corresponding bolt holes in the bottom arch plate.

6.5. *Special Plates*—Plates for forming skewed ends, beveled ends, or curved alignment shall be accurately cut to fit the order plans. Cut edges of plates shall be free of notches, gouges, or burrs, and shall present a workmanlike finish. Legible identification shall be placed on each special plate to designate its proper position in the finished structure and referenced to the approved erection drawings.

6.6. *Structural Reinforcement*—Members for longitudinal or circumferential reinforcing, if required, shall be as sized and located on the order plans and fabricated from materials described in Section 5.3.

7. ZINC COATING

7.1. All structural plates, including fittings and cut ends, shall be zinc coated after cutting, corrugating, punching of holes, and welding (when required), but they may be curved to the required radius either before or after zinc coating when it has been demonstrated that this fabrication can be done on specific tooling and equipment without damage to the zinc coating. All arch bearings and structural reinforcement shall be zinc coated after all fabrication is completed. The zinc used for the coating shall conform to M 120 and shall be at least equal to the grade designated as "Prime Western."

7.2. *Coating Mass (Plates)*—Plates shall be zinc coated to provide an average coating mass of 910 g/m^2 [3.0 oz/ft^2] of sheet (total both surfaces), and a minimum coating mass for any single specimen of 820 g/m^2 [2.7 oz/ft^2] of sheet.

7.2.1. To determine conformance with this specification, each single value for coating mass and the average of all values shall be rounded to the nearest 10 g/m^2 [0.1 oz/ft^2] in accordance with the rounding-off method of ASTM E 29.

7.3. *Coating Mass (Structural Reinforcement and Arch Bearings)*—Members fabricated from rolled shapes shall be zinc coated to conform to M 111M/M 111. Members fabricated from plate material shall be zinc coated as specified in Section 7.2.

7.4. *Repair of Damaged Zinc Coating*—Plate or accessory material on which the metallic coating has been burned by welding, or has been otherwise damaged in fabricating or handling, shall be repaired. The repair shall be done so the completed material shall show careful finished workmanship in all particulars. Material which, in the opinion of the purchaser, has not been cleaned or coated satisfactorily may be rejected. If the purchaser so elects, the repair shall be done in his presence.

7.4.1. The damaged area shall be cleaned to bright metal by blast cleaning, power disk sanding, or wire brushing. The cleaned area shall extend at least 13 mm [$^1/_2$ in.] into the undamaged section of the coating. The cleaned area shall be coated within 24 hours and before any rusting or soiling, using either the procedure in Section 7.4.2 or Section 7.4.3, unless specified otherwise.

7.4.2. *Zinc-Rich Paint Coating*—Zinc-rich paint shall be applied to a dry film thickness of at least 0.13 mm [0.005 in.] over the damaged section and surrounding cleaned area.

7.4.3. *Metallizing Coating*—The damaged area shall be cleaned as described in Section 7.4.1 except it shall be cleaned to the near-white condition. The repair coating applied to the cleaned section shall have a thickness of not less than 0.13 mm [0.005 in.] over the damaged section and shall taper off to zero thickness at the edges of the cleaned undamaged section. Metallizing shall be performed using zinc wire containing not less than 99.98 percent zinc.

Note 5—ASTM A 780 contains additional information on repair of damaged zinc coatings.

7.5. *Coating Adherence*—The coating shall adhere to the base metal so that no peeling or flaking occurs during normal handling.

8. DIMENSIONS AND TOLERANCES

8.1. *Plate Thickness*—Plate thickness shall conform to the requirements of Table 6 as specified by the purchaser from the specified plate thicknesses listed in that table (Note 6). For corrugated plate, the thickness shall be measured on the tangents of the corrugations. The thickness shall include both the base metal and the coating.

Note 6—Determine the required thickness according to the design criteria in *AASHTO LRFD Bridge Design Specifications*, Section 12 or other appropriate guidelines.

Table 6—Thickness for Zinc-Coated Plates[a]

Corrugated Size mm [in.]	Specified Thickness, mm [in.]	Minimum Thickness, mm [in.]
150 × 50 [6 × 2] and 380 × 140 [15 × 5$^1/_2$]	2.82 [0.111]	2.51 [0.099]
	3.56 [0.140]	3.25 [0.128]
	4.32 [0.170]	4.01 [0.158]
	4.78 [0.188]	4.47 [0.176]
	5.54 [0.218]	5.23 [0.206]
	6.32 [0.249]	6.02 [0.237]
	7.11 [0.280]	6.81 [0.268]
	7.87 [0.310]	7.49 [0.295]
	9.65 [0.380]	9.09 [0.358]
400 × 150 [16 × 6]	3.0 [0.118]	2.70 [0.106]
	4.0 [0.157]	3.70 [0.146]
	5.0 [0.197]	4.70 [0.185]
	6.0 [0.236]	5.70 [0.224]
	7.0 [0.276]	6.70 [0.264]

[a] Thickness is measured at any point on the plate not less than 10 mm [$^3/_8$ in.] from an edge and, if corrugated, on the tangents of corrugations. There is no limit on overthickness.

8.2. *Cross-Section Dimensions*—Cross-section dimensions, such as diameter, span and rise, and radius of curvature, shall be measured to the inside crest of corrugations. Tolerances herein specified apply to the as-erected shape before backfill placement. The diameter of circular pipe, based on two measurements at 90 degrees to each other, shall not vary more than ±2 percent from the calculated inside diameter shown in Tables 7 and 8. The span and rise of pipe-arch, arch, underpass, and other noncircular structures shall be as specified within ±2 percent.

Note 7—The purchaser should consult the fabricator to determine the standard dimensions for the various types of structures, other than circular structures.

Table 7—Diameter of Circular Pipe
150 × 50 mm [6 × 2 in.] Corrugation

Nominal Diameter Specified, mm [in.]	Calculated Inside Diameter, mm [in.]
1500 [60]	1475 [58.9]
1650 [66]	1626 [65.0]
1800 [72]	1775 [71.1]
1950 [78]	1935 [77.3]
2100 [84]	2085 [83.4]
2250 [90]	2240 [89.5]
2400 [96]	2390 [95.6]
2550 [102]	2545 [101.7]
2700 [108]	2695 [107.8]
2850 [114]	2850 [113.9]
3000 [120]	3000 [120.0]
3150 [126]	3155 [126.1]
3300 [132]	3310 [132.3]
3450 [138]	3460 [138.4]
3600 [144]	3615 [144.5]
3750 [150]	3765 [150.6]
3900 [156]	3920 [156.7]
4050 [162]	4070 [162.8]
4200 [168]	4225 [168.9]
4350 [174]	4375 [175.0]
4500 [180]	4530 [181.2]
4650 [186]	4685 [187.3]
4800 [192]	4835 [193.4]
4950 [198]	4990 [199.5]
5100 [204]	5140 [205.6]
5250 [210]	5295 [211.7]
5400 [216]	5445 [217.8]
5550 [222]	5600 [223.9]
5700 [228]	5750 [230.0]
5850 [234]	5905 [236.2]
6000 [240]	6060 [242.3]
6150 [246]	6210 [248.4]
6300 [252]	6365 [254.5]
6450 [258]	6515 [260.6]
6600 [264]	6670 [266.7]
6750 [270]	6820 [272.8]
6900 [276]	6975 [278.9]
7050 [282]	7125 [285.0]
7200 [288]	7280 [291.2]
7350 [294]	7435 [297.3]
7500 [300]	7585 [303.4]
7650 [306]	7740 [309.5]
7800 [312]	7890 [315.6]

Table 8—Diameter of Circular Pipe
380 × 140 mm [15 × $5^1/_2$ in.] Corrugation

Nominal Diameter Specified, mm [in.]	Calculated Inside Diameter, mm [in.]
6000 [240]	5965 [238.5]
6380 [255]	6345 [253.7]
6750 [270]	6725 [269.0]
7130 [285]	7110 [284.3]
7500 [300]	7490 [299.6]
7880 [315]	7870 [314.8]
8250 [330]	8255 [330.1]
8630 [345]	8635 [345.4]
9000 [360]	9018 [360.7]
9380 [375]	9400 [376.0]
9750 [390]	9780 [391.2]
10130 [405]	10165 [406.5]
10500 [420]	10545 [421.8]
10880 [435]	10930 [437.1]
11250 [450]	11310 [452.4]
11630 [465]	11690 [467.6]
12000 [480]	12080 [482.9]
12380 [495]	12455 [498.2]
12750 [510]	12840 [513.5]
13130 [525]	13220 [528.7]
13500 [540]	13600 [544.0]
13880 [555]	13990 [559.3]
14250 [570]	14365 [574.6]
14630 [585]	14750 [589.9]
15000 [600]	15130 [605.1]
15380 [615]	15510 [620.4
15750 [630]	15990 [635.7]
16130 [645]	16275 [651.0]
16500 [660]	16660 [666.3]
16880 [675]	17040 [681.5]
17250 [690]	17420 [696.8]
17630 [705]	17810 [712.1]
18000 [720]	18185 [727.4]
18380 [735]	18570 [742.7]
18750 [750]	18950 [757.9]

Table 9—Diameter of Circular Pipe
400 × 150 mm [16 × 6 in.] Corrugation

Nominal Diameter Specified, mm [in.]	Calculated Inside Diameter, mm [in.]
6225 [245]	6075 [239.2]
6495 [256]	6345 [249.8]
6765 [266]	6615 [260.4]
7035 [277]	6885 [271.1]
7305 [288]	7155 [281.7]
7575 [298]	7425 [292.3]
7845 [309]	7695 [303.0]
8115 [319]	7965 [313.6]
8385 [330]	8235 [324.2]
8660 [341]	8510 [335.0]
8930 [352]	8780 [345.7]
9200 [362]	9050 [356.3]
9470 [373]	9320 [366.9]
9740 [383]	9590 [377.6]
10010 [394]	9860 [388.2]
10280 [405]	10130 [398.8]
10550 [415]	10400 [409.4]
10825 [426]	10675 [420.3]
11095 [437]	10945 [430.9]
11365 [447]	11215 [441.5]
11635 [458]	11485 [452.2]
11905 [469]	11755 [462.8]
12175 [479]	12025 [473.4]
12445 [490]	12295 [484.1]
12715 [501]	12565 [494.7]
12985 [511]	12835 [505.3]
13260 [522]	13110 [516.1]
13530 [533]	13380 [526.8]
13800 [543]	13650 [537.4]
14070 [554]	13920 [548.0]
14340 [565]	14190 [558.7]
14610 [575]	14460 [569.3]
14880 [586]	14730 [579.9]
15150 [596]	15000 [590.6]
15420 [607]	15270 [601.2]
15695 [618]	15545 [612.0]
15965 [629]	15815 [622.6]

9. WORKMANSHIP

9.1. Plates, fasteners, and accessories shall be of uniform quality consistent with good manufacturing and inspection practices.

10. SAMPLING AND TESTING

10.1. Sampling and testing of plate for chemical composition shall be according to ASTM A 751, and for mechanical requirements shall be according to the procedure for sheet type specimens in T 244. The manufacturer or steel supplier shall make adequate tests and measurements to ensure that the material produced complies with this specification. If tests are provided by the steel supplier and not the manufacturer, the steel supplier shall also submit documentation supporting that they are ISO 9001 certified or equivalent.

10.2. *Coating Mass Determination*—Except as provided herein, coating mass shall be determined according to T 65M/T 65, using a specimen with an area of 3000 mm^2 [5 $in.^2$] or greater. The average coating mass shall be the average of three or more single-spot tests, each taken from different plates in the order. Instead of using the stripping procedure in T 65M/T 65, the mass may be converted from the sum of the readings on both surfaces of the plate by a magnetic coating thickness gauge suitably checked and demonstrated for accuracy (Note 8), 1 mil (0.001 in.) = 0.59 oz/ft^2 [1 μm = 7.1 g/m^2]. Alternately, the coating mass may be determined by the x-ray fluorescence procedure according to ASTM A 754/A 754M. In case of dispute, results of testing according to T 65M/T 65 shall govern.

Note 8—Several magnetic and electromagnetic types of coating thickness gauges are commercially available and are a satisfactory basis for acceptance when properly calibrated just prior to inspection use. (See ASTM E 376.)

10.3. Mechanical properties shall be determined on plate prior to corrugating or other fabricating, except tests may be made after fabrication by the purchaser for tensile and yield strengths.

10.4. Test results, including chemical composition and mechanical properties, shall be maintained by the steel manufacturer or supplier for 7 years. Test results for coating mass or other tests, and a copy of the steel manufacturer's or supplier's certified test results for chemical composition and mechanical properties shall be maintained by the fabricator for 7 years. Such results shall be made available to the purchaser upon request.

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11. REJECTION AND REHEARING

11.1. Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer, supplier, or fabricator promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer, supplier, or fabricator may make claim for a rehearing.

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12. CERTIFICATION

12.1. When specified in the purchase order or contract, a steel manufacturer's or supplier's certification or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the purchase order or contract, a report of the test results shall be furnished.

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13. PRODUCT MARKING

13.1. Each plate shall be identified by showing the following:

13.1.1. Name of fabricator;

13.1.2. Specified zinc-coated plate thickness;

13.1.3. Specified coating mass;

13.1.4. Identification showing heat number and coating lot number; the heat number may be omitted if the fabricator's records tie the coating lot number to a specific heat number and manufacturer; and

13.1.5. AASHTO Designation.

13.2. The marking shall be so placed that when the structure is erected, the identification will appear on the inside.

Standard Specification for

Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

AASHTO Designation: M 170-10[1]
ASTM Designation: C 76-08a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe

AASHTO Designation: M 170-10[1]
ASTM Designation: C 76-08a

1. SCOPE

1.1 This specification covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

1.2 A complete metric companion to M 170 has been developed—M 170M; therefore, no metric equivalents are presented in this specification.

Note 1—This specification is a manufacturing and purchase specification only, and does not include requirements for bedding, backfill, or the relationship between field load condition and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, and care that installation conforms to the construction specifications. The owner of the reinforced concrete pipe specified herein is cautioned that he must correlate the field requirements with the class of pipe specified and provide inspection at the construction site.

Note 2—Attention is called to the specification for reinforced concrete D-load culvert, storm drain, and sewer pipe (M 242M/M 242).

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 86M/M 86, Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 154, Air-Entraining Admixtures for Concrete
- M 170M, Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe [Metric]
- M 194M/M194, Chemical Admixtures for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 242M/M 242, Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe

- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standards*:

- A 36/A 36M Standard Specification for Carbon Structural Steel
- A 706/A706M Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
- C 1017/C 1017M, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Pipe manufactured in accordance with this specification shall be of five classes identified as Class I, Class II, Class III, Class IV, and Class V. The corresponding strength requirements are prescribed in Tables 1 to 5.

Table 1—Design Requirements for Class I Reinforced Concrete Pipe[a]

	Reinforcement, in.^{2}/Linear ft of Pipe Wall									
	Wall A					Wall B				
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi				
Internal Designated Diameter, in.	Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]		Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]	
		Inner Cage	Outer Cage				Inner Cage	Outer Cage		
60	5	0.25	0.15	0.28		6	0.21	0.13	0.23	
66	$5^{1}/_{2}$	0.30	0.18	0.33		$6^{1}/_{2}$	0.25	0.15	0.28	
72	6	0.35	0.21	0.39		7	0.29	0.17	0.32	
78	$6^{1}/_{2}$	0.40	0.24	0.44		$7^{1}/_{2}$	0.32	0.19	0.36	
84	7	0.45	0.27	0.50		8	0.37	0.22	0.41	
90	$7^{1}/_{2}$	0.49	0.29	0.54		$8^{1}/_{2}$	0.41	0.25	0.46	
96	8	0.54	0.32	0.60		9	0.46	0.28	0.51	
	Concrete Strength, 5000 psi									
102	$8^{1}/_{2}$	0.63	0.38	Inner Circular Plus Elliptical	0.25 0.38	$9^{1}/_{2}$	0.54	0.32	Inner Circular Plus Elliptical	0.22 0.32
108	9	0.68	0.41	Inner Circular Plus Elliptical	0.27 0.41	10	0.61	0.37	Inner Circular Plus Elliptical	0.24 0.37
114	[a]	—	—	—	—	[a]	—	—	—	—
120	[a]	—	—	—	—	[a]	—	—	—	—
126	[a]	—	—	—	—	[a]	—	—	—	—
132	[a]	—	—	—	—	[a]	—	—	—	—
138	[a]	—	—	—	—	[a]	—	—	—	—
144	[a]	—	—	—	—	[a]	—	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading or wall thickness. Pipe over 96 in. in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to design requiring both inner and outer circular cages, the reinforcement may be positioned and proportioned in either of the following manners: (1) An inner circular cage plus an elliptical cage such that area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical gauge shall not be less than that specified for the inner cage in the table; (2) An inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) An inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce a 0.01-in. crack or the D-loads to produce the 0.01-in. crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	800
D-load to produce the ultimate load	1200

Table 2—Design Requirements for Class II Reinforced Concrete Pipe[a]

	Reinforcement, in.^{2}/Linear ft of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 4000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
		Circular Reinforcement[b]				Circular Reinforcement[b]				Circular Reinforcement[b]		
Internal Designated Diameter, in.	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]
12	$1^{3}/_{4}$	0.07[d]	—	—	2	0.07[d]	—	—	$2^{3}/_{4}$	0.07[d]	—	—
15	$1^{7}/_{8}$	0.07[d]	—	—	$2^{1}/_{4}$	0.07[d]	—	—	3	0.07[d]	—	—
18	2	0.07[d]	—	0.07[d]	$2^{1}/_{2}$	0.07[d]	—	0.07[d]	$3^{1}/_{4}$	0.07[d]	—	0.07[d]
21	$2^{1}/_{4}$	0.12	—	0.10	$2^{3}/_{4}$	0.07[d]	—	0.07[d]	$3^{1}/_{2}$	0.07[d]	—	0.07[d]
24	$2^{1}/_{2}$	0.13	—	0.11	3	0.07[d]	—	0.07[d]	$3^{3}/_{4}$	0.07[d]	—	0.07[d]
27	$2^{5}/_{8}$	0.15	—	0.13	$3^{1}/_{4}$	0.13	—	0.11	4[e]	0.07[d]	—	0.07[d]
30	$2^{3}/_{4}$	0.15	—	0.14	$3^{1}/_{2}$	0.14	—	0.12	$4^{1}/_{4}$	0.07[d]	—	0.07[d]
33	$2^{7}/_{8}$	0.16	—	0.15	$3^{3}/_{4}$	0.15	—	0.13	$4^{1}/_{2}$	0.07[d]	—	0.07[d]
36	3	0.14	0.08	0.15	4[e]	0.12	0.07	0.13	$4^{3}/_{4}$	0.07	0.07	0.08
42	$3^{1}/_{2}$	0.16	0.10	0.18	$4^{1}/_{2}$	0.15	0.09	0.17	$5^{1}/_{4}$	0.10	0.07	0.11
48	4	0.21	0.13	0.23	5	0.18	0.11	0.20	$5^{3}/_{4}$	0.14	0.08	0.15
54	$4^{1}/_{2}$	0.25	0.15	0.28	$5^{1}/_{2}$	0.22	0.13	0.24	$6^{1}/_{4}$	0.17	0.10	0.19
60	5	0.30	0.18	0.33	6	0.25	0.15	0.28	$6^{3}/_{4}$	0.22	0.13	0.24
66	$5^{1}/_{2}$	0.35	0.21	0.39	$6^{1}/_{2}$	0.31	0.19	0.34	$7^{1}/_{4}$	0.25	0.15	0.28
72	6	0.41	0.25	0.45	7	0.35	0.21	0.39	$7^{3}/_{4}$	0.30	0.18	0.33
78	$6^{1}/_{2}$	0.46	0.28	0.51	$7^{1}/_{2}$	0.40	0.24	0.44	$8^{1}/_{4}$	0.35	0.21	0.39
84	7	0.51	0.31	0.57	8	0.46	0.28	0.51	$8^{3}/_{4}$	0.41	0.25	0.46
90	$7^{1}/_{2}$	0.57	0.34	0.63	$8^{1}/_{2}$	0.51	0.31	0.57	$9^{1}/_{4}$	0.48	0.29	0.53
96	8	0.62	0.37	0.69	9	0.57	0.34	0.63	$9^{3}/_{4}$	0.55	0.33	0.61

Continued on next page.

Table 2—Design Requirements for Class II Reinforced Concrete Pipe[a] *(Continued)*

	Reinforcement, in.^{2}/Linear ft of Pipe Wall														
	Wall A					Wall B					Wall C				
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi					Concrete Strength, 4000 psi				
Internal Designated Diameter, in.	Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]		Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]		Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]	
		Inner Cage	Outer Cage				Inner Cage	Outer Cage				Inner Cage	Outer Cage		
Concrete Strength, 5,000 psi															
102	8$^1/_2$	0.76	0.46	Inner Circular Plus Elliptical	0.30 0.46	9$^1/_2$	0.68	0.41	Inner Circular Plus Elliptical	5.8 8.6	10¼	0.62	0.37	Inner Circular Plus Elliptical	0.25 0.37
108	9	0.85	0.51	Inner Circular Plus Elliptical	0.34 0.51	10	0.76	0.46	Inner Circular Plus Elliptical	6.4 9.7	10¾	0.70	0.42	Inner Circular Plus Elliptical	0.28 0.42
114	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
120	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
126	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
132	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
138	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
144	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 96 in. in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages, the reinforcement may be positioned and proportioned in either of the following manners: (1) An inner circular cage plus an elliptical cage such that the area of elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) An inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) An inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[d] For these classes and sizes, the minimum practical steel reinforcement is specified. The specified ultimate strength of non-reinforced pipe is greater than the minimum specified strength for the equivalent diameters.

[e] As an alternative, single cage reinforcement may be used. The reinforcement area in square in. per linear foot shall be 0.20 for Wall B and 0.16 for Wall C.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirement in pound-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pound-force per linear foot per foot of diameter) to produce the 0.01-in. crack, or the D-loads to produce the 0.01-in. crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	1000
D-load to produce the ultimate load	1500

Table 3—Design Requirements for Class III Reinforced Concrete Pipe[a]

	Reinforcement, in.^{2}/Linear ft of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 4000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
		Circular Reinforcement[b]				Circular Reinforcement[b]				Circular Reinforcement[b]		
Internal Designated Diameter, in.	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]
12	$1^{3}/_{4}$	0.07[d]	—	—	2	0.07[d]	—	—	$2^{3}/_{4}$	0.07[d]	—	—
15	$1^{7}/_{8}$	0.07[d]	—	—	$2^{1}/_{4}$	0.07[d]	—	—	3	0.07[d]	—	—
18	2	0.07[d]	—	0.07[d]	$2^{1}/_{2}$	0.07[d]	—	0.07[d]	$3^{1}/_{4}$	0.07[d]	—	0.07[d]
21	$2^{1}/_{4}$	0.14	—	0.11	$2^{3}/_{4}$	0.07[d]	—	0.07[d]	$3^{1}/_{2}$	0.07[d]	—	0.07[d]
24	$2^{1}/_{2}$	0.17	—	0.14	3	0.07[d]	—	0.07[d]	$3^{3}/_{4}$	0.07	—	0.07[d]
27	$2^{5}/_{8}$	0.18	—	0.16	$3^{1}/_{4}$	0.16	—	0.14	4	0.08	—	0.07[d]
30	$2^{3}/_{4}$	0.19	—	0.18	$3^{1}/_{2}$	0.18	—	0.15	$4^{1}/_{4}$	0.10	—	0.08
33	$2^{7}/_{8}$	0.21	—	0.20	$3^{3}/_{4}$	0.20	—	0.17	$4^{1}/_{2}$	0.12	—	0.10
36	3	0.21	0.13	0.23	4[e]	0.17	0.10	0.19	$4^{3}/_{4}$[e]	0.08	0.07	0.09
42	$3^{1}/_{2}$	0.25	0.15	0.28	$4^{1}/_{2}$	0.21	0.13	0.23	$5^{1}/_{4}$	0.12	0.07	0.13
48	4	0.32	0.19	0.35	5	0.24	0.14	0.27	$5^{3}/_{4}$	0.16	0.10	0.18
54	$4^{1}/_{2}$	0.38	0.23	0.42	$5^{1}/_{2}$	0.29	0.17	0.32	$6^{1}/_{4}$	0.21	0.13	0.23
60	5	0.44	0.26	0.49	6	0.34	0.20	0.38	$6^{3}/_{4}$	0.25	0.15	0.28
66	$5^{1}/_{2}$	0.50	0.30	0.55	$6^{1}/_{2}$	0.41	0.25	0.46	$7^{1}/_{4}$	0.31	0.19	0.34
72	6	0.57	0.34	0.63	7	0.49	0.29	0.54	$7^{3}/_{4}$	0.36	0.22	0.40
	Concrete Strength, 5000 psi											
78	$6^{1}/_{2}$	0.64	0.38	0.71	$7^{1}/_{2}$	0.57	0.34	0.63	$8^{1}/_{4}$	0.42	0.25	0.47
84	7	0.72	0.43	0.80	8	0.64	0.38	0.71	$8^{3}/_{4}$	0.50	0.30	0.56
					Concrete Strength, 5000 psi				Concrete Strength, 5000 psi			
90	$7^{1}/_{2}$	0.81	0.49	0.90	$8^{1}/_{2}$	0.69	0.41	0.77	$9^{1}/_{4}$	0.59	0.35	0.66
96	8	0.93	0.56	1.03	9	0.76	0.46	0.84	$9^{3}/_{4}$	0.70	0.42	Inner Circular 0.28 Plus Elliptical 0.42
102	$8^{1}/_{2}$	1.03	0.62	Inner Circular 0.41 Plus Elliptical 0.62	$9^{1}/_{2}$	0.90	0.54	Inner Circular 0.36 Plus Elliptical 0.54	$10^{1}/_{4}$	0.83	0.50	Inner Circular 0.33 Plus Elliptical 0.50

Continued on next page.

Table 3—Design Requirements for Class III Reinforced Concrete Pipe[a] *(Continued)*

	Reinforcement, in.^{2}/Linear ft of Pipe Wall														
	Wall A					Wall B					Wall C				
	Concrete Strength, 4000 psi					Concrete Strength, 4000 psi					Concrete Strength, 4000 psi				
		Circular Reinforcement[b]					Circular Reinforcement[b]					Circular Reinforcement[b]			
Internal Designated Diameter, in.	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]		Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]		Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	
108	9	1.22	0.73	Inner Circular Plus Elliptical	0.49 0.62	10	1.08	0.65	Inner Circular Plus Elliptical	0.43 0.54	$10^{3}/_{4}$	0.99	0.59	Inner Circular Plus Elliptical	0.40 0.59
114	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
120	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
126	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
132	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
138	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
144	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 96 in. in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages, the reinforcement may be positioned and proportioned in one of the following manners: (1) an inner circular cage plus an elliptical cage such that the area of elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) an inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) an inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[d] For these classes and sizes, the minimum practical steel reinforcement is specified. The specified ultimate strength of non-reinforced pipe is greater than the minimum specified strength for the equivalent diameters.

[e] As alternative, single cage reinforcement may be used. The reinforcement area in square in. per linear foot shall be 0.30 for Wall B and 0.20 for Wall C.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce the 0.01-in. crack or the D-loads to produce the 0.01-in. crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	1350
D-load to produce the ultimate load	2000

Table 4—Design Requirements for Class IV Reinforced Concrete Pipe[a]

	Reinforcement, in.^{2}/Linear ft of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 4000 psi				Concrete Strength, 4000 psi				Concrete Strength, 4000 psi			
		Circular Reinforcement[b]				Circular Reinforcement[b]				Circular Reinforcement[b]		
Internal Designated Diameter, in.	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, in.	Inner Cage	Outer Cage	Elliptical Reinforcement[c]
12	$1^3/_4$	0.15	—	—	2	0.07	—	—	$2^3/_4$	0.07[d]	—	—
15	$1^7/_8$	0.16	—	—	$2^1/_4$	0.10	—	—	3	0.07[d]	—	—
18	2	0.17	—	0.15	$2^1/_2$	0.14	—	0.11	$3^1/_4$	0.07[d]	—	0.07[d]
21	$2^1/_4$	0.23	—	0.21	$2^3/_4$	0.20	—	0.17	$3^1/_2$	0.07[d]	—	0.07[d]
24	$2^1/_2$	0.29	—	0.27	3	0.27	—	0.23	$3^3/_4$	0.07	0.07	0.08
27	$2^5/_8$	0.33	—	0.31	$3^1/_4$	0.31	—	0.25	4	0.08	0.07	0.09
30	$2^3/_4$	0.38	—	0.35	$3^1/_2$	0.35	—	0.28	$4^1/_4$	0.09	0.07	0.10
33	[a]	—	—	—	$3^3/_4$	0.27	0.16	0.30	$4^1/_2$	0.11	0.07	0.12
36	[a]	—	—	—	4	0.30	0.18	0.33	$4^3/_4$	0.14	0.08	0.15
42	[a]	—	—	—	$4^1/_2$	0.35	0.21	0.39	$5^1/_4$	0.20	0.12	0.22
48	[a]	—	—	—	5	0.42	0.25	0.47	$5^3/_4$	0.26	0.16	0.29
54		—	—	—	$5^1/_2$	0.50	0.30	0.55	$6^1/_4$	0.34	0.20	0.38
					Concrete Strength, 5000 psi							
60	[a]	—	—	—	6	0.59	0.35	0.66	$6^3/_4$	0.41	0.25	0.46
66	[a]	—	—	—	$6^1/_2$	0.69	0.41	0.77	$7^1/_4$	0.51	0.31	0.57
									Concrete Strength, 5000 psi			
72	[a]	—	—	—	7	0.79	0.47	0.88	$7^3/_4$	0.61	0.37	0.68
78	[a]	—	—	—	[a]	—	—	—	$8^1/_4$	0.71	0.43	0.79
84	[a]	—	—	—	[a]	—	—	—	$8^3/_4$	0.85	0.51	0.94
90	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
96	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
102	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
108	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
114	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
120	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
126	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
132	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
138	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
144	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 96 in. in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in one of the following manners: (1) an inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) an inner and outer cage plus quadrant mats in accordance with Figure 1; (3) an inner and outer cage plus an elliptical cage in accordance with Figure 2; or (4) for Wall C, in sizes 24 to 33 in., a single circular cage with an area not less than the sum of the specified inner and outer circular reinforcement areas.

Continued on next page.

Table 4—Design Requirements for Class IV Reinforced Concrete Pipe[a] *(Continued)*

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[d] For these classes and sizes, the minimum practical steel reinforcement is specified.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce the 0.01-in. crack or the D-loads to produce the 0.01-in. crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	2000
D-load to produce the ultimate load	3000

Table 5—Design Requirements for Class V Reinforced Concrete Pipe[a]

Internal Designed Diameter, in.	Reinforcement, in.^{2}/Linear ft of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 6000 psi				Concrete Strength, 6000 psi				Concrete Strength, 6000 psi			
	Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]	Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]	Wall Thickness, in.	Circular Reinforcement[b]		Elliptical Reinforcement[c]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
12	[a]	—	—	—	2	0.10	—	—	2$^3/_4$	0.07[d]	—	—
15	[a]	—	—	—	2$^1/_4$	0.14	—	—	3	0.07[d]	—	—
18	[a]	—	—	—	2$^1/_2$	0.19	—	0.16	3$^1/_4$	0.10	—	—
21	[a]	—	—	—	2$^3/_4$	0.24	—	0.21	3$^1/_2$	0.10	—	—
24	[a]	—	—	—	3	0.30	—	0.24	3$^3/_4$	0.12	0.07	0.13
27	[a]	—	—	—	3$^1/_4$	0.38	0.23	0.42	4	0.14	0.08	0.16
30	[a]	—	—	—	3$^1/_2$	0.41	0.25	0.46	4$^1/_4$	0.18	0.1	0.20
33	[a]	—	—	—	3$^3/_4$	0.46	0.28	0.51	4$^1/_2$	0.23	0.14	0.25
36	[a]	—	—	—	4	0.50	0.30	0.56	4$^3/_4$	0.27	0.16	0.30
42	[a]	—	—	—	4$^1/_2$	0.60	0.36	0.67	5$^1/_4$	0.36	0.22	0.40
48	[a]	—	—	—	5	0.73	0.44	0.81	5$^3/_4$	0.47	0.28	0.52
54	[a]	—	—	—	[a]	—	—	—	6$^1/_4$	0.58	0.35	0.64
60	[a]	—	—	—	[a]	—	—	—	6$^3/_4$	0.70	0.42	0.78
66	[a]	—	—	—	[a]	—	—	—	7$^1/_4$	0.84	0.50	0.93
72	[a]	—	—	—	[a]	—	—	—	7$^3/_4$	0.99	0.59	1.10
78	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
84	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
90	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
96	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
102	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
108	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
114	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
120	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
126	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
132	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
138	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
144	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 96 in. in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages, the reinforcement may be positioned and proportioned in one of the following manners: (1) an inner circular cage plus an elliptical cage such that the area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) an inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) an inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

Continued on next page.

Table 5—Design Requirements for Class V Reinforced Concrete Pipe[a] *(Continued)*

[d] For these classes and sizes, the minimum practical steel reinforcement is specified.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in pounds-force per linear foot of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in pounds-force per linear foot per foot of diameter) to produce the 0.01-in. crack or the D-loads to produce the 0.01-in. crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in feet.

D-load to produce a 0.01-in. crack	3000
D-load to produce the ultimate load	3750

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5. BASIS OF ACCEPTANCE

5.1 Unless otherwise designated by the owner at the time of, or before placing an order, there are two separate and alternative bases of acceptance. Independent of the method of acceptance, the pipe shall be designed to meet both the 0.01 in. crack and ultimate strength requirements specified in Tables 1 to 5.

5.1.1 *Acceptance on the Basis of Plant Load-Bearing Tests, Material Tests, and Inspection of Manufactured Pipe for Visual Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of the three-edge-bearing tests as defined in Section 11.3.1; by such material tests as are required in Sections 6.2, 6.3, 6.5, and 6.6; by an absorption test of the concrete from the wall of the pipe for each mix design that is used for an order; and by visual inspection of the finished pipe to determine its conformance with the accepted design and its freedom from defects.

5.1.2 *Acceptance on the Basis of Material Tests and Inspection of Manufactured Pipe for Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of such material tests as are required in Sections 6.2, 6.3, 6.5, and 6.6; by crushing tests on concrete cores or cured concrete cylinders; by an absorption test of the concrete from the wall of the pipe for each mix design that is used for an order; and by inspection of the finished pipe including amount and placement of reinforcement to determine its conformance with the accepted design and its freedom from defects.

5.1.3 When agreed upon by the owner and the manufacturer, any portion or any combination of the tests itemized in Section 5.1.1 or Section 5.1.2 may form the basis of acceptance.

5.2 *Age for Acceptance*—Pipe shall be considered ready for acceptance when it conforms to the requirements as indicated by the specified tests.

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6. MATERIALS

6.1 The aggregate shall be sized, graded, proportioned, and mixed with such proportions of portland cement, blended hydraulic cement, or portland cement and supplementary cementing materials, or admixtures, or a combination thereof, and water to produce a homogenous concrete mixture of such quality that the pipe will conform to the test and design requirements of the specification. In no case, however, shall the proportion of portland cement, blended hydraulic cement, or a combination of portland cement and supplementary cementing materials be less than 470 lb/yd^3.

6.2 *Cementitious Materials*:

6.2.1 *Cement*—Cement shall conform to the requirements for portland cement of M 85, or shall be portland blast-furnace slag cement, or slag modified portland cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.2.2 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of grade 100 or 120 of M 302.

6.2.3 *Fly Ash*—Fly ash shall conform to the requirements of Class F or Class C of M 295.

6.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1 Portland cement only,

6.2.4.2 Portland-blast furnace slag cement only,

6.2.4.3 Slag modified portland cement only,

6.2.4.4 Portland-pozzolan cement only,

6.2.4.5 A combination of portland cement and ground granulated blast-furnace slag,

6.2.4.6 A combination of portland cement and fly ash, or

6.2.4.7 A combination of portland cement, ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight) and fly ash (not to exceed 25 percent of the total cementitious weight).

6.3 *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—The following admixtures and blends are allowed with the approval of the owner:

6.4.1 Air-entraining admixture conforming to M 154;

6.4.2 Chemical admixtures conforming to M 194;

6.4.3 Chemical admixtures for use in producing flowing concrete conforming to ASTM C 1017/C 1017M; and

6.4.4 Chemical admixture or blend approved by the owner.

6.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to M 32M/M 32 or M 225M/M 225; or of wire fabric conforming to M 55M/M55 or M 221M/M 221; or of bars conforming to M 31M/M 31 Grade 40 or 60, ASTM A36/A 36M, or ASTM A 706/A 706M Grade 60.

6.6 *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers are not prohibited from being used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be used.

7. DESIGN

7.1 *Design Tables*—The diameter, wall thickness, compressive strength of the concrete, and the area of the circumferential reinforcement shall be as prescribed for Class I to V in Tables 1 to 5, except as provided in Section 7.2.

7.1.1 The reinforcement as presented in the tables herein allows single circular cage reinforcement, or separate inner and outer circular cage reinforcement or a combination thereof. Footnotes to the tables are intended to clarify tabulated requirements, or provide acceptable alternative reinforcement designs, either of which are to be considered applicable and binding as if they were contained in the body of the specification.

7.2 *Modified and Special Designs*:

7.2.1 If permitted by the owner, the manufacturer may request approval by the owner of modified designs that differ from the designs in Section 7.1; or special designs for sizes and loads beyond those shown in Tables 1 to 5, Section 7.1, or special designs for pipe sizes that do not have steel reinforcement areas shown in Tables 1 to 5 of Section 7.1.

7.2.2 Such modified or special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of the pipe and shall fully describe to the owner any deviations from the requirements of Section 7.1. The descriptions of modified or special designs shall include the wall thickness, the concrete strength, and the area, type, placement, number of layers, and strength of the steel reinforcement.

7.2.3 The manufacturer shall submit to the owner proof of the adequacy of the proposed modified or special design. Such proof may comprise the submission of certified three-edge-bearing tests already made, which are acceptable to the owner or, if such three-edge-bearing tests are not available or acceptable, the manufacturer may be required to perform proof tests on sizes and classes selected by the owner to demonstrate the adequacy of the proposed design.

7.2.4 Such pipe must meet all of the test and performance requirements specified by the owner in accordance with Section 5.

7.3 *Area*—In this specification, when the word “area” is not described by adjectives, such as cross-section or single wire, it shall be understood to be the cross-sectional area of reinforcement per unit lengths of pipe.

8. REINFORCEMENT

8.1 *Circumferential Reinforcement*—A line of circumferential reinforcement for any given total area may be composed of two layers for pipe with wall thicknesses of less than 7 in. or three layers for pipe with wall thicknesses of 7 in. or greater. The layers shall not be separated by more than the thickness of one longitudinal plus $^1/_4$ in. The multiple layers shall be fastened together to form a single cage. All other specification requirements such as laps, welds, and tolerances of placement in the wall of the pipe, etc., shall apply to this method of fabricating a line of reinforcement.

8.1.1 Where one line of circular reinforcement is used, it shall be placed from 35 to 50 percent of the wall thickness from the inner surface of the pipe, except that for wall thicknesses less than $2^1/_2$ in., the protective cover of the concrete over the circumferential reinforcement in the wall of the pipe shall be $^3/_4$ in.

8.1.2 In pipe having two lines of circular reinforcement, each line shall be so placed that the protective covering of concrete over the circumferential reinforcement in the wall of the pipe shall be 1 in.

8.1.3 In pipe having elliptical reinforcement with wall thicknesses $2^1/_2$ in. or greater, the reinforcement in the wall of the pipe shall be so placed that the protective covering of concrete over the circumferential reinforcement shall be 1 in. from the inner surface of the pipe at the vertical diameter and 1 in. from the outer surface of the pipe at the horizontal diameter. In pipe having elliptical reinforcement with wall thicknesses less than $2^1/_2$ in., the protective covering of the concrete shall be $^3/_4$ in. at the vertical and horizontal diameters.

8.1.4 The location of the reinforcement shall be subject to the permissible variations in dimensions given in Section 12.5.

8.1.5 The spacing center-to-center of circumferential reinforcement in a cage shall not exceed 4 in. for pipe up to and including pipe having a 4-in. wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 6 in.

8.1.6 Where the wall reinforcement does not extend into the joint, the maximum longitudinal distance to the last circumferential from the inside shoulder of the bell or the shoulder of the spigot shall be 3 in., except that if this distance exceeds one-half the wall thickness, the pipe wall shall contain at least a total reinforcement area of the minimum specified area per linear foot times the laying length of the pipe section. The minimum cover on the last circumferential near the spigot shoulder shall be $^1/_2$ in.

8.1.6.1 Where reinforcement is in the bell or spigot the minimum end cover on the last circumferential shall be $^1/_2$ in. in the bell or $^1/_4$ in. in the spigot.

8.1.7 The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe, except that when agreed upon by the owner, lift eyes or holes may be provided in each pipe for the purpose of handling.

8.1.8 If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire, and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire.

8.1.8.1 When splices are welded and are not lapped to the minimum requirements above, pull tests of representative specimens shall develop at least 50 percent of the minimum specified strength of the steel, and there shall be a minimum lap of 2 in. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 percent of the minimum specified strength of the steel.

8.2 *Longitudinal Reinforcement*—Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members, to maintain the reinforcement in shape and in position within the form to comply with permissible variations in Section 8.1. The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

8.3 *Joint Reinforcement*—The length of the joint as used herein means the inside length of the bell or the outside length of the spigot from the shoulder to the end of the pipe section. The end distances or cover on the end circumferential shall apply to any point on the circumference of the pipe or joint. When convoluted reinforcement is used, these distances and reinforcement areas shall be taken from the points on the convolutions closest to the end of the pipe section. Unless otherwise permitted by the owner, the following requirements for joint reinforcement shall apply.

8.3.1 *Joint Reinforcement for Non-Rubber Gasket Joints*:

8.3.1.1 For pipe 36 in. and larger in diameter, either the bell or spigot shall contain circumferential reinforcement. This reinforcement shall be an extension of a wall cage, or may be a separate cage of at least the area per foot of that specified for the outer cage or one-half of that specified for single cage wall reinforcement, whichever is less.

8.3.1.2 Where bells or spigots require reinforcement, the maximum end cover on the last circumferential shall be one-half the length of the joint or 3 in., whichever is less.

8.3.2 *Joint Reinforcement for Rubber Gasket Joints*:

8.3.2.1 For pipe 12 in. and larger in diameter, the bell ends shall contain circumferential reinforcement. This reinforcement shall be an extension of the outer cage or a single wall cage, whichever is less, or may be a separate cage of at least the same area per foot with longitudinals as required in Section 8.2. If a separate cage is used, the cage shall extend into the pipe with the last circumferential wire at least one in past the inside shoulder where the pipe barrel meets the bell of the joint.

8.3.2.2 Where bells require reinforcement, the maximum end cover on the last circumferential shall be 2 in.

9. JOINTS

9.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 12.

10. MANUFACTURE

10.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water–cementitious materials ratio not exceeding 0.53 by weight. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 470 lb/yd^3 unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

10.2 *Curing*—Pipe shall be subjected to any one of the methods of curing described in Sections 10.2.1 to 10.2.4 or to any other method or combination of methods approved by the owner, that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the specified D-load is obtained when acceptance is based on Section 5.1.1 or so that the concrete will develop the specified compressive strength at 28 days or less when acceptance is based on Section 5.1.2.

10.2.1 *Steam Curing*—Pipe may be placed in a curing chamber, free of outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

10.2.2 *Water Curing*—Concrete pipe may be water cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

10.2.3 The manufacturer may, at the manufacturer's option, combine the methods described in Sections 10.2.1 to 10.2.4, provided the required concrete compressive strength is attained.

10.2.4 A sealing membrane conforming to the requirements of M 148 may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 10ºF of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

11. PHYSICAL REQUIREMENTS

11.1 *Test Specimens*—The specified number of pipe required for the tests shall be furnished without charge by the manufacturer and shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order. Unless designated otherwise by the owner in the order, the manufacturer shall select the type of test (external load crushing strength test, compression test of cylinders or compression test of cores) to be used to determine the acceptability of the pipe strength. Pipe that fails to meet the strength requirements as determined by the selected test type may not be retested using one of the other test types without approval of the owner.

11.2 *Number and Type of Tests Required for Various Delivery Schedules*:

11.2.1 *Preliminary Tests for Extended Delivery Schedules*—An owner of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to such tests, preliminary to delivery of pipe, as are required by the type of basis of acceptance specified by the owner in Section 5, of not more than three sections of pipe covering each size in which the owner is interested.

11.2.2 *Additional Tests*—After the preliminary tests described in Section 11.2.1, an owner shall be entitled to additional tests at such times as the owner may deem necessary, provided that the total number of pipe tested (including preliminary tests) shall not exceed one pipe or one percent, whichever is the greater, of each size of pipe delivered.

11.3 *External Load Crushing Strength*:

11.3.1 The load to produce a 0.01-in. crack or the ultimate load, as determined by the three-edge-bearing method as described in T 280, shall be not less than that prescribed in Tables 1 to 5 for each respective class of pipe. Pipe that support the prescribed load to produce the 0.01-in. crack and do not show a wider crack shall be considered to have met the test requirement. It is not a requirement of this specification that the pipe be cracked or loaded to failure during these tests. Pipe that have been tested only to the formation of a 0.01-in. crack and that meet the 0.01-in. crack or lesser crack load requirements shall be accepted for use. Three-edge-bearing test to ultimate load is not required for any class of pipe 60 in. or less in diameter listed in Tables 1 to 5 provided all other requirements of this specification are met.

Note 3—As used in this specification, the 0.01-in. crack is a test criterion for pipe tested in the three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

11.3.2 *Retests of Pipe Not Meeting the External Load Crushing Strength Requirements*—Pipe shall be considered as meeting the strength requirements when all test specimens conform to the strength requirements. Should any of the test specimens fail to meet the strength requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

11.4 *Type of Specimen*—Compression tests determining concrete compressive strength may be made on either standard rodded concrete cylinders or concrete cylinders compacted and cured in like manner as the pipe, or on cores drilled from the pipe.

11.5 *Compression Testing of Cylinders*:

11.5.1 *Cylinder Production*—Cylinders shall be prepared, cured, and tested in accordance with Section 11 of T 280.

11.5.2 *Number of Cylinders*—Prepare no fewer than five test cylinders from a group (one day's production of each concrete strength) of pipe sections.

11.5.3 *Acceptability on the Basis of Cylinder Test Results*:

11.5.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the required concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.5.3.2 When the average compressive strength of all cylinders tested is equal to or greater than the required concrete strength, and not more than 10 percent of the cylinders tested have a compressive strength less than the required concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the required concrete strength, then the group shall be accepted.

11.5.3.3 The pipe shall be acceptable only when the compressive strength of the cylinders tested conforms to the acceptance criteria stated in Section 11.5.3.1 or Section 11.5.3.2.

11.6 *Compression Testing of Cores*:

11.6.1 *Obtaining Cores*—Cores shall be obtained and prepared in accordance with Section 6 of T 280.

11.6.2 *Number of Cores*—One core shall be taken from a pipe section selected at random from each day's production run of a single concrete strength.

11.7 *Acceptability on the Basis of Core Test Results*:

11.7.1 When the compressive strength of a core tested for a group of pipe sections is equal to or greater than the required concrete strength, the compressive strength of the concrete for the group is acceptable.

11.7.2 If the compressive strength of the core tested is less than the required concrete strength, two additional cores shall be taken from that pipe section and tested. Concrete represented by these three core tests shall be considered acceptable if: (1) the average of three core strengths is equal to at least 85 percent of the required strength, and (2) no single core is less than 75 percent of the required strength.

11.7.3 If the compressive strength of the three cores does not meet the requirements of Section 11.7.2, the pipe section from which the core was taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and cored and tested for conformance with either Section 11.7.1 or Section 11.7.2. If both pipe sections meet the core strength requirements of either Section 11.7.1 or Section 11.7.2, the remainder of the group shall be acceptable. If both pipe sections do not meet the test strength requirement, the remainder of the group shall be either rejected or, at the option of the manufacturer, each pipe section of the remaining group shall be cored and accepted individually and any of the pipe sections that have core strengths less than the requirements of Section 11.7.1 or Section 11.7.2 shall be rejected.

11.8 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.9 *Absorption*—The absorption of a sample from the wall of the pipe, as determined in accordance with T 280, shall not exceed nine percent of the dry mass. Each sample shall have a minimum mass of 1.0 kg, shall be free of visible cracks, and shall represent the full wall thickness of the pipe. When the initial absorption sample from a pipe fails to conform to this specification, the absorption test shall be made on another sample from the same pipe and the results of the retest shall be substituted for the original test results.

11.10 *Retests of Pipe*—When not more than 20 percent of the concrete specimens fail to pass the requirements of this specification, the manufacturer may cull the project stock and may eliminate whatever quantity of pipe desired and shall mark those pipe so that they will not be shipped. The required tests shall be made on the balance of the order and the pipes shall be accepted if they conform to the requirements of this specification.

11.11 *Test Equipment*—Every manufacturer furnishing pipe under this specification shall furnish all facilities and personnel necessary to carry out the tests described in T 280.

12. PERMISSIBLE VARIATIONS

12.1 *Internal Diameter*—The internal diameter of 12 through 24-in. pipe shall vary not more than ±2 percent of the design diameter for 12-in. pipe and ±1.5 percent for 24 in. pipe with intermediate sizes variation being a linear scale between 2 percent and 1.5 percent. The internal diameter of sizes 27 in. and larger shall not vary by more than ±1 percent of the design diameter or $\pm{}^{3}/_{8}$ in., whichever is greater. These diameter requirements are based on the average of four diameter measurements at a distance of 12 in. from the end of the bell or spigot end of the pipe. Diameter verification shall be made on the number of pipe selected for test per section 11.

12.2 *Wall Thickness*—The wall thickness shall not vary more than shown in the design or specified wall by more than ±5 percent or ${}^{3}/_{16}$ in., whichever is greater. A specified wall thickness greater than required in the design is not cause for rejection. Pipe having localized variations in wall thickness exceeding those specified above shall be accepted if the three-edge-bearing strength and minimum steel cover requirements are met.

12.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of the pipe shall not be more than ${}^{1}/_{4}$ in. for all sizes through 24-in. internal diameter, and not more than ${}^{1}/_{8}$ in./ft for all sizes larger with a maximum of ${}^{5}/_{8}$ in. in any length of pipe through 84-in. internal diameter, and a maximum of ${}^{3}/_{4}$ in. for 90-in. internal diameter or larger, except where beveled end pipe for laying on curves is specified by the owner.

12.4 *Length of Pipe*—The underrun in length of a section of pipe shall not be more than $^1/_8$ in./ft with a maximum of $^1/_2$ in. in any length of pipe. Regardless of the underrun or overrun in any section of the pipe, the end cover requirements of Sections 8 and 12 shall apply.

12.5 *Position or Area of Reinforcement*:

12.5.1 *Position*—The maximum variation in the position of a line of circumferential reinforcement shall be ±10 percent of the wall thickness or $\pm^1/_2$ in., whichever is greater. Pipe having variations in the position of a line of circumferential reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative specimen are met. In no case, however, shall the cover over the circumferential reinforcement be less than $^1/_4$ in. as measured to the end of the spigot or $^1/_2$ in. as measured to any other surface. The preceding minimum cover limitations do not apply to mating surfaces of non-rubber gasket joints or gasket grooves in rubber gasket joints. If convoluted reinforcement is used, the convoluted circumferential end wire may be at the end surface of the joint providing the alternate convolutions have at least 1-in. cover from the end surface of the joint.

12.5.2 *Area of Reinforcement*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the requirements of Sections 7.1 or 7.2. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing. When inner cage and outer cage reinforcing is used, the inner cage nominal area may vary to the lower limit of 85 percent of the elliptical nominal area and the outer cage nominal area may vary to the lower limit of 51 percent of the elliptical nominal area provided that the total nominal area of the inner cage plus the outer cage shall not vary beyond the lower limit of 140 percent of the elliptical nominal area.

13. REPAIRS

13.1 Pipe may be repaired, if necessary, because of imperfections in manufacture or damage during handling and will be acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

14. INSPECTION

14.1 The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by the owner.

15. REJECTION

15.1 Pipe shall be subject to rejection if it fails to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:

15.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint.

15.1.2 Defects that indicate proportioning, mixing, and molding not in compliance with Section 10.1 or surface defects indicating honey-combed or open texture that would adversely affect the function of the pipe.

15.1.3 The ends of the pipe are not normal to the walls and centerline of the pipe, within the limits of variations given in Sections 12.3 and 12.4.

15.1.4 Damaged or cracked ends where such damage would prevent making a satisfactory joint.

15.1.5 Any continuous crack having a surface width of 0.01 in. or more and extending for a length of 12 in. or more, regardless of position in the wall of the pipe.

16. PRODUCT MARKING

16.1 The following information shall be legibly marked on each section of pipe:

16.1.1 The pipe class and specification designation,

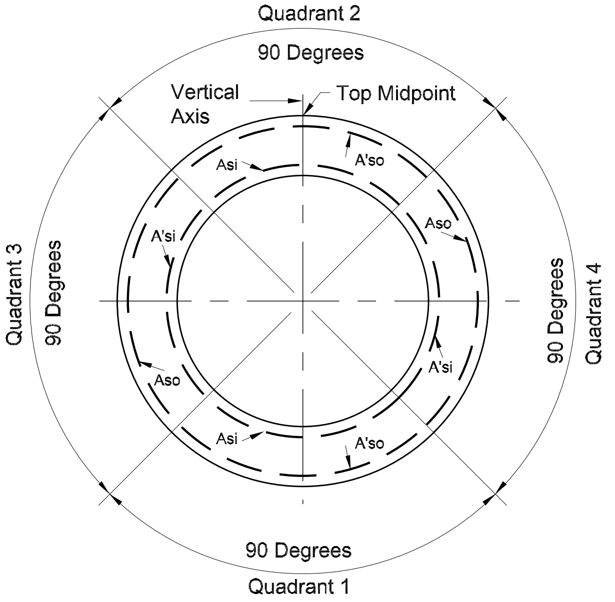
16.1.2 The date of manufacture,

16.1.3 The name or trademark of the manufacturer, and

16.1.4 Identification of plant.

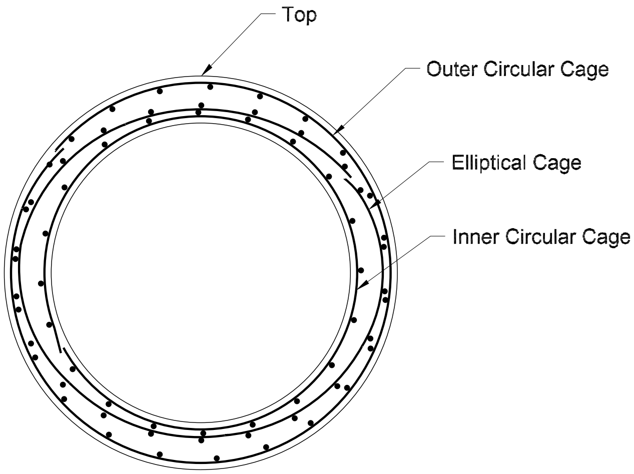
16.2 One end of each section of pipe with elliptical or quadrant reinforcement shall be clearly marked during the process of manufacturing or immediately thereafter, on the inside and the outside of opposite walls along the minor axis of the elliptical reinforcing or along the vertical axis for quadrant reinforcing.

16.3 Markings shall be indented on the pipe section or painted thereon with waterproof paint.



Notes:
1. The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Tables 1 to 5.
2. The total reinforcement area (Aso) of the outer cage plus the quadrant mat in Quadrants 3 and 4 shall not be less than that specified for the outer cage in Tables 1 to 5.
3. The total reinforcement area (A′si) of the inner cage in Quadrants 3 and 4 shall not be less than 25 percent of that specified for the inner cage in Tables 1 to 5.
4. The total reinforcement area (A′so) of the outer cage in Quadrants 1 and 2 shall not be less than 25 percent of that specified for the outer cage in Tables 1 to 5.
5. If the reinforcement area (A′so) of the outer cage in Quadrants 1 and 2 is less than 50 percent of that specified for the outer cage in Tables 1 to 5, the quadrant mats used for the outer cage in Quadrants 3 and 4 shall extend into Quadrants 1 and 2 not less than a distance equal to the wall thickness as specified in Tables 1 to 5.

Figure 1—Quadrant Reinforcement



Notes:
1. The total reinforcement area of the inner circular cage and the elliptical cage shall not be less than that specified for the inner cage in Tables 1 to 5.
2. The total reinforcement area of the outer circular cage and the elliptical cage shall not be less than that specified for the outer cage in Tables 1 to 5.

Figure 2—Triple Cage Reinforcement

17. KEYWORDS

17.1 Circular pipe; culvert; D-load; pipe; reinforced concrete; sewer pipe; storm drain.

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[1] Agrees with ASTM C 76-08a except for limiting the absorption testing to the five-hour boil method, the manufacturer is not afforded the option to supply SI sized pipe when the order is placed in inch-pound units, the use of synthetic fibers are at the option of the owner, and the method of acceptance is changed as per Sections 11.1, 11.5.3.3, and 11.7.3.

Standard Specification for

Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe [Metric]

AASHTO Designation: M 170M-10[1]
ASTM Designation: C 76M-08a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe [Metric]

AASHTO Designation: M 170M-10[1]
ASTM Designation: C 76M-08a

1. SCOPE

1.1 This specification covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

1.2 This specification is the metric counterpart of M 170.

Note 1—This specification is a manufacturing and purchase specification only, and does not include requirements for bedding, backfill, or the relationship between field load condition and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, controlled manufacture in the plant, and care that installation conforms to the construction specifications. The owner of the reinforced concrete pipe specified herein is cautioned that he must correlate the field requirements with the class of pipe specified and provide inspection at the construction site.

Note 2—Attention is called to the specification for reinforced concrete D-load culvert, storm drain, and sewer pipe (M 242M/M 242).

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 86M/M 86, Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 154 Air-Entraining Admixtures for Concrete
- M 170, Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
- M 194M/M194 Chemical Admixtures for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 242M/M 242, Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe

- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standards*:

- A 36/A 36M Standard Specification for Carbon Structural Steel
- A 706/A706M Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
- C 1017, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Pipe manufactured in accordance with this specification shall be of five classes identified as Class I, Class II, Class III, Class IV, and Class V. The corresponding strength requirements are prescribed in Tables 1 to 5.

Table 1—Design Requirements for Class I Reinforced Concrete Pipe[a]

	Reinforcement, cm^2/Linear m of Pipe Wall									
	Wall A					Wall B				
	Concrete Strength, 27.6 MPa					Concrete Strength, 27.6 MPa				
		Circular Reinforcement[b]					Circular Reinforcement[b]			
Internal Designated Diameter, mm	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]		Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	
1500	125	5.3	3.2	5.9		150	4.4	2.6	4.9	
1650	138	6.4	3.8	7.0		163	5.3	3.2	5.9	
1800	150	7.4	4.4	8.3		175	6.1	3.7	6.8	
1950	163	8.5	5.1	9.3		188	6.8	4.1	7.6	
2100	175	9.5	5.7	10.6		200	7.8	4.7	8.7	
2250	188	10.4	6.2	11.4		213	8.7	5.2	9.7	
2400	200	11.4	6.8	12.7		225	9.7	5.8	10.8	
	Concrete Strength, 34.5 MPa									
2250	213	13.3	8.0	Inner Circular Plus Elliptical	5.3 8.0	238	11.4	6.8	Inner Circular Plus Elliptical	4.6 6.8
2700	225	14.4	8.6	Inner Circular Plus Elliptical	5.8 8.6	250	12.9	7.7	Inner Circular Plus Elliptical	5.2 7.7
2850	[a]	—	—	—	—	[a]	—	—	—	—
3000	[a]	—	—	—	—	[a]	—	—	—	—
3150	[a]	—	—	—	—	[a]	—	—	—	—
3300	[a]	—	—	—	—	[a]	—	—	—	—
3450	[a]	—	—	—	—	[a]	—	—	—	—
3600	[a]	—	—	—	—	[a]	—	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading or wall thickness. Pipe more than 2400 mm in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to design requiring both inner and outer circular cages, the reinforcement may be positioned and proportioned in one of the following manners: (1) An inner circular cage plus an elliptical cage such that area of the elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) An inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) An inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

Note: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in newtons per linear meter of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear meter per millimeter of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3mm crack and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimeters.

D-load to produce a 0.3-mm crack	40.0
D-load to produce the ultimate load	60.0

Table 2—Design Requirements for Class II Reinforced Concrete Pipe[a]

	Reinforcement, cm^2/Linear m of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa			
		Circular Reinforcement[b]				Circular Reinforcement[b]				Circular Reinforcement[b]		
Internal Designated Diameter, mm	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]
300	44	1.5[d]	—	—	50	1.5[d]	—	—	69	1.5[d]	—	—
375	47	1.5[d]	—	—	57	1.5[d]	—	—	75	1.5[d]	—	—
450	50	1.5[d]	—	1.5	63	1.5[d]	—	1.5[d]	82	1.5[d]	—	1.5[d]
525	57	2.5	—	2.1	69	1.5[d]	—	1.5[d]	88	1.5[d]	—	1.5[d]
600	63	2.8	—	2.3	75	1.5[d]	—	1.5[d]	94	1.5[d]	—	1.5[d]
675	66	3.2	—	2.8	82	2.8	—	2.3	100	1.5[d]	—	1.5[d]
750	69	3.2	—	3.0	88	3.0	—	2.5	106	1.5[d]	—	1.5[d]
825	72	3.4	—	3.2	94	3.2	—	2.8	113	1.5[d]	—	1.5[d]
900	75	3.0	1.8	3.2	100[e]	2.5	1.5	2.8	119[e]	1.5	1.5	1.7
1050	88	3.4	2.0	3.8	113	3.2	1.9	3.6	132	2.1	1.5	2.3
1200	100	4.5	2.7	4.9	125	3.8	2.3	4.2	144	3.0	1.8	3.2
1350	113	5.3	3.2	5.9	138	4.7	2.8	5.1	157	3.6	2.2	4.0
1500	125	6.4	3.8	7.0	150	5.3	3.2	5.9	169	4.7	2.8	5.1
1650	138	7.4	4.4	8.3	163	6.6	4.0	7.2	182	5.3	3.2	5.9
1800	150	8.7	5.2	9.5	175	7.4	4.4	8.3	194	6.4	3.8	7.0
1950	163	9.7	5.8	10.8	188	8.5	5.1	9.3	207	7.4	4.4	8.3
2100	175	10.8	6.5	12.1	200	9.7	5.8	10.8	219	8.7	5.2	9.7
2250	188	12.1	7.3	13.3	213	10.8	6.5	12.1	232	10.2	6.1	11.2
2400	200	13.1	7.9	14.6	225	12.1	7.3	13.3	244	11.6	7.0	12.9
Concrete Strength, 34.5 MPa												
2550	213	16.1	9.7	Inner Circular 6.4 Plus Elliptical 9.7	238	14.4	8.6	Inner Circular 5.8 Plus Elliptical 8.6	257	13.1	7.9	Inner Circular 5.2 Plus Elliptical 7.9
2700	225	18.0	10.8	Inner Circular 7.2 Plus Elliptical 10.8	250	16.1	9.7	Inner Circular 6.4 Plus Elliptical 9.7	269	14.8	8.9	Inner Circular 5.9 Plus Elliptical 8.9
2850	[a]	—	—	— —	[a]	—	—	— —	[a]	—	—	— —
3000	[a]	—	—	— —	[a]	—	—	— —	[a]	—	—	— —
3150	[a]	—	—	— —	[a]	—	—	— —	[a]	—	—	— —
3300	[a]	—	—	— —	[a]	—	—	— —	[a]	—	—	— —
3450	[a]	—	—	— —	[a]	—	—	— —	[a]	—	—	— —
3600	[a]	—	—	— —	[a]	—	—	— —	[a]	—	—	— —

Continued on next page.

Table 2—Design Requirements for Class II Reinforced Concrete Pipe[a] *(Continued)*

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 2400 mm in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages, the reinforcement may be positioned and proportioned in one of the following manners: (1) An inner circular cage plus an elliptical cage such that the area of elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) An inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) An inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means through the entire casting operation.

[d] For these classes and size, the minimum practical steel reinforcement is specified. The specified ultimate strength of nonreinforced pipe is greater than the minimum specified strength for the equivalent diameters.

[e] As an alternative, single cage reinforcement may be used. The reinforcement area in square centimeters per linear meter shall be 4.2 for Wall B and 3.4 for Wall C.

Note: See Section 5 for basis of acceptance specified by the owner. The strength test requirement in newtons per linear meter of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear meter per millimeter of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimeter.

D-load to produce a 0.3-mm crack	50.0
D-load to produce the ultimate load	75.0

Table 3—Design Requirements for Class III Reinforced Concrete Pipe[a]

Internal Designated Diameter, mm	Reinforcement, cm^2/Linear m of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa			
	Wall Thickness, mm	Circular Reinforcement[b]		Elliptical Reinforcement[c]	Wall Thickness, mm	Circular Reinforcement[b]		Elliptical Reinforcement[c]	Wall Thickness, mm	Circular Reinforcement[b]		Elliptical Reinforcement[c]
		Inner Cage	Outer Cage			Inner Cage	Outer Cage			Inner Cage	Outer Cage	
300	44	1.5[d]	—	—	50	1.5[d]	—	—	69	1.5[d]	—	—
375	47	1.5[d]	—	—	57	1.5[d]	—	—	75	1.5[d]	—	—
450	50	1.5[d]	—	1.5[d]	63	1.5[d]	—	1.5[d]	82	1.5[d]	—	1.5[d]
525	57	3.0	—	2.3	69	1.5[d]	—	1.5[d]	88	1.5[d]	—	1.5[d]
600	63	3.6	—	3.0	75	1.5[d]	—	1.5[d]	94	1.5	—	1.5[d]
675	66	3.8	—	3.4	82	3.4	—	3.0	100	1.7	—	1.5[d]
750	69	4.0	—	3.8	88	3.8	—	3.2	107	2.1	—	1.7
825	72	4.4	—	4.2	94	4.2	—	3.6	113	2.5	—	2.1
900	75	4.4	2.6	4.7	100[e]	3.6	2.2	4.0	119[e]	1.7	1.5	1.9
1050	88	5.3	3.2	5.9	113	4.4	2.6	4.9	132	2.5	1.5	2.8
1200	100	6.8	4.1	7.4	125	5.1	3.1	5.7	144	3.4	2.0	3.8
1350	113	8.0	4.8	8.9	138	6.1	3.7	6.8	157	4.4	2.6	4.9
1500	125	9.3	5.6	10.4	150	7.2	4.3	8.0	169	5.3	3.2	5.9
1650	138	10.6	6.4	11.6	163	9.1	5.5	9.7	182	6.6	4.0	7.2
1800	150	12.1	7.3	13.3	175	10.4	6.2	11.4	194	7.6	4.6	8.5
	Concrete Strength, 34.5 MPa											
1950	163	13.5	8.1	15.0	188	12.1	7.3	13.3	207	8.9	5.3	9.9
2100	175	15.2	9.1	16.9	200	13.5	8.1	15.0	219	10.6	6.4	11.9
					Concrete Strength, 34.5 MPa				Concrete Strength, 34.5 MPa			
2250	188	17.1	10.3	19.1	213	14.6	8.8	16.3	232	12.5	7.5	14.0
2400	200	19.7	11.8	21.8	225	16.1	9.7	17.8	244	14.8	8.9	Inner Circular 5.9 Plus Elliptical 8.9
2550	213	21.8	13.1	Inner Circular 8.7 Plus Elliptical 13.1	238	19.1	11.5	Inner Circular 7.6 Plus Elliptical 11.5	257	17.6	10.6	Inner Circular 7.0 Plus Elliptical 10.6

Continued on next page.

Table 3—Design Requirements for Class III Reinforced Concrete Pipe[a] *(Continued)*

	Reinforcement, cm^2/Linear m of Pipe Wall														
	Wall A					Wall B					Wall C				
	Concrete Strength, 27.6 MPa					Concrete Strength, 27.6 MPa					Concrete Strength, 27.6 MPa				
		Circular Reinforcement[b]					Circular Reinforcement[b]					Circular Reinforcement[b]			
Internal Designated Diameter, mm	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]		Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]		Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	
2700	225	25.8	15.5	Inner Circular Plus Elliptical	10.3 15.5	250	22.9	13.7	Inner Circular Plus Elliptical	9.2 13.7	269	21.0	12.6	Inner Circular Plus Elliptical	8.4 12.6
2850	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
3000	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
3150	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
3300	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
3450	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—
3600	[a]	—	—	—	—	[a]	—	—	—	—	[a]	—	—	—	—

[a] For modified or special designs, see Section 7.2 or with the permission of the owner utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 2400 mm in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in one of the following manners: (1) An inner circular cage plus an elliptical cage such that the area of elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) An inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) An inner and outer cage plus an elliptical cage in accordance with Figure 2.

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[d] For these classes and sizes, the minimum practical steel reinforcement is specified. The specified ultimate strength of non-reinforced pipe is greater than the minimum specified strength for the equivalent diameters.

[e] As an alternative, single cage reinforcement may be used. The reinforcement area in square centimeters per linear meter shall be 6.4 for Wall B and 4.2 for Wall C.

Note: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in newtons per linear meter of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear meter per millimeter of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimeters.

D-load to produce a 0.3-mm crack	65.0
D-load to produce the ultimate load	100.0

Table 4—Design Requirements for Class IV Reinforced Concrete Pipe[a]

	Reinforcement, cm^2/Linear m of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 34.5 MPa				Concrete Strength, 27.6 MPa				Concrete Strength, 27.6 MPa			
		Circular Reinforcement[b]				Circular Reinforcement[b]				Circular Reinforcement[b]		
Internal Designated Diameter, mm	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]
300	44	3.2	—	—	50	1.5	—	—	69	1.5[d]	—	—
375	47	3.4	—	—	57	2.1	—	—	75	1.5[d]	—	—
450	50	3.6	—	3.2	63	3.0	—	2.3	82	1.5[d]	—	1.5[d]
525	57	4.9	—	4.4	69	4.2	—	3.6	88	1.5[d]	—	1.5[d]
600	63	6.1	—	5.7	75	5.7	—	4.9	94	1.5	1.5	1.7
675	66	7.0	—	6.6	82	6.6	—	5.3	100	1.7	1.5	1.9
750	69	8.0	—	7.4	88	7.4	—	5.9	107	1.9	1.5	2.1
825	[a]	—	—	—	94	5.7	3.4	6.3	113	2.3	1.5	2.5
900	[a]	—	—	—	100	6.3	3.8	7.0	119	3.0	1.8	3.2
1050	[a]	—	—	—	113	7.4	4.4	8.3	132	4.2	2.5	4.7
1200	[a]	—	—	—	125	8.9	5.3	9.9	144	5.5	3.3	6.1
1350		—	—	—	138	10.6	6.4	11.6	157	7.2	4.3	8.0
					Concrete Strength, 34.5 MPa							
1500	[a]	—	—	—	150	12.5	7.5	14.0	169	8.7	5.2	9.7
1650	[a]	—	—	—	163	14.6	8.8	16.3	182	10.8	6.5	12.1
									Concrete Strength, 34.5 MPa			
1800	[a]	—	—	—	175	16.7	10.0	18.6	194	12.9	7.7	14.4
1950	[a]	—	—	—	[a]	—	—	—	207	15.0	9.0	16.7
2100	[a]	—	—	—	[a]	—	—	—	219	18.0	10.8	19.9
2250	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2400	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2550	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2700	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2850	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3000	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3150	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3300	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3450	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3600	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 2400 mm in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in one of the following manners: (1) an inner circular cage plus an elliptical cage such that the area of elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) an inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) an inner and outer cage plus an elliptical cage in accordance with Figure 2; or (4) For Wall C, in sizes 600 to 825 mm, a single circular cage with an area not less than the sum of the specified inner and outer circular reinforcement areas.

Continued on next page.

Table 4—Design Requirements for Class IV Reinforced Concrete Pipe[a] *(Continued)*

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[d] For these classes and sizes, the minimum practical steel reinforcement is specified.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in newtons per linear meter of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear meter per millimeter of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimeters.

D-load to produce a 0.3-mm crack	100.0
D-load to produce the ultimate load	150.0

Table 5—Design Requirements for Class V Reinforced Concrete Pipe[a]

	Reinforcement, cm^2/Linear m of Pipe Wall											
	Wall A				Wall B				Wall C			
	Concrete Strength, 41.4 MPa				Concrete Strength, 41.4 MPa				Concrete Strength, 41.4 MPa			
		Circular Reinforcement[b]				Circular Reinforcement[b]				Circular Reinforcement[b]		
Internal Designed Diameter, mm	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]	Wall Thickness, mm	Inner Cage	Outer Cage	Elliptical Reinforcement[c]
300	[a]	—	—	—	50	2.1	—	—	69	1.5[d]	—	—
375	[a]	—	—	—	57	3.0	—	—	75	1.5[d]	—	—
450	[a]	—	—	—	63	4.0	—	3.4	82	2.1	—	—
525	[a]	—	—	—	69	5.1	—	4.4	88	2.1	—	—
600	[a]	—	—	—	75	6.4	—	5.1	94	2.5	1.5	2.8
675	[a]	—	—	—	82	8.0	4.8	8.9	100	3.0	1.8	3.4
750	[a]	—	—	—	88	8.7	5.2	9.7	107	3.8	2.3	4.2
825	[a]	—	—	—	94	9.7	5.8	10.8	113	4.9	2.9	5.3
900	[a]	—	—	—	100	10.6	6.4	11.9	119	5.7	3.4	6.3
1050	[a]	—	—	—	113	12.7	7.6	14.2	132	7.6	4.6	8.5
1200	[a]	—	—	—	125	15.5	9.3	17.1	144	9.9	5.9	11.0
1350	[a]	—	—	—	[a]	—	—	—	157	12.3	7.4	13.5
1500	[a]	—	—	—	[a]	—	—	—	169	14.8	8.9	16.5
1650	[a]	—	—	—	[a]	—	—	—	182	17.8	10.7	19.7
1800	[a]	—	—	—	[a]	—	—	—	194	21.0	12.6	23.3
1950	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2100	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2250	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2400	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2550	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2700	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
2850	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3000	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3150	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3300	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3450	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—
3600	[a]	—	—	—	[a]	—	—	—	[a]	—	—	—

[a] For modified or special designs, see Section 7.2 or, with the permission of the owner, utilize the provision of M 242M/M 242. Steel areas may be interpolated between those shown for variations in diameter, loading, or wall thickness. Pipe more than 2400 mm in diameter shall have two circular cages or an inner circular cage plus one elliptical cage.

[b] As an alternative to designs requiring both inner and outer circular cages the reinforcement may be positioned and proportioned in one of the following manners: (1) an inner circular cage plus an elliptical cage such that the area of elliptical cage shall not be less than that specified for the outer cage in the table and the total area of the inner circular cage plus the elliptical cage shall not be less than that specified for the inner cage in the table; (2) an inner and outer cage plus quadrant mats in accordance with Figure 1; or (3) an inner and outer cage plus an elliptical cage in accordance with Figure 2.

Continued on next page.

Table 5—Design Requirements for Class V Reinforced Concrete Pipe[a] *(Continued)*

[c] Elliptical and quadrant steel must be held in place by means of holding rods, chairs, or other positive means throughout the entire casting operation.

[d] For these classes and sizes, the minimum practical steel reinforcement is specified.

Notes: See Section 5 for basis of acceptance specified by the owner. The strength test requirements in newtons per linear meter of pipe under the three-edge-bearing method shall be either the D-load (test load expressed in newtons per linear meter per millimeter of diameter) to produce the 0.3-mm crack, or the D-loads to produce the 0.3-mm crack, and the ultimate load as specified below, multiplied by the internal diameter of the pipe in millimeters.

D-load to produce a 0.3-mm crack	140.0
D-load to produce the ultimate load	175.0

5. BASIS OF ACCEPTANCE

5.1 Unless otherwise designated by the owner at the time of, or before placing an order, there are two separate and alternative bases of acceptance. Independent of the method of acceptance, the pipe shall be designed to meet both the 0.3-mm crack and ultimate strength requirements specified in Tables 1 to 5.

5.1.1 *Acceptance on the Basis of Plant Load-Bearing Tests, Material Tests, and Inspection of Manufactured Pipe for Visual Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of the three-edge-bearing tests as defined in Section 11.3.1; by such material tests as are required in Sections 6.2, 6.3, 6.5, and 6.6; by an absorption test of the concrete from the wall of the pipe for each mix design that is used on an order; and by visual inspection of the finished pipe to determine its conformance with the accepted design and its freedom from defects.

5.1.2 *Acceptance on the Basis of Material Tests and Inspection of Manufactured Pipe for Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of such material tests as are required in Sections 6.2, 6.3, 6.5, and 6.6; by crushing tests on concrete cores or cured concrete cylinders; by an absorption test of the concrete from the wall of the pipe for each mix design that is used on an order; and by inspection of the finished pipe including amount and placement of reinforcement to determine its conformance with the accepted design and its freedom from defects.

5.1.3 When agreed upon by the owner and the manufacturer, any portion or any combination of the tests itemized in Section 5.1.1 or Section 5.1.2 may form the basis of acceptance.

5.2 *Age for Acceptance*—Pipe shall be considered ready for acceptance when it conforms to the requirements as indicated by the specified tests.

6. MATERIALS

6.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.2 *Cementitious Materials*:

6.2.1 *Cement*—Cement shall conform to the requirements for portland cement of M 85, or shall be portland blast-furnace slag cement, or slag modified portland cement, or portland-pozzolan cement conforming to the requirements of M 240 except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.2.2 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of grade 100 or 120 of M 302.

6.2.3 *Fly Ash*—Fly ash shall conform to the requirements of Class F or Class C of M 295.

6.2.4 *Admixtures and Blends*—The following admixtures and blends are allowable with the approval of the owner:

6.2.4.1 Portland cement only,

6.2.4.2 Portland blast-furnace slag cement only,

6.2.4.3 Slag modified portland cement only,

6.2.4.4 Portland-pozzolan cement only,

6.2.4.5 A combination of portland cement and ground granulated blast-furnace slag,

6.2.4.6 A combination of portland cement and fly ash, or

6.2.4.7 A combination of portland cement, ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight) and fly ash (not to exceed 25 percent of the total cementitious weight.)

6.3 *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—Admixtures and blends may be used with the approval of the owner.

6.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to M 32M/M 32 or M 225M/M 225; or of wire fabric conforming to M 55M/M 55 or M 221M/M 221; or of bars conforming to M 31M/M 31 Grade 280 or 420, ASTM A36/A 36M, or ASTM A 706/A 706M Grade 420.

6.6 *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers are not prohibited from being used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM Specification C 1116 shall be used.

7. DESIGN

7.1 *Design Tables*—The diameter, wall thickness, compressive strength of the concrete, and the area of the circumferential reinforcement shall be as prescribed for Class I to V in Tables 1 to 5, except as provided in Section 7.2.

7.1.1 The reinforcement as presented in the tables herein allows single circular cage reinforcement, or separate inner and outer circular cage reinforcement or a combination thereof. Footnotes to the tables are intended to clarify tabulated requirements, or provide acceptable alternative reinforcement designs, either of which are to be considered applicable and binding as if they were contained in the body of the specification.

7.2 *Modified and Special Designs*:

7.2.1 If permitted by the owner the manufacturer may request approval by the owner of modified designs that differ from the designs in Section 7.1; or special designs for sizes and loads beyond those shown in Tables 1 to 5, Section 7.1, or special designs for pipe sizes that do not have steel reinforcement areas shown in Tables 1 to 5 of Section 7.1.

7.2.2 Such modified or special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of the pipe and shall fully describe to the owner any deviations from the requirements of Section 7.1. The descriptions of modified or special designs shall include the wall thickness, the concrete strength, and the area, type, placement, number of layers, and strength of the steel reinforcement.

7.2.3 The manufacturer shall submit to the owner proof of the adequacy of the proposed modified or special design. Such proof may comprise the submission of certified three-edge-bearing tests already made, which are acceptable to the owner or, if such three-edge-bearing tests are not available or acceptable, the manufacturer may be required to perform proof tests on sizes and classes selected by the owner to demonstrate the adequacy of the proposed design.

7.2.4 Such pipe must meet all of the test and performance requirements specified by the owner in accordance with Section 5.

7.3 *Area*—In this specification, when the word "area" is not described by adjectives, such as cross-section or single wire, it shall be understood to be the cross-sectional area of reinforcement per unit lengths of pipe.

8. REINFORCEMENT

8.1 *Circumferential Reinforcement*—A line of circumferential reinforcement for any given total area may be composed of two layers for pipe with wall thicknesses of less than 180 mm or three layers for pipe with wall thicknesses of 180 mm or greater. The layers shall not be separated by more than the thickness of one longitudinal plus 6 mm. The multiple layers shall be fastened together to form a single cage. All other specification requirements such as laps, welds, and tolerances of placement in the wall of the pipe, etc. shall apply to this method of fabricating a line of reinforcement.

8.1.1 Where one line of circular reinforcement is used, it shall be placed from 35 to 50 percent of the wall thickness from the inner surface of the pipe, except that for wall thicknesses less than 63 mm, the protective cover of the concrete over the circumferential reinforcement in the wall of the pipe shall be 19 mm.

8.1.2 In pipe having two lines of circular reinforcement, each line shall be so placed that the protective covering of concrete over the circumferential reinforcement in the wall of the pipe shall be 25 mm.

8.1.3 In pipe having elliptical reinforcement with wall thicknesses 63 mm or greater, the reinforcement in the wall of the pipe shall be so placed that the protective covering of concrete over the circumferential reinforcement shall be 25 mm from the inner surface of the pipe at the vertical diameter and 25 mm from the outer surface of the pipe at the horizontal diameter. In pipe having elliptical reinforcement with wall thicknesses less than 63 mm, the protective covering of the concrete shall be 19 mm at the vertical and horizontal diameters.

8.1.4 The location of the reinforcement shall be subject to the permissible variations in dimensions given in Section 12.5.

8.1.5 The spacing center-to-center of circumferential reinforcement in a cage shall not exceed 100 mm for pipe up to and including pipe having a 100-mm wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 150 mm.

8.1.6 Where the wall reinforcement does not extend into the joint, the maximum longitudinal distance to the last circumferential from the inside shoulder of the bell or the shoulder of the spigot shall be 75 mm, except that if this distance exceeds one-half the wall thickness, the pipe wall shall contain at least a total reinforcement area of the minimum specified area per linear meter times the laying length of the pipe section. The minimum cover on the last circumferential near the spigot shoulder shall be 13 mm.

8.1.6.1 Where reinforcement is in the bell or spigot the minimum end cover on the last circumferential shall be 13 mm in the bell or 6 mm in the spigot.

8.1.7 The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe, except that when agreed upon by the owner, lift eyes or holes may be provided in each pipe for the purpose of handling.

8.1.8 If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire, and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire.

8.1.8.1 When splices are welded and are not lapped to the minimum requirements above, pull tests of representative specimens shall develop at least 50 percent of the minimum specified strength of the steel, and there shall be a minimum lap of 50 mm. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 percent of the minimum specified strength of the steel.

8.2 *Longitudinal Reinforcement*—Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members, to maintain the reinforcement in shape and in position within the form to comply with permissible variations in Section 8.1. The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

8.3 *Joint Reinforcement*—The length of the joint as used herein means the inside length of the bell or the outside length of the spigot from the shoulder to the end of the pipe section. The end distances or cover on the end circumferential shall apply to any point on the circumference of the pipe or joint. When convoluted reinforcement is used, these distances and reinforcement areas shall be taken from the points on the convolutions closest to the end of the pipe section. Unless otherwise permitted by the owner, the following requirements for joint reinforcement shall apply.

8.3.1 *Joint Reinforcement for Non-Rubber Gasket Joints*:

8.3.1.1 For pipe 900 mm and larger in diameter, either the bell or spigot shall contain circumferential reinforcement. This reinforcement shall be an extension of a wall cage, or may be a separate cage of at least the area per meter of that specified for the outer cage or one-half of that specified for single cage wall reinforcement, whichever is less.

8.3.1.2 Where bells or spigots require reinforcement, the maximum end cover on the last circumferential shall be one-half the length of the joint or 75 mm, whichever is less.

8.3.2 *Joint Reinforcement for Rubber Gasket Joints*:

8.3.2.1 For pipe 300 mm and larger in diameter, the bell ends shall contain circumferential reinforcement. This reinforcement shall be an extension of the outer cage or a single wall cage, whichever is less, or may be a separate cage of at least the same area per meter with longitudinals as required in Section 8.2. If a separate cage is used, the cage shall extend into the pipe with the last circumferential wire at least 25 mm past the inside shoulder where the pipe barrel meets the bell of the joint.

8.3.2.2 Where bells require reinforcement, the maximum end cover on the last circumferential shall be 38 mm.

9. JOINTS

9.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that when the sections are laid together they will make a continuous line of pipe with a smooth interior free from appreciable irregularities in the flow line, all compatible with the permissible variations given in Section 12.

10. MANUFACTURE

10.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water–cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

10.2 *Curing*—Pipe shall be subjected to any one of the methods of curing described in Sections 10.2.1 to 10.2.4 or to any other method or combination of methods approved by the owner, that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the specified D-load is obtained when acceptance is based on Section 5.1.1 or so that the concrete will develop the specified compressive strength at 28 days or less when acceptance is based on Section 5.1.2.

10.2.1 *Steam Curing*—Pipe may be placed in a curing chamber, free of outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

10.2.2 *Water Curing*—Concrete pipe may be water cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

10.2.3 The manufacturer has the option of combining the methods described in Sections 10.2.1 to 10.2.4, provided the required concrete compressive strength is attained.

10.2.4 A sealing membrane conforming to the requirements of M 148 may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 6ºC of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

11. PHYSICAL REQUIREMENTS

11.1 *Test Specimens*—The specified number of pipe required for the tests shall be furnished without charge by the manufacturer and shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order. Unless designated otherwise by the owner in the order, the manufacturer shall select the type of test (external load crushing strength test, compression test of cylinders or compression test of cores) to be used to determine the acceptability of the pipe strength. Pipe that fails to meet the strength requirements as determined by the selected test type may not be retested using one of the other test types without approval of the owner.

11.2 *Number and Type of Tests Required for Various Delivery Schedules*:

11.2.1 *Preliminary Tests for Extended Delivery Schedules*—An owner of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to such tests, preliminary to delivery of pipe, as are required by the type of basis of acceptance specified by the owner in Section 5, of not more than three sections of pipe covering each size in which the owner is interested.

11.2.2 *Additional Tests*—After the preliminary tests described in Section 11.2.1, an owner shall be entitled to additional tests at such times as the owner may deem necessary, provided that the total number of pipe tested (including preliminary tests) shall not exceed 1 pipe or 1 percent, whichever is the greater, of each size of pipe delivered.

11.3 *External Load-Crushing Strength*:

11.3.1 The load to produce a 0.3-mm crack or the ultimate load, as determined by the three-edge-bearing method as described in T 280, shall be not less than that prescribed in Tables 1 to 5 for each respective class of pipe. Pipe that support the prescribed load to produce the 0.3-mm crack and do not show a wider crack shall be considered to have met the test requirement. It is not a requirement of this specification that the pipe be cracked or loaded to failure during these tests. Pipe that have been tested only to the formation of a 0.3-mm crack or lesser crack and that meet the 0.3-mm crack load requirements shall be accepted for use. Three-edge-bearing test to ultimate load is not required for any class of pipe 1500 mm or less in diameter listed in Tables 1–5 provided all other requirements of this specification are met.

Note 3—As used in this specification, the 0.3-mm crack is a test criterion for pipe tested in the three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

11.3.2 *Retests of Pipe Not Meeting the External Load-Crushing Strength Requirements*—Pipe shall be considered as meeting the strength requirements when all test specimens conform to the strength requirements. Should any of the test specimens fail to meet the strength requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

11.4 *Type of Specimen*—Compression tests determining concrete compressive strength may be made on either standard rodded concrete cylinders or concrete cylinders compacted and cured in like manner as the pipe, or on cores drilled from the pipe.

11.5 *Compression Testing of Cylinders*:

11.5.1 *Cylinder Production*—Cylinders shall be prepared, cured, and tested in accordance with Section 11 of T 280.

11.5.2 *Number of Cylinders*—Prepare no fewer than five test cylinders from a group (one day's production of each concrete strength) of pipe sections.

11.5.3 *Acceptability on the Basis of Cylinder Test Results*:

11.5.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the required concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.5.3.2 When the average compressive strength of all cylinders tested is equal to or greater than the required concrete strength, and not more than 10 percent of the cylinders tested have a compressive strength less than the required concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the required concrete strength, then the group shall be accepted.

11.5.3.3 The pipe shall be acceptable only when the compressive strength of the cylinders tested conform to the acceptance criteria stated in Section 11.5.3.1 or Section 11.5.3.2.

11.6 *Compression Testing of Cores*:

11.6.1 *Obtaining Cores*—Cores shall be obtained and prepared in accordance with Section 6 of T 280.

11.6.2 *Number of Cores*—One core shall be taken from a pipe section selected at random from each day's production run of a single concrete strength.

11.7 *Acceptability on the Basis of Core Test Results*:

11.7.1 When the compressive strength of a core tested for a group of pipe sections is equal to or greater than the required concrete strength, the compressive strength of the concrete for the group is acceptable.

11.7.2 If the compressive strength of the core tested is less than the required concrete strength, two additional cores shall be taken from that pipe section and tested. Concrete represented by these core tests shall be considered acceptable if: (1) the average of three cores is equal to at least 85 percent of the required strength, and (2) no single core is less than 75 percent of the required strength.

11.7.3 If the compressive strength of the three cores does not meet the requirements of Section 11.7.2, the pipe section from which the core was taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and cored and tested for conformance with either Section 11.7.1 or Section 11.7.2. If both pipe sections meet the core strength requirements of Section 11.7.1 or Section 11.7.2, the remainder of the group shall be acceptable. If both pipe sections do not meet the test strength requirement, the remainder of the group shall be either rejected or, at the option of the manufacturer, each pipe section of the remaining group shall be cored and accepted individually and any of the pipe sections that have core strengths less than the requirements of Section 11.7.1 or Section 11.7.2 shall be rejected.

11.8 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.9 *Absorption*—The absorption of a sample from the wall of the pipe, as determined in accordance with T 280, shall not exceed 9 percent of the dry mass. Each sample shall have a minimum mass of 1.0 kg, shall be free of visible cracks, and shall represent the full wall thickness of the pipe. When the initial absorption sample from a pipe fails to conform to this specification, the absorption test shall be made on another sample from the same pipe and the results of the retest shall be substituted for the original test results.

11.10 *Retests of Pipe*—When not more than 20 percent of the concrete specimens fail to pass the requirements of this specification, the manufacturer may cull the project stock and may eliminate whatever quantity of pipe desired and shall mark those pipes so that they will not be shipped. The required tests shall be made on the balance of the order and the pipes shall be accepted if they conform to the requirements of this specification.

11.11 *Test Equipment*—Every manufacturer furnishing pipe under this specification shall furnish all facilities and personnel necessary to carry out the tests described in T 280.

12. PERMISSIBLE VARIATIONS

12.1 *Internal Diameter*—See Table 6. The internal diameter shall be one of two alternatives, the Designated Diameter or, contingent upon the owner's approval, the Converted English Diameter. Pipe sections that are intended to be jointed to each other shall be furnished with the same internal diameter alternative. The internal diameter of pipe manufactured to the Designated Diameters shall vary not more than ±1.5 percent from the Designated Diameters for 300 to 600 mm and ±1 percent or ±10 mm, whichever is greater, for larger pipe. The internal diameter of pipe manufactured to the Converted English Diameters shall vary not more than ±1.5 percent from the Converted English Diameters for 305 to 610 mm and ±1 percent or ±10 mm, whichever is greater, for larger pipe. For pipe manufactured to Converted English Diameters, the corresponding Designated Diameter shown in Table 6 shall apply for all other requirements of this specification.

Table 6—Design Internal Diameter

Designated Diameter of Pipe, mm	Equivalent English Dia, in.	Converted English Dia, mm
300	12	305
375	15	381
450	18	457
525	21	533
600	24	610
675	27	686
750	30	762
825	33	838
900	36	914
1050	42	1067
1200	48	1219
1350	54	1372
1500	60	1524
1650	66	1676
1800	72	1829
1950	78	1981
2100	84	2134
2250	90	2286
2400	96	2438
2550	102	2591
2700	108	2743
2850	114	2896
3000	120	3048
3150	126	3200
3300	132	3353
3450	138	3505
3600	144	3658

12.2 *Wall Thickness*—The wall thickness shall not vary more than shown in the design or specified wall by more than ±5 percent or 5 mm, whichever is greater. A specified wall thickness more than required in the design is not cause for rejection. Pipe having localized variations in wall thickness exceeding those specified above shall be accepted if the three-edge-bearing strength and minimum steel cover requirements are met.

12.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of the pipe shall not be more than 6 mm for all sizes through 600-mm internal diameter, and not more than 10 mm/m of internal diameter for all sizes larger with a maximum of 16 mm in any length of pipe through 2100-mm internal diameter, and a maximum of 19 mm for 2250-mm internal diameter or larger, except where beveled end pipe for laying on curves is specified by the owner.

12.4 *Length of Pipe*—The underrun in length of a section of pipe shall not be more than 10 mm/m with a maximum of 13 mm in any length of pipe. Regardless of the underrun or overrun in any section of pipe, the end cover requirements of Sections 8 and 12 shall apply.

12.5 *Position or Area of Reinforcement*:

12.5.1 *Position*—The maximum variation in the position of a line of circumferential reinforcement shall be ±10 percent of the wall thickness or ±13 mm, whichever is greater. Pipe having variations in the position of a line of circumferential reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative specimen are met. In no case, however, shall the cover over the circumferential reinforcement be less than 6 mm as measured to the end of the spigot or 13 mm as measured to any other surface. The preceding minimum cover limitations do not apply to mating surfaces of non-rubber gasket joints or gasket grooves in rubber gasket joints. If convoluted reinforcement is used, the convoluted circumferential end wire may be at the end surface of the joint providing the alternate convolutions have at least 25 mm cover from the end surface of the joint.

12.5.2 *Area of Reinforcement*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the requirements of Section 7.1 or Section 7.2. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing. When inner cage and outer cage reinforcing is used, the inner cage nominal area may vary to the lower limit of 85 percent of the elliptical nominal area and the outer cage nominal area may vary to the lower limit of 51 percent of the elliptical nominal area provided that the total nominal area of the inner cage plus the outer cage shall not vary beyond the lower limit of 140 percent of the elliptical nominal area.

13. REPAIRS

13.1 Pipe may be repaired, if necessary, because of imperfections in manufacturing or damage during handling and will be acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

14. INSPECTION

14.1 The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by the owner.

15. REJECTION

15.1 Pipe shall be subject to rejection if it fails to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:

15.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint.

15.1.2 Defects that indicate proportioning, mixing, and molding not in compliance with Section 10.1 or surface defects indicating honey-combed or open texture that would adversely affect the function of the pipe.

15.1.3 The ends of the pipe are not normal to the walls and centerline of the pipe, within the limits of variations given in Sections 12.3 and 12.4.

15.1.4 Damaged or cracked ends where such damage would prevent making a satisfactory joint.

15.1.5 Any continuous crack having a surface width of 0.3 mm or more and extending for a length of 300 mm or more, regardless of position in the wall of the pipe.

16. PRODUCT MARKING

16.1 The following information shall be clearly marked on each section of pipe:

16.1.1 The pipe class and specification designation,

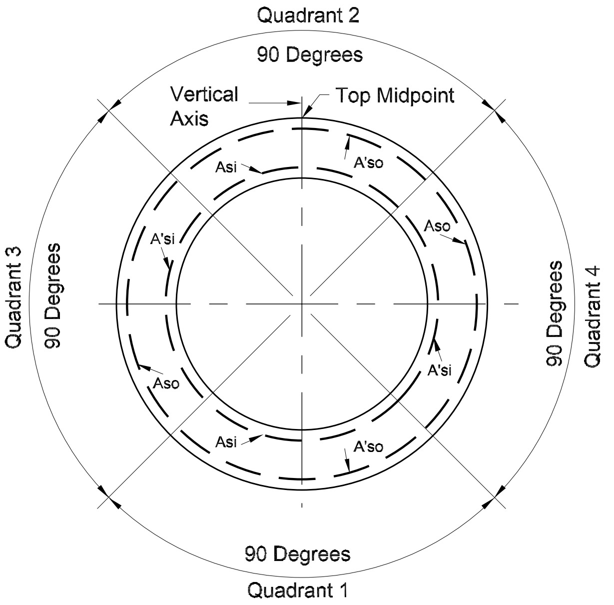
16.1.2 The date of manufacture,

16.1.3 The name or trademark of the manufacturer, and

16.1.4 Identification of plant.

16.2 One end of each section of pipe with elliptical or quadrant reinforcement shall be clearly marked during the process of manufacturing or immediately thereafter, on the inside and the outside of opposite walls along the minor axis of the elliptical reinforcing or along the vertical axis for quadrant reinforcing.

16.3 Markings shall be indented on the pipe section or painted thereon with waterproof paint.



Notes: 1. The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Tables 1 to 5.

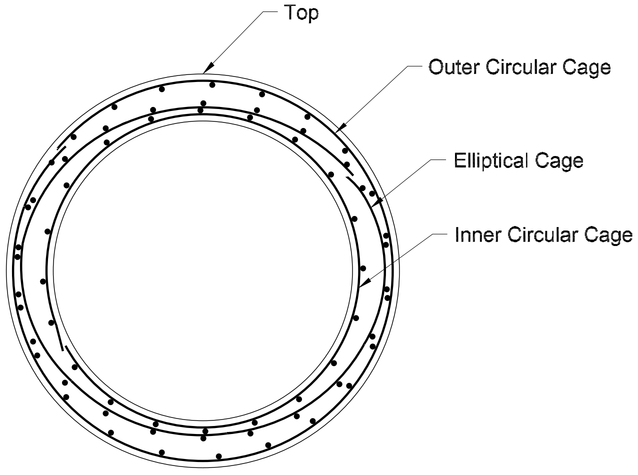
2. The total reinforcement area (Aso) of the outer cage plus the quadrant mat in Quadrants 3 and 4 shall not be less than that specified for the outer cage in Tables 1 to 5.

3. The total reinforcement area (A′si) of the inner cage in Quadrants 3 and 4 shall not be less than 25 percent of that specified for the inner cage in Tables 1 to 5.

4. The total reinforcement area (A′so) of the outer cage in Quadrants 1 and 2 shall not be less than 25 percent of that specified for the outer cage in Tables 1 to 5.

5. If the reinforcement area (A′so) of the outer cage in Quadrants 1 and 2 is less than 50 percent of that specified for the outer cage in Tables 1 to 5, the quadrant mats used for the outer cage in Quadrants 3 and 4 shall extend into Quadrants 1 and 2 not less than a distance equal to the wall thickness as specified in Tables 1 to 5.

Figure 1—Quadrant Reinforcement



Notes: 1. The total reinforcement area of the inner circular cage and the elliptical cage shall not be less than that specified for the inner cage in Tables 1 to 5.

2. The total reinforcement area of the outer circular cage and the elliptical cage shall not be less than that specified for the outer cage in Tables 1 to 5.

Figure 2—Triple Cage Reinforcement

17. KEYWORDS

17.1 Circular pipe; culvert; D-load; pipe; reinforced concrete; sewer pipe; storm drain.

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[1] Agrees with ASTM C 76M-08a except for limiting the absorption testing to the 5-hour boil method, the use of synthetic fibers are at the option of the owner, supplying inch-pound sized pipe when the order is placed in SI units is contingent upon owner approval, and the method of acceptance is changed as per Sections 11.1, 11.5.3.3, and 11.7.3.

Standard Specification for

Perforated Concrete Pipe

AASHTO Designation: M 175M/M 175-05 (2009)
ASTM Designation: C 444M-03 and C 444-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Perforated Concrete Pipe

AASHTO Designation: M 175M/M 175-05 (2009)
ASTM Designation: C 444M-03 and C 444-03

1. SCOPE

1.1 This specification covers perforated concrete pipe intended to be used for underdrainage.

1.2 This specification is applicable for orders in either SI units (M 175M) or in inch-pound units (M 175). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 175.

2. REFERENCED DOCUMENT

2.1 *AASHTO Standards*:

- M 86M/M 86, Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe
- M 262, Concrete Pipe and Related Products

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Pipe manufactured according to this specification shall be of two classes known as Type 1 and Type 2, which cover two arrangements of perforations to be used with pipe manufactured according to any of the standard specifications for plain or reinforced concrete pipe, and any of the classifications within those standard specifications.

4.1.1 Type 1 perforated pipe shall have circular perforations conforming to Section 6.1 and Table 1.

4.1.2 Type 2 perforated pipe shall have slotted perforations conforming to Section 6.2 and Table 2.

4.1.3 It is intended that perforated pipe shall be specified by reference to this specification and the specification for the type and class of pipe desired.

Note 1—Example—“Perforated concrete pipe shall conform to the requirements of M 175M/M 175, Type 2, and all applicable requirements of M 86, Class 2.”

5. BASIS OF ACCEPTANCE

5.1 The acceptability of the pipe shall be determined by the results of all applicable tests (Note 2) prescribed for the type and class of pipe specified, and by inspection to determine whether the pipe conforms to this specification as to design and freedom from defects.

Note 2—It is intended that all tests will be applicable except those having to do with permeability and the hydrostatic test.

6. PERFORATIONS

6.1 *Type 1*—Perforations shall be circular, not more than 8 mm [$^5/_{16}$ in.] or less than 5 mm [$^3/_{16}$ in.] in diameter, and arranged in rows parallel to the axis of the pipe. Perforations shall be 75 mm [3 in.] center-to-center, along rows. The spigot or tongue end shall not be perforated for a length equal to the depth of the socket, or depth of the groove plus 19 mm [$^3/_4$ in.] and perforations shall continue at uniform spacing along the entire length of the barrel. The total number of rows shall be as shown in Table 1. The rows shall be spaced over not more than 165 degrees of circumference. Rows shall be symmetrically arranged with respect to the intended top or bottom of the pipe.

Table 1—Number of Rows of Perforations Required

Internal Designation Diameter		Rows of Perforations
mm	in.	
100	4	4
150	6	4
200	8	4
250	10	6
300	12	6
350	14	6
375	15	6
400	16	6
450	18	8
500	20	8
525	21	8
600	24	8
675 and larger	27 and larger	space rows approximately 150 mm [6 in].

6.2 *Type 2*—Slots shall be circumferential in direction, not more than 5 mm [$^3/_{16}$ in.] or less than 3 mm [$^1/_8$ in.] in width, and of the lengths shown in Table 2. There shall be two rows of slots, spaced 165 degrees apart, and centered, in the case of elliptically reinforced pipe, about the minor axis of the reinforcing. Slots shall be spaced as shown in Table 2, except as modified herein for plain-end pipe. The distance from the spigot end, or from the shoulder of the tongue end, to the first pair of slots shall be not more than 25 mm [1 in.] greater than the specified slot spacing, nor less than 25 mm [1 in.] less than the specified slot spacing. Slots shall continue at uniform spacing along the entire length of the barrel.

Table 2—Requirements for Length and Spacing of Slots

Internal Designation Diameter		Slot Length		Slot Spacing[a]	
mm	in.	mm	in.	mm	in.
100	4	25	1	75	3
150	6	38	1½	75	3
200	8	50	2	100	4
250	10	50	2	100	4
300	12	75	3	150	6
350	14	75	3	150	6
375	15	75	3	150	6
400	16	75	3	150	6
450	18	75	3	150	6
500	20	75	3	150	6
525	21	75	3	150	6
600	24	75	3	150	6
675 and larger	27 and larger	100	4	150	6

[a] See Section 6.2 for exceptions for plain-end pipe.

6.2.1 Slots in plain-end pipe shall be spaced as shown in Table 2 except that smaller spacing shall be used where necessary to provide not less than three equally spaced slots in each row. Slots shall be centered with respect to the ends of the pipe and there shall be not more than the specified slot spacing from the pipe end to the first pair of slots, or less than one-half of the slot spacing employed.

6.3 The manufacturer shall submit to the owner for approval, prior to manufacture, sizes and arrangements of perforations other than specified herein.

7. JOINTS

7.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 8.

8. PERMISSIBLE VARIATION IN DIMENSIONS

8.1 The permissible variation in circular perforation size or slot width shall be as specified in Section 6. Slot length tolerance is +6 mm [$+^{1}/_{4}$ in.] or –3 mm [$-^{1}/_{8}$ in.] Variation in row spacing, or in the spacing of holes or slots in any row, shall be ±13 mm [$\pm^{1}/_{2}$ in.] except as required to provide specified cover for reinforcing steel.

9. REPAIRS

9.1 Pipe repaired because of imperfections in manufacture or damage during handling will be acceptable, if in the opinion of the owner, the repairs are sound and properly finished and cured and the pipe conforms to the requirements of this specification.

10. MARKING OF REJECTED SPECIMENS

10.1 All rejected pipe shall be marked clearly by the owner and shall be replaced by the manufacturer with pipe that will meet the requirements of this specification, without additional cost to the owner.

11. INSPECTION

11.1 The quality of all materials and the finished pipe shall be subject to inspection and approval by the owner. Such inspection shall be performed at the point of manufacture or delivery. The method of marking as to acceptance or rejection of the pipe shall be agreed upon, prior to inspection, between the owner and manufacturer. Rejected pipe shall be replaced by the manufacturer with pipe that meets the requirements of this specification.

12. REJECTION

12.1 Pipe shall be subject to rejection on account of any of the applicable causes for rejection listed for the type and class of pipe specified, or on account of any of the following:

12.1.1 Variations in dimensions exceeding those specified in Sections 6 and 8, or

12.1.2 Any spall more than 19 mm [$^3/_4$ in.] in diameter or 5 mm [$^3/_{16}$ in.] in depth caused by making perforations or slots.

13. KEYWORDS

13.1 Concrete pipe; perforated; subsurface drainage; underdrainage.

Standard Specification for

Porous Concrete Pipe

AASHTO Designation: M 176M/M 176-07[1]
ASTM Designation: C 654M-05a and C 654-05a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Porous Concrete Pipe

AASHTO Designation: M 176M/M 176-07[1]

ASTM Designation: C 654M-05a and C 654-05a

1. SCOPE

1.1 This specification covers porous nonreinforced concrete pipe for use in underdrains.

1.2 This specification is applicable for orders in either SI units (M 176M) or in inch-pound units (M 176). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 176.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 154, Air-Entraining Admixtures for Concrete
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standard*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Pipe manufactured according to this specification shall be of two classes identified as "Standard-Strength Porous Nonreinforced Concrete Pipe" and "Extra-Strength Porous Nonreinforced Concrete Pipe."

5. BASIS OF ACCEPTANCE

5.1 The acceptability of the pipe shall be determined by the results of the strength and porosity or rate of infiltration tests, and by inspection to determine whether the pipe conforms to this specification as to design and freedom from defects.

5.2 The pipe shall be acceptable under the strength tests when they have met the requirements as prescribed in Section 10.

5.3 *Acceptance as to Infiltration Properties*—Pipe shall be acceptable under the infiltration test when all test pipe conform to the test requirements as prescribed in Section 10.

6. MATERIALS

6.1 *Concrete*—The concrete shall consist of cementitious materials, aggregates, and water.

6.2 *Cementitious Materials*:

6.2.1 *Cement*—Cement shall conform to the requirements of M 85 or shall be portland blast-furnace slag cement or slag modified portland cement, or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash and shall not exceed 25 percent by weight.

6.2.2 *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of grade 100 or 120 of Specification C 989.

6.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1 Portland cement only,

6.2.4.2 Portland blast-furnace slag cement only,

6.2.4.3 Slag modified portland cement only,

6.2.4.4 Portland-pozzolan cement only, or

6.2.4.5 A combination of portland cement and fly ash.

6.2.4.6 A combination of portland cement and ground granulated blast-furnace slag, or

6.2.4.7 A combination of portland cement, fly ash (not to exceed 25 percent of the total cementitious weight) and ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight).

Note 1—The user of this specification is advised that porous pipe may experience leaching detrimental to durability when subjected to drainage of soft or acid waters (less than 50 ppm hardness or less than 6.0 pH). Type V portland cement should be specified where high sulfate resistance is required, and Type II or IIA portland cement should be specified where the pipe will be exposed to moderate sulfate conditions. More than 3,000 mg/L [ppm] of chiefly sodium or magnesium sulfates, or both, may be considered high sulfate content.

6.3 *Aggregates*—Aggregates shall conform to M 6 and M 80 except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—Admixtures and blends shall only be used with the approval of the owner.

6.5 *Synthetic Fibers*—Polypropylene fibers are permitted, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

7. DESIGN

7.1 *Design Table*—Design requirements shall be in accordance with Tables 1 and 2 and Figure 1. Wall thickness used shall be not less than the value shown, except as affected by the tolerance herein specified.

Table 1—Physical and Dimensional Requirements of Porous Concrete Pipe

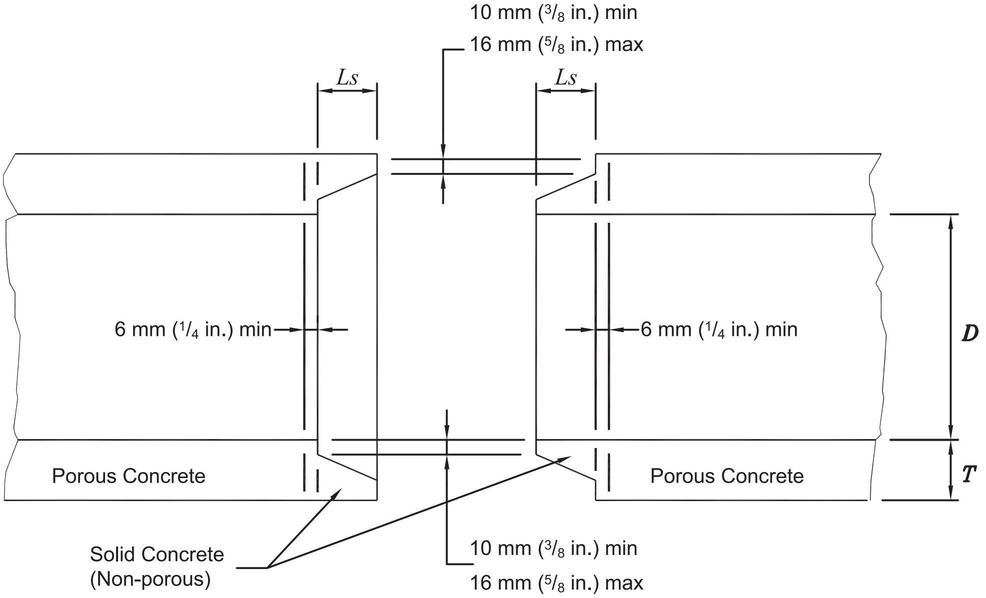
Internal Designated Diameter, *D*		Minimum Wall Thickness, *T*		Minimum Laying Length[a]		Minimum Socket Depth, *Ls*		Minimum Strength Three-Edge-Bearing		Minimum Infiltration	
mm	in.	mm	in.	mm	in.	mm	in.	kN/m	lbf/ft	(*L*/s)/m	(gal/min)/ft
100	4	25	1	600	24	25	1	14.5	1000	0.8	4
150	6	25	1	600	24	25	1	16.0	1100	1.0	6
200	8	32	$1^{1}/_{4}$	600	24	32	$1^{1}/_{4}$	19.0	1300	1.5	8
250	10	35	$1^{1}/_{8}$	600	24	35	$1^{1}/_{8}$	20.5	1400	2.0	10
300	12	38	$1^{1}/_{2}$	600	24	38	$1^{1}/_{2}$	22.0	1500	2.5	12
375	15	44	$1^{3}/_{4}$	600	24	44	$1^{3}/_{4}$	25.5	1750	3.0	15
450	18	50	2	600	24	50	2	29.0	2000	3.5	18
525	21	57	$2^{1}/_{4}$	600	24	57	$2^{1}/_{4}$	32.0	2200	4.0	21
600	24	63	$2^{1}/_{2}$	600	24	63	$2^{1}/_{2}$	35.0	2400	4.5	24

[a] Normally, the minimum laying length is 600 mm [24 in.] in length, but if the owner has no objections, then 450 mm [18-in.] length pipe up to 300 mm [12 in.] in diameter shall be acceptable.

Table 2—Physical and Dimensional Requirements of Extra-Strength Porous Concrete Pipe

Internal Designated Diameter, *D*		Minimum Wall Thickness, *T*		Minimum Laying Length[a]		Minimum Socket Depth, *Ls*		Minimum Strength Three-Edge-Bearing		Minimum Infiltration	
mm	in.	mm	in	mm	in.	mm	in	kN/m	lbf/ft	(L/s)/m	(gal/min)/ft
150	6	32	$1^{1}/_{4}$	600	24	32	$1^{1}/_{4}$	32.0	2200	1.0	6
200	8	38	$1^{1}/_{2}$	600	24	38	$1^{1}/_{2}$	38.0	2600	1.5	8
250	10	41	$1^{5}/_{8}$	600	24	41	$1^{5}/_{8}$	41.0	2800	2.0	10
300	12	50	2	600	24	50	2	44.0	3000	2.5	12
375	15	57	$2^{1}/_{4}$	600	24	57	$2^{1}/_{4}$	46.5	3200	3.0	15
450	18	63	$2^{1}/_{2}$	600	24	63	$2^{1}/_{2}$	46.5	3200	3.5	18

[a] Normally, the minimum laying length is 600 mm [24 in.] length, but if the owner has no objections, then 450 mm [18-in.] length pipe up to 300 mm [12 in.] in diameter shall be acceptable.



Note: See Tables 1 and 2 for values of *D*, *T*, and *Ls*.

Figure 1—Joint Dimensions

8. JOINTS

8.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 7.

9. MANUFACTURE

9.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed in a batch mixer with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification.

9.2 *Curing*—Pipe shall be subjected to any one of the methods of curing described in Sections 9.2.1 through 9.2.3, or to any other method or combination of methods approved by the owner that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the concrete will develop the specified strength requirement at 28 days or less.

9.2.1 *Steam Curing*—Pipe shall be placed in a curing chamber, free from outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and at such temperature as needed to enable the pipe to meet the strength requirements. The curing chamber shall be constructed as to allow full circulation of steam around the entire pipe.

9.2.2 *Water Curing*—Concrete pipe shall be water cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

9.2.3 The manufacturer has the option to combine the methods described in Sections 9.2.1 and 9.2.2 provided the specified strength is attained.

9.3 *Specials*:

9.3.1 *General Requirements*—Special shapes or fittings such as wyes, tees, bends, and adapters for use with concrete pipe conforming to this specification shall be made of porous or nonporous concrete in such manner as will provide strength at least equal to the class of the adjacent pipe to which they are joined, and shall conform to all other requirements specified for pipe of corresponding class and internal diameter, except minimum infiltration. Joints shall be the same types as used in the adjoining pipe.

9.3.2 *Wyes and Tees*—Fabricated branches for wyes and tees shall be securely attached to the wall of the pipe and shall be flush with the inside surface of the pipe.

10. PHYSICAL REQUIREMENTS

10.1 *Test Specimen*—The specified number of pipe required for the tests shall be furnished by the manufacturer and shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order. The test pipe shall first be freed from all visible moisture. When dry, each pipe shall be measured and inspected. The results of these observations shall be recorded.

10.2 *Number and Types of Test Specimens*—The manufacturer shall furnish pipe for crushing tests, up to 0.5 percent of the number of pipe of each size included in the order, except that in no case shall fewer than two pipes be furnished.

10.3 *External Load Crushing Requirements*—The crushing strength of porous nonreinforced concrete pipe shall conform to the requirements prescribed in Tables 1 and 2. The individual results of the various tests for each size of pipe and for each shipment and plant shall be tabulated separately. The crushing strength shall ordinarily be applied to not less than 75 percent of the pipe received for purpose of test. All tests shall be made in accordance with T 280. Pipe shall be acceptable when all test pipe conform to the specified strength requirement. Should any of the preliminary test pipe provided in Section 10.2 fail to meet the strength requirement, the manufacturer will be allowed to test two pipes for each pipe that failed, and the pipe shall be acceptable only when all of these additional test pipe meet the strength requirement.

10.4 *Infiltration Requirement*—Infiltration (or porosity) shall conform to the requirements in Tables 1 or 2.

10.4.1 The test pipe shall be placed with a spigot end down on a soft rubber nonpermeable mat, or its equivalent, and weighted or clamped down if necessary to prevent the escape of water through the spigot end of the pipe.

10.4.2 Water shall be introduced into the pipe, and the distance above the bottom of the porous section at which the water level becomes constant shall be determined. The rate of flow shall be at least equal to the required minimum infiltration for 1 m [ft] of pipe as given in Tables 1 or 2.

10.4.3 When using metric units, the rate of infiltration per meter of pipe shall be determined as follows:

$$\mathit{LITERS/S} = L/h$$

where:

$\mathit{LITERS/S}$ = infiltration rate in liters per second per meter of pipe,

L = liters per second of flow introduced into the test pipe, and

h = height in meters from the bottom of the porous section of the pipe at which the level of water becomes constant.

When using inch pound units the rate of infiltration per foot of pipe shall be determined as follows:

$$\mathit{GPM} = g/h$$

where:

GPM = infiltration rate in gallons per minute per foot of pipe,

g = gallons per minute of flow introduced into the test pipe, and

h = height in feet from the bottom of the porous section of the pipe at which the level of water becomes constant.

10.5 *Test Equipment*—The manufacturer shall furnish all equipment, facilities, and personnel necessary to perform at his plant the tests specified in Section 10. In the event that the owner elects to have tests performed at any other location, the manufacturer will not be required to furnish equipment, facilities, or personnel.

11. PERMISSIBLE VARIATIONS

11.1 *Size and Dimensions*—Pipe shall be furnished in the sizes, internal diameters, and dimensions prescribed in Tables 1, 2, and 3 and Figure 1.

Table 3—Permissible Variations in Dimensions of Porous Concrete Pipe

Internal Designated Diameter		Internal Diameter[a]		Length, Two Opposite Sides		Wall Thickness[a]		Length[a]		Depth of Socket[a]	
mm	in.	mm	in.	mm	in.	mm	in.	mm/m	in./ft	mm	in.
100	4	± 3	± $^{1}/_{8}$	– 2	– $^{1}/_{16}$	6	$^{1}/_{4}$	– 20	– $^{1}/_{4}$	– 3	– $^{1}/_{8}$
150	6	± 3	± $^{1}/_{8}$	– 2	– $^{1}/_{16}$	6	$^{1}/_{4}$	– 20	– $^{1}/_{4}$	– 3	– $^{1}/_{8}$
200	8	± 6	± $^{1}/_{4}$	– 2	– $^{1}/_{16}$	8	$^{5}/_{16}$	– 20	– $^{1}/_{4}$	– 6	– $^{1}/_{4}$
250	10	± 6	± $^{1}/_{4}$	– 2	– $^{1}/_{16}$	10	$^{3}/_{8}$	– 20	– $^{1}/_{4}$	– 6	– $^{1}/_{4}$
300	12	± 6	± $^{1}/_{4}$	– 2	– $^{1}/_{16}$	10	$^{3}/_{8}$	– 20	– $^{1}/_{4}$	– 6	– $^{1}/_{4}$
375	15	± 6	± $^{1}/_{4}$	– 2	– $^{3}/_{32}$	11	$^{7}/_{16}$	– 20	– $^{1}/_{4}$	– 6	– $^{1}/_{4}$
450	18	± 6	± $^{1}/_{4}$	– 2	– $^{3}/_{32}$	13	$^{1}/_{2}$	– 20	– $^{1}/_{4}$	– 6	– $^{1}/_{4}$
525	21	± 6	± $^{1}/_{4}$	– 3	– $^{1}/_{8}$	14	$^{9}/_{16}$	– 20	– $^{1}/_{4}$	– 6	– $^{1}/_{4}$
600	24	± 6	± $^{1}/_{4}$	– 3	– $^{1}/_{8}$	14	$^{9}/_{16}$	– 31	– $^{3}/_{8}$	– 6	– $^{1}/_{4}$

[a] The minus sign (–) indicates that the plus variation is not limited; the plus and minus sign (±) indicates variation in both excess and deficiency in dimension.

11.2 Permissible variations from the dimensions described in Tables 1 and 2 shall not exceed those stated in Table 3. This is not to be construed, however, that heavier wall thickness pipe cannot be furnished at the option of the manufacturer. Pipe intended to be straight shall not have variation in alignment of more than 10 mm/m [$^{1}/_{8}$ in./ft] of length.

12. REPAIRS

12.1 Pipe repaired because of imperfections in manufacturing or damage during handling is acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

13. INSPECTION

13.1 The quality of all materials, the process of manufacture, and the finished pipe shall be subject to the inspection and approval by the owner. Such inspection shall be performed either at the point of manufacture or delivery.

14. REJECTION

14.1 Pipe shall be subject to rejection if it fails to conform to any of the specification requirements. It is not prohibited for individual sections of pipe to be rejected because of any of the following:

14.1.1 Fractures or cracks passing through the wall or joints, except a single crack not exceeding 50 mm [2 in.] in length at either end of a pipe or a single fracture in the joints not exceeding 75 mm [3 in.] in width and not more than 50 mm [2 in.] in length, shall not be considered cause for rejection unless these defects exist in more than 5 percent of the entire shipment or delivery.

14.1.2 The planes of the ends of the pipe are not perpendicular to the longitudinal axis, subject to the limits of variation as shown in Table 3.

14.1.3 Defects that indicate mixing and molding not in accordance with Section 9.1.

14.1.4 Cracks sufficient to impair the strength, durability, or serviceability of the pipe.

15. MARKING

15.1 The letters “ES” shall be legibly stamped with waterproof ink, or other permanent matter, on all extra-strength porous concrete pipe.

16. KEYWORDS

16.1 Concrete pipe; nonreinforced; porous; underdrains.

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[1] Agrees with ASTM C 654M-05a and C 654-05a except for limiting absorption testing to the 5-hour boil method, the manufacturer is not afforded the option to supply inch-pound sized pipe when the order is placed in SI units and the use of fibers in Section 6.5 is at the owner’s option.

Standard Specification for

Concrete Drain Tile

AASHTO Designation: M 178M/M 178-07[1]
ASTM Designation: C 412M-05a and C 412-05a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Concrete Drain Tile

AASHTO Designation: M 178M/M 178-07[1]
ASTM Designation: C 412M-05a and C 412-05a

1. SCOPE

1.1 This specification covers concrete drain tile with internal diameters from 100 mm (4 in.) to 900 mm (36 in.) that is intended to be used for surface and subsurface drainage.

1.2 This specification is applicable for orders in either SI units (M 178M) or in inch-pound units (M 178). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 178.

Note 1—This specification is a manufacturing and purchase specification only and does not include requirements for bedding, backfill, or the relationship between field load condition and the strength classification of drain tile. However, experience has shown that the successful performance of the product depends upon the proper selection of the class of drain tile, type of bedding and backfill, and care that the installation conforms to the construction specifications. The owner of the reinforced concrete pipe specified herein is cautioned that the field requirements must be correlated with the class of pipe specified and provide inspection at the construction site.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standard:*

- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Drain tile manufactured according to this specification shall be of the following four classes:

4.1.1 *Standard-Quality Concrete Drain Tile*—intended for land drainage of ordinary soils where the tile are laid in trenches of moderate depths and widths. Standard-Quality concrete drain tile are not recommended for use where internal diameters in excess of 300 mm [12 in.] are required.

4.1.2 *Extra-Quality Concrete Drain Tile*—intended for land drainage of ordinary soils where the tile are laid in trenches of considerable depths or widths, or both.

4.1.3 *Heavy-Duty Extra-Quality Concrete Drain Tile*—intended for land drainage of ordinary soils where the tile are laid in trenches of large depths or widths, or both.

4.1.4 *Special-Quality Concrete Drain Tile*—intended for land drainage where special precautions are necessary for concrete tile laid in soils that are markedly acid or contain unusual quantities of sulfates (Section 7), and where the tile are laid in trenches of considerable depths or widths, or both.

4.1.4.1 Where the calculated loads are in excess of the crushing strengths prescribed in the physical requirements for extra-quality and special-quality concrete drain tile, tile strengths must be specified in advance by the owner.

5. BASIS OF ACCEPTANCE

5.1 The acceptability of drain tile shall be determined by (1) the results of the physical tests as specified in Section 8, and in T 280, (2) measurements and inspection to ascertain whether the tile conform to the requirements regarding dimensions, shape, and freedom from visible defects, and (3) the manufacturer's certification in writing that the tile have been made in accordance with any special provisions, such as strength, absorption, permeability, type of cement, admixture, curing conditions, etc.

5.2 The owner shall specify in writing the class or classes of concrete tile to be supplied, whether Standard-Quality, Extra-Quality, Heavy-Duty Extra-Quality, or Special-Quality. Unless Extra-Quality, Heavy-Duty Extra-Quality, or Special-Quality concrete drain tile have been specified, Standard-Quality drain tile shall be accepted.

6. MATERIALS

6.1 *Concrete*—The concrete shall consist of cementitious materials, mineral aggregates, and water.

6.2 *Cementitious Materials*:

6.2.1 *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or slag modified portland cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.2.2 *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of Specification C 989.

6.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1 Portland cement only,

6.2.4.2 Portland blast-furnace slag cement only,

6.2.4.3 Slag modified portland cement only,

6.2.4.4 Portland-pozzolan cement only,

6.2.4.5 A combination of portland cement and fly ash,

6.2.4.6 A combination of portland cement and ground granulated blast-furnace slag, or

6.2.4.7 A combination of portland cement, fly ash (not to exceed 25 percent of the total cementitious weight) and ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight).

6.3 *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—Admixtures and blends shall only be used with the approval of the owner.

6.5 *Synthetic Fibers*—At the owner's option, collated fibrillated virgin polypropylene fibers are not prohibited from being used as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be used.

7. CHEMICAL REQUIREMENTS

7.1 *Acid and Sulfate Resistance*:

7.1.1 The owner is not prohibited from specifying special requirements in order to increase the durability of the drain tile in cases where the soils, soil waters, or drainage waters are markedly acid (Section 7.1.1.1) or contain moderate or severe quantities of soil sulfates (Section 7.1.1.2). Without a specific agreement in advance, no drain tile shall be rejected by reason of its composition as determined later by chemical analyses.

7.1.1.1 Soils or drainage water with a pH of 6.0 or lower shall be considered to be markedly acid.

7.1.1.2 Where the sulfates are chiefly sodium or magnesium, singly or in combination, from 400 to 2000 ppm in the soil or drainage water samples shall be considered to constitute moderate sulfate quantities, while in excess of 2000 ppm shall be considered to be severe sulfate quantities.

7.1.2 Concrete drain tile that will be installed in markedly acid soils shall meet the physical requirements given in the table for Special-Quality concrete drain tile.

7.1.3 Tile that will be exposed to moderate or severe sulfate quantities (Note 2) if required by the owner, shall be specified to meet the physical requirements for Special-Quality concrete drain tile (Section 8.3.4). Tile that will be exposed to moderate sulfate quantities (Note 2) if required by the owner, shall be specified to be made with portland cement (M 85) containing not more than 8 percent tricalcium aluminate (C_3A). Tile that will be exposed to severe sulfate quantities (Note 2) if required by the owner, shall be specified to be made with portland cement (M 85) containing not more than 5 percent C_3A. If mutually agreed by the manufacturer and owner, other cements, as described in Section 6, that have been proven to be adequately sulfate resistant shall be used.

8. PHYSICAL REQUIREMENTS

8.1 *Test Specimens*—The drain tile to be tested shall be selected at random by the owner or his representative at the point or points specified in the order. If agreeable to the owner, the tile shall be inspected and tested in advance of shipment. Any additional expense for making tests and inspection in advance of shipment shall be paid by the manufacturer.

8.2 *Standard Sample*—Each standard physical test shall be made on five individual tiles of each size ranging from 100 mm [4-in.] through 300 mm [12-in.] diameters; two individual tiles of each size ranging from 350 mm [14-in.] through 600 mm [24-in.] diameters; or on one tile of each size exceeding 600 mm [24 in.] in diameter. The manufacturer shall furnish tile without separate charge up to 0.5 percent of each size. The owner shall pay for all the tile in excess of 0.5 percent at the same price as paid for other tile of the same size and quality.

8.3 *External Load Crushing Strength Test Requirements*:

8.3.1 For Standard-Quality concrete drain tile, the three-edge-bearing crushing strength shall meet the requirements given in Table 1, Column A, where no absorption test is required, or the three-edge-bearing crushing strength shall meet the requirements given in Table 1, Column B, where an absorption test is required of the limits noted in Table 1.

Table 1—Physical Test Requirements for Standard-Quality Concrete Drain Tile

		Standard Quality Concrete Drain Tile									
				Three-Edge-Bearing Crushing Strength[a]						Absorption	
Internal Designated Diameter,		Maximum Wall Thickness for Indicated Strength,[c]		Minimum Average, A		Minimum Average, B		Minimum for Individual Tile,		Minimum Average, percent	Minimum for Individual Tile, percent
mm	in.	mm	in.	kN/linear m	lbf/linear ft	kN/linear m	lbf/linear ft	kN/linear m	lbf/linear ft		
100	4	—	—	—	—	12	800	10	700	10	11
125	5	14	$^{9}/_{16}$	13	900	12	800	10	700	10	11
125	5	16	$^{5}/_{8}$	15	1000	12	800	10	700	10	11
150	6	16	$^{5}/_{8}$	13	900	12	800	10	700	10	11
150	6	19	$^{3}/_{4}$	15	1000	12	800	10	700	10	11
200	8	19	$^{3}/_{4}$	13	900	12	800	10	700	10	11
200	8	22	$^{7}/_{8}$	15	1000	12	800	10	700	10	11
250	10	22	$^{7}/_{8}$	13	900	12	800	10	700	10	11
250	10	25	1	15	1000	12	800	10	700	10	11
300	12	25	1	13	900	12	800	10	700	10	11
300[b]	12[b]	29	$1^{1}/_{8}$	15	1000	12	800	10	700	10	11

[a] Drain tile meeting the above strength requirements are not necessarily safe against cracking in deep and wide trenches.

[b] Tile with diameters greater than 12 in. shall meet the requirements specified in Table 2 for Extra-Quality, Table 3 for Heavy-Duty Extra-Quality, or Table 4 for Special-Quality concrete drain tile.

[c] Maximum wall thickness for the indicated minimum average crushing strength, Column A, when no absorption test is required.

8.3.2 For Extra-Quality concrete drain tile, the three-edge-bearing crushing strength shall meet the requirements given in Table 2, Column A, where no absorption test is required, or the three-edge-bearing crushing strength shall meet the requirements given in Table 2, Column B, where an absorption test is required of the limits noted in Table 2.

Table 2—Physical Test Requirements for Extra-Quality Concrete Drain Tile

		Extra-Quality Concrete Drain Tile											
						Three-Edge-Bearing Crushing Strength[a]						Absorption	
Internal Designated Diameter,		Wall Thickness,		Maximum Wall Thickness for Indicated Strength,[b]		Minimum Average, A		Minimum Average, B		Minimum for Individual Tile,			Minimum for Individual Tile, percent
mm	in.	mm	in.	mm	in.	kN/ linear m	lbf/ linear ft	kN/ linear m	lbf/ linear ft	kN/ linear m	lbf/ linear ft	Minimum Average, percent	
100	4	13	1/2	—	—	—	—	16	1100	15	990	9	10
125	5	14	9/16	14	9/16	18	1200	16	1100	15	990	9	10
125	5	14	9/16	16	5/8	19	1300	16	1100	15	990	9	10
150	6	16	5/8	16	5/8	18	1200	16	1100	15	990	9	10
150	6	16	5/8	19	3/4	19	1300	16	1100	15	990	9	10
200	8	19	3/4	19	3/4	18	1200	16	1100	15	990	9	10
200	8	19	3/4	22	7/8	19	1300	16	1100	15	990	9	10
250	10	22	7/8	—	—	—	—	16	1100	15	990	9	10
300	12	25	1	—	—	—	—	16	1100	15	990	9	10
350	14	29	1 1/8	—	—	—	—	16	1100	15	990	9	10
375	15	32	1 1/4	—	—	—	—	16	1100	15	990	9	10
400	16	35	1 3/8	—	—	—	—	16	1100	15	990	9	10
450	18	38	1 1/2	—	—	—	—	18	1200	16	1080	9	10
500	20	41	1 5/8	—	—	—	—	20	1330	18	1200	9	10
550	22	44	1 3/4	—	—	—	—	22	1460	19	1320	9	10
600	24	50	2	—	—	—	—	24	1600	21	1440	9	10
650	26	54	2 1/8	—	—	—	—	25	1730	23	1560	9	10
700	28	60	2 3/8	—	—	—	—	28	1870	25	1680	9	10
750	30	63	2 1/2	—	—	—	1200	29	2000	27	1800	9	10
800	32	66	2 5/8	—	—	—	1300	31	2130	28	1920	9	10
850	34	72	2 7/8	—	—	—	1200	33	2270	30	2040	9	10
900	36	75	3	—	—	—	1300	35	2400	32	2160	9	10

[a] For crushing strengths greater than or equal to those shown in the above table, it is not prohibited to supply tile designed with increased wall thickness, higher strength concrete, or reinforcing.

[b] Maximum wall thickness for the indicated minimum average crushing strength, Column A, when no absorption test is required.

8.3.3 For Heavy-Duty Extra-Quality concrete drain tile, the three-edge-bearing crushing strength shall meet the requirements given in Table 3.

Table 3—Physical Test Requirements for Heavy-Duty Extra-Quality Concrete Drain Tile

		Heavy-Duty Extra-Quality Concrete Drain Tile							
				Three-Edge-Bearing Crushing Strength[a]				Absorption	
Internal Designated Diameter,		Wall Thickness,		Minimum Average,[b]		Minimum for Individual Tile,			
mm	in.	mm	in.	kN/linear m	lbf/linear ft	kN/linear m	lbf/linear ft	Minimum Average, percent	Minimum for Individual Tile, percent
100	4	13	$^{1}/_{2}$	19.0	1300	17.0	1170	9	10
125	5	14	$^{9}/_{16}$	19.0	1300	17.0	1170	9	10
150	6	16	$^{5}/_{8}$	19.0	1300	17.0	1170	9	10
200	8	19	$^{3}/_{4}$	19.0	1300	17.0	1170	9	10
250	10	22	$^{7}/_{8}$	20.5	1400	18.0	1260	9	10
300	12	25	1	22.0	1500	19.5	1350	9	10
350	14	29	$1^{1}/_{8}$	25.5	1750	23.0	1580	9	10
375	15	32	$1^{1}/_{4}$	27.5	1870	24.5	1690	9	10
400	16	35	$1^{3}/_{8}$	29.0	2000	26.5	1800	9	10
450	18	38	$1^{1}/_{2}$	33.0	2250	29.5	2030	9	10
500	20	41	$1^{5}/_{8}$	36.5	2500	33.0	2250	9	10
550	22	44	$1^{3}/_{4}$	40.0	2750	36.0	2470	9	10
600	24	50	2	44.0	3000	39.5	2700	9	10
650	26	54	$2^{1}/_{8}$	47.5	3250	43.0	2930	9	10
700	28	60	$2^{3}/_{8}$	51.0	3500	46.0	3150	9	10
750	30	63	$2^{1}/_{2}$	54.5	3750	49.5	3380	9	10
800	32	66	$2^{5}/_{8}$	58.5	4000	52.5	3600	9	10
850	34	72	$2^{7}/_{8}$	62.0	4250	55.5	3820	9	10
900	36	75	3	65.5	4500	59.0	4050	9	10

[a] For crushing strengths greater than or equal to those shown in the above table, it is not prohibited to supply tile designed with increased wall thickness, higher strength concrete, or reinforcing.

[b] Calculated average crushing strength for tile size above 10-in. diameter is based on a minimum ultimate three-edge-bearing load of 1500 *D*, where *D* is the internal diameter of tile in feet.

8.3.4 For Special-Quality concrete drain tile, the three-edge-bearing crushing strength shall meet the requirements given in Table 4, or the higher specified load.

Table 4—Physical Test Requirements for Special-Quality Concrete Drain Tile

		Special-Quality Concrete Drain Tile (for Tile Exposed to Corrosive Waters)						
Internal Designated Diameter,		Minimum Wall Thickness,		Minimum Individual Three-Edge-Bearing Crushing Strength,[a]		Absorption		
mm	in.	mm	in.	kN/ linear m	lbf/ linear ft	Maximum Average, percent	Maximum for Individual Tile, percent	Sulfate Exposures
100	4	13	$^{1}/_{2}$	16.0	1100	8	9	For sulfate exposures, sulfate-resistant cement should be specified. (See Section 7.)
125	5	14	$^{9}/_{16}$	16.0	1100	8	9	
150	6	16	$^{5}/_{8}$	16.0	1100	8	9	
200	8	19	$^{3}/_{4}$	16.0	1100	8	9	
250	10	22	$^{7}/_{8}$	16.0	1100	8	9	
300	12	25	1	16.0	1100	8	9	
350	14	29	1$^{1}/_{8}$	16.0	1100	8	9	
375	15	32	1$^{1}/_{4}$	16.0	1100	8	9	
400	16	35	1$^{3}/_{8}$	16.0	1100	8	9	
450	18	38	1$^{1}/_{2}$	17.5	1200	8	9	
500	20	41	1$^{5}/_{8}$	19.5	1330	8	9	
550	22	44	1$^{3}/_{4}$	21.5	1460	8	9	
600	24	50	2	23.5	1600	8	9	
650	26	54	2$^{1}/_{8}$	25.0	1730	8	9	
700	28	60	2$^{3}/_{8}$	27.5	1870	8	9	
750	30	63	2$^{1}/_{2}$	29.0	2000	8	9	
800	32	66	2$^{5}/_{8}$	31.0	2130	8	9	
850	34	72	2$^{7}/_{8}$	33.0	2270	8	9	
900	36	75	3	35.0	2400	8	9	

[a] For crushing strengths greater than or equal to those shown in the above table, tile may be supplied using designs with increased wall thickness, higher strength concrete, or reinforcing.

Note 2—To meet the crushing strength requirements shown in the tables, it is not prohibited to supply tile designed with increased wall thickness, high-compressive strength concrete, or reinforcing, or a combination.

8.4 *Absorption Tests*:

8.4.1 For Standard-Quality concrete drain tile, the boiling absorption test shall meet the requirements given in Table 1. No absorption tests are required if the strength requirements of Table 1, Column A, are met.

8.4.2 For Extra-Quality concrete drain tile, the boiling absorption test shall meet the requirements given in Table 2. No absorption tests are required if the strength requirements of Table 2, Column A, are met.

8.4.3 For Heavy-Duty Extra-Quality concrete drain tile, the boiling absorption test shall meet the requirements given in Table 3.

8.4.4 For Special-Quality concrete drain tile, the boiling absorption test shall meet the requirements given in Table 4.

8.4.5 Specimens for the boiling absorption tests shall be selected in accordance with the following provisions:

8.4.5.1 For the tile with inside diameters of 300 mm [12 in.] or less, and lengths of 300 mm [12 in.], the absorption test shall be made on one full-length quarter segment taken from each of the five tile broken in the strength test, constituting a standard sample as defined in Section 8.2. By quarter segment is meant one of the four pieces into which a tile usually breaks in the strength test. If a tile breaks in such a manner that a satisfactory quarter segment cannot be obtained, then the absorption test shall be made of two or more pieces that approximate the area of a quarter tile of that size selected so that both ends and the center portion of the tile are represented. The average absorption of the pieces so selected shall be considered the absorption for that tile.

8.4.5.2 For nonreinforced tile with inside diameters or lengths in excess of 300 mm [12 in.], the absorption test shall be made on three specimens; one of the specimens shall be taken from one end of the tile, another specimen from the opposite end, and the third specimen from near the center. The average absorption of the three specimens shall be considered the absorption for that tile.

8.4.5.3 For reinforced tile the absorption test shall be made on one specimen taken from each test tile.

8.4.5.4 The specimens shall be the full thickness of the tile, as broken or cut from segments that result from the strength test. Each specimen shall have a minimum area of not less than 0.016 m^2 [25 $in.^2$] as measured on one wall surface.

8.4.5.5 The average absorption for Standard-Quality, Extra-Quality, and Heavy-Duty Extra-Quality tile shall be the average of the absorption tests for the standard sample as defined in Section 8.2 or the average of the absorption tests for the strongest and the weakest tile as measured by the crushing strength of the standard sample. When drain tile fail to meet the absorption test requirement as computed by averaging the absorptions from the weakest and the strongest tile of a standard sample, then the average absorption test shall be computed by averaging the absorption tests from all the tile from the standard sample. The average absorption for the Special-Quality tile shall be the average of the absorption tests for the tile constituting the standard sample.

8.5 *Retests*:

8.5.1 Should the tile first selected fail to conform to the test requirements, the manufacturer, at his expense, is not prohibited from culling the tile and selecting other tile for retest from the remaining stock. For such retests, the number of tile shall be twice the number of tile used in the previous failed test for each standard physical test. In the event of failure of the tile after retest, reject the tile without further test. The manufacturer shall pay all cost for any retest demanded and made.

8.6 *Apparatus*—All apparatus used shall be in accordance with that described in T 280.

8.7 *Test Methods*—The test methods shall be as described in T 280.

9. PERMISSIBLE VARIATIONS

9.1 *Internal Diameter*—Permissible variations are as prescribed in Table 5.

Table 5—Permissible Variation in Internal Diameter

Designated Diameter of tile		Permissible Variation in Internal Diameter of Tile			
		Minimum		Maximum	
mm	in.	mm	in.	mm	in.
100	4	93	$3^{3}/_{4}$	107	$4^{1}/_{4}$
125	5	118	$4^{3}/_{4}$	132	$5^{1}/_{4}$
150	6	140	$5^{5}/_{8}$	160	$6^{3}/_{8}$
200	8	190	$7^{5}/_{8}$	210	$8^{3}/_{8}$
250	10	237	$9^{1}/_{2}$	263	$10^{1}/_{2}$
300	12	287	$11^{1}/_{2}$	313	$12^{1}/_{2}$
350	14	337	$13^{1}/_{2}$	363	$14^{1}/_{2}$
375	15	359	$14^{3}/_{8}$	391	$15^{5}/_{8}$
400	16	384	$15^{3}/_{8}$	416	$16^{5}/_{8}$
450	18	434	$17^{3}/_{8}$	466	$18^{5}/_{8}$
500	20	481	$19^{1}/_{4}$	519	$20^{3}/_{4}$
550	22	531	$21^{1}/_{4}$	569	$22^{3}/_{4}$
600	24	581	$23^{1}/_{4}$	619	$24^{3}/_{4}$
650	26	625	25	675	27
700	28	675	27	725	29
750	30	725	29	775	31
800	32	775	31	825	33
850	34	825	33	875	35
900	36	875	35	925	37

9.2 *Wall Thickness*:

9.2.1 No wall thickness is specified for Standard-Quality concrete drain tile where the crushing strength and the absorption tests are used to determine the tile quality. When only the crushing strength is used to determine Standard Quality tile then the wall thickness for Standard-Quality tile shall be as indicated in Table 1. The wall thickness of Extra-Quality and Heavy-Duty Extra-Quality concrete drain tile at any point shall not be less than the full thickness specified in Tables 2 or 3 by more than 2 mm [$^{1}/_{16}$ in.] for the tile having inside diameters of 100 mm [4 in.], 125 mm [5 in.], and 150 mm [6 in.]; 2 mm [$^{3}/_{32}$ in.] for tile having inside diameters of 200 mm [8 in.] to 250 mm [10 in.]; 3 mm [$^{1}/_{8}$ in.] for tile having inside diameters of 200 mm [12 in.] to 250 mm [24 in.]; and 3 mm [$^{5}/_{32}$ in.] for tile having inside diameters of 650 mm [26 in.] to 900 mm [36 in.] The minimum thickness of Special-Quality drain tile walls at any point shall be not less than shown in Table 4.

9.2.2 The tile wall thickness shall be recorded as the average of 12 wall thickness measurements as made at the top, center, and bottom locations on each of the four quarter tile segments that usually result when a tile is tested for crushing strength. If a tile breaks in such a manner that a satisfactory quarter segment is not obtained, then the 12 wall thickness measurements shall be made on the broken pieces that best represent the top, center, and bottom on the four circumferential location of the tile.

9.3 *Length of Tile*—The length of drain tile smaller than 300 mm [12 in.] in diameter shall be not less than 300 mm [12 in.] Tile of 300 mm [12 in.] to 900 mm [36 in.] in diameter, inclusive, shall have lengths not less than the diameters. The underrun of individual tile shall not exceed 3 percent of the length.

9.4 *Shape*—All drain tile shall be circular in cross section, except when otherwise specified in advance. They shall be approximately straight, except in the case of special connections. The ends of tile shall be so regular and smooth as to readily permit the making of satisfactory close joints and shall be so formed that when the tile are laid together the effective space at the joints will be satisfactory for good drainage.

10. INSPECTION

10.1 All drain tile shall be given a thorough inspection at the agreed delivery point by an inspector approved by the owner, unless a satisfactory inspection has been made in advance of delivery as specified in Section 8.1. The purpose of the inspection shall be to determine whether the tile, independently of meeting the physical test requirements, conform to the specifications as regards shapes and sizes as prescribed in Section 9 and to eliminate defective tile as defined in Section 11. The manufacturer of the drain tile shall afford the inspector all reasonable facilities for his work—both as to the selection of tile for tests and as to inspection of the tile. Inspection shall be completed and reported promptly and full reports of all tests and inspection shall be furnished the manufacturer upon his request.

11. REJECTION

11.1 The owner shall plainly designate all drain tile that he rejects, and such rejected tile shall be removed promptly by the manufacturer, from any job to which the tile have been delivered.

11.2 Drain tile that, when placed in a vertical position, do not give a metallic ring when struck with a light metal hammer, or that are observed to have cracks that extend through the tile wall and are of a length in excess of 13 mm [$^1/_2$ in.], or other defects in the form or dimensions in excess of the limits permitted in this specification, shall be discarded. Outside surface irregularities that do not affect the tile strength shall not be considered reason for rejection of the tile.

12. KEYWORDS

12.1 Concrete drain tile; subsurface drainage; surface drainage; tile.

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[1] Agrees with ASTM C 412M-05a and C 412-05a except for limiting absorption testing to the 5-hour boil method and the manufacturer is not afforded the option to supply inch-pound sized pipe when the order is placed in SI units.

Standard Specification for

Bituminous-Coated Corrugated Metal Culvert Pipe and Pipe Arches

AASHTO Designation: M 190-04 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Bituminous-Coated Corrugated Metal Culvert Pipe and Pipe Arches

AASHTO Designation: M 190-04 (2008)

1. SCOPE

1.1 This specification covers bituminous-coated corrugated metal pipe and pipe-arches intended to be used for the construction of metal culverts of the following types.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 36, Corrugated Steel Pipe, Metallic-Coated, for Sewers and Drains
- M 196, Corrugated Aluminum Pipe for Sewers and Drains
- T 44, Solubility of Bituminous Materials
- T 49, Penetration of Bituminous Materials

2.2 *ASTM Standards*:

- A 849, Standard Specification for Post-Applied Coatings, Pavings, and Linings for Corrugated Steel Sewer and Drainage Pipe
- A 862/A 862M, Standard Practice for Application of Asphalt Coatings to Corrugated Steel Sewer and Drainage Pipe
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 6, Standard Test Method for Loss on Heating of Oil and Asphaltic Compounds
- D 1005, Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers

3. DESCRIPTION

3.1 This specification covers four types of pipe as follows:

Type A—Fully Bituminous-Coated

Type B—Half Bituminous-Coated with Paved-Invert

Type C—Fully Bituminous-Coated and Paved-Invert

Type D—Fully Bituminous-Coated and 100 Percent Paved or Lined

3.2 Bituminous-coated corrugated metal culvert pipe and pipe-arches shall conform to the requirements of M 36 or M 196 and, in addition, shall be coated with bituminous material as hereinafter described for the particular type specified.

3.2.1 *Type A*—The pipe shall be uniformly coated, inside and outside, to a minimum thickness of 1.3 mm measured on the crest of the corrugations or, in the case of Type 1A pipe, over the inner surface of the pipe. This coating is also used for Type 1A pipe.

3.2.2 *Type B*—The pipe shall be uniformly coated for approximately one-half the circumference of the pipe (bottom of the pipe installed), inside and outside to a minimum thickness of 1.3 mm and, in addition, the bituminous material shall be applied in such a manner that one or more smooth pavements will be formed in the invert (inside bottom of the pipe when installed), filling the corrugations for at least 25 percent of the circumference of a pipe and 40 percent of the circumference of a pipe-arch. The pavement shall have a minimum thickness of 3.2 mm above the crest of the corrugations, except where the upper edges intersect the corrugations.

3.2.3 *Type C*—The pipe shall be fully coated as required for Type A and, in addition, a smooth pavement shall be provided as required for Type B.

3.2.4 *Type D*—The pipe shall be fully coated as required for Type A and, in addition, a smooth lining of asphalt shall be centrifugally spun inside the pipe. The lining shall have a minimum thickness of 3.2 mm above the crest of the corrugations.

4. BITUMINOUS MATERIAL

4.1 The bituminous material for coating shall be an asphalt having the following properties:

	Limit, percent
Solubility in trichloroethylene, not less than	99.0
Loss on heating to 163°C, not more than	1
Penetration of residue after heating compared with penetration of same sample before testing for loss on heating, not less than	85

4.2 *Shock Test*—The bitumen shall be considered acceptable if not more than one of four test specimens shows a crack. If it is difficult to determine visually whether a specimen has cracked, the specimen should be removed from the test apparatus and subjected to a slight bending.

4.3 *Flow Tests*—The bitumen shall be considered acceptable if the flow does not exceed 6.4 mm on either of the two test specimens.

5. TANK CONTROL AND MAINTENANCE

5.1 *Tank Temperature*—The asphalt temperature in the tank shall be maintained between 200 and 210°C during the coating operation.

5.2 *Tank Cleanliness*:

5.2.1 The asphalt in the tank shall be kept free of contaminants such as dirt, drum paper, and asphalt drippings from the shop floor.

5.2.2 The asphalt tank shall be cleaned as necessary with a minimum frequency of once per year.

5.2.3 The foam that results from the inadvertent introduction of moisture to the tank shall be skimmed off or moved to the side of the tank before inserting or extracting the product.

6. PROCEDURE

6.1 *Coating Application*—Apply the asphalt coating by inserting the product into the bath twice; the first application results in a thin coating to achieve good adherence, and the second achieves the coating thickness required in Section 3.2.

6.1.1 Steel surfaces shall be free of dirt, grease, dust, and moisture before placement in the asphalt bath. The product shall be prepared immediately prior to the coating operation.

6.1.2 Rotate any large structures in the tank to ensure that all surfaces are coated.

6.1.3 The product must remain in the tank until it achieves a minimum temperature of 190°C. The specific time requirements will depend on factors unique to each operation and the product being coated. The time to reach the required temperature is dependent on the initial temperature of the product, the steel thickness, the size of the product, and the volume of the tank.

6.1.4 The following table contains minimum immersion times:

Steel Thickness, mm	Time, min
1.32	2 to 2.5
1.63	2.5 to 3
2.01	3.5 to 5
2.77	5 to 6
3.50	6.5 to 8
4.27	8 to 14

6.1.5 Cool the product to ambient temperature before application of the second coat.

6.1.6 Insert the product a second time to provide the minimum thickness of each surface.

6.2 *Paving*:

6.2.1 Pave the interior of the coated pipe by applying the hot asphalt from the tank to the interior surface of the pipe to provide a thickness over the crest of the corrugation as required by Section 3.2. Pump the hot asphalt to the pipe by appropriate mechanical means, not by transfer with buckets. The asphalt used for paving shall be at least 200°C to ensure good adhesion to the coated pipe. Pave the pipe as soon as possible after coating to avoid poor adhesion associated with the accumulation of dirt and other residue on the coating surface.

6.2.2 Place end dams of wood or heavy paper at the ends of the pipe to retain the asphalt in the pipe. Three or more applications are usually required for most operations.

6.3 *Smooth Lining*:

6.3.1 Line the interior of the pipe that has been coated by covering the corrugations with hot asphalt. Provide a thickness over the crest of the corrugations as required by Section 3.2.

6.3.2 Spray the hot asphalt, taken from the tank, while rotating the pipe on a powered rotary device to provide a uniform smooth lining.

6.4 *Storage and Handling*:

6.4.1 Store and handle the coated product properly to avoid bruising, scaling, or scuffing of the asphalt coating.

6.5 *Repair*—Repair damaged coatings with a cold-applied asphalt mastic material described in ASTM A 849. Repair coatings shall be of equal thickness to the previous coating as a minimum and shall have equal adherence.

7. POST TESTING OF APPLIED ASPHALT

7.1 All asphalt used by pipe fabricators/coaters shall be purchased to meet the requirements of Section 4.1. Post testing of applied asphalt coatings shall be in accordance with state Department Of Transportation requirements and follow the procedures described in this specification. Samples of the bituminous coating shall be obtained by gathering strippings, sufficient to make a 0.283-kg sample, from the inside top of one or more lengths of pipe on or about to be delivered to the project. Care shall be taken in sampling to avoid contamination from sand or soapstone that may have been applied after dipping.

7.2 Testing of the asphalts shall be in accordance with the following standard methods of the American Association of State Highway and Transportation Officials:

Solubility in trichloroethylene	T 44
Loss on heating	D 6
Penetration of residue	T 49

7.3 Physical requirements of the coating.

7.3.1 *Shock Test*—The apparatus for making the test consists of a rigid metal anvil or base plate not less than 12.7 mm thick resting on a solid foundation; a 2000-gr hammer arranged to fall freely in suitable guides against a 1000-gr plunger sliding freely in a vertical sleeve; the lower end of the plunger being spherical in shape with a radius of 12.7 mm; means for raising the hammer and dropping it through a distance of 130 mm upon the head of the plunger.

7.3.1.1 Four test specimens shall be prepared in the form of disks 44.5 mm in diameter and 9.5 mm thick. Approximately 110 g of the bituminous sample shall be heated over a low flame until it becomes fluid and then poured into a brass mold or molds. Care must be exercised to melt the sample at the lowest possible temperature and to stir thoroughly until it is homogeneous and free from air bubbles. The test specimens may be molded separately or the material may be poured in one cylinder 44.5 mm in diameter and of such length that the four specimens may be cut from it with a wire cutter.

Split brass molds, coated with a suitable release agent (Note 1) having an inside diameter of 44.5 mm, slightly tapered outside surfaces, and held together by slip rings will be found suitable for molding the test specimens.

7.3.1.2 If disk molds are used to prepare the specimens, they shall be removed after the asphalt has cooled to room temperature. The four specimens shall be cooled for a period of at least 1 hour in a bath of ice and salt brine at a temperature of –1°C. The specimens shall then be removed from the bath one at a time and quickly placed on the anvil of the test apparatus and centered under the plunger, the hammer tripped to fall through a height of 130 mm upon the head of the plunger. Not more than 8 seconds shall elapse from the time each specimen is removed from the bath until the hammer strikes the plunger.

7.3.1.3 *Precision*—The shock test described in this method is defined as a determination that at least three of four separate specimens comprising a single test sample will exhibit no cracking to yield an acceptable result. Analysis of an interlaboratory study (a blind study carried out by nine laboratories on four different materials with three replicates of each material) reveals a pass/fail ratio for tests on the same material ranging from 0.22 to 1.45, with an overall pass/fail ratio for all 108 samples (27 samples of each of 4 materials) of 0.54. Further, in each of 11, out of the total of 36 cases, where three replicate samples of the same material were tested in the same laboratory, the same laboratory obtained passing results on one of the three replicate samples and failing results on the other two replicate samples or vice versa.

7.3.1.4 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in the test method for measuring shock, no statement on bias is being made.

7.3.2 *Flow Tests*—The apparatus for making the test shall consist of corrugated brass plate approximately 0.8 mm thick, 203.2 mm long, and 101.6 mm wide, with corrugations running lengthwise of the plate, and a metal support to hold the plate on a 45-degree angle with the horizontal. The corrugations shall have a crest-to-crest dimension of 15.9 mm and a depth of 4.8 mm. A line shall be scribed 150 mm from the lower edge.

7.3.2.1 Test specimens shall be in the form of cylinders 9.5 mm in diameter and 19.0 mm in length. Two specimens shall be used for each test. These shall be made by pouring the excess bituminous material from the specimens for the shock test into split brass molds coated with a suitable release agent (Note 1).

Note 1—Mixtures of glycerine and dextrin or talc, Dow-Corning Stop Cock Grease, and castor oil—Versamid 900 (100:1 mixture by mass heated to 204 to 232ºC and stirred until homogeneous), have proven suitable. Other release agents may be used provided results obtained are comparable to those obtained when using one of the above.

7.3.2.2 With the corrugated plate held at an angle of 45 degrees with the horizontal, lay each test specimen in a corrugation so that its lower end will rest exactly along the line scribed 150 mm from the bottom edge of the plate and place the test apparatus in an oven maintained at a temperature of 65 ± 1ºC. After 4 hours in the oven, remove the apparatus and specimens and allow to cool to room temperature. Measure the distance from the bottom of the corrugated plate to the lower edge of the test specimens. This distance subtracted from 150 mm determines the amount of flow.

7.3.2.3 *Precision*:

Single Operator Precision-Flow Test—The single operator coefficient of variation for a single test result (a test result in this method has been defined as the measurements on two separate specimens) has been found to be 65 percent (Note 2). Therefore, two properly conducted tests by the same operator (each consisting of measurements on two specimens from the same sample) should not differ by more than 184 percent (Note 2) of their average. The range (difference between the highest and lowest) of the two individual measurements comprising a test result should not exceed 260 percent (Note 3) of the average of the two.

Multilaboratory Precision-Flow Test—The multilaboratory coefficient of variation of a single test result (a test result in this method has been defined as the measurements on two separate specimens) has been found to be 97 percent (Note 2). Therefore, results of two properly conducted tests in different laboratories on the same bituminous coating should not differ by more than 275 percent (Note 2) of their average.

Note 2—These numbers represent respectively the (1s percent) and (d2s percent) limits described in ASTM C 670.

Note 3—Calculated as described in the paragraph on precision of individual measurements averaged to obtain a test result in ASTM C 670.

Note 4—These precision statements are based on results of an interlaboratory test program using three replicates of each of four materials. Nine laboratories participated in the tests.

7.3.2.4 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in the test method for measuring flow, no statement on bias is being made.

7.3.3 *Imperviousness Test*—A 25 percent solution of sulfuric acid, a 25 percent solution of sodium hydroxide, and a saturated solution of sodium chloride shall be held in separate valleys of the coated corrugations for a period of 48 hours, during which time no loosening or separation of the bituminous material from the galvanizing shall have taken place. This test may be made on an uncut section of pipe provided provision is made to prevent excessive evaporation of the three test solutions.

7.3.3.1 *Precision and Bias*—No statement is made about either the precision or the bias of the imperviousness test since the result only states whether there is conformance to the criteria for success specified in the procedure.

8. INSPECTION

8.1 The purchaser or his representative shall have free access to the fabricating plant for inspection, and every facility shall be extended to him for this purpose. This inspection shall include an examination of the pipe for defects in the coating. Defects include bruising, cracking, disbanding, or other damage.

8.2 On a random basis, samples may be taken for analysis and asphalt coating measurements for check purposes. These samples may be taken from post-coated pipe or from the dip tank during the dipping process. The thickness of the asphalt coating shall be measured in accordance with test ASTM D 1005.

9. REJECTION

9.1 Asphalt coatings failing to conform to the specific requirements of this specification, or that show poor workmanship in general or poor workmanship in limited areas that have not been repaired in accordance with Section 6.5 are subject to rejection. This requirement applies not only to the individual pipe, but to any shipment as a whole in which a substantial number of pipes have defective coatings.

10. CERTIFICATION

10.1 Pipe fabricator/coater shall furnish certifications from the asphalt suppliers that the asphalt meets the requirements of Section 4 and that the asphalt for the supplied pipe has been applied in accordance with this specification and the appropriate tank control and maintenance have been performed in accordance with this specification.

Standard Specification for

Corrugated Aluminum Pipe for Sewers and Drains

AASHTO Designation: M 196-92 (2008)
ASTM Designation: B 745/B 745M-95

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Corrugated Aluminum Pipe for Sewers and Drains

AASHTO Designation: M 196-92 (2008)
ASTM Designation: B 745/B 745M-95

1. SCOPE

1.1. This specification covers corrugated aluminum pipe intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses. Pipe covered by this specification is not normally used for the conveyance of sanitary or industrial wastes.

1.2. This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and sheet thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of sheet thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The purchaser must correlate the above factors and also the corrosion and abrasion requirements of the field installation with the sheet thickness. The structural design of corrugated aluminum pipe and the proper installation procedures are given in *AASHTO LRFD Bridge Design Specifications* and *AASHTO LRFD Bridge Construction Specifications*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 197, Aluminum Alloy Sheet for Corrugated Aluminum Pipe
- M 198, Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- T 249, Helical Lock Seam Corrugated Pipe
- *AASHTO LRFD Bridge Design Specifications*
- *AASHTO LRFD Bridge Construction Specifications*

2.2. *ASTM Standards*:

- B 221M, Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]
- B 316/B 316M, Standard Specification for Aluminum and Aluminum-Alloy Rivet and Cold-Heading Wire and Rods
- B 633, Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
- B 666/B 666M, Standard Practice for Identification Marking of Aluminum and Magnesium Products
- D 1056, Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber

- F 467M, Standard Specification for Nonferrous Nuts for General Use [Metric]
- F 468M, Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]
- F 568M, Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners
- F 593, Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs
- F 594, Standard Specification for Stainless Steel Nuts
- F 738M, Standard Specification for Stainless Steel Metric Bolts, Screws, and Studs
- F 836M, Standard Specification for Style 1 Stainless Steel Metric Nuts

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1. *fabricator*—the producer of the pipe.

3.2. *manufacturer*—the producer of the sheet.

3.3. *purchaser*—the purchaser of the finished product.

4. CLASSIFICATION

4.1. The corrugated aluminum pipe covered by this specification is classified as follows:

4.1.1. *Type I*—This pipe shall have a full circular cross section, with a single thickness of corrugated sheet, fabricated with annular (circumferential) or helical corrugations.

4.1.2. *Type IA*—This pipe shall have a full circular cross section, with an outer shell of corrugated sheet and an inner liner of smooth (uncorrugated) sheet, fabricated with helical corrugations and lock seams.

4.1.3. *Type IR*—This pipe shall have a full circular cross section with a single thickness of smooth sheet, fabricated with helical ribs projecting outwardly.

4.1.4. *Type II*—This pipe shall be a Type I pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.5. *Type IIA*—This pipe shall be a Type IA pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.6. *Type IIR*—This pipe shall be a Type IR pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.7. *Type III*—This pipe, intended for use as underdrains or for underground disposal of water, shall be a Type I pipe which has been perforated to permit the inflow or outflow of water.

4.1.8. *Type IIIR*—This pipe, intended for the underground disposal of water or for subsurface drainage, shall be a Type IR pipe that has been perforated to permit the outflow or inflow of water.

4.2. Perforations in Type III pipe are classified as Class 1 or Class 2 and perforations in Type IIIR pipe are classified as Class 4, as described in Section 8.3.2.

5. ORDERING INFORMATION

5.1. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product:

5.1.1. Name of material (corrugated aluminum pipe);

5.1.2. AASHTO designation and year of issue;

5.1.3. Type of pipe (Section 4.1);

5.1.4. Method of fabrication for Type I and Type II pipe (Section 7.1);

5.1.5. Diameter of circular pipe (Section 8.1.1), or span and rise of pipe-arch section (Section 8.2.1);

5.1.6. Length, either total length or length of each piece and number of pieces;

5.1.7. Description of corrugations (Section 7.2);

5.1.8. Sheet thickness (Section 8.1.2);

5.1.9. Coupling bands, number, and type (Section 9.1) if special type is required;

5.1.10. Gaskets for coupling bands, if required (Section 9.3);

5.1.11. For perforated pipe, the class of perforations. If no class is specified for Type III pipe, Class 1 perforations will be furnished. Type IIIR pipe is furnished with Class 4 perforations only (Section 8.3.2);

5.1.12. Certification, if required (Section 13.1); and

5.1.13. Special requirements.

6. MATERIALS

6.1. *Aluminum Sheet for Pipe*—All pipe fabricated under this specification shall be formed from aluminum alloy sheet conforming to M 197.

6.2. *Aluminum Sheet for Coupling Bands*—The sheet used in fabricating coupling bands shall conform to M 197.

6.3. *Rivets*—The material used for rivets in riveted pipe shall conform to the requirements of ASTM B 316/B 316M for alloy 6053-T4, with the following mechanical properties:

Tensile strength, min, MPa	170
Yield strength, min, MPa	95
Shear strength, min, MPa	105
Elongation in 50 mm, or 4 × diameter, min, percent	16

If bolts and nuts are substituted for rivets (see Section 7.3.1), they shall meet the following requirements for either steel bolts and nuts, stainless steel bolts and nuts, or aluminum alloy bolts and nuts:

	Bolts	Nuts
For M 196 pipe:		
(Steel)	F 568, Cl 4.6	M 291M, Cl 5
(Stainless steel)	F 738, Alloy Grp A1, A2, or A4	F 836, Alloy Grp A1, A2, or A4
(Aluminum alloy)	F 468M, Alloy 6061-T6	F 467M, Alloy 6061-T6

The steel bolts and nuts shall be hot-dip galvanized in conformance with M 232M/M 232, or be mechanically galvanized in conformance with M 298, Class 40.

6.4. *Hardware for Coupling Bands*—Bolts and nuts for coupling bands shall conform to the requirements shown in Section 6.3 except for the coating on steel bolts and nuts. Steel bolts, nuts, and other threaded steel items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 8; or mechanical process as provided in M 298, Class 8. Other steel hardware items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633 Class Fe/Zn 25; or mechanical process as provided in M 298, Class 25. Aluminum angles and lugs shall conform to the requirements of ASTM B 221M for alloy 6063-T6.

6.5. *Gaskets*—If gaskets are used in couplings, they shall be a band of expanded rubber meeting the requirements of ASTM D 1056 for the “RE” closed cell grades, or O-rings meeting the requirements of M 198.

7. FABRICATION

7.1. *General Requirements*—Pipe shall be fabricated in full circular cross section.

7.1.1. Type I pipe shall have annular corrugations with lap joints fastened with rivets or shall have helical corrugations with a continuous lock seam extending from end to end of each length of pipe. As there are important differences in the structural characteristics of annular riveted pipe versus helical pipe, it is important for the purchaser to stipulate, for Type I and Type II pipe, the method of fabrication desired. If the method of fabrication is not stated in the ordering information, the fabrication method shall be at the option of the fabricator.

7.1.2. Type IA pipe shall be fabricated with a smooth liner and helically corrugated shell integrally attached at helical lock seams extending from end to end of each length of pipe. The shell shall have corrugations of nominal 68- or 75-mm pitch.

7.1.3. Type IR pipe shall be fabricated with helical ribs projecting outward with a continuous lock seam extending from end to end of each length of pipe.

7.2. *Corrugations*—The corrugations shall be either annular or helical as provided in Section 7.1. The direction of the crests and valleys of helical corrugations shall not be less than 60 degrees from the axis of the pipe for pipe diameters larger than 525 mm, and not less than 45 degrees from the axis for pipe diameters of 525 mm and smaller.

7.2.1. For Type I and IA pipe, corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 1 for the size indicated in the order.

Table 1—Corrugated Requirements for Types I, IA, II, and III Pipe

Nominal Size, mm	Max Pitch,[a] mm	Min Depth,[b] mm	Inside Radius[c]	
			Nominal, mm	Min, mm
38 × 6.5[d]	48	6.0	7	6.5
68 × 13	73	12[e]	17	12
75 × 25	83	24	14	12
150 × 25	160	24	56	51

[a] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe, to the bottom of the intervening valley.

[c] Minimum inside radius requirement does not apply to a corrugation containing a helical lock seam.

[d] The corrugation size of 38 × 6.5 mm is available only in helically corrugated pipe.

[e] For pipe 300 to 525 mm diameter inclusive, the minimum corrugation depth shall be 11 mm.

7.2.2. For Type IR pipe, the corrugations shall be essentially rectangular ribs projecting outward from the pipe wall. The dimensions and spacings of the ribs shall be in accordance with Table 2 for the size indicated in the order. For the 292-mm rib spacing, a stiffener shall be included midway between the ribs if the sheet between the ribs does not include a lock seam. This stiffener shall have a nominal radius of 6.4 mm and a minimum height of 5.1 mm toward the outside of the pipe.

Table 2—Rib Requirements for Type IR Pipe

Nominal Size, mm	Rib			Bottom Outside Radius, Min, mm	Bottom Outside Radius,[d] Max Avg, mm	Top Outside Radius, Min, mm	Top Outside Radius,[d] Max Avg, mm
	Width,[a] Min, mm	Depth,[b] Min, mm	Spacing,[c] Max, mm				
19 × 19 × 190	17	19	197	2.5	6.0	2.5 + ^{t}	6.0 + ^{t}
19 × 25 × 292	17	24	298	2.5	6.0	2.5 + ^{t}	6.0 + ^{t}

[a] Width is a dimension of the inside of the rib, but is measured on the outside of the pipe (outside of the rib) and shall meet or exceed the stated minimum width plus two times the wall thickness; that is, 2t + 17 mm.

[b] Depth is an average of three ribs (one sheet width) measured from the inside by placing a straightedge across the open rib and measuring to the bottom of the ribs.

[c] Spacing is an average of three ribs (one sheet width) measured center-to-center of the ribs at 90 degrees to the direction of the ribs.

[d] The average of the four rib radii (Top and Bottom) shall be within the minimum and maximum tolerances. The outside radius refers to the surface outside of the pipe.

Note 1—The nominal dimensions and properties for smooth corrugations and for ribs are given in *AASHTO LRFD Design Specifications*, Section 12.

7.3. *Riveted Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any rivet. Pipe to be reformed into pipe-arch shape shall have seams meeting the longitudinal seam requirement of Section 8.2.2.

Note 2—Fabrication of pipe without longitudinal seams in 120 degrees of arc, so that the pipe may be installed without longitudinal seams in the invert, is subject to negotiation between the purchaser and fabricator.

7.3.1. The size of rivets, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 3, depending on sheet thickness, corrugation size, and diameter of pipe. For pipe with 25-mm deep corrugations, M12 diameter bolts and nuts may be used in lieu of rivets on a one-for-one replacement ratio. Circumferential seams shall be riveted using rivets of the same size as for longitudinal seams and shall have a maximum rivet spacing of 150 mm measured on centers, except that six rivets will be sufficient in 300-mm diameter pipe.

Table 3—Riveted Longitudinal Seams

Specified Sheet Thickness, mm	Nominal Corrugation Size		
	68×13 mm[a,b]	75×25 mm[c,d]	150×25 mm[d,e]
	Rivet Diameters, Min, mm		
1.52	8.0	9.5	12.7
1.91	8.0	9.5	12.7
2.67	9.5	12.7	12.7
3.43	9.5	12.7	12.7
4.17	9.5	12.7	12.7

[a] One rivet each valley for pipe diameters 900 mm and smaller. Two rivets each valley for pipe diameters 1050 mm and larger.

[b] Minimum width of lap 38 mm for pipe diameters 900 mm and smaller, and 75 mm for pipe diameters 1050 mm and larger.

[c] Two rivets each valley for all pipe diameters.

[d] Minimum width of lap 75 mm for pipe of all diameters.

[e] Two rivets each crest and valley for all pipe diameters.

7.3.2. All rivets shall be driven cold in such a manner that the sheets shall be drawn tightly together throughout the entire lap. The center of a rivet shall be no closer than twice its diameter from the edge of the sheet. The distance between the centerlines of the two rows of rivets, where two rows are required, shall not be less than 38 mm. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the purchaser, shall be driven without bending, and shall completely fill the hole.

7.4. *Helical Lock Seams*—The lock seam for Type I pipe shall be formed in the tangent element of the corrugation profile with its center near the neutral axis of the corrugation profile. The lock seam for Type IA pipe shall be in the valley of the corrugation, shall be spaced not more than 760 mm apart, and shall be formed from both the liner and the shell in the same general manner as Type I helical lock seam pipe. The lock seam for Type IR pipe shall be formed in the flat zone of the pipe wall, midway between two ribs.

7.4.1. The edges of the sheets within the cross section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of –10 percent of lap width allowable. The lapped surfaces shall be in tight contact. The profile of the sheet shall include a retaining offset adjacent to the 180-degree fold (as described in T 249) of one sheet thickness on one side of the lock seam, or one-half sheet thickness on both sides of the lock seam, at the fabricator's option. There shall be no visual cracks in the metal, loss of metal-to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam. The lock seam shall be mechanically staked (indented) at periodic intervals, or otherwise specially constructed to prevent slippage.

7.4.2. Specimens cut from production pipe normal to and across the lock seam shall develop the tensile strength as provided in Table 4, when tested according to T 249. For Type IA pipe, the lock seam strength shall be as tabulated based on the thickness of the corrugated shell.

7.4.3. When the ends of helically corrugated lock seam pipe have been rerolled to form annular corrugations, either with or without a flanged end finish, the lock seam in the rerolled end shall not contain any visible cracks in the base metal and the tensile strength of the lock seam shall be not less than 60 percent of that required in Section 7.4.2.

Table 4—Specified Aluminum Alloy Sheet Thickness and Lock Seam Tensile Strength

Specified Sheet Thickness,[a, b] mm	Lock Seam Tensile Strength, Min, kN/mm
0.91	17
1.22	25
1.52	30
1.91	43
2.67	74
3.43	96
4.17	122

[a] Thicknesses listed are those included in M 197.

[b] For Type IA pipe, the lock seam tensile strength requirements shall be based on the thickness of the corrugated shell.

7.5. *End Finish*:

7.5.1. To facilitate field jointing, the ends of individual pipe sections with helical corrugations or ribs may be rerolled to form annular corrugations extending at least two corrugations from the pipe end, or to form an upturned flange meeting the requirements in Section 7.5.3, or both. The diameter of ends shall not exceed that of the pipe barrel by more than the depth of the corrugation. All types of pipe ends, whether rerolled or not, shall be matched in a joint such that the maximum difference in the diameter of abutting pipe ends is 13 mm.

7.5.2. When pipe with helical corrugations or ribs is rerolled to form annular corrugations in the ends, the usual size of annular corrugations is 68 × 13 mm.

7.5.3. If a flanged finish is used on the ends of individual pipe sections to facilitate field jointing, the flange shall be uniform in width, not less than 13 mm wide, and square to the longitudinal axis of the pipe.

7.5.4. The ends of all pipe that will form the inlet and outlet of culverts, fabricated of sheets having nominal thicknesses of 1.91 mm and less, shall be reinforced in a manner approved by the purchaser, when specified.

8. PIPE REQUIREMENTS

8.1. *Type I, Type IA, and Type IR Pipe*:

8.1.1. *Pipe Dimensions*—The nominal diameter of the pipe shall be as stated in the order, selected from the sizes listed in Table 5. The size of corrugations that are standard for each size of pipe are also shown in Table 5. The average inside diameter of circular pipe and pipe to be reformed into pipe-arches shall not vary more than 1 percent or 13 mm, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugations. Alternately, for pipe having annular corrugations, conformance with the inside diameter requirement may be determined by measuring the outside circumference, for which minimum values are given in Table 5.

Note 3—The outside circumference of helically corrugated pipe is influenced by the corrugation size and the angle of the corrugations, affecting the number of corrugations crossed; therefore, no minimum circumferential measurement can be specified.

Table 5—Pipe Sizes

Nominal Inside Diameter, mm	Corrugation Sizes[a]					Min Outside Circumference,[c] mm
	38 × 6.5 mm	68 × 13 mm	75 × 25 mm	150 × 25 mm	Ribbed Pipe[b]	
100	X					284
150	X					441
200	X					598
250	X					755
300		X				912
375		X			X	1226
450		X			X	1383
525		X			X	1540
600		X			X	1854
675		X			X	2169
750		X	X		X	2483
825		X	X		X	2561
900		X	X		X	2797
1050		X	X		X	3269
1200		X	X	X	X	3739
1350		X	X	X	X	4209
1500		X	X	X	X	4875
1600		X	X	X	X	4987
1650		X	X	X	X	5142
1800		X	X	X	X	5609
1950			X	X	X	6075
2100			X	X	X	6542
2250			X	X		7008
2400			X	X		7475
2550			X	X		7941
2700			X	X		8408
2850			X	X		8874
3000			X			9341

[a] An “X” indicates standard corrugation sizes for each nominal diameter of pipe.

[b] Rib size 19 × 19 × 190 mm and 19 × 25 × 292 mm.

[c] Measured in valley of annular corrugations. Not applicable to helically corrugated pipe.

8.1.2. *Sheet Thickness*—Sheet thickness shall be specified by the purchaser from the specified sheet thicknesses listed in Table 4 (Notes 4 and 5). For Type IA pipe, the thickness of both the shell and the liner shall be given; the thickness of the corrugated shell shall be at least 60 percent of the thickness of the equivalent Type I pipe; the liner shall have a nominal thickness of at least 0.91 mm; and the sum of the specified thicknesses of shell and liner shall equal or exceed the specified thickness of an equivalent pipe of identical corrugations as the shell according to the design criteria in the *AASHTO LRFD Bridge Design Specifications*.

Note 4—The sheet thicknesses indicated in Table 4 are the thicknesses listed as available in M 197.

Note 5—The purchaser should determine the required thickness for Type I, IA, or IR pipe, or Type I, IA, or IR pipe to be reformed into Type II, IIA, or IIR pipe according to the design criteria in *AASHTO LRFD Bridge Design Specifications*, or other appropriate guidelines. Specified thickness of 0.91 mm is generally used only for Type IA pipe.

8.1.3. When specified by the purchaser, the finished pipe shall be factory elongated to the extent specified. The elongation shall be accomplished by the use of a mechanical apparatus that will produce a uniform deformation throughout the length of the section.

Note 6—When corrugated aluminum pipe is designed and installed according to *AASHTO LRFD Bridge Construction Specifications*, vertical elongation (factory or field) is not required for structural purposes.

8.2. *Type II, IIA, and IIR Pipe*:

8.2.1. *Pipe-Arch Dimensions*—Pipe furnished as Type II, IIA, or IIR shall be made from Type I, IA, or IR pipe respectively, and shall be reformed to provide a pipe-arch shape. All applicable requirements for Types I, IA, or IR pipe shall be met by finished Types II, IIA, and IIR respectively. Pipe-arches shall conform to the dimensional requirements of Tables 6, 7, or 8. All dimensions shall be measured from the inside crest of corrugations for Type II pipe or from the inside liner or surface for Types IIA or IIR pipe, respectively.

Table 6—Pipe-Arch Requirements—68 × 13 mm Corrugations

Pipe Arch Size, mm	Equiv Dia, mm	Span,[a] mm	Rise,[a] mm	Min Corner Radius, mm	Max B,[b] mm
430 × 330	375	430	330	75	135
530 × 380	450	530	380	75	155
610 × 460	525	610	460	75	185
710 × 510	600	710	510	75	205
780 × 560	675	780	560	75	225
885 × 610	750	870	610	75	240
970 × 690	825	970	690	75	255
1060 × 740	900	1060	740	90	265
1240 × 840	1050	1240	840	100	290
1440 × 970	1200	1440	970	130	345
1620 × 1100	1350	1620	1100	155	380
1800 × 1200	1500	1800	1200	180	420
1950 × 1320	1650	1950	1320	205	460
2100 × 1450	1800	2100	1450	230	510

[a] A tolerance of ±25 mm or 2 percent of equivalent diameter, whichever is greater, is permissible in span and rise.

[b] B is defined as the vertical dimension from a horizontal line across the widest portion of the arch to the lowest portion of the base.

Table 7—Pipe-Arch Requirements—75 × 25 mm Corrugations

Pipe Arch Size, mm	Equiv Dia, mm	Span,[a] mm	Rise,[a] mm	Min Corner Radius, mm
1340 × 1050	1200	1340 – 60	1050 + 60	180
1520 × 1170	1350	1520 – 70	1170 + 70	205
1670 × 1300	1500	1670 – 75	1300 + 75	230
1850 × 1400	1650	1150 – 85	1400 + 85	305
2050 × 1500	1800	2050 – 90	1500 + 95	355
2200 × 1620	1950	2200 – 110	1620 + 110	355
2400 × 1720	2100	2400 – 120	1720 + 120	410
2600 × 1820	2250	2600 – 130	1820 + 130	410
2840 × 1920	2400	2840 – 145	1920 + 145	460
2970 × 2020	2550	2970 – 150	2020 + 150	460
3240 × 2120	2700	3240 – 165	2120 + 165	460
3470 × 2220	2850	3470 – 175	2220 + 175	460
3600 × 2320	3000	3600 – 180	2320 + 180	460

[a] Negative and positive number listed with span and rise dimensions are negative and positive tolerances, zero tolerance in opposite direction.

Table 8—Pipe-Arch Requirements—19 × 19 mm and 19 × 25 × 292 mm Rib Corrugations

Pipe Arch Size, mm	Equiv Dia, mm	Span,[a] mm	Rise,[a] mm	Min Corner Radius, mm
500 × 410	450	500 – 25	410 + 25	130
580 × 490	525	580 – 25	490 + 25	130
680 × 540	600	680 – 40	540 + 40	130
750 × 620	675	750 – 40	620 + 40	130
830 × 670	750	830 – 40	670 + 40	130
900 × 750	825	900 – 45	750 + 45	130
1010 × 790	900	1010 – 45	790 + 45	130
1160 × 920	1050	1160 – 55	920 + 55	155
1340 × 1050	1200	1340 – 60	1050 + 60	180
1520 × 1170	1350	1520 – 70	1170 + 70	205
1670 × 1300	1500	1670 – 75	1300 + 75	230
1850 × 1400	1650	1850 – 85	1400 + 85	305
2050 × 1500	1800	2050 – 95	1500 + 95	355

[a] Negative and positive number listed with span and rise dimensions are negative and positive tolerances, zero tolerance in opposite direction.

8.2.2. *Longitudinal Seams*—Longitudinal seams of riveted pipe-arches shall not be placed in the corner radius.

8.2.3. Reforming Type IR pipe into Type IIR pipe shall be done in a manner that avoids damage to the external ribs.

8.3. *Type III and IIIR Pipe*:

8.3.1. Type III and IIIR pipe shall have a full circular cross section and shall conform to the requirements for Type I or Type IR pipe and, in addition, shall contain perforations conforming to one of the classes described in Section 8.3.2.

8.3.2. *Perforations*—The perforations in Type III pipe shall conform to the requirements for Class 1 or Class 2 as specified in the order and described in Section 8.3.2.1 and Section 8.3.2.2, respectively. The perforations in Type IIIR pipe shall conform to the requirements for Class 4 as described in Section 8.3.2.3. Class 1 perforations are for pipe intended to be used for subsurface drainage. Class 2 and Class 4 perforations are for pipe intended to be used for subsurface disposal of water, but pipe containing these classes of perforations may also be used for subsurface drainage.

8.3.2.1. *Class 1 Perforations*—The perforations shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm nor greater than 9.5 mm; and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests or along the neutral axis of the corrugations, with one perforation in each row for each corrugation. Pipe connected by couplings or bands may be unperforated within 100 mm of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the centerlines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the centerlines of the uppermost rows above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 9.

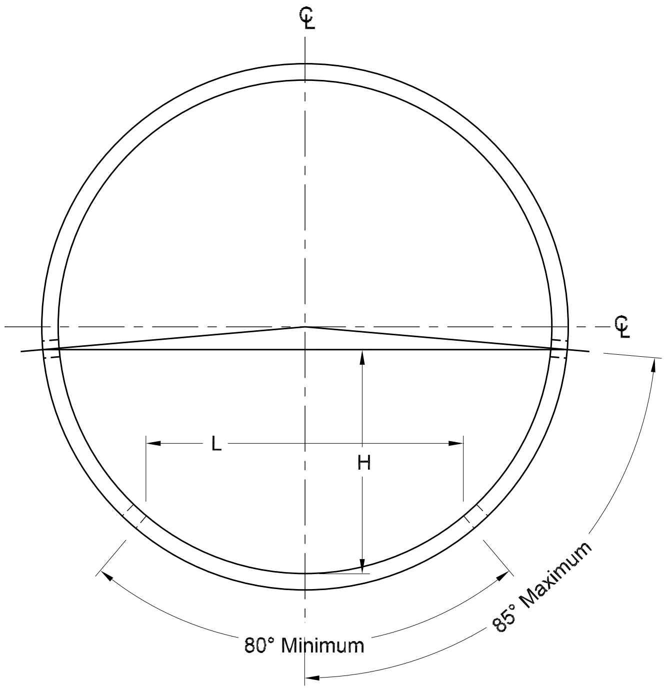

Figure 1—Circumferential Location of Class 1 Perforations

Table 9—Rows of Perforations, Height *H* of the Centerline of the Uppermost Rows Above the Invert, and Chord Length *L* of Unperforated Segment, for Class 1 Perforations

Internal Diameter, mm	Rows of Perforation[a]	*H*, Max,[b] mm	*L*, Min,[b] mm
100	2	46	64
150	4	69	96
200	4	92	128
250	4	115	160
300	6	138	192
375	6	172	240
450	6	207	288
525	6	241	338
600 and larger	8	[c]	[c]

[a] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and fabricator. Note that the number of perforations per unit length in each row (and inlet area) is dependent on the corrugation pitch.

[b] See Figure 1 for location of dimensions H and L.

[c] H(max) = 0.46D; L(min) = 0.64D, where D = internal diameter of pipe, mm.

Note 7—Pipe with Class 1 perforations is generally available in diameters from 100 to 500 mm inclusive, although perforated pipe in larger sizes may be obtained.

8.3.2.2. *Class 2 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm, or slots with nominal width of 4.8 to 8.0 mm and maximum length of 13 mm. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 230 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

Note 8—323 perforations, 9.5-mm diameter per square meter satisfies the inlet area requirement for Class 2 perforations.

8.3.2.3. *Class 4 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm, or slots with nominal width of 4.8 to 8.0 mm and maximum length of 12.7 mm. All perforations shall occur in the flat sheet between spiral ribs or lock seam with the center of any hole no closer than 19.0 mm from the outside edge of a rib. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 140 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

Note 9—There is no provision for Class 3 perforations in this specification.

9. COUPLING BANDS

9.1. *Types of Coupling Bands*—Field joints for each type of corrugated aluminum pipe shall maintain pipe alignment during construction and prevent infiltration of fill material during the life of the installation.

9.1.1. *Coupling bands may be of the following types*:

9.1.1.1. Bands with annular corrugations;

9.1.1.2. Bands with helical corrugations;

9.1.1.3. Bands with projections (dimples);

9.1.1.4. Channel bands for upturned flanges, with or without annular corrugations;

9.1.1.5. Flat bands; and

9.1.1.6. Smooth sleeve-type couplers.

9.1.2. Except as provided in Sections 9.1.3 through 9.1.7, the type of coupling furnished shall be at the option of the fabricator unless the type is specified in the order.

Note 10—Bands are classified according to their ability to resist shear, moment, and tensile forces as described in *AASHTO LRFD Bridge Construction Specifications*, and identified as “standard joints” and “special joints.” The four types of bands listed in Sections 9.1.1.1 through 9.1.1.4, and meeting the requirements of Section 9.2, are expected to meet the requirements for “standard joints.” Some may also be able to meet the requirements for “special joints,” but such capability should be determined by analysis or test.

9.1.3. Coupling bands with annular corrugations shall be used only with pipe with annular corrugations, or helical pipe in which the ends have been rerolled to form annular corrugations. The corrugations in the band shall have the same dimensions as the corrugations in the pipe end, or may be of a special design to engage either the first or second corrugation from the end of each pipe. The band may also include a U-shaped channel to accommodate upturned flanges on the pipe.

9.1.4. Coupling bands with helical corrugations shall be used only with pipe with helically corrugated ends. The corrugations in the bands shall be designed to properly mesh with the corrugations in the pipe.

9.1.5. Coupling bands with projections (dimples) may be used with pipe with either annular or helical corrugations. The bands shall be formed with the projections in annular rows with one projection for each corrugation of helical pipe. Bands 265 mm wide shall have two annular rows of projections, and bands 415 and 660 mm wide shall have four annular rows of projections.

9.1.6. Channel bands may be used only with pipe having upturned flanges on the pipe ends.

9.1.7. Smooth sleeve-type couplers and flat bands may be used with Type III pipe of 300-mm diameter or smaller.

9.2. *Requirements*—Coupling bands shall be fabricated to lap on an equal portion of each of the pipe sections to be connected. The ends of the bands shall lap or be fabricated to form a tightly closed joint upon installation. Coupling band thickness shall conform to the requirements in Table 10, based on the sheet thickness of the pipe to be connected, except as provided in Sections 9.2.1 and 9.2.2. The band width shall be not less than as shown in Table 11. The bands shall be connected in a manner approved by the purchaser with suitable aluminum or galvanized steel devices, such as angles, or integrally or separately formed and attached flanges, bolted with bolts as described in Section 6.4; bars and straps; wedge lock and straps; or lugs. Coupling bands shall be fastened with the following size of bolts: pipe diameters 450 mm and less—M10 diameter; pipe diameters 525 mm and greater—M12 diameter.

Table 10—Coupling Band Thickness

Nominal Pipe Thickness, mm	Nominal Coupling Band Thickness, Min, mm
2.67 and thinner	1.22
3.43	1.52
4.17	1.91

Table 11—Coupling Band Width Requirements

Nominal Corrugation Size,[a] mm	Nominal Pipe Inside Dia,[b] mm	Coupling Band Width, Min Annular Corrugated Bands, mm	Coupling Band Width, Min Helically Corrugated Bands, mm	Coupling Band Width, Min Bands with Projections, mm
38 × 65	100 to 250	265	180	265
68 × 13	300 to 900	180	300	265
	1000 to 1800	265	300	265
	2000 to 3000[c]	265	300	415
75 × 25	800 to 1800	300	350	265
	2000 to 3000	300	350	415
150 × 25	1200 to 2700	600	600	660

[a] For helically corrugated pipe with rerolled ends, the nominal corrugation size refers to the dimension of the end corrugations in the pipe.

[b] Equivalent diameter of Type II, Type IIA, and Type IIR pipe.

[c] Diameters through 3000 mm for annular corrugated bands used on rerolled ends of helically corrugated pipe.

9.2.1. If flanges are provided on the pipe ends, the coupling may also be made by interlocking the flanges with a preformed channel band or other band incorporating a locking channel not less than 19 mm in width. The depth of the channel shall be not less than 13 mm. The channel band shall have a minimum nominal thickness of 1.91 mm.

9.2.2. Smooth sleeve-type couplings and flat bands shall be aluminum sheet having a nominal thickness of not less than 0.91 mm or, as an option, may be a plastic sleeve to provide equivalent strength. The coupling shall be close-fitting to hold the pipe firmly in alignment without the use of sealing compounds or gaskets. The coupling or flat band shall contain a device so that the band or coupling will lap equally on the two pipes being joined. The overall length of the coupling shall be equal to or greater than the nominal diameter of the pipe.

9.3. *Gaskets*—Where infiltration or exfiltration is a concern, the couplings may be required to have gaskets. The closed-cell expanded rubber gaskets shall be a continuous band, approximately 180 mm wide and approximately 9.5 mm thick. Rubber O-ring gaskets shall be 20-mm diameter for pipe diameters of 900 mm or smaller, and 22-mm diameter for larger pipe diameters, having 13 mm deep end corrugations. Rubber O-ring gaskets shall be 35-mm diameter for pipe having 25 mm deep end corrugations.

Note 11—Riveted pipe is not watertight, having small openings at the intersection of longitudinal and circumferential seams. Therefore, this type of fabrication should not be used where watertightness is a concern unless the pipe is bituminous coated or lined prior to installation.

9.4. Other types of coupling bands or fastening devices that are equally effective as those described, and which comply with the joint performance criteria of *AASHTO LRFD Bridge Construction Specifications*, may be used when approved by the purchaser.

10. WORKMANSHIP

10.1. The completed pipe shall show careful, finished workmanship in all particulars. Pipe that has been damaged, either during fabrication or in shipping, may be rejected unless repairs are made that are satisfactory to the purchaser. Among others, the following defects shall be considered as constituting poor workmanship:

10.1.1. Variation from a straight centerline;

10.1.2. Elliptical shape in pipe intended to be round;

10.1.3. Dents or bends in the metal;

10.1.4. Lack of rigidity;

10.1.5. Illegible markings on the aluminum sheet;

10.1.6. Ragged or diagonal sheared edges;

10.1.7. Uneven laps in riveted pipe;

10.1.8. Loose, unevenly lined, or unevenly spaced rivets; and

10.1.9. Loosely formed lock seams.

11. INSPECTION

11.1. When agreed as part of the purchase contract, the purchaser or representative shall have free access to the fabricating plant for inspection, and every facility shall be extended for this purpose. This inspection shall include an examination of the pipe for the items in Section 10.1 and the specific requirements of this specification applicable to the type of pipe and method of fabrication.

11.2. On a random basis, samples may be taken for chemical analysis and mechanical property determination for check purposes. These samples will be secured from fabricated pipe or from sheets or coils of the material used in fabrication of the pipe. Testing shall be as described in M 197.

12. REJECTION

12.1. Pipe failing to conform to the requirements of this specification may be rejected. This requirement applies not only to the individual pipe, but to any shipment as a whole in which a substantial number of pipes are defective. If the average deficiency in length of any shipment of pipe is greater than 1 percent, the shipment may be rejected.

13. CERTIFICATION

13.1. When specified in the purchase order or contract, a manufacturer's or fabricator's certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the order, a report of the mechanical test results and chemical composition limits shall be furnished.

Note 12—As the identity of the sheet is not maintained from the original ingot production, if numerical results are required by the purchaser, tests should be performed on the finished sheet.

14. PRODUCT MARKING

14.1. If the aluminum alloy sheet was not marked by the manufacturer as indicated in M 197, it shall be marked by the fabricator as described in Section 14.2, during the course of corrugating the sheet and fabricating the pipe.

14.2. Each corrugated sheet used in annular corrugated pipe, and each 0.6 to 1.5 m of coiled sheet used in helically corrugated pipe, shall be identified by the fabricator, showing the following:

14.2.1. Name of sheet manufacturer;

14.2.2. Identification of the pipe fabricator, if different than the sheet manufacturer;

14.2.3. Alloy and temper;

14.2.4. Specified thickness;

14.2.5. Fabricator's date of corrugating or forming into pipe by a six-digit number indicating, in order, the year, month, and day of the month; and

14.2.6. AASHTO designation number.

14.3. The marking shall be applied to the sheet by a permanent method, such as coining, in accordance with ASTM B 666/B 666M. This identification shall appear on the outside of the pipe.

Standard Specification for

Aluminum Alloy Sheet for Corrugated Aluminum Pipe

AASHTO Designation: M 197-06[1]
ASTM Designation: B 744/B 744M-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Aluminum Alloy Sheet for Corrugated Aluminum Pipe

AASHTO Designation: M 197-06[1]
ASTM Designation: B 744/B 744M-05

1. SCOPE

1.1. This specification covers aluminum alloy sheets used in the fabrication of corrugated aluminum pipe intended for use for storm water drainage, underdrains, culverts, and similar uses. The material is furnished corrugated in cut lengths, and uncorrugated in coils and cut lengths.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:
- B 209M, Standard Specification for Aluminum-Alloy Sheet and Plate [Metric]
- B 666/B 666M, Standard Practice for Identification Marking of Aluminum and Magnesium Products

2.2. *ANSI*:
- H35.2M, Dimensional Tolerances for Aluminum Mill Products [Metric]

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1. *fabricator*—the producer of the pipe.

3.2. *manufacturer*—the producer of the sheet.

3.3. *purchaser*—the purchaser of the finished pipe.

4. ORDERING INFORMATION

4.1. Sheet covered by this specification shall be ordered only to the specified thicknesses listed in Table 1.

Table 1—Sheet Thickness[a]

Specified Thickness, mm	Minimum Thickness, mm
1.22	1.14
1.52	1.44
1.91	1.82
2.67	2.55
3.43	3.29
4.17	3.99

[a] Thickness is measured at any point on the sheet not less than 10 mm from an edge and, if corrugated, on the tangents of corrugations.

4.2. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product.

4.2.1. Name of material (aluminum alloy sheet for corrugated aluminum pipe),

4.2.2. AASHTO designation number and year of issue,

4.2.3. Corrugation size, if corrugated (Section 8.4),

4.2.4. Dimensions (thickness; width, either flat or overall corrugated; and length, if cut length),

4.2.5. Coil size requirements (specify maximum outside diameter (OD), acceptable inside diameter (ID), and maximum mass)),

4.2.6. Certification, if required (Section 11.1), and

4.2.7. Special requirements.

Note 1—Typical ordering descriptions are as follows: Aluminum alloy sheet for corrugated aluminum pipe conforming to M 197-____, 2.67 by 760 mm by coil, 1200 mm OD max, 600 mm ID min, 5000 kg max, certified with test report.

5. GENERAL REQUIREMENTS

5.1. Aluminum alloy sheets or coils supplied under this specification shall conform to the applicable requirements of ASTM B 209M for alclad alloy 3004-H34 for annular pipe and alclad alloy 3004-H32 for helical pipe.

6. CHEMICAL COMPOSITION

6.1. The sheet material shall conform to the chemical composition limits in ASTM B 209M, as shown in Table 2.

Table 2—Chemical Composition[a]

	Sheet Core, percent	Sheet Cladding,[b] percent
Alloy	3004	7072
Silicon	0.30	(Si + Fe) = 0.7
Iron	0.7	
Copper	0.25	0.10
Manganese	1.0–1.5	0.10
Magnesium	0.8–1.3	0.10
Zinc	0.25	0.8–1.3
Other each	0.05	0.05
Total	0.15	0.15
Aluminum	Remainder	Remainder

[a] Composition in mass percent maximum unless shown as range.

[b] Composition of cladding alloy as applied during the course of manufacture. Samples from finished sheet or plate shall not be required to conform to these limits.

7. MECHANICAL REQUIREMENTS

7.1. The sheet material shall conform to the requirements for mechanical properties specified in ASTM B 209M, as shown in Table 3 when tested prior to corrugating or other fabrication.

Note 2—Sheet material tested after corrugating and other fabricating should conform to the specified tensile and yield strength requirements, but due to cold working, conformance to the elongation requirements may not be obtained.

Table 3—Mechanical Requirements, Alclad Alloy 3004-H34

Specified Thickness, mm	Tensile Strength		Yield Strength (0.2 Percent Offset), Min, MPa	Elongation in 50 mm, Min, Percent
	Min, MPa	Max, MPa		
Alclad 3004-H32 alloy				
0.91, 1.20	185	235	140	3
1.2 through 4.17	185	235	140	5
Alclad 3004-H34 alloy				
0.91, 1.20	215	260	165	3
1.20 through 4.17	215	260	165	4

8. DIMENSIONS AND TOLERANCES

8.1. Sheet thickness shall conform to dimensions prescribed in Table 1.

8.2. The nominal cladding thickness on each side shall be 5 percent of the total composite thickness. The average cladding thickness, determined according to Section 9.4, shall not be less than 4 percent of the total composite thickness.

8.3. Permissible variations in flat width, length, and squareness shall be in accordance with ANSI H35.2M.

8.4. Corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 4.

8.5. Covering width of corrugated sheet shall be in accordance with Table 5. Covering width is the distance between the crests of the extreme corrugations. There is no established tolerance for overall width since the covering width and lip dimensions are the governing factors for the formed product. The lip dimension of corrugated sheet shall be in accordance with Table 6. This dimension is measured along the radial curvature from the crest of the corrugation to the edge of the sheet.

Table 4—Corrugation Requirements

Nominal Size, mm	Max Pitch[a], mm	Min Depth[b], mm	Inside Radius	
			Nominal, mm	Min, mm
68 × 13	73	12	17	12
75 × 25	83	24	14	12

[a] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests to the bottom of the intervening valley.

Table 5—Covering Width Tolerance for Corrugated Sheet

Covering Width, mm	Tolerance Over and Under, mm
To 610, inclusive	6.5
Over 610 to 915, inclusive	9.5
Over 915 to 1220, inclusive	13

Table 6—Corrugated Sheet Lip Dimensions

Nominal Corrugation Size, mm	Lip Dimension	
	Min, mm	Max, mm
68 × 13	19	24
75 × 25	22	28
150 × 25	22	38

9. SAMPLING AND TESTING

9.1. Sampling and testing shall be according to ASTM B 209M. The manufacturer shall make adequate tests and measurements to ensure that the material produced complies with this specification.

9.1.1. Test results, including chemical composition, mechanical properties, and cladding thickness, shall be maintained by the sheet manufacturer for 7 years and shall be made available to the fabricator and purchaser upon request, for examination at the manufacturer's facility unless otherwise agreed upon.

9.2. The fabricator or the purchaser may make such tests as are necessary to determine the acceptability of the material or to verify the correctness of a certification.

9.3. Mechanical properties shall be determined on sheet prior to corrugating or other fabricating, except tests may be made after fabrication by the purchaser for tensile and yield strengths.

9.4. When the thickness of the cladding is to be determined on finished material, no fewer than three transverse samples approximately 19 mm in length shall be mounted to expose a transverse cross section and polished for examination with a metallurgical microscope. Using a 100X magnification, the maximum and minimum cladding thickness shall be measured in each of five fields approximately 2.5 mm apart along both sides of the cross section. The average of ten thickness measurements on each side is the average cladding thickness.

Note 3—If necessary to better define the interface between core and cladding, the polished surface may be etched with Keller's etch or equivalent. Keller's etch contains: 1 part HF conc., 1.5 parts HCl conc., 2.5 parts HNO_3 conc., and 95 parts water.

10. REJECTION

10.1. Material tested by the purchaser and found not conforming to this specification may be rejected.

11. CERTIFICATION

11.1. When specified in the purchase order or contract, a manufacturer's certification shall be furnished to the purchaser of the sheet (fabricator) or to the purchaser of the finished pipe stating that samples representing each lot have been tested and inspected in accordance with this specification and the requirements have been met. When specified in the purchase order or contract, a report of the mechanical test results and the chemical composition limits shall be furnished.

Note 4—As the identity of the sheet is not maintained from the original ingot production, if numerical results are required by the purchaser, tests should be performed on the finished sheet.

12. PRODUCT MARKING

12.1. Each corrugated sheet furnished for use in annular corrugated pipe shall be identified by the sheet manufacturer showing the following:

12.1.1. Name or trademark of sheet manufacturer,

12.1.2. Alloy and temper,

12.1.3. Specified thickness,

12.1.4. Date of corrugating by a six-digit number indicating, in order, the year, month, and day of the month, and

12.1.5. AASHTO designation number.

12.2. Coils and cut-length flat sheets shall be similarly marked by the manufacturer (except Section 12.1.4) at 0.6 to 1.5 m intervals, or the information shall be included on a tag so that the fabricator can mark the sheet at the time of fabrication.

12.3. The marking shall be applied to the sheet by a permanent method such as coining in accordance with ASTM B 666/B 666M.

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[1] This specification is equivalent to ASTM B 744/B 744M-05 except for including requirements from ASTM B 209M on cladding thickness, chemical composition, and mechanical requirements.

Standard Specification for

Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants

AASHTO Designation: M 198-10
ASTM Designation: C 990-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants

AASHTO Designation: M 198-10
ASTM Designation: C 990-09

AASHTO M 198-10 is identical to ASTM C 990-09 except that references to the ASTM standards contained in ASTM C 990-09, listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Documents

ASTM	AASHTO	ASTM	AASHTO	ASTM	AASHTO
C 14	M 86M/M 86	C 507	M 207M/M 207	D 92	T 48
C 76	M 170	C 655	M 242M/M 242	D 113	T 51
C 478	M 199M/M 199	C 822	M 262		
C 506	M 206M/M 206	C 1433	M 259 and M 273		

Standard Specification for

Precast Reinforced Concrete Manhole Sections

AASHTO Designation: M 199M/M 199-10[1]
ASTM Designation: C 478M-09 and C 478-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Precast Reinforced Concrete Manhole Sections

AASHTO Designation: M 199M/M 199-10[1]
ASTM Designation: C 478M-09 and C 478-09

PART I—GENERAL

1. SCOPE

1.1 This specification covers the manufacture and purchase requirements of products used for the assembly and construction of circular vertical precast reinforced concrete manholes and structures used in sewer, drainage, and water works.

1.2 Part I, Sections 1 through 11, of this specification presents general requirements and requirements that are common to each precast concrete product covered by this specification.

1.3 Part II of this specification presents specific requirements for each manhole product in the following sections:

Product	Section
Grade rings	12
Flat slab tops	13
Risers and conical tops	14
Base sections	15
Steps and ladders	16

Note 1—Future products will be included in Part II in a future revision of this specification.

1.4 This specification is applicable for orders in either SI units (M 199M) or in inch-pound units (M 199). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 199.

Note 2—This specification is a manufacturing and purchase specification only, and does not include requirements for backfill, or the relationship between field load conditions and the strength requirements of the manhole products and appurtenances. Experience has shown, however, that the successful performance of this product depends upon the proper selection of the product strength, type of foundation and backfill, and care in the field installation of the manhole products and connecting pipes. The owner of the project for which these products are specified herein is cautioned to require inspection at the construction site.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 154, Air-Entraining Admixtures for Concrete
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 194M/M 194, Chemical Admixtures for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standard*:

- A706/A 706M, Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
- C 1017/C1017M, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

2.3 *ACI Standard*:

- 318, Building Code, Requirements for Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete manholes, see M 262.

4. MATERIALS AND MANUFACTURE

4.1 General material requirements for precast reinforced concrete manhole products are presented in Sections 4.1.1 through 4.1.8. Other materials or additional requirements for a product, if any, are covered in the Part II section for that specific product.

4.1.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel reinforcement has been embedded in such a manner so that the steel reinforcement and concrete act together.

4.1.2 *Cementitious Materials*:

4.1.2.1 *Cement*—Cement shall conform to the requirements for portland cement of M 85, or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

4.1.2.2 *Fly Ash*—Fly ash shall conform to the requirements of Class F or Class C of M 295.

4.1.2.3 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of M 302.

4.1.3 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

4.1.3.1 Portland cement only,

4.1.3.2 Portland blast-furnace slag cement only,

4.1.3.3 Slag modified portland cement only,

4.1.3.4 Portland-pozzolan cement only, or

4.1.3.5 A combination of portland cement and ground granulated blast furnace slag,

4.1.3.6 A combination of portland cement and fly ash, or

4.1.3.7 A combination of portland cement, ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight).

4.1.4 *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

4.1.5 *Admixtures and Blends*—Admixtures and blends shall only be used with the approval of the owner.

4.1.5.1 Air-Entraining Admixture conforming to M 154;

4.1.5.2 Chemical Admixture conforming to M 194M/M 194;

4.1.5.3 Chemical Admixture for use in producing flowing concrete conforming to ASTM C 1017/C 1017M;

4.1.5.4 Chemical Admixture or Blend approved by the owner.

4.1.6 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to M 32M/M 32 or M 225M/M 225, of wire fabric conforming to M 55M/M 55 or M 221M/M 221, or of bars of Grade 300 [40] steel conforming to M 31M/M 31 or bars confirming to Specification A706/A 706M.

4.1.7 *Secondary Synthetic Fiber*—Collated fibrillated polypropylene virgin fibers shall not be prohibited when used in steel reinforced concrete manholes as a non-structural manufacturing enhancement. Only fibers designed and manufactured specifically for use in concrete and so certified by the manufacturer shall be accepted.

4.1.8 *Other Materials*—Other materials required for a product and not covered in Section 4 will be covered in the Part II section for that specific product.

5. DESIGN

5.1 Design requirements for a product are prescribed in the specific Part II section for that product.

5.1.1 The minimum compressive strength of concrete manhole products covered by this specification shall be 27.6 MPa [4000 psi] unless specified otherwise in Part II of this specification.

5.2 *Modified or Special Design*:

5.2.1 Manufacturers are not prohibited from submitting to the owner, for approval prior to manufacture, designs other than those prescribed in the specific section for a product. If such approval is obtained, then the product shall meet all the tests and performance requirements specified by the owner in accordance with the appropriate sections on manufacture and physical requirements.

5.2.2 If permitted by the owner, the manufacturer is not prohibited from requesting approval of designs of special sections, such as reducers, tees, and bases.

6. REINFORCEMENT

6.1 This section presents requirements for reinforcement cover, continuity, laps, welds, and splices. Other reinforcement requirements are presented in Section 4 and any additional requirements are given in the Part II section for a specific product.

6.2 *Cover*—The exposure of the ends of reinforcement, stirrups or spacers used to position the reinforcement during placement of the concrete shall not be cause for rejection.

6.3 *Continuity*—The continuity of the circumferential reinforcement shall not be destroyed during the manufacture of the product, except when lift holes or pipe openings are provided in the product.

6.4 *Welded Steel Cage Laps, Welds, and Splices*:

6.4.1 If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars, and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded wire fabric are used without welding, the lap shall contain a longitudinal wire.

6.4.2 When splices are welded and are not lapped to the minimum requirements in Section 6.4.1, pull tests of representative specimens shall develop at least 50 percent of the minimum specified strength of the steel, and there shall be a minimum lap of 50 mm [2 in.] For butt welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 percent of the minimum specified strength of the steel.

6.5 *Steel Hoop Splices*—A representative sample steel hoop with welded splices shall develop at least 50 percent of the minimum specified strength of the steel, and there shall be a minimum lap of

50 mm [2 in.] For butt-welded splices, the representative steel hoop sample shall develop at least 75 percent of the minimum specified strength of the steel.

7. PRECAST CONCRETE MANUFACTURE

7.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the products will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious ratio not exceeding 0.53 by weight. Cementitious materials shall be as specified in Section 4.1.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 [470 lb/yd^3], unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the product meet the requirements of this specification.

7.2 *Curing*—Concrete products shall be subjected to any one of the methods of curing prescribed in Sections 7.2.1 through 7.2.4 or to any other method or combination of methods approved by the owner that will give satisfactory results.

7.2.1 *Steam Curing*—Concrete products are placed in a curing chamber, free of outside drafts, and cured in a moist atmosphere maintained by the injection of steam for such time and such temperatures as needed to enable the products to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of the steam around the entire product.

7.2.2 *Water Curing*—Concrete products are water cured by covering with water-saturated material, or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the products moist during the curing period.

7.2.3 *Sealing Membrane*—A sealing membrane conforming to the requirements of M 148 is applied and shall be left intact until the required concrete strength requirements are met. The concrete at the time of application of the membrane shall be within 6ºC [10ºF] of the atmospheric temperature. All concrete surfaces shall be kept moist prior to the application of the membrane and shall be damp when the membrane is applied.

7.2.4 The manufacturer is not prohibited from combining the methods prescribed in Sections 7.2.1 through 7.2.3 provided the required concrete compressive strength is attained.

8. ACCEPTANCE

8.1 *Acceptance Procedures*:

8.1.1 Unless otherwise designated by the owner at the time of, or before, placing an order, acceptance procedures for precast reinforced concrete manhole products shall be as specified in the Part II section for a particular product, and shall not be prohibited from consisting of one or more of the following:

8.1.1.1 Acceptance of a product on the basis of tests of materials, including concrete compressive strength and absorption;

8.1.1.2 Acceptance of a product on the basis of inspection of the finished product, including amount and placement of reinforcement to determine conformance with the design prescribed under this specification, and freedom from defects.

8.2 *Test Methods*:

8.2.1 *Concrete Compressive Strength Test*:

8.2.1.1 *Type of Specimen*—Compression tests for satisfying the minimum specified concrete strength requirement shall be made on either concrete cylinders or, at the option of the manufacturer, on cores cut from the concrete manhole product.

8.2.1.2 *Compression Testing of Cylinders*—Cylinders shall be made in accordance with T 280, and shall be tested in accordance with T 22. For manhole products, an owner shall not be prohibited from requiring concrete compressive tests on cylinder specimens numbering in the amount of 5 percent of the total order of a manhole product, but not to exceed two cylinders for each day's production. The average compressive strength of all cylinders tested shall be equal to or greater than the specified strength of the concrete. Not more than 10 percent of the cylinders tested shall fall below the specified strength of the concrete. In no case shall any cylinder tested fall below 80 percent of the specified strength of the concrete.

8.2.1.3 *Compression Testing of Cores*—Cores shall be cut from the concrete manhole product and tested in accordance with Test Methods T 280 except that the requirements for moisture conditioning shall not apply. One core shall be taken from a manhole product selected at random from each day's production run of a single concrete strength. When the concrete compressive strength of the core is equal to or greater than 80 percent of the specified strength of the concrete, the concrete strength of the production run is acceptable. If the core does not meet the preceding concrete strength requirement, another core from the same manhole product shall be taken and tested.

8.2.1.4 If the concrete compressive strength of the recore is equal to or greater than 80 percent of the specified strength of the concrete, the concrete strength of the production run is acceptable. If the recore does not meet the preceding concrete strength requirement, that manhole product shall be rejected. Two manhole products from the remainder of the day's production run shall be selected at random and one core taken from each manhole product and tested. When the average concrete strength of the two cores is equal to or greater than 80 percent of the specified strength of the concrete with no core below 75 percent of the specified strength of the concrete, the concrete strength of the day's production run shall be acceptable.

8.2.1.5 If the concrete strength of the two cores does not meet the preceding concrete strength requirement, then the remainder of the day's production run shall be either rejected, or, at the option of the manufacturer, each manhole product of the remainder of the day's production run is not prohibited from being cored and accepted individually.

8.2.1.6 *Plugging Core Holes*—Core holes on accepted concrete manhole products shall be plugged and sealed by the manufacturer in a manner such that the manhole products will meet all of the requirements of this specification. Manhole sections so sealed shall be considered as satisfactory for use.

8.2.2 *Absorption Test*:

8.2.2.1 The absorption of a specimen from a concrete product, as determined in T 280, shall not exceed 9 percent of the dry mass. All specimens shall be free of visible cracks and shall represent the full thickness of the product.

8.2.2.2 Each specimen tested shall have a minimum mass of 1.0 kg [2.2 lb].

8.2.2.3 When the initial absorption specimen from a concrete product fails to conform to this specification, the absorption test shall be made on another specimen from the same product and the results of the retest shall be substituted for the original test results.

8.2.3 *Retests*—When not more than 20 percent of the concrete test specimens tested under either Section 8.2.2.1 or Section 8.2.2.2 fail to pass the requirements of this specification, the manufacturer is not prohibited from culling his stock and eliminating whatever quantity of product he desires, and shall so mark the culled product that they will not be shipped for the order. The required tests shall be made on the balance of the order and the products shall be accepted if in conformance with the requirements of this specification.

8.3 *Test Equipment*—Every manufacturer furnishing manhole products under this specification shall furnish all facilities and personnel necessary to carry out the tests required for acceptance.

9. REPAIRS

9.1 Repair of manhole products shall not be prohibited, if necessary, because of imperfections in manufacture or damage during handling, and will be acceptable if, in the opinion of the owner, the repaired products conform to the requirements of this specification.

10. INSPECTION

10.1 The quality of materials, the process of manufacture, and the finished manhole products shall be subject to inspection and approval by the owner.

11. PRODUCT MARKING

11.1 The following information shall be legibly marked on each precast concrete product:

11.1.1 Specification and product designation: MH for manhole base, riser, conical tops, and grade rings;

11.1.2 Date of manufacture; and

11.1.3 Name or trademark of the manufacturer.

11.2 Marking shall be indented into the concrete or shall be painted thereon with waterproof paint.

PART II—PRODUCTS

12. GRADE RINGS

12.1 *Scope*—This section covers precast reinforced concrete grade rings used for final adjustment of manholes to grade.

12.2 *Acceptance*—Acceptability of grade rings covered by this specification shall be determined by the results of such tests of materials as are required by Section 4; by compressive strength tests on concrete cores or concrete cylinders required by Section 8; and by inspection of the finished product, including amount and placement of reinforcement as prescribed by Sections 12.4, 12.5, and 12.6, to determine its conformance with the design prescribed under this specification and its freedom from defects.

12.3 *Design*—The minimum wall thickness shall be one-twelfth of the internal diameter of the grade ring or 100 mm [4 in.], whichever is greater.

12.3.1 *Joints*—Grade rings are not required to have the joint formed with male and female ends.

12.4 *Circumferential Reinforcement*:

12.4.1 The circumferential reinforcement shall have an equivalent area of not less than 150 mm^2/vertical m [0.07 in.^2/vertical ft], but not less than 15 mm^2 [0.024 in.^2] in any one grade ring.

12.4.2 The circumferential reinforcement shall be one line in the center third of the wall of the grade ring.

12.5 *Permissible Variations*:

12.5.1 *Internal Diameter*—The internal diameter of grade rings shall not vary more than ±1 percent.

12.5.2 *Wall Thickness*—The wall thickness of grade rings shall be not less than that prescribed in the design by more than 5 percent or ±5 mm [$\pm{}^3/_{16}$ in.], whichever is greater. A wall thickness greater than that prescribed in the design shall not be cause for rejection.

12.5.3 Height of Two Opposite Sides—Variations in laying height of two opposite sides of grade rings shall be not more than 6 mm [${}^1/_4$ in.].

12.5.4 *Height of Grade Ring*—The underrun in height of a grade ring shall be not more than 20 mm/m [${}^1/_8$ in./ft] of height.

12.5.5 *Position of Reinforcement*—For grade rings with a 100 mm [4-in.] wall thickness, the maximum variation in the design position of circumferential reinforcement from that described in Section 12.4.1 shall be ±10 percent of the wall thickness or ±6 mm [$\pm{}^1/_4$ in.], whichever is greater. For grade rings with a wall thickness greater than 100 mm [4 in.], the maximum variation from the design position of reinforcement shall be ±10 percent of the wall thickness or ±16 mm [$\pm{}^5/_8$ in.], whichever is the lesser. In no case, however, shall the cover over the reinforcement be less than 19 mm [${}^3/_4$ in.] The preceding minimum cover limitation does not apply to the mating surfaces of the joint.

12.5.6 *Area of Reinforcement*—Steel reinforcement areas that are 10 mm^2/linear m [0.005 in.^2/linear ft] less than called for by design shall be considered as meeting the required steel reinforcement area.

12.6 *Rejection*:

12.6.1 Grade rings shall be subject to rejection for failure to conform to any of the specification requirements. In addition, an individual grade ring shall be subject to rejection because of any of the following:

12.6.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint;

12.6.1.2 Defects that indicate mixing and molding not in compliance with Section 7.1 or surface defects indicating honey-combed or open texture that would adversely affect the function of the grade ring;

12.6.1.3 The planes of the ends are not perpendicular to the longitudinal axis of the grade ring, within the limits of permissible variations prescribed in Section 12.5;

12.6.1.4 Damaged or cracked ends, where such damage would prevent making a satisfactory joint; and

12.6.1.5 Any continuous crack having a surface width of 0.3 mm [0.01 in.] or more, and extending for a length of 300 mm [12 in.] or more, regardless of position in the wall.

13. FLAT SLAB TOPS

13.1 *Scope*—This section covers precast reinforced concrete flat slab tops used in the construction of manholes for use in sewer, drainage, and water works.

13.2 *Acceptance*:

13.2.1 Acceptability of flat slab tops shall be determined by the results of such tests of materials as are required by Section 4; by compressive strength tests on concrete cores or concrete cylinders required by Section 8; and by inspection of the finished product, including amount and placement of reinforcement as prescribed by Sections 13.4 and 13.6, to determine its conformance with the design prescribed under this specification and its freedom from defects;

13.2.2 Unless otherwise designated by the owner at the time of, or before, placing an order, two separate and alternative methods of acceptance are permitted for flat slab top manufacturer designs, in addition to tests of materials and inspection required in Section 13.2.1;

13.2.2.1 *Acceptance on the Basis of Proof-of-Design Test*—Acceptance of flat slab tops on the basis of the results of a proof-of-design test performed in accordance with Section 13.5 in lieu of submission of design calculations and detailed drawings; and

13.2.2.2 *Acceptance on the Basis of Rational Design*—Acceptance of flat slab tops on the basis of design calculations by a rational method and detailed drawings.

13.3 *Design*:

13.3.1 The basis of flat slab top designs shall be the appropriate sections of the latest edition of ACI 318.

13.3.2 Flat slab tops shall have a minimum thickness of 150 mm [6 in.] for risers up to and including 1200 mm [48 in.] in diameter and 200 mm [8 in.] for larger diameters.

13.3.3 The flat slab top access opening shall be a minimum of 600 mm [24 in.] in diameter.

13.3.4 *Joint*—The reinforced concrete flat slab top shall be formed with or without a male or female end so that when the manhole base, riser and top section are assembled, they will make a continuous and uniform manhole compatible with the tolerances given in Section 13.6.

13.3.4.1 Joints are designed to perform in axial compression; therefore, shear or load testing of the joint is not required.

13.4 *Reinforcement*:

13.4.1 Flat slab tops manufactured with a joint or with other indication of the top or bottom of the slab shall be manufactured with one layer of reinforcement placed near the bottom surface so that the protective cover over the reinforcement shall be 25 mm [1 in.].

13.4.2 Flat slab tops manufactured without a joint or without other indication of the top or bottom of the slab shall be manufactured with two layers of steel reinforcement, one located near the bottom surface and one near the top surface so that the protective cover over each layer is 25 mm [1 in.].

13.4.3 A layer of reinforcement shall have a minimum area of 250 mm^2/liner m [0.12 in.^2/linear foot] in both directions.

13.4.4 Openings in flat slab tops shall be additionally reinforced with a minimum of the equivalent of 130 mm^2 [0.20 in.^2] of steel at 90 degrees. Straight rods used to reinforce openings shall have a minimum length equal to the diameter of the opening plus 50 mm [2 in.].

13.5 *Physical Requirements*: Physical requirements for tests shall conform to the requirements of Section 8.

13.5.1 *Proof-of-Design Test*:

13.5.1.1 If Section 13.2.2.2 has been designated as the basis of acceptance, one flat slab top for each design shall be tested unless the owner has indicated otherwise.

13.5.1.2 The flat slab top proof-of-design test procedures shall be in accordance with T 280.

13.5.1.3 The ultimate test load shall be the sum of at least 130 percent of the dead load on the slab plus at least 217 percent of the live-plus impact load on the slab. Dead load is the mass of the column of earth over the slab plus the mass of the riser supported by the slab. Live load is the maximum anticipated wheel load that may be transmitted through the riser to the slab.

13.5.1.4 The flat slab top shall be acceptable if it supports the required ultimate test load without failure. Ultimate strength failure is defined as the inability of the slab to resist an increase in the applied load.

13.5.1.5 When agreed upon by the owner and manufacturer, the flat slab top shall be acceptable based on certified copies of the results of tests performed on identical flat slab tops instead of requiring new proof-of-design acceptance tests.

13.6 *Permissible Variations*:

13.6.1 *Internal Diameter*—The internal diameter of the flat slab tops entrance hole shall not vary more than ±1 percent.

13.6.2 *Thickness*—The thickness of flat slab tops shall be not less than that prescribed in the design by more than 5 percent or ±5 mm [$\pm ^3/_{16}$ in.], whichever is greater. A thickness greater than that prescribed in the design shall not be cause for rejection.

13.6.3 *Length of Two Opposite Sides*—Variations in lengths of two opposite sides of flat slab tops shall be not more than 6 mm [$^1/_4$ in.]

13.6.4 *Length*—The underrun in length of a flat slab top shall be not more than 20 mm/m [$^1/_8$ in./ft] of length.

13.6.5 *Position of Reinforcement*—For flat slab tops with less than a 150 mm [6 in.] thickness, the maximum variation in the position of reinforcement from that prescribed in Section 13.4 shall be ±10 percent of the thickness or ±6 mm [±$^1/_4$ in.], whichever is greater. For flat slab tops with a thickness greater than 150 mm [6 in.], the maximum variation shall be ±10 percent of the thickness or ±16 mm [±$^5/_8$ in.], whichever is the lesser. In no case, however, shall the cover over the reinforcement be less than 19 mm [$^3/_4$ in.].

13.6.6 *Area of Reinforcement*—Steel reinforcement areas that are 10 mm^2/linear m [0.005 in.^{2}/linear ft] less than called for by design shall be considered as meeting the required steel reinforcement area.

13.7 *Rejection*:

13.7.1 Flat slab tops shall be subject to rejection for failure to conform to any of the specification requirements. In addition, an individual flat slab top shall be subject to rejection because of any of the following:

13.7.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint;

13.7.1.2 Defects that indicate mixing and molding not in compliance with Section 7.1 or surface defects indicating honey-combed or open texture that would adversely affect the function of the flat slab top;

13.7.1.3 The planes of the ends are not perpendicular to the longitudinal axis of the flat slab top, within the limits of permissible variations prescribed in Section 13.6;

13.7.1.4 Damaged or cracked ends, where such damage would prevent making a satisfactory joint; and

13.7.1.5 Any continuous crack having a surface width of 3 mm [0.01 in.] or more and extending for a length of 300 mm [12 in.] or more, regardless of position in the slab.

14. RISERS AND CONICAL TOPS

14.1 *Scope*—This section covers precast reinforced concrete risers and conical tops used in construction of manholes for use in sewer, drainage, and water works.

14.2 *Acceptance*—Acceptability of risers and conical tops covered by this specification shall be determined by the results of such tests of materials as required by Section 4; by compressive strength tests on concrete cores or concrete cylinders required by Section 8; and by inspection of the finished product, including the amount of reinforcement as prescribed by Sections 14.4 or 14.5, and meeting permissible variations as prescribed by Section 14.7, to determine its conformance with the design prescribed under this specification and its freedom from defects.

14.3 *Design*—The minimum wall thickness shall be one-twelfth of the largest internal diameter of the riser or conical top.

14.4 *Welded Steel Cage Reinforcement*:

14.4.1 *Circumferential Reinforcement for Risers and Conical Tops*:

14.4.1.1 Circumferential reinforcement shall consist of either one or two lines of steel. The total area of reinforcement per vertical meter [foot] shall be not less than 0.0021 [0.0025] times the internal diameter in millimeters [inches].

14.4.1.2 A line of circumferential reinforcement for any given total area may be composed of two layers if the layers are not separated by more than the thickness of one cross member plus 6 mm [$^1/_4$ in.] The two layers shall be tied together to form a single cage. All other specification requirements such as laps, welds, and tolerances of placement in the wall of the riser or conical top shall apply to this method of fabricating a line of reinforcement.

14.4.1.3 Where one line of circumferential reinforcement is used, it shall be placed in the center third of the wall. The protective cover over the circumferential reinforcement in the wall shall be no less than 19 mm [$^3/_4$ in.] in accordance with Section 14.7.

14.4.1.4 Where two lines of circumferential reinforcement are used, each line shall be so placed that the protective covering over the circumferential reinforcement in the wall shall be 25 mm [1 in.].

14.4.1.5 The location of the reinforcement shall be subject to the permissible variations in dimensions prescribed in Section 14.7.

14.4.1.6 The spacing center-to-center of circumferential reinforcement in a cage shall not exceed 150 mm [6 in.].

14.4.2 *Longitudinal Members*—Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members to maintain the reinforcement in shape and position within the form to comply with permissible variations in Section 14.7.

14.4.3 *Joint Reinforcement*—The tongue or groove of the joint is not required to contain circumferential reinforcement.

14.5 *Steel Hoop Reinforcement*:

14.5.1 *Continuous Circumferential Reinforcement for Risers and Conical Tops Up to and Including 1200 mm [48-in.] Diameters*:

Note 3—Care shall be taken to ensure that none of the steel hoop reinforcement is cut prior to installation of the riser or conical top.

14.5.1.1 Circumferential reinforcement for manhole risers and conical tops up to and including 600 mm [24 in.] in height shall consist of no less than two hoops of steel wire or reinforcing bars. The steel hoop shall have a minimum cross-sectional diameter of 6 mm [0.250 in.] and shall be located in each end quarter of the riser or conical top, with a minimum distance of 25 mm [1 in.] from the shoulder of the riser or conical top.

14.5.1.2 Circumferential reinforcement for manhole risers and conical tops greater in height than 600 mm [24 in.] and up to and including 1200 mm [48 in.] in height shall consist of no less than three hoops of steel wire or reinforcing bars. The steel hoops shall have a minimum cross-sectional diameter of 6 mm [0.250 in.] and shall have a hoop located in each end quarter of the riser or conical top with a minimum distance of 25 mm [1 in.] from the shoulder of the riser or conical top. The third, or middle, hoop shall be located from the shoulder of the riser or conical top a distance equal to one-half the section height ±150 mm [±6 in.].

14.5.1.3 Circumferential reinforcement for manhole risers and conical tops greater in height than 1200 mm [48 in.] and up to and including 1800 mm [72 in.] in height shall consist of no less than four hoops of steel wire or reinforcing bars spaced equally ±75 mm [±3 in.] throughout the height of the riser or conical top. The steel hoops shall have a minimum cross-sectional diameter of 6 mm [0.250 in.] and shall have a hoop located in each end quarter of the riser or conical top with a minimum distance of 1 in. from the shoulder of the riser or conical top.

14.5.1.4 The hoop reinforcement shall be placed in the center third of the riser wall or conical top. The concrete cover over the hoop reinforcement in the wall of the section shall be no less than 19 mm [$^{3}/_{4}$ in.] in accordance with Section 14.7.

14.5.2 *Joint Reinforcement*—The tongue or groove of the joint is not required to contain circumferential reinforcement.

14.6 *Joints*—Precast reinforced concrete risers and conical tops shall be designed and manufactured with male and female ends, so that the assembled manhole base, riser, and conical top shall make a continuous and uniform manhole, compatible with the tolerances given in Section 14.7.

14.6.1 Joints are designed to perform in axial compression; therefore, shear or load testing of the joint is not required.

14.7 *Permissible Variations*:

14.7.1 *Internal Diameter*—The internal diameter of risers and conical tops shall not vary more than 1 percent.

14.7.2 *Wall Thickness*—The wall thickness of risers and conical tops shall be not less than that prescribed in the design by more than 5 percent or ±5 mm [±$^{3}/_{16}$ in.], whichever is greater. A wall thickness greater than that prescribed in the design shall not be cause for rejection.

14.7.3 *Height of Two Opposite Sides*—Variations in laying heights of two opposite sides of risers or conical tops shall be not more than 16 mm [$^{5}/_{8}$ in.].

14.7.4 *Height of Section*—The underrun in height of a riser or conical top shall be not more than 20 mm/m [$^{1}/_{4}$ in./ft] of height with a maximum of 13 mm [$^{1}/_{2}$ in.] in any one section.

14.7.5 *Position of Reinforcement*—For risers or conical tops with a 100 mm [4-in.] wall thickness or less, the maximum variation in the position of reinforcement from that prescribed in Sections 14.5 and 14.6 shall be ±10 percent of the wall thickness or ±6 mm [±$^{1}/_{4}$ in.], whichever is greater. For sections with a wall thickness greater than 100 mm [4 in.], the maximum variation in the position of reinforcement shall be ±10 percent of the wall thickness or ±16 mm [±$^{5}/_{8}$ in.], whichever is the lesser. In no case, however, shall the cover over the reinforcement be less than 19 mm [$^{3}/_{4}$ in.]. The preceding minimum cover limitation does not apply to the mating surfaces of the joint.

14.7.6 *Area of Reinforcement*—Steel reinforcement areas that are 0.1 mm^{2}/linear m [0.005 in.^{2}/linear ft] less than called for by design shall be considered as meeting the required steel reinforcement area.

14.8 *Rejection*:

14.8.1 Risers and conical tops shall be subject to rejection for failure to conform to any of the specification requirements. In addition, an individual riser or conical top shall be subject to rejected because of any of the following:

14.8.1.1 Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint;

14.8.1.2 Defects that indicate mixing and molding not in compliance with Section 7.1 or surface defects indicating honey-combed or open texture that would adversely affect the function of the riser or conical top;

14.8.1.3 The planes of the ends are not perpendicular to the longitudinal axis of the riser or conical top, within the limits of permissible variations prescribed in Section 14.7;

14.8.1.4 Damaged or cracked ends, where such damage would prevent making a satisfactory joint; and

14.8.1.5 Any continuous crack having a surface width of 0.3 mm [0.01 in.] or more and extending for a length of 300 mm [12 in.] or more, regardless of position in the wall.

15. BASE SECTIONS

15.1 *Scope*—This section covers three types of precast reinforced concrete base sections manufactured for use in the construction of manholes used in sewer and water works. The three types of base sections are (1) a base with riser wall and base slab cast monolithically as a single unit with or without benching, (2) a base consisting of a riser section with a secondary poured integral base slab with or without benching, and (3) a two-piece base consisting of a separate precast base slab and a riser section with a sealed joint between the two. The riser portions of a base section shall meet all the requirements of Section 14.

15.2 *Acceptance*—Acceptability of base sections covered by this specification shall be determined by the results of such tests of materials as are required by Section 4; by compressive strength tests on concrete cores or concrete cylinders required by Section 8; and by inspection of the finished product, including amount and placement of reinforcement as prescribed by Sections 15.4 and 15.6, to determine conformance with the design prescribed under this specification and its freedom from defects.

15.3 *Design*:

15.3.1 The basis of base slab designs shall be the appropriate sections of the latest edition of ACI 318.

15.3.2 Base slabs shall have a minimum thickness of 150 mm [6 in.] for manholes up to and including 1200 mm [48 in.] in diameter and 200 mm [8 in.] for larger diameter manholes.

15.3.2.1 When a base section is precast monolithically with a benched invert, the minimum concrete thickness from the invert to bottom of the base slab shall be 100 mm [4 in.].

15.3.3 Benched inverts cast either monolithically with the base section or as a secondary casting in a cured base section shall have the following minimum dimensions:

15.3.3.1 Minimum slope of 40 mm/m [$^1/_2$ in./ft] from the channel to the inside diameter (I.D.) of riser wall for the benching.

15.3.3.2 Minimum channel invert depth of one-half the pipe I.D.;

15.3.3.3 When a channel is cast in a cured base section, the minimum concrete thickness under the invert shall be 50 mm [2 in.];

15.3.3.4 Width of channel at top of benching shall be a minimum equal to the pipe I.D.;

15.3.3.5 Invert shall provide a positive flow between inlet to outlet pipes; and

15.3.3.6 The minimum channel centerline radius shall be equal to the pipe I.D.

15.4 *Reinforcement*:

15.4.1 *Base Section Circumferential Reinforcement*—Circumferential reinforcement shall meet all the requirements of Section 14 except that Section 14.5 is not permitted.

15.4.2 *Base Slab Reinforcement*:

15.4.2.1 A layer of reinforcement shall be placed above the midpoint, and shall have a minimum area of 250 mm^2/linear m [0.12 $in.^2$/linear ft] in both directions.

15.4.2.2 The minimum protective cover over the reinforcement shall be 25 mm [1 in.].

15.4.3 *Longitudinal Members*—Longitudinal bars or members used to maintain a cage of circumferential reinforcement in shape and position within the form shall meet all the requirements of Section 14.

15.4.4 *Joint Reinforcement*—The mating surface of the base section joint is not required to contain circumferential reinforcement.

Note 4—(Advisory) Base sections with multiple openings, large openings, or both may require special consideration of their handling reinforcement.

15.5 *Joints*—Precast reinforced base sections shall be designed and manufactured with a male or female end, so that the assembled manhole base, riser, and top will make a continuous and uniform manhole, compatible with the tolerances given in Section 15.6.

15.5.1 Joints are designed to perform in axial compression; therefore, shear or load testing of the joint is not required.

15.6 *Permissible Variations*:

15.6.1 *Internal Diameter*—The internal diameter of base sections shall not vary more than 1 percent.

15.6.2 *Thickness*—The thickness of base slabs with or without benching shall be not less than that prescribed in the design by more than 5 percent. A thickness greater than that prescribed in the design shall not be cause for rejection.

15.6.3 *Height of Two Opposite Sides*—Variations in laying heights of two opposite sides of base sections shall be not more than 16 mm [$^5/_8$ in.].

15.6.4 *Height of Sections*—The underrun in height of a base section shall be not more than $^1/_4$ in./ft of height with a maximum of 13 mm [$^1/_2$ in.] in any one base section.

15.6.5 *Position of Reinforcement*—For base slabs with monolithic benched inverts with a 100 mm [4-in.] thickness or less, the maximum variation in the position of reinforcement from that prescribed in Section 15.4 shall be ±10 percent of the thickness or ±6 mm [$\pm^1/_4$ in.], whichever is greater. For base slabs with a thickness greater than 100 mm [4 in.], the maximum variation shall be ±10 percent of the thickness or ±16 mm [$\pm^5/_8$ in.], whichever is the lesser. In no case, however, shall the cover over the reinforcement be less than 19 mm [$^3/_4$ in.]. The preceding minimum cover limitation does not apply to the mating surfaces of base section joints.

15.6.6 *Area of Reinforcement*—Steel reinforcement areas that are 10 mm^2/linear m [0.005 in.^{2}/linear ft] less than called for by design shall be considered as meeting the required steel reinforcement area.

15.7 *Rejection*:

15.7.1 Base sections shall be subject to rejection for failure to conform to any of the specification requirements. In addition, an individual base section with a flat slab floor, integral floor or integral floor with benching shall be subject to rejection because of any of the following:

15.7.1.1 Fractures or cracks passing through the riser wall, except for a single end crack that does not exceed the depth of the joint;

15.7.1.2 Defects that indicate mixing and molding not in compliance with Section 7.1 or surface defects indicating honey-combed or open texture that would adversely affect the function of the base section;

15.7.1.3 The planes of the ends are not perpendicular to the longitudinal axis of the base section, within the limits of permissible variations prescribed in Section 15.6;

15.7.1.4 Damaged or cracked ends, where such damage would prevent making a satisfactory joint; and

15.7.1.5 Any continuous crack having a surface width of 0.3mm [0.01 in.] or more and extending for a length of 300 mm [12 in.] or more, regardless of position in the base section.

16. STEPS AND LADDERS

16.1 *Scope*:

16.1.1 This section covers manhole steps and ladders used for providing access through manholes for use in sewer and water works.

16.1.2 The user of this specification is advised that access through manholes may be by steps that are cast, mortared, or attached by mechanical means into the walls of base, riser, or conical top sections or by ladder.

16.2 *Acceptance*—Unless otherwise designated by the owner at the time of, or before, placing an order, acceptance of steps and ladders installed in manholes will be on the basis of tests and inspection of the completed product.

16.3 *Materials*:

16.3.1 Except as required in this section, manhole steps and ladders shall conform to the requirements of the Occupational Safety and Health Standards, U.S. Department of Labor.

16.3.2 Manhole steps that are cast, mortared, or attached by mechanical means into the walls of base, riser, or conical top sections shall meet the requirements of Sections 16.4 and 16.5 in addition to the following:

16.3.2.1 When dissimilar types of materials are used in the steps, appurtenances, and fastenings, the materials shall be treated to prevent deleterious effects.

16.3.2.2 That portion of the step projecting into the base section, riser, or conical top opening shall be free of splinters, sharp edges, burrs, or projections which may be a hazard.

16.4 *Design*:

16.4.1 Steps in base section, riser, and conical top sections shall be aligned in each section so as to form a continuous ladder with rungs equally spaced vertically in the assembled manhole at a maximum design distance of 400 mm [16 in.] apart.

16.4.2 Steps shall be embedded in the base section, riser, or conical top section wall a minimum distance of 75 mm [3 in.].

16.5 *Dimensions*:

16.5.1 Ferrous metal steps not painted or treated to resist corrosion shall have a minimum cross-sectional dimension of 25 mm [1 in.].

16.5.2 The minimum width of rungs or cleats shall be 250 mm [10 in.].

16.5.3 The rung or cleat shall project a uniform clear distance of 100 mm (minimum) to 150 mm (maximum) ±6 mm [4 in. (minimum) to 6 in. (maximum) $\pm{}^{1}/_{4}$ in.] from the wall of the base, riser, or conical top section measured from the point of embedment to the embedment side of the rung.

Note 5—Embedment point is considered the junction of the centerline of the step leg and the wall of the base, riser or conical top section.

16.5.4 The minimum clear distance between the rung or cleat and the opposite wall of the base, riser, or conical top shall be 450 mm [18 in.] measured at the center face of the rung or cleat.

16.5.5 The vertical spacing and vertical alignment between adjacent manhole steps and horizontal distance from the inside wall to the centerline of a manhole step may vary 25 mm [1 in.] from the design dimension.

16.6 *Physical Requirements*:

16.6.1 *Testing*:

16.6.1.1 The manufacturer furnishing manhole sections with steps under this specification shall furnish all facilities and personnel necessary to carry out the tests required in the Manhole Step Test section of T 280.

16.6.1.2 One installed manhole step of the type to be used on a project shall be tested unless certified test results are available.

16.6.1.3 Vertical and horizontal load test procedures for manhole steps shall be in accordance with T 280.

16.6.1.4 The horizontal pull out load shall be 1800 N [400 lb.].

16.6.1.5 The vertical load shall be 3600 N [800 lb.].

16.6.2 *Acceptance*—The step shall be acceptable if the following requirements are met:

16.6.2.1 The step remains solidly embedded after application of the horizontal load test.

16.6.2.2 The step sustains a permanent set of 13 mm [$^1/_2$ in.] or less after application of the vertical load test.

16.6.2.3 No cracking or fracture of the step nor spalling of the concrete is evident.

16.6.2.4 If certified test results are not available and the step selected fails to conform to the test requirements, the manufacturer may select two other steps for retests. If either of these steps fail the retest, the steps shall be rejected.

17. KEYWORDS

17.1 Absorption; acceptance criteria; base sections; compressive strength; concrete; cone tops; design; flat slab tops; grade rings; ladders; manhole; manufacture; reinforced; riser sections; sewer; steps; tests; water.

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[1] Agrees with ASTM C 478M-09 and C478-09 except for limiting absorption testing to the 5-hour boil method and the method of retest in case of failure of absorption specimens and compressive strength determination.

Standard Specification for

Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe

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AASHTO Designation: M 206M/M 206-10[1]
ASTM Designation: C 506M-09 and C 506-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe

AASHTO Designation: M 206M/M 206-10[1]
ASTM Designation C 506M-09 and C 506-09

1. SCOPE

1.1 This specification covers reinforced arch-shaped concrete pipe to be used for the conveyance of sewage, industrial wastes, storm water, and for the construction of culverts.

1.2 This specification is applicable for orders in either SI units (M 206M) or in inch-pound units (M 206). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 206.

Note 1—This specification is a manufacturing and purchase specification only, and does not include requirements for bedding, backfill, or the relationship between field load condition and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, and care that the installation conforms to the construction specifications. The owner of the reinforced concrete pipe specified herein is cautioned that he must correlate the field requirements with the class of pipe specified and provide inspection at the construction site.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 154, Air-Entraining Admixtures for Concrete
- M 194M/M 194, Chemical Admixtures for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standards*:

- A 36/A 36M, Standard Specification for Carbon Structural Steel
- A 706/A 706M, Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
- C 1017/C 1017M, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1 Pipe manufactured according to this specification shall be of three classes identified as Class A-II, A-III, and A-IV. The strength requirements are prescribed in Table 1 for SI units or Table 2 for inch-pound units.

5. BASIS OF ACCEPTANCE

5.1 Unless otherwise designated by the owner at the time of or before placing an order, there are two separate and alternative bases of acceptance. Independent of the method of acceptance, the pipe shall be designed to meet both the 0.3-mm [0.01-in.] crack and ultimate strength requirements.

5.1.1 *Acceptance on Basis of Plant Load Bearing Tests, Material Tests, and Inspection of Manufactured Pipe for Visual Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of the three-edge-bearing tests as defined in Section 11.3.1; by such material tests as are required in accordance with Sections 6.2, 6.3, 6.5, and 6.6, by an absorption test of the concrete from the wall of the pipe for each mix design that is used on an order; and by visual inspection of the finished pipe to determine its conformance with the accepted design and its freedom from defects.

5.1.2 *Acceptance on Basis of Material Tests and Inspection of the Complete Product*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or 7.2 shall be determined by the results of such material tests as are required in Sections 6.2, 6.3, 6.5, and 6.6; by crushing tests on concrete cores or cured concrete cylinders; by an absorption test of the concrete from the wall of the pipe for each mix design that is used on an order; and by inspection of the finished pipe, including amount and placement of reinforcement, to determine its conformance with the accepted design and its freedom from defects.

5.1.3 When agreed upon by the owner and the manufacturer, any portion or any combination of tests itemized in Section 5.1.1 or Section 5.1.2 may form the basis of acceptance.

5.2 *Age for Acceptance*—Pipe shall be considered ready for acceptance when they conform to the requirements as indicated by the specified tests.

Table 1—Strength Requirements for Reinforced Concrete Pipe (SI units)[a]

				f'_c MPa[b]			Double Line Reinforcement[c]														Single Line Reinforcement		
				Class			Continuous Basic Reinforcement = A_s[d]						Additional Requirement = A_s[d]										
							Inner Cage			Outer Cage			"U" (Inner Cage)				"V" (Outer Cage)						
Approx. Equiv.-Round Size, mm	T, mm	Min. Rise, mm	Min. Span, mm	A-II	A-III	A-IV	A-II	A-III	A-IV	A-II	A-III	A-IV	Dimension, mm	A-II	A-III	A-IV	Dimension, mm	A-II	A-III	A-IV	A-II	A-III	A-IV
375	57	280	460	27.6	27.6	27.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.7	2.5	3.6
450	63	345	560	27.6	27.6	27.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.3	3.0	5.5
525	69	395	660	27.6	27.6	27.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.8	3.6	6.1
600	75	460	725	27.6	27.6	27.6	—	—	—	—	—	—	660	—	—	—	735	—	—	—	3.4	4.6	6.8
750	88	570	920	27.6	27.6	27.6	1.9	2.5	3.8	1.5	1.9	3.0	760	1.9	2.5	3.8	865	1.5	1.9	2.8	3.8	5.1	7.6
900	100	675	1110	27.6	27.6	27.6	2.3	3.2	4.6	1.9	2.5	3.6	865	2.3	3.2	4.6	990	1.9	2.5	3.4	4.6	6.3	9.3
1050	113	795	1300	27.6	27.6	27.6	2.8	3.8	5.7	2.1	3.0	4.4	1065	2.8	3.8	5.7	1090	2.1	3.0	4.6	5.5	7.6	11.4
1200	125	915	1485	27.6	27.6	—	3.2	4.6	—	2.5	3.6	—	1220	3.2	4.6	—	1245	2.5	3.6	—	6.3	9.3	—
1350	138	1015	1650	27.6	27.6	—	3.8	5.1	—	3.0	4.0	—	1320	3.8	5.1	—	1395	3.0	4.0	—	7.6	10.2	—
1500	150	1145	1855	27.6	27.6	—	4.4	5.9	—	3.6	4.6	—	1525	4.4	5.9	—	1700	3.6	4.6	—	8.9	11.8	—
1800	175	1370	2235	27.6	34.5	—	5.5	7.6	—	4.2	5.9	—	1725	5.5	7.6	—	1955	4.2	5.9	—	11.0	15.2	—
2100	200	1575	2590	27.6	34.5	—	6.8	9.3	—	5.1	7.2	—	—	6.8	9.3	—	—	5.1	7.2	—	13.5	18.6	—
2250	213	1830	2920	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2400	225	1960	3100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2700	250	2215	3505	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3000	275	2460	3910	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3300	250	2705	4285	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a] For modified or special designs, designs, see Section 7.3.

[b] f'_c MPa = minimum compressive strength of concrete in megapascals.

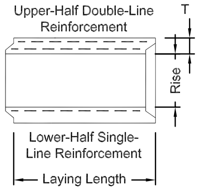
[c] As an alternative to designs requiring double line reinforcement, the reinforcement may be positioned and proportional so that the total reinforcement of the inner cage plus the middle cage shall not be less than that specified for the inner cage continuous basic reinforcement, and the additional reinforcement "U" and the total reinforcement of the outer cage plus the middle cage shall not be less than that specified for the outer cage continuous basic reinforcement and the additional reinforcement "V".

[d] A_s = circumferential steel area in square millimeters per longitudinal centimeter of pipe barrel in each continuous basic cage and additional cages in area denoted "U" and "V" Dimensions "U" and "V" are measured on the centerline of the culvert wall.

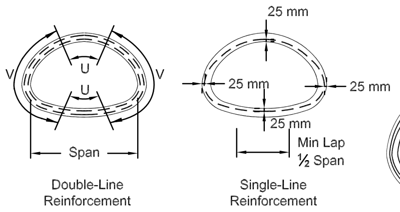
D-Loads for Three-Edge-Bearing Method

Class	0.3-mm Crack	Ultimate
A-II	50.0	75.0
A-III	65.0	100.0
A-IV	100.0	150.0

Note: Test load in newtons per linear meter equals D-load × inside span in millimeters.



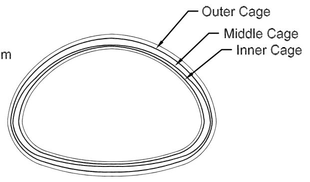
Typical Longitudinal Section



Double-Line Reinforcement

Single-Line Reinforcement

Sections



Triple-Line Reinforcement

Table 2—Strength Requirements for Reinforced Concrete Pipe (inch-pound units)[a]

							Double Line Reinforcement[c]																
				f'_c ksi[b]			Continuous Basic Reinforcement = A_s[d]						Additional Requirement = A_s[d]										
				Class			Inner Cage			Outer Cage			"U" (Inner Cage)				"V" (Outer Cage)				Single Line Reinforcement		
Approx. Equiv. Round Size, in.	T, in.	Min. Rise, in.	Min Span, in.	A-II	A-III	A-IV	A-II	A-III	A-IV	A-II	A-III	A-IV	Dimension, in.	A-II	A-III	A-IV	Dimension, in.	A-II	A-III	A-IV	A-II	A-III	A-IV
15	$2\frac{1}{4}$	11	18	4	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.08	0.12	0.17
18	$2\frac{1}{2}$	$13\frac{1}{2}$	22	4	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.11	0.14	0.26
21	$2\frac{3}{8}$	$15\frac{1}{2}$	26	4	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.13	0.17	0.29
24	3	18	$28\frac{1}{2}$	4	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.16	0.22	0.32
30	$3\frac{1}{2}$	$22\frac{1}{2}$	$36\frac{1}{4}$	4	4	4	0.09	0.12	0.18	0.07	0.09	0.14	26	0.09	0.12	0.18	29	0.07	0.09	0.13	0.18	0.24	0.36
36	4	$26\frac{5}{8}$	$43\frac{3}{8}$	4	4	4	0.11	0.15	0.22	0.09	0.12	0.17	30	0.11	0.15	0.22	34	0.09	0.12	0.16	0.22	0.30	0.44
42	$4\frac{1}{2}$	$31\frac{5}{16}$	$51\frac{1}{8}$	4	4	4	0.13	0.18	0.27	0.10	0.14	0.21	34	0.13	0.18	0.27	39	0.10	0.14	0.22	0.26	0.36	0.54
48	5	36	$58\frac{1}{2}$	4	4	—	0.15	0.22	—	0.12	0.17	—	42	0.15	0.22	—	43	0.12	0.17	—	0.30	0.44	—
54	$5\frac{1}{2}$	40	65	4	4	—	0.18	0.24	—	0.14	0.19	—	48	0.18	0.24	—	49	0.14	0.19	—	0.36	0.48	—
60	6	45	73	4	4	—	0.21	0.28	—	0.17	0.22	—	52	0.21	0.28	—	55	0.17	0.22	—	0.42	0.56	—
72	7	54	88	4	5	—	0.26	0.36	—	0.20	0.28	—	60	0.26	0.36	—	67	0.20	0.28	—	0.52	0.72	—
84	8	62	102	4	5	—	0.32	0.44	—	0.24	0.34	—	68	0.32	0.44	—	77	0.24	0.34	—	0.64	0.88	—
90	$8\frac{1}{2}$	72	115	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
96	9	$77\frac{1}{2}$	122	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
108	10	$87\frac{1}{8}$	138	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
120	11	$96\frac{7}{8}$	154	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
132	10	$106\frac{1}{2}$	$168\frac{3}{4}$	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a] For modified or special designs, designs, see Section 7.3.

[b] f'_c ksi = minimum compressive strength of concrete in thousands of pounds-force per square inch.

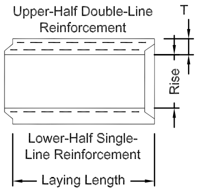
[c] As an alternative to designs requiring double line reinforcement, the reinforcement may be positioned and proportional so that the total reinforcement of the inner cage plus the middle cage shall not be less than that specified for the inner cage continuous basic reinforcement, and the additional reinforcement "U" and the total reinforcement of the outer cage plus the middle cage shall not be less than that specified for the outer cage continuous basic reinforcement and the additional reinforcement "V".

[d] A_s = circumferential steel area in square inches per longitudinal foot of pipe barrel in each continuous basic cage and additional cages in area denoted "U" and "V" Dimensions "U" and "V" are measured on the centerline of the culvert wall.

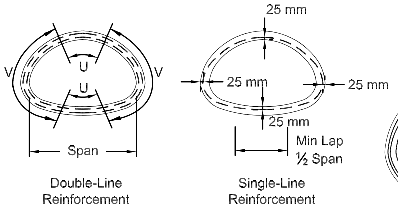
D-Loads for Three-Edge-Bearing Method

Class	0.01-in. Crack	Ultimate
II	1000	1500
III	1350	2000
IV	2000	3000

Note: Test load in pounds per linear foot equals
D-load × inside span in feet.



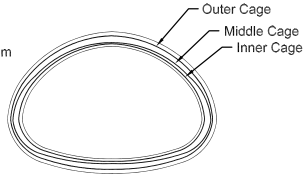
Typical Longitudinal Section



Double-Line Reinforcement

Single-Line Reinforcement

Sections



Triple-Line Reinforcement

6. MATERIALS

6.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.2 *Cementitious Materials*:

6.2.1 *Cement*—Cement shall conform to the requirements of M 85 or shall be portland blast-furnace slag cement, or slag modified portland cement, or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.2.2 *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of M 302

6.2.3 *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1 Portland cement only,

6.2.4.2 Portland blast furnace slag cement only,

6.2.4.3 Slag modified portland cement only,

6.2.4.4 Portland-pozzolan cement only, or

6.2.4.5 A combination of portland cement and ground granulated blast-furnace slag,

6.2.4.6 A combination of portland cement and fly ash, or

6.2.4.7 A combination of portland cement, ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight) and fly ash (not to exceed 25 percent of the total cementitious weight).

6.3 *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

6.4 *Admixtures and Blends*—The following admixtures and blends are allowable:

6.4.1 Air-entraining admixture conforming to M 154;

6.4.2 Chemical admixture conforming to M 194;

6.4.3 Chemical admixture for use in producing flowing concrete conforming to C 1017/C 1017M; and

6.4.4 Chemical admixture or blend approved by the owner.

6.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to M 32M/M 32 or M 225M/M 225; or of wire reinforcement conforming to M 55M/M 55 or M 221M/M 221; or of bars conforming to M 31M/M 31 Grade 280 [40] or 420 [60], ASTM A 36/A 36M, or ASTM A 706/A 706M Grade 420 [60].

6.6 *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers may be used at the owner's option in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

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7. DESIGN

7.1 *Size and Dimensions*—The standard sizes of arch pipe are listed in Table 3 for pipe specified in SI units or Table 4 for pipe specified in inch-pound units. The internal dimensions for each standard size shall be as defined in Table 3 or Table 4, subject to the permissible variations of Section 12.

7.2 *Design Tables*—The wall thickness, compressive strength of concrete, and the area of circumferential reinforcement shall be as prescribed in Table 1 or Table 2, subject to the provisions of Sections 7.3, 11, and 12.

7.2.1 Footnotes to the tables herein are intended to be amplifications of the tabulated requirements and are to be considered applicable and binding as if they were contained in the body of the specification.

7.3 *Modified and Special Designs*:

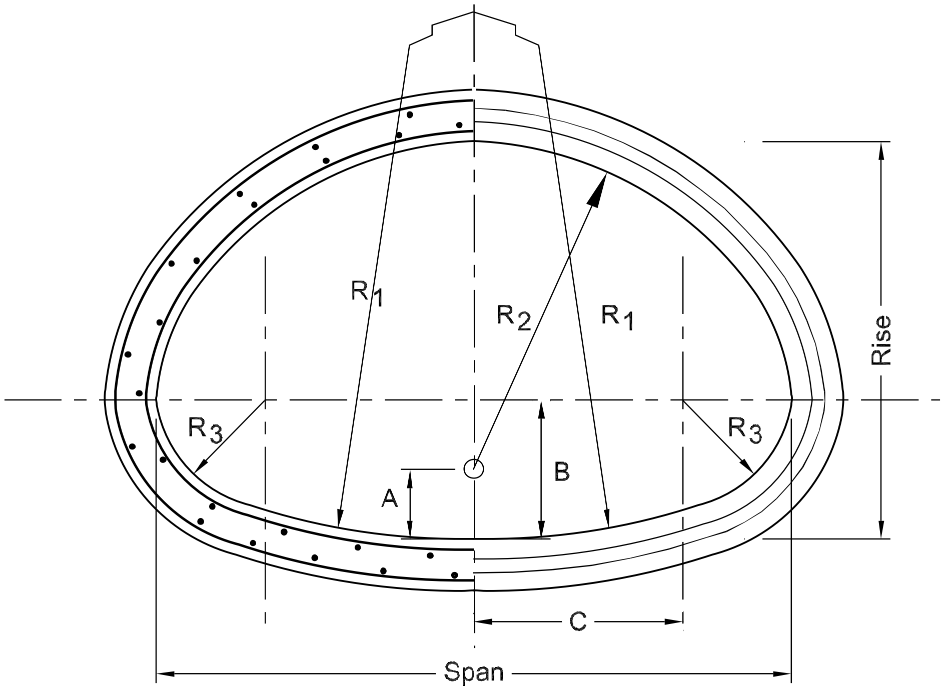
7.3.1 If permitted by the owner, the manufacturer may request approval by the owner of modified designs that differ from the designs in this Section 7 or special designs for sizes and loads beyond those shown in Table 1 or Table 2 as appropriate for the units being used: or special designs for pipe sizes that do not have steel reinforcement areas shown in Table 1 or Table 2.

7.3.2 Such modified or special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of pipe and shall fully describe to the owner any deviations from the requirements of this Section 7. The descriptions of modified or special designs shall include the wall thickness; the concrete strength; the area, type, placement, number of layers; and strength of the steel reinforcement.

7.3.3 The manufacturer shall submit to the owner proof of the adequacy of the proposed modified or special design. Such proof may comprise the submission of certified three-edge-bearing tests already made, which are acceptable to the owner or, if such three-edge-bearing tests are not available or acceptable, the manufacturer may be required to perform proof tests on sizes and classes selected by the owner to demonstrate the adequacy of the proposed design.

7.3.4 Such pipe must meet all of the test and performance requirements specified by the owner in accordance with Section 5.

7.4 *Area*—In this specification, when the word "area" is not described by adjectives such as cross-sectional or single wire, it shall be understood to be the cross-sectional area of reinforcement per unit lengths of pipe.



$$A = \text{Rise} - R_2$$

$$B = A + \sqrt{(R_2 - R_3)^2 - C^2}$$

$$C = \frac{\text{Span}}{2} - R_3$$

Figure 1—Cross-Sectional Shape of Arch Pipe

Table 3—Sizes and Dimensions of Arch Pipe (SI units) (See Figure 1 for definition of terms)

Approximate Equivalent Round Size, mm	Water Area, m^2	Rise, mm	Span, mm	A, mm	B, mm	C, mm	R_1, mm	R_2, mm	R_3, mm
375	0.10	280	460	10	121	128	580	270	102
450	0.15	345	560	–5	153	145	700	350	135
525	0.20	395	660	20	158	195	900	375	135
600	0.26	460	725	90	153	248	1035	370	115
750	0.41	570	920	95	194	305	1300	475	155
900	0.59	675	1110	105	218	395	1575	570	160
1050	0.82	795	1300	130	258	460	1855	665	190
1200	1.06	915	1485	155	297	522	2135	760	220
1350	1.33	1015	1650	170	330	575	2350	850	250
1500	1.64	1145	1855	190	373	642	2670	955	285
1800	2.38	1370	2235	225	428	798	3200	1145	320
2100	3.21	1575	2590	255	475	940	4130	1320	355
2250	4.13	1830	2920	330	604	970	4650	1500	490
2400	4.80	1960	3100	385	616	1040	5535	1575	510
2700	6.13	2215	3505	435	681	1182	6835	1780	570
3000	7.60	2460	3910	480	740	1345	7655	1980	610
3300	9.21	2705	4285	530	835	1458	8355	2175	685

Table 4—Sizes and Dimensions of Arch Pipe (inch-pound units) (See Figure 1 for definition of terms)

Approximate Equivalent Round Size, in.	Water Area, ft^2	Rise, in.	Span, in.	A, in.	B, in.	C, in.	R_1, in.	R_2, in.	R_3, in.
15	1.1	11	18	$^3/_8$	$4^{11}/_{16}$	$4^{31}/_{32}$	$22^7/_8$	$10^5/_8$	$4^1/_{32}$
18	1.65	$13^1/_2$	22	$-^1/_4$	6	$5^3/_4$	$27^1/_2$	$13^3/_4$	$5^1/_4$
21	2.2	$15^1/_2$	26	$^3/_4$	$6^1/_4$	$7^3/_4$	$35^1/_2$	$14^3/_4$	$5^1/_4$
24	2.8	18	$28^1/_2$	$3^7/_{16}$	$5^{29}/_{32}$	$9^{21}/_{32}$	$40^{11}/_{16}$	$14^9/_{16}$	$4^{19}/_{32}$
30	4.4	$22^1/_2$	$36^1/_4$	$3^3/_4$	$7^{11}/_{16}$	$12^3/_{32}$	51	$18^3/_4$	$6^1/_{32}$
36	6.4	$26^5/_8$	$43^3/_4$	$4^1/_8$	$8^9/_{16}$	$15^1/_2$	62	$22^1/_2$	$6^3/_8$
42	8.8	$31^5/_{16}$	$51^1/_8$	$5^1/_{16}$	$10^1/_{16}$	18	73	$26^1/_4$	$7^9/_{16}$
48	11.4	36	$58^1/_2$	6	$11^{19}/_{32}$	$20^1/_2$	84	30	$8^3/_4$
54	14.3	40	65	$6^5/_8$	13	$22^{11}/_{16}$	$92^1/_2$	$33^3/_8$	$9^{13}/_{16}$
60	17.7	45	73	$7^1/_2$	$14^{11}/_{16}$	$25^9/_{32}$	105	$37^1/_2$	$11^7/_{32}$
72	25.6	54	88	9	17	$31^7/_{16}$	126	45	$12^9/_{16}$
84	34.6	62	102	10	$18^{21}/_{32}$	$37^1/_{32}$	$162^1/_2$	52	$13^{31}/_{32}$
90	44.5	72	115	13	$23^{13}/_{16}$	$38^7/_{32}$	183	59	$19^9/_{32}$
96	51.7	$77^1/_4$	122	$15^1/_4$	$24^{11}/_{32}$	$40^{15}/_{16}$	218	62	$20^1/_{16}$
108	66.0	$87^1/_8$	138	$17^1/_8$	$26^{27}/_{32}$	$46^5/_8$	269	70	$22^3/_8$
120	81.8	$96^7/_8$	154	$18^7/_8$	$29^7/_{32}$	53	$301^3/_8$	78	24
132	99.1	$106^1/_2$	168¾	$20^7/_8$	$32^{15}/_{16}$	$57^1/_2$	329	$85^5/_8$	$26^7/_8$

8. REINFORCEMENT

8.1 *Circumferential Reinforcement*—A line of circumferential reinforcement for any given total area may be composed of two layers for pipe with wall thicknesses of less than 180 mm [7 in.] or three layers for pipe with wall thicknesses of 180 mm [7 in.] or greater. The layers shall not be separated by more than the thickness of one longitudinal plus 6 mm [$^1/_4$ in.] The multiple layers shall be fastened together to form a single cage. All other specification requirements such as laps, welds, tolerances of placement in the wall of the pipe, etc., shall apply to this method of fabricating a line of reinforcement.

8.1.1 Where one line of reinforcement is used, it shall be placed so that the cover of the concrete over the circumferential reinforcement at the vertical and horizontal diameters of the pipe is 25 mm [1 in.] from the inside and outside surfaces of the pipe, except for wall thicknesses less than 62 mm [$2^1/_2$ in.], the protective cover of the concrete over the circumferential reinforcement in the wall of the pipe shall be 18 mm [$^3/_4$ in.].

8.1.2 Where two lines of reinforcement of arch shape corresponding to the contour of the pipe are used, each line shall be so placed that the covering of concrete over the reinforcement is 25 mm [1 in.].

8.1.3 The location of the reinforcement shall be subject to the permissible variations in dimensions given in Section 12.5. Requirements for placement and protective covering of the concrete from the inner or outer surface of the pipe do not apply to that portion of a cage which is flared so as to extend into the bell or is reduced in diameter so as to extend into the spigot.

8.1.4 The spacing center-to-center of circumferential reinforcement in a cage shall not exceed 100 mm [4 in.] for pipe up to and including pipe having a 100-mm [4-in.] wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 150 mm [6 in.].

8.1.5 The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe, except that when agreed upon by the owner, lift eyes or holes may be provided in each pipe for the purpose of handling.

8.1.6 If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire.

8.1.6.1 When splices are welded and are not lapped to the minimum requirements in Section 8.1.6, pull tests of representative specimens shall develop at least 50 percent of the minimum specified strength of the steel and there shall be a minimum lap of 50 mm [2 in.]. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 percent of the minimum specified strength of the steel.

8.2 *Longitudinal Reinforcement*—Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members, to maintain the reinforcement in shape and in position within the form to comply with permissible variations in Section 8.1. The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

8.3 *Joint Reinforcement*—In all pipe 900 mm [36 in.] or larger in diameter, either the bell or the spigot of the joint shall contain circumferential reinforcement.

8.3.1 For single-cage pipe, joint reinforcement shall be at least equal in area to that required for an equivalent length of pipe wall.

8.3.2 For double-cage and triple-cage pipe, joint reinforcement shall be at least equal in area to that required for an equivalent length of the outer circular cage if placed in the bell, or at least equal in area to that required for an equivalent length of the inner circular cage if placed in the spigot.

9. JOINTS

9.1 The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 12.

10. MANUFACTURE

10.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 [470 lb/yd^3] unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

10.2 *Curing*—Pipe shall be subjected to any one of the methods of curing described in Sections 10.2.1 to 10.2.4, or to any other method or combination of methods approved by the owner, that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the specified

D-load is obtained when acceptance is based on Section 5.1.1 or so that the concrete will develop the specified compressive strength at 28 days or less when acceptance is based on Section 5.1.2.

10.2.1 *Steam Curing*—Pipe may be placed in a curing chamber free from outside drafts and cured in a moist atmosphere maintained by the injection of steam for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

10.2.2 *Water Curing*—Concrete pipe may be water cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

10.2.3 The manufacturer may, at his option, combine the methods described in Sections 10.2.1 to 10.2.4 as long as the required concrete compressive strength is attained.

10.2.4 A sealing membrane conforming to the requirements of M 148 may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 6ºC [10ºF] of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

11. PHYSICAL REQUIREMENTS

11.1 *Test Specimens*—The specified number of pipe required for the tests shall be furnished without charge by the manufacturer, shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order. Unless designated otherwise by the owner in the order, the manufacturer shall select the type of test (external load crushing strength test, compression test of cylinders, or compression test of cores) to be used to determine the acceptability of the pipe strength. Pipe that fails to meet the strength requirements as determined by the selected test type may not be retested using one of the other test types without approval of the owner.

11.2 *Number and Type of Tests Required for Various Delivery Schedules*:

11.2.1 *Preliminary Tests for Extended Delivery Schedules*—An owner of pipe whose needs require shipments at intervals over extended periods of time shall be entitled to such tests as are required by the type of basis of acceptance specified by the owner in Section 5. The tests shall be preliminary to delivery of pipe and of not more than three sections of pipe covering each size in which the owner is interested.

11.2.2 *Additional Tests*—After the preliminary tests described in Section 11.2.1, an owner shall be entitled to additional tests at such times as the owner may deem necessary provided that the total number of pipe tested (including preliminary tests) shall not exceed one pipe or 1 percent, whichever is the greater, of each size of pipe delivered.

11.3 *External Load Crushing Strength*:

11.3.1 The load required to produce a 0.3-mm [0.01-in.] crack or the ultimate load, as determined by the three-edge-bearing method described in T 280, shall be not less than that prescribed in Table 1or Table 2, for each respective class of pipe. Pipe that have been tested only to the formation of a 0.3-mm [0.01-in.] crack and that meets the 0.3-mm [0.01-in.] crack load requirements shall be accepted for use.

Note 2—As used in this specification, the 0.3-mm [0.01-in.] crack is a test criterion for pipe under load in a three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

11.3.2 *Retests of Pipe Not Meeting the External Load Crushing Strength Requirements*—Pipe shall be considered as meeting the strength requirements when all test specimens conform to the requirements. Should any of the test specimens fail to meet the requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

11.4 *Type of Specimen*—Compression tests determining concrete compressive strength may be made on either standard rodded concrete cylinders or concrete cylinders compacted and cured in like manner as the pipe, or on cores drilled from the pipe.

11.5 *Compression Testing of Cylinders*:

11.5.1 *Cylinder Production*—Cylinders shall be prepared in accordance with Section 11 of T 280.

11.5.2 *Number of Cylinders*—Prepare no fewer than five test cylinders from a group (one day's production of each concrete strength) of pipe sections.

11.5.3 *Acceptability on the Basis of Cylinder Test Results*:

11.5.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the required concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.5.3.2 When the average compressive strength of all cylinders tested is equal to or greater than the required concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the required concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the required concrete strength, then the group shall be accepted.

11.5.3.3 The pipe shall be acceptable only when the compressive strength of the cylinders tested conforms to the acceptance criteria stated in Section 11.5.3.1 or Section 11.5.3.2.

11.6 *Compression Testing of Cores*:

11.6.1 *Obtaining Cores*—Cores shall be obtained and prepared in accordance with Section 6 of T 280.

11.6.2 *Number of Cores*—One core shall be taken from a pipe section selected at random from each day's production run of a single concrete strength.

11.7 *Acceptability on the Basis of Core Test Results*:

11.7.1 When the compressive strengths of cores tested for a group of pipe sections is equal to or greater than the required concrete strength, the compressive strength of the concrete for the group is acceptable.

11.7.2 If the compressive strength of the core tested is less than the required concrete strength, two additional cores shall be taken from that pipe section and tested. Concrete represented by these three core tests shall be considered acceptable if: (1) the average of the three core strengths is equal to at least 85 percent of the required strength and (2) no single core is less than 75 percent of the required strength.

11.7.3 If the compressive strength of the three cores does not meet the requirements of Section 11.7.2, the pipe from which the cores were taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and cored and tested for conformance with either Section 11.7.1 or Section 11.7.2. If both pipe sections meet the core strength requirements of either Section 11.7.1 or Section 11.7.2, the remainder of the group shall be acceptable. If both pipe sections do not meet the test strength requirement, the remainder of the group shall be either rejected or, at the option of the manufacturer, each pipe section of the remaining group shall be cored and accepted individually and any of the pipe sections that have core strengths less than the requirements of Section 11.7.1 or Section 11.7.2 shall be rejected.

11.8 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.9 *Absorption*—The absorption of a sample from the wall of the pipe, as determined in accordance with T 280, shall not exceed 9 percent of the dry mass. Each sample shall have a minimum mass of 1.0 kg, shall be free of visible cracks, and shall represent the full wall thickness of the pipe. When the initial absorption sample from a pipe fails to conform to this specification, the absorption test shall be made on another sample from the same pipe and the results of the retest shall be substituted for the original test results.

11.10 *Retests of Pipe*—When not more than 20 percent of the concrete specimens fail to pass the requirements of the specification, the manufacturer may cull the project stock, may eliminate whatever quantity of pipe desired, and shall mark those pipes so that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the requirements of this specification.

11.11 *Test Equipment*—Every manufacturer furnishing pipe under this specification shall furnish all facilities and personnel necessary to carry out the tests described in T 280.

12. PERMISSIBLE VARIATIONS

12.1 *Internal Dimensions*—The internal dimensions of arch pipe shall not vary more than ±2 percent from the internal dimensions shown in Table 3 or Table 4. Variation shall normally be determined by measuring the span and rise. When measurement of other dimensions is necessary, templates constructed to maximum and minimum sizes shall be used.

12.2 *Wall Thickness*—The wall thickness shall not vary more than shown in the design or specified wall by more than ±5 percent or 5 mm [$^3/_{16}$ in.], whichever is greater. A specified wall thickness that is more than required in the design is not cause for rejection. Pipe having localized variations in wall thickness exceeding those specified above shall be accepted if the three-edge-bearing strength and minimum steel cover requirements are met.

12.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of the pipe shall not be more than 6 mm [$^1/_4$ in.] for all sizes through 600-mm [24-in.] internal equivalent diameter, not more than 10 mm/m [$^1/_8$ in./ft] of internal equivalent diameter for all sizes larger with a maximum of 16 mm [$^5/_8$ in.] in any length of pipe through 2100-mm [84-in.] internal equivalent diameter, and a maximum of 19 mm [$^3/_4$ in.] for 2250-mm [90-in.] internal equivalent diameter or larger, except where beveled-end pipe for laying on curves is specified by the owner.

12.4 *Length of Pipe*—The underrun in length of a section of pipe shall be not more than 10 mm/m [$^1/_8$ in./ft] with a maximum of 13 mm [$^1/_2$ in.] in any length of pipe.

12.5 *Position or Area of Reinforcement*:

12.5.1 *Position*—The maximum variation in the position of the reinforcement shall be ±10 percent of the wall or ±13 mm [$\pm^1/_2$ in.], whichever is the greater. Pipe having variations in the position of the reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative specimen are met. In no case, however, shall the cover over the circumferential reinforcement be less than 13 mm [$^1/_2$ in.]. The preceding minimum cover limitation does not apply to the mating surfaces of the joint.

12.5.2 *Area of Reinforcement*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the requirements of Sections 7.2 or Section 7.3. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing.

13. REPAIRS

13.1 Pipe may be repaired, if necessary, because of imperfections in manufacture or damage during handling and will be acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

14. INSPECTION

14.1 The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by the owner.

15. REJECTION

15.1 Pipe shall be subject to rejection if it fails to conform to any of the specification requirements. Individual sections of pipe may be rejected because of any of the following:

15.1.1 Fractures or cracks passing through the wall, except for a single-end crack that does not exceed the depth of the joint;

15.1.2 Defects that indicate mixing and molding not in compliance with Section 10.1, or surface defects indicating honeycombed or open texture that would adversely affect the function of the pipe;

15.1.3 The ends of the pipe are not normal to the walls and center line of the pipe, within the limits of variations given in Sections 12.3 and 12.4;

15.1.4 Damaged or cracked ends, where such damage would prevent making a satisfactory joint; and

15.1.5 Any continuous crack having a surface width of 0.3 mm [0.01 in.] or more and extending for a length of 300 mm [12 in.] or more, regardless of position in the wall of the pipe. See Note 2 in Section 11.

16. PRODUCT MARKING

16.1 The following information shall be legibly marked on each section of pipe:

16.1.1 The pipe class and specification designation,

16.1.2 The date of manufacture,

16.1.3 The name or trademark of the manufacturer, and

16.1.4 Identification of the plant.

16.2 Markings shall be indented on the pipe section or painted thereon with waterproof paint.

17. KEYWORDS

17.1 Arch pipe; culvert; D-load; reinforced concrete; sewer pipe; storm drain.

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[1] Agrees with ASTM C 506M-09 and C 506-09 except for limiting the absorption testing to the 5-hour boil method, the use of synthetic fibers are at the option of the owner, and the method of acceptance is changed as per Sections 11.1 and 11.5.3.3.

Standard Specification for

Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe

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AASHTO Designation: M 207M/M 207-10[1]
ASTM Designation: C 507M-09 and C 507-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe

AASHTO Designation: M 207M/M 207-10[1]
ASTM Designation: C 507M-09 and C 507-09

1. SCOPE

1.1. This specification covers reinforced elliptically shaped concrete pipe to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

1.2. Pipe designed for placement with the major axis horizontal shall be designated as “Horizontal Elliptical Pipe.” Pipe designed for placement with the major axis vertical shall be designated as “Vertical Elliptical Pipe.”

1.3. This specification is applicable for orders in either SI units (M 207M) or in inch-pound units (M 207). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 207.

Note 1—This specification is a manufacturing and purchase specification only, and does not include requirements for bedding, backfill, or the relationship between field load condition and the strength classification of pipe. However, experience has shown that the successful performance of this product depends upon the proper selection of the class of pipe, type of bedding and backfill, and care that the installation conforms to the construction specifications. The owner of the reinforced concrete pipe specified herein is cautioned that he must correlate the field requirements with the class of pipe specified and provide inspection at the construction site.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 154, Air-Entraining Admixtures for Concrete
- M 194M/M 194, Chemical Admixtures for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement

- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2. *ASTM Standards*:

- A 36/A 36M, Specification for Carbon Structural Steel
- A 706/A 706M, Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
- C 1017/C 1017M, Specification for Chemical Admixtures for use in Producing Flowing Concrete
- C 1116, Specification for Fiber-Reinforced Concrete and Shotcrete

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. CLASSIFICATION

4.1. Pipe manufactured according to this specification shall be of five classes each for horizontal elliptical and vertical elliptical pipe with identification as follows:

Horizontal Elliptical Pipe	Vertical Elliptical Pipe
Class HE-A	Class VE-II
Class HE-I	Class VE-III
Class HE-II	Class VE-IV
Class HE-III	Class VE-V
Class HE-IV	Class VE-VI

4.2. The strength requirements for horizontal elliptical pipe are prescribed in Table 1 when using SI units and Table 2 when using inch-pound units; and for vertical elliptical pipe are prescribed in Table 3 when using SI units and Table 4 when using inch-pound units.

Table 1—Design Requirements for Horizontal Elliptical (HE) Pipe (SI units)[a]

Designated Diameter, Equivalent Round Size, mm	Designated Rise, mm × Span, mm	Minimum Wall Thickness, mm	Reinforcement, cm^2/Linear m									
			Class HE-A		Class HE-I		Class HE-II		Class HE-III		Class HE-IV	
			D-Loads									
			0.3 = 30 Ult = 45		0.3 = 40 Ult = 60		0.3 = 50 Ult = 75		0.3 = 65 Ult = 100		0.3 = 100 Ult = 150	
			In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage
450	365 × 575	69	1.7	—	2.3	—	3.0	—	4.0	—	5.7	—
600	490 × 770	82	2.3	—	3.2	—	4.0	—	5.5	—	8.3	—
675	550 × 865	88	3.0	—	3.8	—	4.9	—	6.6	—	9.7	—
750	610 × 960	94	2.1	2.1	2.8	2.8	3.6	3.6	4.9	4.9	7.2	7.2
825	670 × 1055	94	2.5	2.5	3.6	3.6	4.4	4.4	5.9	5.9	8.7	8.7
900	730 × 1150	113	2.3	2.3	3.2	3.2	4.0	4.0	5.5	5.5	8.3	8.3
975	795 × 1250	119	2.8	2.8	3.6	3.6	4.4	4.4	6.1	6.1	9.3	9.3
1050	855 × 1345	125	3.2	3.2	4.2	4.2	5.1	5.1	7.0	7.0	10.6	10.6
1200	975 × 1535	138	3.6	3.6	4.9	4.9	5.9	5.9	8.3	8.3	—	—
1350	1095 × 1730	150	4.2	4.2	5.7	5.7	7.2	7.2	9.5	9.5	—	—
1500	1220 × 1920	163	5.1	5.1	6.8	6.8	8.5	8.5	11.2	11.2	—	—
1650	1340 × 2110	175	5.7	5.7	7.6	7.6	9.5	9.5	12.9	12.9	—	—
1800	1465 × 2305	188	6.6	6.6	8.7	8.7	11.0	11.0	14.8	14.8	—	—
1950	1585 × 2495	200	7.2	7.2	9.5	9.5	11.9	11.9	16.5	16.5	—	—
2100	1705 × 2690	213	8.0	8.0	10.6	10.6	13.3	13.3	18.6	18.6	—	—
2250	1830 × 2880	225	—	—	—	—	—	—	—	—	—	—
2400	1950 × 3070	238	—	—	—	—	—	—	—	—	—	—
2550	2075 × 3265	244	—	—	—	—	—	—	—	—	—	—
2700	2195 × 3455	250	—	—	—	—	—	—	—	—	—	—
2850	2315 × 3648	263	—	—	—	—	—	—	—	—	—	—
3000	2440 × 3840	275	—	—	—	—	—	—	—	—	—	—
3300	2680 × 4225	300	—	—	—	—	—	—	—	—	—	—
3600	2925 × 4610	325	—	—	—	—	—	—	—	—	—	—
Concrete strength[b], MPa			27.6		27.6		27.6		450 to 1650 mm 27.6		27.6	
									1800 to 2100 mm 34.5			

[a] For size and loads beyond those shown in this table, pipe designs are available which make use of one or a combination of the following: shear steel, multiple cages, or thicker walls in accordance with the provision of Section 7.3.

[b] Concrete strength for designs with reinforcement tabulated. For modified or special designs, see Section 7.3.

Notes:
1. The test load in kilonewtons per linear meter equals D-load × inside span in millimeters.
2. Single cage reinforcement, providing tension steel at the top, bottom, and spring line, shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be 112 percent of the tabulated inner cage area.
3. An inner and outer cage plus quadrant mats shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 1.
4. An inner and outer cage plus a middle cage shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 2.

Table 2—Design Requirements for Horizontal Elliptical (HE) Pipe (inch-pound units)[a]

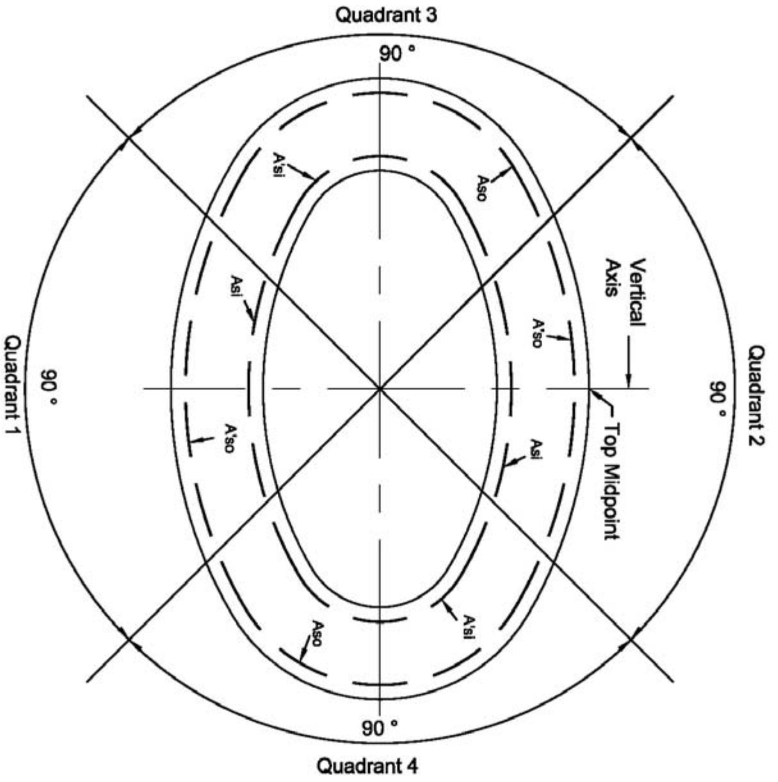
Designated Diameter, Equivalent Round Size, in.	Designated Rise, in. × Span, in.	Minimum Wall Thickness, in.	Reinforcement, in.^{2}/Linear ft									
			Class HE-A		Class HE-I		Class HE-II		Class HE-III		Class HE-IV	
			D-Loads									
			0.01 = 600 Ult = 900		0.01 = 800 Ult = 1200		0.01 =1000 Ult = 1500		0.01 = 1350 Ult = 2000		0.01 = 2000 Ult = 3000	
			In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage
18	14 × 23	$2^{3}/_{4}$	0.08	—	0.11	—	0.14	—	0.19	—	0.27	—
24	19 × 30	$3^{1}/_{4}$	0.11	—	0.15	—	0.19	—	0.26	—	0.39	—
27	22 × 34	$3^{1}/_{2}$	0.14	—	0.18	—	0.23	—	0.31	—	0.46	—
30	24 × 38	$3^{3}/_{4}$	0.10	0.10	0.13	0.13	0.17	0.17	0.23	0.23	0.34	0.34
33	27 × 42	$3^{3}/_{4}$	0.12	0.12	0.17	0.17	0.21	0.21	0.28	0.28	0.41	0.41
36	29 × 45	$4^{1}/_{2}$	0.11	0.11	0.15	0.15	0.19	0.19	0.26	0.26	0.39	0.39
39	32 × 49	$4^{3}/_{4}$	0.13	0.13	0.17	0.17	0.21	0.21	0.29	0.29	0.44	0.44
42	34 × 53	5	0.15	0.15	0.20	0.20	0.24	0.24	0.33	0.33	0.50	0.50
48	38 × 60	$5^{1}/_{2}$	0.17	0.17	0.23	0.23	0.28	0.28	0.39	0.39	—	—
54	43 × 68	6	0.20	0.20	0.27	0.27	0.34	0.34	0.45	0.45	—	—
60	48 × 76	$6^{1}/_{2}$	0.24	0.24	0.32	0.32	0.40	0.40	0.53	0.53	—	—
66	53 × 83	7	0.27	0.27	0.36	0.36	0.45	0.45	0.61	0.61	—	—
72	58 × 91	$7^{1}/_{2}$	0.31	0.31	0.41	0.41	0.52	0.52	0.70	0.70	—	—
78	63 × 98	8	0.34	0.34	0.45	0.45	0.56	0.56	0.78	0.78	—	—
84	68 × 106	$8^{1}/_{2}$	0.38	0.38	0.50	0.50	0.63	0.63	0.88	0.88	—	—
90	72 × 113	9	—	—	—	—	—	—	—	—	—	—
96	77 × 121	$9^{1}/_{2}$	—	—	—	—	—	—	—	—	—	—
102	82 × 128	$9^{3}/_{4}$	—	—	—	—	—	—	—	—	—	—
108	87 × 136	10	—	—	—	—	—	—	—	—	—	—
114	92 × 143	$10^{1}/_{2}$	—	—	—	—	—	—	—	—	—	—
120	97 × 151	11	—	—	—	—	—	—	—	—	—	—
132	106 × 166	12	—	—	—	—	—	—	—	—	—	—
144	116 × 180	13	—	—	—	—	—	—	—	—	—	—
Concrete strength[b] psi			4000		4000		4000		18 to 66 in. 4000 72 to 84 in. 5000		4000	

[a] For sizes and loads beyond those shown in this table, pipe designs are available which make use of one or a combination of the following: shear steel, multiple cages, or thicker walls in accordance with the provision of Section 7.3.

[b] Concrete strength for designs with reinforcement tabulated. For modified or special designs, see Section 7.3.

Notes:

1. The test load in pounds per linear foot equals D-load × inside span in feet.
2. Single cage reinforcement, providing tension steel at the top, bottom, and spring line, shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be 112 percent of the tabulated inner cage area.
3. An inner and outer cage plus quadrant mats shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 1.
4. An inner and outer cage plus a middle cage shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 2.



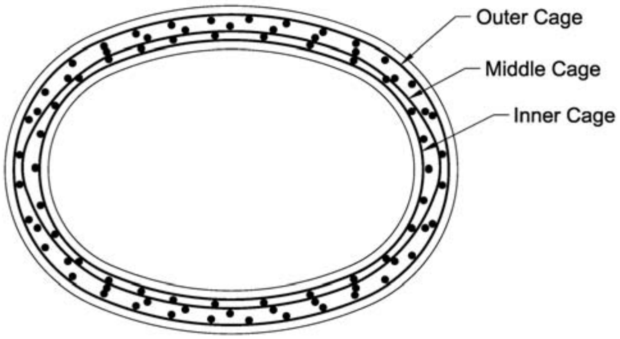
Notes: 1. The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Table 1 or Table 2.

2. The total reinforcement area (Aso) of the outer cage plus the quadrant mat in Quadrants 3 and 4 shall not be less than that specified for the outer cage in Table 1 or Table 2.

3. The reinforcement area (A′si) of the inner cage in Quadrants 3 and 4 shall not be less than 25 percent of that specified for the inner cage in Table 1 or Table 2.

4. The reinforcement area (A′so) of the outer cage in Quadrants 1 and 2 shall not be less than 25 percent of that specified for the outer cage in Table 1 or Table 2.

Figure 1—Quadrant Reinforcement, Horizontal Elliptical Pipe



Notes: 1. The total reinforcement area of the inner cage plus the middle cage shall not be less than that specified for the inner cage in Table 1 or Table 2.

2. The total reinforcement area of the outer cage plus the middle cage shall not be less than that specified for the outer cage in Table 1 or Table 2.

Figure 2—Horizontal Elliptical Pipe

Table 3—Design Requirements for Vertical Elliptical (VE) Pipe (SI units)[a]

Designated Diameter, Equivalent Round Size, mm	Designated Rise, mm × Span, mm	Minimum Wall Thickness, mm	Reinforcement, cm^2/Linear m									
			Class VE-II		Class VE-III		Class VE-IV		Class VE-V		Class VE-VI	
			D-Loads									
			0.3 = 50 Ult = 75		0.3 = 65 Ult = 100		0.3 = 100 Ult = 150		0.3 = 140 Ult = 175		0.3 = 190 Ult = 235	
			In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage
900	1150 × 730	113	1.7	1.1	2.3	1.5	3.4	2.1	4.9	3.0	6.6	4.0
975	1250 × 795	119	1.9	1.1	2.5	1.5	3.8	2.3	5.5	3.4	7.4	4.4
1050	1345 × 855	125	2.1	1.3	2.8	1.7	4.2	2.5	6.1	3.6	8.0	4.9
1200	1535 × 975	138	2.3	1.5	3.2	1.9	4.7	2.8	7.0	4.2	9.3	5.5
1350	1730 × 1095	150	2.8	1.7	3.8	2.3	5.7	3.4	8.5	5.1	11.2	5.8
1500	1920 × 1220	163	3.4	2.1	4.4	2.8	6.6	4.0	9.9	5.9	—	—
1650	2110 × 1340	175	3.8	2.3	5.3	3.2	7.6	4.7	11.6	7.0	—	—
1800	2305 × 1465	188	4.4	2.8	5.9	3.6	8.7	5.3	—	—	—	—
1950	2495 × 1585	200	4.9	3.0	6.6	4.0	9.9	5.9	—	—	—	—
2100	2690 × 1705	213	5.5	3.4	7.4	4.4	11.2	6.8	—	—	—	—
2250	2880 × 1830	225	—	—	—	—	—	—	—	—	—	—
2400	3070 × 1950	238	—	—	—	—	—	—	—	—	—	—
2550	3265 × 2075	244	—	—	—	—	—	—	—	—	—	—
2700	3455 × 2195	250	—	—	—	—	—	—	—	—	—	—
2850	3648 × 2315	263	—	—	—	—	—	—	—	—	—	—
3000	3840 × 2440	275	—	—	—	—	—	—	—	—	—	—
3300	4225 × 2680	300	—	—	—	—	—	—	—	—	—	—
3600	4610 × 2925	325	—	—	—	—	—	—	—	—	—	—
Concrete strength,[b] MPa			27.6		27.6		27.6		34.5		41.4	

[a] For size and loads beyond those shown in this table, pipe designs are available which make use of one or a combination of the following: shear steel, multiple cages, or thicker walls in accordance with the provision of Section 7.3.

[b] Concrete strength for designs with reinforcement tabulated. For modified or special designs, see Section 7.3.

Notes:

1 Test load in kilonewtons per linear meter equals D-load × inside span in millimeters.

2. An inner and outer cage plus quadrant mats shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 3.

3. Single cage reinforcement, providing tension steel at the top, bottom, and spring line, shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be 112 percent of the tabulated inner cage area.

4. An inner and outer cage plus a middle cage shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 4.

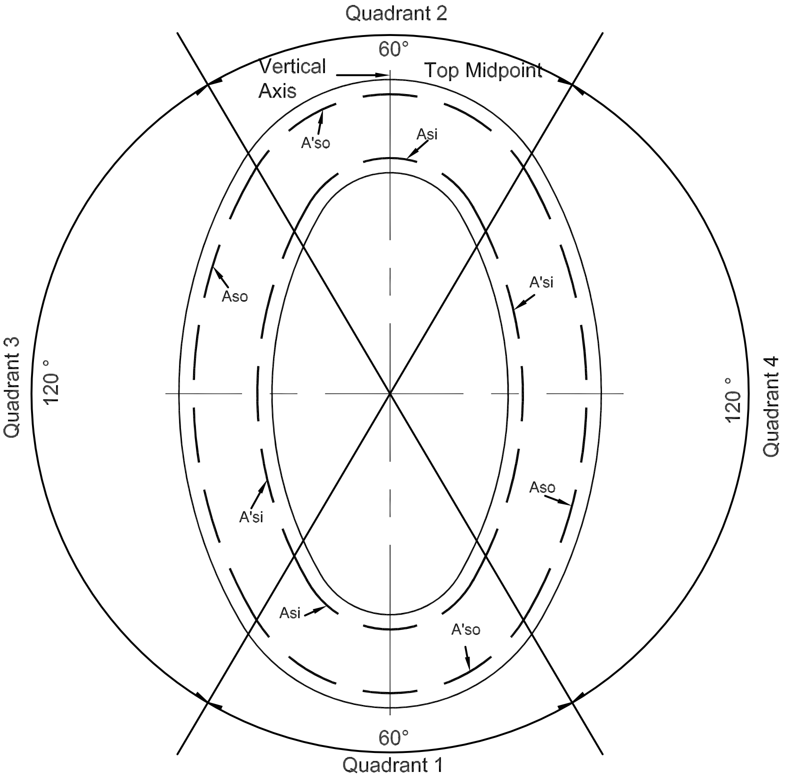
Table 4—Design Requirements for Vertical Elliptical (VE) Pipe (inch-pound units)[a]

Designated Diameter, Equivalent Round Size, in.	Designated Rise, in. × Span, in.	Minimum Wall Thickness, in.	Reinforcement, in.^{2}/Linear ft									
			Class VE-II		Class VE-III		Class VE-IV		Class VE-V		Class VE-VI	
			D-Loads									
			0.01 = 1000 Ult = 1500		0.01 = 1350 Ult = 2000		0.01 = 2000 Ult = 3000		0.01 = 3000 Ult = 3750		0.01 = 4000 Ult = 5000	
			In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage	In Cage	Out Cage
36	45 × 29	$4^{1}/_{2}$	0.08	0.05	0.11	0.07	0.16	0.10	0.23	0.14	0.31	0.19
39	49 × 32	$4^{3}/_{4}$	0.09	0.05	0.12	0.07	0.18	0.11	0.26	0.16	0.35	0.21
42	53 × 34	5	0.10	0.06	0.13	0.08	0.20	0.12	0.29	0.17	0.38	0.23
48	60 × 38	$5^{1}/_{2}$	0.11	0.07	0.15	0.09	0.22	0.13	0.33	0.20	0.44	0.26
54	68 × 43	6	0.13	0.08	0.18	0.11	0.27	0.16	0.40	0.24	0.53	0.32
60	76 × 48	$6^{1}/_{2}$	0.16	0.10	0.21	0.13	0.31	0.19	0.47	0.28	—	—
66	83 × 53	7	0.18	0.11	0.25	0.15	0.36	0.22	0.55	0.33	—	—
72	91 × 58	$7^{1}/_{2}$	0.21	0.13	0.28	0.17	0.41	0.25	—	—	—	—
78	98 × 63	8	0.23	0.14	0.31	0.19	0.47	0.28	—	—	—	—
84	106 × 68	$8^{1}/_{2}$	0.26	0.16	0.35	0.21	0.53	0.32	—	—	—	—
90	113 × 72	9	—	—	—	—	—	—	—	—	—	—
96	121 × 77	$9^{1}/_{2}$	—	—	—	—	—	—	—	—	—	—
102	128 × 82	$9^{3}/_{4}$	—	—	—	—	—	—	—	—	—	—
108	136 × 87	10	—	—	—	—	—	—	—	—	—	—
114	143 × 92	$10^{1}/_{2}$	—	—	—	—	—	—	—	—	—	—
120	151 × 97	11	—	—	—	—	—	—	—	—	—	—
132	166 × 106	12	—	—	—	—	—	—	—	—	—	—
144	180 × 116	13	—	—	—	—	—	—	—	—	—	—
Concrete strength,[b] psi			4000		4000		4000		5000		6000	

[a] For size and loads beyond those shown in this table, pipe designs are available which make use of one or a combination of the following: shear steel, multiple cages, or thicker walls in accordance with the provision of Section 7.3.

[b] Concrete strength for designs with reinforcement tabulated. For modified or special designs, see Section 7.3.

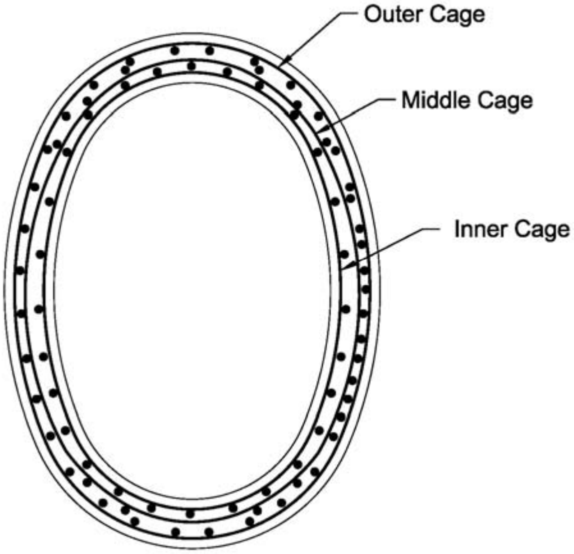
Notes:
1. Test load in pounds per linear foot equals D-load × inside span in feet.
2. An inner and outer cage plus quadrant mats shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 3.
3. Single cage reinforcement, providing tension steel at the top, bottom, and spring line shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be 112 percent of the tabulated inner cage area.
4. An inner and outer cage plus a middle cage shall be permitted instead of double cage reinforcement. The area of such reinforcement shall be in accordance with Figure 4.



Notes:

1. The total reinforcement area (Asi) of the inner cage plus the quadrant mat in Quadrants 1 and 2 shall not be less than that specified for the inner cage in Table 3 or Table 4.
2. The total reinforcement area (Aso) of the outer cage plus the quadrant mat in Quadrants 3 and 4 shall not be less than that specified for the outer cage in Table 3 or Table 4.
3. The reinforcement area (A′si) of the inner cage in Quadrants 3 and 4 shall not be less than 25 percent of that specified for the inner cage in Table 3 or Table 4.
4. The reinforcement area (A′so) of the outer cage in Quadrants 1 and 2 shall not be less than 25 percent of that specified for the outer cage in Table 3 or Table 4.

Figure 3—Quadrant Reinforcement, Vertical Elliptical Pipe



Notes: 1. The total reinforcement area of the inner cage plus the middle cage shall not be less than that specified for the inner cage in Table 3 or Table 4.

2. The total reinforcement area of the outer cage plus the middle cage shall not be less than that specified for the outer cage in Table 3 or Table 4.

Figure 4—Vertical Elliptical Pipe

5. BASIS OF ACCEPTANCE

5.1. Unless otherwise designated by the owner at the time of or before placing an order, there are two separate and alternative bases of acceptance. Independent of the method of acceptance, the pipe shall be designated to meet both the 0.3 -mm [0.01 -in] crack and ultimate strength requirements specified in Table 1.

5.1.1. *Acceptance on Basis of Plant Load Bearing Tests, Material Tests, and Inspection of the Manufactured Pipe for Visual Defects and Imperfections*—Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of the three-edge-bearing tests as defined in 11.3.1; by such material tests as are required in Sections 6.2, 6.3, 6.5, and 6.6; by an absorption test of the concrete from the wall of the pipe for each mix design that is used on an order; and by inspection of the finished pipe to determine its conformance with the accepted design and its freedom from defects.

5.1.2. *Acceptance on the Basis of Material Tests and Inspection of Manufactured Pipe for Visual Defects and Imperfections* —Acceptability of the pipe in all diameters and classes produced in accordance with Section 7.1 or Section 7.2 shall be determined by the results of such material tests as are required in accordance with Sections 6.2, 6.3, 6.5, and 6.6; by crushing tests on concrete cores or cured concrete cylinders; by an absorption test on concrete from the wall of the pipe for each mix design that is used on an order; and by inspection of the finished pipe, including amount and placement of reinforcement, to determine its conformance with the accepted design and its freedom from defects.

5.1.3. When agreed upon by the owner and the manufacturer, any portion or any combination of the tests itemized in Section 5.1.1 or Section 5.1.2 may form the basis of acceptance.

5.2. *Age for Acceptance*—Pipe shall be considered ready for acceptance when they conform to the requirements as indicated by the specified tests.

6. MATERIALS

6.1. *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.2. *Cementitious Materials*:

6.2.1. *Cement*—Cement shall conform to the requirements of M 85, or shall be portland blast-furnace slag cement, or slag modified portland cement, or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.2.2. *Ground Granulated Blast-Furnace Slag (GGBFS)*—GGBFS shall conform to the requirements of Grade 100 or 120 of M 302

6.2.3. *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.4. *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.4.1. Portland cement only,

6.2.4.2. Portland blast-furnace slag cement only,

6.2.4.3. Slag modified portland cement only,

6.2.4.4. Portland-pozzolan cement only, or

6.2.4.5. A combination of portland cement and ground granulated blast-furnace slag,

6.2.4.6. A combination of portland cement and fly ash, or

6.2.4.7. A combination of portland cement, ground granulated blast-furnace slag (not to exceed 25 percent of the total cementitious weight) and fly ash (not to exceed 25 percent of the total cementitious weight).

6.3. *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirement for gradation shall not apply.

6.4. *Admixtures and Blends*—The following admixtures and blends are allowable:

6.4.1. Air-entraining admixture conforming to M 154;

6.4.2. Chemical admixture conforming to M 194;

6.4.3. Chemical admixture for use in producing flowing concrete conforming to C 1017/C 1017M; and

6.4.4. Chemical admixture or blend approved by the owner.

6.5. *Steel Reinforcement*—Reinforcement shall consist of wire conforming to M 32M/M 32 or M 225M/M 225; or of wire reinforcement conforming to M 55M/M 55 or M 221M/M 221; or of bars conforming to M 31M/M 31 Grade 280 [40] or 420 [60], ASTM A 36/A 36M, or ASTM A 706/A 706M Grade 420 [60].

6.6. *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers may be used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

7. DESIGN

7.1. *Size and Shape*—The standard sizes of elliptical pipe shall be as listed in Tables 1 and 3 for SI units or Tables 2 and 4 for inch-pound units. The internal shape for each size pipe shall be defined by the internal dimensions shown in Table 5 for SI units or Table 6 for inch-pound units, subject to the permissible variations of Section 12.1.

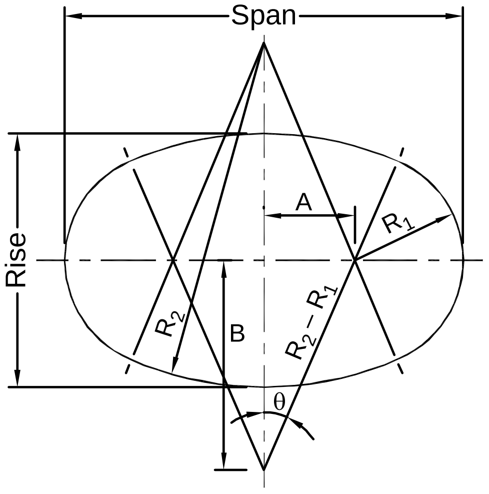
7.2. *Design Tables*—The wall thickness, compressive strength of concrete, and the area of circumferential reinforcement shall be as prescribed in Tables 1 or 2 and 3 or 4, subject to the provisions of Sections 7.3, 11, and 12.

7.2.1. Footnotes to the tables herein are intended to be amplifications of the tabulated requirements and are to be considered applicable and binding as if they were contained in the body of the specification.

7.3. *Modified and Special Designs*:

7.3.1. If permitted by the owner, the manufacturer may request approval by the owner of modified designs which differ from the designs in this Section 7; or special designs for sizes and loads beyond those shown in Tables 1 or 2 and 3 or 4, or special designs for pipe sizes that do not have steel reinforcement areas shown in Tables 1 or 2 and 3 or 4.

7.3.2. Such modified and special designs shall be based on rational or empirical evaluations of the ultimate strength and cracking behavior of pipe and shall fully describe to the owner any deviations from the requirements of this Section 7. The descriptions of modified or special designs shall include the wall thickness; the concrete strength; and the area, type, placement, number of layers, and strength of the steel reinforcement.



Symmetrical about Axes

Figure 5—Cross-Sectional Shape of Elliptical Pipe

Table 5—Internal Dimensions of Elliptical Pipe (SI units) (See Figure 5 for definition of Terms)

Approximate Equivalent Round Size, mm	Full Flow Water Area, m^2	Rise, mm	Span, mm	*A*, mm	*B*, mm	R_1, mm	R_2, mm	θ Degrees
450	0.170	360	580	135	325	155	505	22.6
600	0.305	490	770	176	420	210	665	22.6
675	0.383	550	865	198	475	235	750	22.6
750	0.474	610	960	220	530	260	835	22.6
825	0.588	680	1065	243	580	290	920	22.6
900	0.684	730	1155	263	635	315	1000	22.6
975	0.816	800	1255	283	685	345	1085	22.6
1050	0.948	865	1355	308	733	370	1165	22.6
1200	1.20	970	1520	345	825	415	1310	22.6
1350	1.55	1105	1725	388	933	475	1485	22.6
1500	1.90	1225	1920	435	1143	525	1655	22.6
1650	2.30	1345	2110	475	1143	580	1815	22.6
1800	2.73	1470	2300	520	1245	630	1980	22.6
1950	3.21	1595	2490	560	1348	685	2145	22.6
2100	3.73	1715	2680	605	1448	735	2305	22.6
2250	4.28	1840	2870	645	1550	790	2470	22.6
2400	4.87	1960	3065	688	1655	845	2635	22.6
2550	5.49	2085	3250	730	1753	895	2795	22.6
2700	6.17	2210	3440	770	1850	950	2955	22.6
2850	6.87	2330	3635	813	1950	1005	3115	22.6
3000	7.63	2455	3825	858	2053	1055	3280	22.7
3300	9.22	2700	4205	938	2255	1165	3605	22.6
3600	11.0	2950	4590	1025	2460	1270	3935	22.6

Note: Rise, span, and radii are fixed; other dimensions and angles are calculated.

Table 6—Internal Dimensions of Elliptical Pipe (inch-pound units) (See Figure 5 for definition of Terms)

Approximate Equivalent Round Size, in.	Full Flow Water Area, ft^2	Rise, in.	Span, in.	*A*, in.	*B*, in.	R_1, in.	R_2, in.	θ Degrees
18	1.83	$14^{1}/_{4}$	$22^{3}/_{4}$	$5^{3}/_{8}$	$12^{7}/_{8}$	6	20	22.6
24	3.28	$19^{1}/_{4}$	$30^{1}/_{4}$	$6^{7}/_{8}$	$16^{5}/_{8}$	$8^{1}/_{4}$	$26^{1}/_{4}$	22.6
27	4.12	$21^{1}/_{2}$	34	$7^{3}/_{4}$	$18^{1}/_{2}$	$9^{1}/_{4}$	$29^{1}/_{4}$	22.6
30	5.10	24	$37^{3}/_{4}$	$8^{5}/_{8}$	$20^{3}/_{4}$	$10^{1}/_{4}$	$32^{3}/_{4}$	22.6
33	6.33	$26^{3}/_{4}$	42	$9^{1}/_{2}$	$22^{7}/_{8}$	$11^{1}/_{2}$	$36^{1}/_{2}$	22.6
36	7.36	$28^{3}/_{4}$	$45^{1}/_{2}$	$10^{1}/_{2}$	$24^{7}/_{8}$	$12^{1}/_{4}$	$39^{1}/_{4}$	22.6
39	8.78	$31^{1}/_{2}$	$49^{1}/_{2}$	$11^{1}/_{4}$	27	$13^{1}/_{2}$	$42^{3}/_{4}$	22.6
42	10.2	34	$53^{1}/_{4}$	$12^{1}/_{8}$	29	$14^{1}/_{2}$	46	22.6
48	12.9	$38^{1}/_{4}$	60	$13^{1}/_{2}$	$32^{3}/_{8}$	$16^{1}/_{2}$	$51^{1}/_{2}$	22.6
54	16.7	$43^{1}/_{2}$	68	$15^{1}/_{4}$	$36^{3}/_{4}$	$18^{3}/_{4}$	$58^{1}/_{2}$	22.6
60	20.5	$48^{1}/_{4}$	$75^{1}/_{2}$	17	$40^{7}/_{8}$	$20^{3}/_{4}$	65	22.6
66	24.8	53	83	$18^{3}/_{4}$	45	$22^{3}/_{4}$	$71^{1}/_{2}$	22.6
72	29.4	$57^{3}/_{4}$	$90^{1}/_{2}$	$20^{1}/_{2}$	$49^{1}/_{8}$	$24^{3}/_{4}$	78	22.6
78	34.6	$62^{3}/_{4}$	98	22	$53^{1}/_{8}$	27	$84^{1}/_{2}$	22.6
84	40.1	$67^{1}/_{2}$	$105^{1}/_{2}$	$23^{3}/_{4}$	57	29	$90^{3}/_{4}$	22.6
90	46.1	$72^{1}/_{2}$	113	$25^{1}/_{2}$	61	31	$97^{1}/_{4}$	22.6
96	52.4	$77^{1}/_{4}$	$120^{1}/_{2}$	27	$65^{1}/_{8}$	$33^{1}/_{4}$	$103^{3}/_{4}$	22.6
102	59.1	82	128	$28^{3}/_{4}$	69	$35^{1}/_{4}$	110	22.6
108	66.4	87	$135^{1}/_{2}$	$30^{1}/_{4}$	$72^{3}/_{4}$	$37^{1}/_{2}$	$116^{1}/_{4}$	22.6
114	73.9	$91^{3}/_{4}$	143	32	$76^{7}/_{8}$	$39^{1}/_{2}$	$122^{3}/_{4}$	22.6
120	82.1	$96^{3}/_{4}$	$150^{3}/_{4}$	$33^{7}/_{8}$	$80^{7}/_{8}$	$41^{1}/_{2}$	$129^{1}/_{4}$	22.7
132	99.2	$106^{1}/_{2}$	$165^{1}/_{2}$	37	$88^{3}/_{4}$	$45^{3}/_{4}$	142	22.6
144	118	116	$180^{3}/_{4}$	$40^{3}/_{8}$	$96^{3}/_{4}$	50	$154^{3}/_{4}$	22.6

Note: Rise, span, and radii are fixed; other dimensions and angles are calculated.

7.3.3. The manufacturer shall submit to the owner proof of the adequacy of the proposed modified and special design. Such proof may comprise the submission of certified three-edge-bearing tests already made which are acceptable to the owner or, if such three-edge-bearing tests are not available or acceptable, the manufacturer may be required to perform proof tests on sizes and classes selected by the owner to demonstrate the correctness and adequacy of the proposed design.

7.3.4. Such pipe shall meet all of the test and performance requirements specified by the owner in accordance with Section 5.

7.4. *Area*—In this specification, when the word "area" is not described by adjectives such as cross-sectional or single wire, it shall be understood to be the cross-sectional area of reinforcement per unit lengths of pipe.

8. REINFORCEMENT

8.1. *Circumferential Reinforcement*—A line of circumferential reinforcement for any given total area may be composed of two layers for pipe with wall thicknesses of less than 180 mm [7 in.] or three layers for pipe with wall thicknesses of 180 mm [7 in.] or greater. The layers shall not be separated by more than the thickness of one longitudinal plus 6 mm [$^{1}/_{4}$ in.] The multiple layers shall be fastened together to form a single cage. All other specification requirements such as laps, welds, and tolerances of placement in the wall of the pipe, etc., shall apply to this method of fabricating a line of reinforcement.

8.1.1. Where one line of reinforcement is used, it shall be placed so that the cover of the concrete over the circumferential reinforcement at the vertical and horizontal diameters of the pipe is 25 mm [1 in.] from the inside and outside surfaces of the pipe, except for wall thicknesses less than 62 mm [$2^1/_2$ in.], the protective cover of the concrete over the circumferential reinforcement in the wall of the pipe shall be 18 mm [$^3/_4$ in.].

8.1.2. Where two lines of reinforcement of elliptical shape corresponding to the contour of the pipe are used, each line shall be so placed that the covering of concrete over the reinforcement is 25 mm [1 in.].

8.1.3. The location of the reinforcement shall be subject to the permissible variations in dimensions given in Section 12.5. Requirements for placement and protective covering of the concrete from the inner or outer surface of the pipe do not apply to that portion of a cage which is flared so as to extend into the bell or reduced in diameter so as to extend into the spigot.

8.1.4. The spacing center-to-center of circumferential reinforcement in a cage shall not exceed 100 mm [4 in.] for pipe up to and including pipe having a 100 mm [4-in.] wall thickness nor exceed the wall thickness for larger pipe, and shall in no case exceed 150 mm [6 in.].

8.1.5. The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe except that, when agreed upon by the owner, lift eyes or holes may be provided in each pipe for the purpose of handling.

8.1.6. If splices are not welded, the reinforcement shall be lapped not less than 20 diameters for deformed bars and deformed cold-worked wire and 40 diameters for plain bars and cold-drawn wire. In addition, where lapped cages of welded-wire fabric are used without welding, the lap shall contain a longitudinal wire.

8.1.6.1. When splices are welded and are not lapped to the minimum requirements in Section 8.1.6, pull tests of representative specimens shall develop at least 50 percent of the minimum specified strength of the steel and there shall be a minimum lap of 50 mm [2 in.]. For butt-welded splices in bars or wire, permitted only with helically wound cages, pull tests of representative specimens shall develop at least 75 percent of the minimum specified strength of the steel.

8.2. *Longitudinal Reinforcement*—Each line of circumferential reinforcement shall be assembled into a cage that shall contain sufficient longitudinal bars or members to maintain the reinforcement rigidly in shape and in position within the form to comply with permissible variations in Section 8.1. The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete shall not be a cause for rejection.

8.3. *Joint Reinforcement*—In all pipe 900 mm [36 in.] or larger in diameter, either the bell or the spigot of the joint shall contain circumferential reinforcement.

8.3.1. For single-cage pipe, joint reinforcement shall be at least equal in area to that required for an equivalent length of pipe wall.

8.3.2. For double-cage and triple-cage pipe, joint reinforcement shall be at least equal in area to that required for an equivalent length of the outer circular cage if placed in the bell or at least equal in area to that required for an equivalent length of the inner circular cage if placed in the spigot.

9. JOINTS

9.1. The joints shall be of such design and the ends of the concrete pipe sections so formed that the pipe can be laid together to make a continuous line of pipe compatible with the permissible variations given in Section 12.

10. MANUFACTURE

10.1. *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 [470 lb/yd^3] unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

10.2. *Curing*—Pipe shall be subjected to any one of the methods of curing described in Sections 10.2.1 to 10.2.4 or to any other method or combination of methods approved by the owner that will give satisfactory results. The pipe shall be cured for a sufficient length of time so that the specified D-load is obtained when acceptance is based on Section 5.1.1 or so that the concrete will develop the specified compressive strength at 28 days or less when acceptance is based on Section 5.1.2.

10.2.1. *Steam Curing*—Pipe may be placed in a curing chamber, free from outside drafts and cured in a moist atmosphere maintained by the injection of steam, for such time and such temperature as may be needed to enable the pipe to meet the strength requirements. The curing chamber shall be so constructed as to allow full circulation of steam around the entire pipe.

10.2.2. *Water Curing*—Concrete pipe may be water cured by covering with water-saturated material or by a system of perforated pipes, mechanical sprinklers, porous hose, or by any other approved method that will keep the pipe moist during the specified curing period.

10.2.3. The manufacturer may, at his option, combine the methods described in Sections 10.2.1 to 10.2.4, provided the required strength is attained.

10.2.4. A sealing membrane conforming to the requirements of M 148 may be applied and should be left intact until the required strength requirements are met. The concrete at the time of application shall be within 6ºC [10ºF] of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

11. PHYSICAL REQUIREMENTS

11.1. *Test Specimens*—The specified number of pipe required for the tests shall be furnished without charge by the manufacturer, shall be selected at random by the owner, and shall be pipe that would not otherwise be rejected under this specification. The selection shall be made at the point or points designated by the owner when placing the order. Unless designated otherwise by the owner in the order, the manufacturer shall select the type of test (external load crushing strength test, compression test of cylinders, or compression test of cores) to be used to determine the acceptability of the pipe strength. Pipe that fails to meet the strength requirements as determined by the selected test type may not be retested using one of the other test types without approval of the owner.

11.2. *Number and Type of Tests Required for Various Delivery Schedules*:

11.2.1. *Preliminary Tests for Extended Delivery Schedules*—An owner of pipe whose needs require shipments at intervals over extended periods of time shall be entitled to such tests, preliminary to delivery of pipe, as are required by the type of basis of acceptance specified by the owner in Section 5, of not more than three sections of pipe covering each size in which the owner is interested.

11.2.2. *Additional Tests*—After the preliminary tests described in Section 11.2.1, an owner shall be entitled to additional tests at such times as the owner may deem necessary, provided that the total number of pipe tested (including preliminary tests) shall not exceed one pipe or one percent, whichever is the greater, of each size of pipe delivered.

11.2.3. A owner who places orders of 50 or fewer pipe sections for a particular size and class shall be entitled to one test for each size and class.

11.3. *External Load Crushing Strength*:

11.3.1. The load required to produce a 0.3 -mm [0.01-in.] crack or the ultimate load as determined by the three-edge-bearing method described in T 280 shall be not less than that prescribed in Tables 1or 2 and 3 or 4 for each respective class of pipe. Pipe that have been tested only to the formation of a 0.3 -mm [0.01-in.] crack and that meet the 0.3 -mm [0.01-in.] crack load requirements shall be accepted for use.

Note 2—As used in this specification, the 0.3-mm [0.01-in.] crack is a test criterion for pipe tested in a three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

11.3.2. *Retests of Pipe Not Meeting the External Load Crushing Strength Requirements*—Pipe shall be considered as meeting the strength requirements when all test specimens conform to the strength requirements. Should any of the test specimens fail to meet the strength requirements, the manufacturer shall be allowed a retest on two additional specimens for each specimen that failed and the pipe shall be acceptable only when all of the retest specimens meet the strength requirements.

CONCRETE TESTING

11.4. *Type of Specimen*—Compression tests determining concrete compressive strength may be made on either standard rodded concrete cylinders or concrete cylinders compacted and cured in like manner as the pipe or on cores drilled from the pipe.

11.5. *Compression Testing of Cylinders*:

11.5.1. *Cylinder Production*—Cylinders shall be prepared in accordance with Section 11 of T 280.

11.5.2. *Number of Cylinders*—Prepare no fewer than five test cylinders from a group (one day’s production of each concrete strength) of pipe sections.

11.5.3. *Acceptability on the Basis of Cylinder Test Results*:

11.5.3.1. When the compressive strengths of all cylinders tested for a group are equal to or greater than the required concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.5.3.2. When the average compressive strength of all cylinders tested is equal to or greater than the required concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the required concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the required concrete strength, then the group shall be accepted.

11.5.3.3. The pipe shall be acceptable only when the compressive strength of the cylinders tested conforms to the acceptance criteria stated in Section 11.5.3.1 or Section 11.5.3.2.

11.6. *Compression Testing of Cores*:

11.6.1. *Obtaining Cores*—Cores shall be obtained and prepared in accordance with Section 6 of T 280.

11.6.2. *Number of Cores*—One core shall be taken from a pipe section selected at random from each day's production run of a single concrete strength.

11.7. *Acceptability on the Basis of Core Test Results*:

11.7.1. When the compressive strength of a core tested for a group of pipe sections is equal to or greater than the required concrete strength, the compressive strength of the concrete for the group is acceptable.

11.7.2. If the compressive strength of the core tested is less than the required concrete strength, two additional cores shall be taken from that pipe section and tested. Concrete represented by these three core tests shall be considered acceptable if: (1) the average of the three core strengths is equal to at least 85 percent of the required strength, and (2) no single core is less than 75 percent of the required strength.

11.7.3. If the compressive strength of the three cores does not meet the requirements of Section 11.7.2, the pipe from which the cores were taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and cored and tested for conformance with either Section 11.7.1 or Section 11.7.2. If both pipe sections meet the core strength requirements of either Section 11.7.1 or Section 11.7.2, the remainder of the group shall be acceptable. If both pipe sections do not meet the test strength requirement, the remainder of the group shall be either rejected or, at the option of the manufacturer, each pipe section of the remaining group shall be cored and accepted individually and any of the pipe sections that have core strengths less than the requirements of Section 11.7.1 or Section 11.7.2 shall be rejected.

11.8. *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.9. *Absorption*—The absorption of a sample from the wall of the pipe, as determined in accordance with T 280, shall not exceed nine percent of the dry mass. Each sample shall have a minimum mass of 1.0 kg, shall be free of visible cracks, and shall represent the full wall thickness of the pipe. When the initial absorption sample from a pipe fails to conform to this specification, the absorption test shall be made on another sample from the same pipe and the results of the retest shall be substituted for the original test results.

11.10. *Retests of Pipe*—When not more than 20 percent of the concrete specimens fail to pass the requirements of this specification, the manufacturer may cull the project stock, may eliminate whatever quantity of pipe desired, and shall mark those pipe so that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the requirements of this specification.

11.11. *Test Equipment*—Every manufacturer furnishing pipe under this specification shall furnish all facilities and personnel necessary to carry out the tests described in T 280.

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12. PERMISSIBLE VARIATIONS

12.1. *Internal Dimensions*—The internal dimensions of the elliptical pipe shall not vary more than ±2 percent from the internal dimensions shown in Table 5 or Table 6. The variation shall normally be determined by measuring the major and minor axes of the pipe. Where measurements at other points are necessary, the lengths so measured shall not depart from those shown in Table 5 or Table 6 by more than ±2 percent.

12.2. *Wall Thickness*—The wall thickness shall not vary more than shown in the design or specified wall by more than ±5 percent or 5mm [$^3/_{16}$ in.], whichever is greater. A specified wall thickness that is more than required in the design is not cause for rejection. Pipe having localized variations in wall thickness exceeding those specified above shall be accepted if the three-edge-bearing strength and minimum steel cover requirements are met.

12.3. *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of the pipe shall not be more than 6 mm [$^1/_4$ in.] for all sizes through 600 mm [24-in.] internal equivalent diameter, not more than 10 mm/m [$^1/_8$ in./ft] of internal equivalent diameter for all sizes larger with a maximum of 16 mm [$^5/_8$ in.] in any length of pipe through 2100 mm [84 in.] internal equivalent diameter, and a maximum of 19 mm [$^3/_4$ in.] for 2250 mm [90-in.] internal equivalent diameter or larger, except where beveled-end pipe for laying on curves is specified by the owner.

12.4. *Length of Pipe*—The underrun in length of a section of pipe shall be not more than 10 mm/m [$^1/_8$ in./ft] with a maximum of 13 mm [$^1/_2$ in.] in any length of pipe.

12.5. *Position or Area of Reinforcement*:

12.5.1. *Position*—The maximum variation in the position of the reinforcement shall be ±10 percent of the wall or ±13 mm [$\pm^1/_2$ in.], whichever is the greater. Pipe having variations in the position of reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative specimen are met. In no case, however, shall the cover over the circumferential reinforcement be less than 13 mm [$^1/_2$ in.]. The preceding minimum cover limitation does not apply to the mating surfaces of the non-rubber gasket joints or gasket grooves in rubber gasket joints. If convoluted reinforcement is used, the convoluted circumferential end wire may be at the end surface of the joint, providing that alternative convolutions have at least 1 in. cover from the end surface of the joint.

12.5.2. *Area of Reinforcement*—Reinforcement will be considered as meeting the design requirements if the area, computed on the basis of nominal area of the wire or bars used, equals or exceeds the requirements of Section 7.2 or Section 7.3. Actual area of the reinforcing used may vary from the nominal area according to permissible variations of the standard specifications for the reinforcing.

13. REPAIRS

13.1. Pipe may be repaired, if necessary, because of imperfections in manufacture or damage during handling and will be acceptable if, in the opinion of the owner, the repaired pipe conforms to the requirements of this specification.

14. INSPECTION

14.1. The quality of materials, the process of manufacture, and the finished pipe shall be subject to inspection and approval by the owner.

15. REJECTION

15.1. Pipe shall be subject to rejection on account of failure to conform to any of the specification requirements. Individual sections of pipe may be rejected because of the following:

15.1.1. Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint;

15.1.2. Defects that indicate mixing and molding not in compliance with Section 10.1 or surface defects indicating honeycombed or open texture that would adversely affect the function of the pipe;

15.1.3. The ends of the pipe are not normal to the walls and centerline of the pipe within the limits of variations given in Sections 12.3 and 12.4;

15.1.4. Damaged or cracked ends where such damage would prevent making a satisfactory joint; and

15.1.5. Any continuous crack having a surface width of 0.3 mm [0.01 in.] or more and extending for a length of 300 mm [12 in.] or more, regardless of position in the wall of the pipe.

16. PRODUCT MARKING

16.1. The following information shall be legibly marked on each section of pipe:

16.1.1. Pipe class and specification designation,

16.1.2. Date of manufacture,

16.1.3. Name or trademark of the manufacturer, and

16.1.4. Identification of plant.

16.2. Pipe with quadrant reinforcement shall be marked with the letter “Q”.

16.3. Markings shall be indented on the pipe section or painted thereon with waterproof paint.

17. KEYWORDS

17.1. Culvert; D-load; elliptical pipe; reinforced concrete; sewer pipe; storm drain.

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[1] Agrees with ASTM C 507M-09 and C 507-09 except for limiting the absorption testing to the five-hour boil method, the use of synthetic fibers are at the option of the owner and the method of acceptance is changed as per Sections 11.1 and 11.5.3.3.

Standard Specification for

Steel Sheet, Zinc-Coated (Galvanized), for Corrugated Steel Pipe

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AASHTO Designation: M 218-03 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Sheet, Zinc-Coated (Galvanized), for Corrugated Steel Pipe

AASHTO Designation: M 218-03 (2007)

1. SCOPE

1.1. This specification covers steel sheet used in the manufacture of corrugated steel pipe (CSP) for storm sewers, culverts, drains, and similar uses. The sheet is zinc-coated (galvanized) by the hot-dip process, and is produced in two coating weights, 610 g/m^2 and 1220 g/m^2. Material for this use is furnished in coils, flat in cut lengths, and corrugated in cut lengths.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 120, Zinc
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *ASTM Standards*:

- A 754, Standard Test Method for Coating Weight (Mass) of Metallic Coatings on Steel by X-Ray Fluorescence
- A 902, Standard Terminology Relating to Metallic Coated Steel Products
- A 924/A 924M, Standard Specification for General Requirements for Steel Sheet, Metallic-Coated by the Hot-Dip Process
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Test Methods

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms used in this standard, refer to ASTM A 902. The following definitions are as stated in that standard.

3.1.1. *fabricator*—(1) the organization that produces the finished pipe, or (2) for structural plate pipe, the organization that processes flat sheets and other items needed for the field assembly of the finished products.

3.1.2. *manufacturer*—the organization that produces the metal sheet from which pipe is made.

3.1.3. *purchaser*—the person or agency that purchases the finished pipe.

Note 1—With regard to this specification for sheet for corrugated steel pipe, the fabricator may also be considered as the "purchaser" of the sheet, where that term is used in this specification. Such interpretation would not restrict the purchaser of the finished pipe from enforcing any provisions of this specification.

4. ORDERING INFORMATION

4.1. All sheet, both flat and formed, covered by this specification shall be ordered only to the specified thicknesses listed in Table 4.

4.2. Unless otherwise specified in the purchase order, all material furnished to this specification shall be chemically treated.

4.3. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product:

4.3.1. Name of material (galvanized steel sheet for CSP);

4.3.2. AASHTO designation and year of issue as M 218-___;

4.3.3. Coating thickness (610 g/m^2 or 1220 g/m^2). A coating weight of 610 g/m^2 will be supplied as a default if no coating weight is specified;

4.3.4. *Quantity and dimensions*:

4.3.4.1. *Cut Lengths*—show number of sheets; thickness; width; either flat or overall corrugated; length; pitch and depth of corrugations, if corrugated;

4.3.4.2. *Coiled Sheet*—show total mass; thickness; width; coil requirements (maximum outside diameter, acceptable inside diameter, and maximum mass of individual coils);

4.3.5. Certification, if required (Section 11.1); and

4.3.6. Special requirements.

Note 2—A typical ordering description is as follows: Galvanized steel sheet for CSP in accordance with M 218-___, 610 g/m^2, 45000 kg, 2.77 by 700 mm by coil, 1500 mm max OD, 600 mm ID, 7000 kg max, certified.

5. CHEMICAL COMPOSITION

5.1. *Base Metal Analysis*—The base metal cast or product analyses shall conform to the chemical requirements of Table 1.

Table 1—Chemical Composition

	Cast Analysis	Product Analysis
Sulfur, max, percent	0.05	0.06
Sum of carbon, manganese, phosphorous, silicon, and sulfur, max, percent	0.70	0.74

5.2. *Coating Bath Composition (Zinc Coating)*—the coating bath metal shall contain not less than 99 percent zinc.

6. MECHANICAL PROPERTIES

6.1. The galvanized steel sheet shall conform to the mechanical requirements in Table 2.

Table 2—Mechanical Requirements
(Properties of Flat Sheet Prior to Fabrication)[a]

Tensile strength, min,[b] MPa	310
Yield point, min,[b] MPa	230
Elongation in 50 mm,[c] min, percent	20

[a] To determine conformance with this specification, round each value for tensile strength and for yield strength to the nearest 1 MPa and each value for elongation to the nearest 1 percent, both in accordance with the rounding method of ASTM E 29.

[b] Yield point and tensile strength are based on thickness of the base metal. If tests are made after coating, determine the base metal thickness after stripping the coating from the ends of the specimen contacting the grips of the tension-testing machine prior to tensile testing.

[c] Elongation requirement does not apply to material tested after corrugating.

6.2. Two tension tests shall be made on random samples of finished material from each cast or heat. When the finished material from said cast or heat is less than 45 Mg, one test is sufficient. When material rolled from one cast or heat differs 1.25 mm or more in thickness, one tension test shall be made from both the thickest and thinnest material rolled regardless of the mass represented. The samples shall be prepared and tested in accordance with the method specified in ASTM A 924M.

7. COATING REQUIREMENTS

7.1. The mass of zinc coating shall conform to the requirements in Table 3. The mass of coating is the total amount on both surfaces of the sheet expressed in g/m^2 of sheet.

Table 3—Coating Mass Requirements

Coating Mass, Total Both Sides		Equivalent Coating Thickness, Total Both Sides[a]	
Triple Spot Average, Min, g/m^2	Single Spot, Min, g/m^2	Triple Spot Average, Min, µm	Single Spot, Min, µm
610	550	86	78
1220	1100	172	156

[a] Coating thicknesses are approximate, for information only. (See Section 9.5.1.) Conversion is based on the following relationship: 1 g/m^2 = 0.1415 µm.

7.2. Adhesion of the coating shall be such that no peeling or flaking occurs while the coated sheet is being corrugated and formed into pipe.

8. DIMENSIONS AND TOLERANCES

8.1. *Thickness*—Sheet thickness shall conform to dimensions prescribed in Table 4. The thickness of the sheet includes both the base steel and the zinc coating.

Table 4—Coated Steel Sheet Thickness Requirements

Specified Thickness, mm	Minimum Thickness, mm
1.02	0.91
1.32	1.17
1.63	1.45
2.01	1.83
2.77	2.57
3.51	3.28
4.27	4.04

Note: Thickness is measured not less than 10 mm from an edge. On corrugated sheet, thickness is measured on the tangents of corrugations. For 1220 g/m^2 coating, the specified thickness and the minimum thickness shall be increased by 0.076 mm to account for the greater thickness as compared with the 610 g/m^2.

8.2. *Length*—Permissible variations in length of cut-length sheets, both flat and corrugated, shall be in accordance with ASTM A 924M.

8.3. *Flat Sheet*—Permissible variations in width and camber of flat materials shall be in accordance with ASTM A 924M. Flatness tolerances are shown in Table 5.

Table 5—Flatness Tolerances (Cut Lengths Only)

Specified Thickness, mm	Specified Width, mm	Flatness Tolerance (Maximum Deviation from a Horizontal Flat Surface), mm
1.63 and thicker	To 1500, incl	13
1.32 and thinner	To 900, incl	13
	Over 900 to 1500, incl	19

Note: This table also applies to sheets cut to length from coils by the fabricator when adequate flattening measures are performed.

8.4. *Corrugated Sheet*:

8.4.1. *Corrugations*—Corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 6.

Table 6—Corrugation Size

			Radius of Curvature, mm	
Nominal Size, mm	Max Pitch,[a] mm	Min Depth,[b] mm	Nominal	Min
68 by 13	73	12	17	12
75 by 25	83	24	14	12
125 by 25	135	24	40	36

[a] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests to the bottom of the intervening valley.

8.4.2. *Covering Width and Lip Dimension*—Covering width of corrugated sheet shall be in accordance with Table 7. Covering width is the distance between the crests of the extreme corrugations. The lip dimension of corrugated sheet shall be in accordance with Table 8 and is measured along the radial curvature from the crest of the corrugation to the edge of the sheet. There is no established tolerance for overall width since the covering width and lip dimensions are the governing factors for the formed product.

Table 7—Covering Width Tolerance for Corrugated Sheet

Covering Width, mm	Tolerance Over and Under, mm
To 600, inclusive	6
Over 600 to 900, inclusive	10
Over 900 to 1200, inclusive	13

Table 8—Corrugated Sheet Lip Dimensions

Nominal Corrugation Size, mm	For Riveted Pipe Construction,[a] mm	For Spot-Welded Pipe Construction, Min, mm
68 by 13	19	11
75 by 25	22	13
125 by 25	22	13

[a] Tolerances, +5 mm, –0.

9. TESTING

9.1. The manufacturer shall make such tests and measurements as deemed necessary to ensure that the coated sheet produced complies with this specification.

9.2. The purchaser may make tests and measurements as determined to be necessary to confirm conformance with this specification.

9.3. *Chemical Analysis of Steel*—Cast analysis (by the manufacturer) and product analysis (by the purchaser) shall be in accordance with ASTM A 924M.

9.4. *Mechanical Testing*—Mechanical property tests shall be conducted on the sheet prior to corrugating or other fabrication, when possible, and shall be in accordance with ASTM A 924M. If tests are made after corrugating, specimens shall be taken on the tangents of corrugations and used for determination of tensile and yield strengths only.

9.5. *Coating Mass*:

9.5.1. Sampling for coating mass determinations shall be in accordance with ASTM A 924M. The mass of coating shall be determined according to T 65M/T 65.

9.5.2. The mass may be converted from the sum of readings on both surfaces of the sheet by a magnetic thickness gauge suitably checked and demonstrated for accuracy (Note 3) 1 μm = 7.1 g/m^2 each surface. When a magnetic thickness gauge is used and a dispute arises, the mass shall be determined by the stripping test in T 65M/T 65.

9.5.3. The mass of coating may be determined from the coating thickness measured by the x-ray fluorescence method, according to ASTM A 754. When this method is used and a dispute arises, the mass shall be determined by the stripping test in T 65M/T 65.

Note 3—Several magnetic and electromagnetic types of coating thickness gauges are commercially available and are a satisfactory basis for acceptance when properly calibrated just prior to inspection use. (See ASTM E 376.)

10. REJECTION AND REHEARING

10.1. Material tested by the purchaser and found not conforming to this specification may be rejected subject to the rejection and rehearing provisions of ASTM A 924M.

11. CERTIFICATION

11.1. When specified in the purchase order or contract, a manufacturer's certification shall be furnished to the purchaser. The certification shall be in accordance with the provisions of ASTM A 924M and shall include reference to this product specification designation.

11.2. Test results, including chemical composition, mechanical properties, and mass of coating for each heat and coating lot, shall be maintained by the sheet manufacturer for 7 years and shall be made available to the fabricator and purchaser upon request.

12. PRODUCT MARKING

12.1. Each 0.5 to 1.5 m of sheet in coils or cut lengths shall be identified by showing the following:

12.1.1. Name of manufacturer;

12.1.2. Brand name;

12.1.3. Specified thickness;

12.1.4. Specified coating mass;

12.1.5. Identification symbols relating to a specific heat number and coating lot number; and

12.1.6. AASHTO designation number.

12.2. The brand shall be removed, obliterated, or rebranded "Non-Specification" on each 0.5 to 1.5 m of sheet in a coating lot or heat in which control tests show, as prescribed herein, nonconformance to this specification.

Standard Specification for

Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches

AASHTO Designation: M 219-92 (2008)
ASTM Designation: B 746/B 746M-92

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches

AASHTO Designation: M 219-92 (2008)
ASTM Designation: B 746/B 746M-92

1. SCOPE

1.1. This specification covers corrugated aluminum alloy structural plate used in the construction of pipe, pipe-arches, arches, underpasses, and special shapes for field assembly. Appropriate fasteners are also described. The pipe, arches, and other shapes are generally used for drainage purposes, pedestrian and vehicular underpasses, and utility tunnels.

1.2. This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and plate thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of plate thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The purchaser must correlate the above factors and also the corrosion and abrasion requirements of the field installation with the plate thickness. The structural design of corrugated aluminum structural plate pipe and the proper installation procedures are given in *AASHTO LRFD Bridge Design Specifications* and the *AASHTO LRFD Bridge Construction Specifications*. The *installation* is according to *AASHTO LRFD Bridge Construction Specifications*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 164M, High-Strength Bolts for Structural Steel Joints [Metric] (Discontinued)
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- *AASHTO LRFD Bridge Design Specifications*
- *AASHTO LRFD Bridge Construction Specifications*

2.2. *ASTM Standards*:

- B 209M, Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate [Metric]
- B 221M,Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes [Metric]
- B 666M, Standard Practice for Identification Marking of Aluminum Products [Metric]
- E 29,Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- F 467M, Standard Specification for Nonferrous Nuts for General Use [Metric]
- F 468M, Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use [Metric]

- F 568, Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners
- F 593, Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs
- F 594, Standard Specification for Stainless Steel Nuts
- F 738, Standard Specification for Stainless Steel Metric Bolts, Screws, and Studs
- F 836, Standard Specification for Stainless Steel Metric Nuts

2.3. *American National Standards Institute*:

- B18.2.3.6M, Bolts, Metric Heavy Hex
- B18.2.4.6M, Hex Nuts, Heavy, Metric

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3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *arch*—a partial circle shape spanning an open invert between the footings on which it rests.

3.1.2. *box culvert*—a rectangular box with short-radius in upper corners and a long-radius crown. It can be with full invert or with footings pads.

3.1.3. *fabricator*—the producer of the components for the finished product.

3.1.4. *flat plate*—sheet or plate used to fabricate structural plate.

3.1.5. *manufacturer*—the producer of the flat plate and accessories.

3.1.6. *pipe*—a conduit having full circular shape; also, in a general context, all structure shapes covered by this specification.

3.1.7. *pipe-arch*—an arch shape with an approximate semicircular crown, small-radius corners, and large-radius invert.

3.1.8. *pipe, horizontal ellipse*—an elliptically shaped pipe with the horizontal diameter approximately 20 percent greater than the nominal diameter.

3.1.9. *pipe, vertically elongated*—an elliptically shaped pipe with the vertical diameter up to 10 percent greater than the nominal diameter.

3.1.10. *purchaser*—the purchaser of the finished product.

3.1.11. *special shape*—a shape, other than described elsewhere in this section, suitable for fabrication with structural plate.

3.1.12. *structural plate*—a corrugated and curved plate, which is field assembled with other structural plates to form the required structure.

3.1.13. *vehicular underpass*—a high arch shape with an approximate semicircular crown, large-radius sides, small-radius corners between sides and invert, and large-radius invert.

4. ORDERING INFORMATION

4.1. Orders for material under this specification shall include the following information as necessary to adequately describe the desired product:

4.1.1. Name of material (aluminum alloy structural plate and accessories);

4.1.2. Description of structure (see Section 3);

4.1.3. Number of structures;

4.1.4. AASHTO designation and year of issue;

4.1.5. Dimensions of structure (diameter or span and rise, and length, etc.) (Section 7.2);

4.1.6. Thickness of plate (Section 7.1);

4.1.7. Type of bolts; whether aluminum, stainless steel, or steel bolts are required or permitted; if not specified, steel bolts and nuts shall be furnished (Section 5.3 and Note 2);

4.1.8. End treatment (bevel, skew, grade or slope corrections, or other special provision if required by the project plans or specifications);

4.1.9. Special requirements (including extrusion reinforcement locations and shapes), if required; and

4.1.10. Certification, if required.

Note 1—Typical ordering descriptions are as follows: Structural plates and fasteners for one aluminum alloy structural plate pipe arch, conforming to M 219-___, 3860-mm span by 2460-mm rise, 3.81-mm plate thickness, 27.0-m nominal centerline length with square ends.

5. MATERIALS

5.1. *Flat Plate*—Insofar as applicable, flat plate shall conform to the requirements of ASTM B 209M. The plates shall be fabricated from alloy 5052-H141. The mechanical properties for alloy 5052-H141 shall conform to the requirements of Table 1.

Table 1—Mechanical Properties of Aluminum Structural Plate, Alloy 5052-H141[a]

Specified Thickness, mm	Tensile Strength, Min, MPa	Yield Strength (0.2 Percent Offset), Min, MPa	Elongation Percent, Min in 50 mm
2.54–3.81	245	165	6
4.44–6.35	235	165	8

[a] To determine conformance with this specification, each value for tensile strength and for yield strength shall be rounded to the nearest 1 MPa and each value for elongation to the nearest 0.5 percent, both in accordance with the rounding method of ASTM E 29.

5.2. *Extrusions*—The extrusions for circumferential or longitudinal stiffeners, or secondary structural components, shall be fabricated from aluminum alloys 6061-T6 or 6063-T6 conforming to ASTM B 221M.

5.3. *Assembly Fasteners*—Except as provided elsewhere in this section, bolts and nuts shall conform to the requirements specified in Table 2. The bearing surface of both bolts and nuts shall be shaped to a 25-mm radius spherical surface, or to a uniform taper of approximately 22 degrees to form a conical surface. In lieu of bolts and nuts with the special bearing surface, standard type bolts and nuts with special washers may be used. The number of nuts and bolts of each size and length furnished shall be 2 percent in excess of the theoretical number required to field erect the structure or structures. Bolt lengths shall be such as to result in at least "full nut" engagement when tightened in place.

Table 2—(M 219) Bolt and Nut Requirements

	Bolts	Nuts
General dimensions	ANSI B18.2.3.6M Heavy Hex	ANSI B18.2.4.6M Heavy Hex
Steel bolts and nuts	F 568 Class 4.6[a]	M 291M Class 5
Zinc coating	M 232M/M 232 or M 298 Class 50	M 232M/M 232 or M 298 Class 50
Stainless steel bolts and nuts	F 738 Alloy Group A1, A2, or A4	F 836 Alloy Group A1, A2, or A4
Aluminum bolts and nuts	F 468M Alloy 6061-T6	F 467M Alloy 6061-T6
Nominal diameter, metric size	M 20	M 20

[a] Bolts through Class 8.8 with suitable nuts may be substituted.

Note 2—Aluminum bolts and nuts, due to lower strength properties than steel bolts, have lower allowable design seam strengths in pipe with all plate thicknesses, but especially so for plate thicknesses greater than 4.5 mm. The purchaser should indicate which bolts and nuts are acceptable or required based on his design calculations. Corrosion should be considered in selecting bolt types for use in corrosive environments.

6. FABRICATION

6.1. Structural plates shall be fabricated from flat sheets or plates, corrugated in accordance with Section 6.2, punched for bolted lap seams in accordance with Section 6.3, and curved to the required radius.

6.2. *Corrugations*—Corrugations shall form smooth continuous curves and tangents. Corrugations shall form annular rings (complete or partial) about the axis of the structure. The dimensions of the corrugations shall be in accordance with Table 3.

Table 3—Corrugation Requirements

			Inside Radius	
Nominal Size, mm	Max Pitch,[a] mm	Min Depth,[b] mm	Nominal, mm	Min, mm
230 × 64	238	60	57	51

[a] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on corrugation crests parallel to the axis of the pipe, to the bottom of the intervening valley.

6.3. *Bolt Holes*—The bolt holes shall be punched so that all plates having like dimensions, curvature, and same number of bolts per foot of seam shall be interchangeable. Longitudinal seams shall have holes for four bolts per corrugation, with two holes in each valley and two holes in each crest, with the holes placed 45 mm apart. Circumferential seams in the finished product shall provide for a bolt spacing of not more than 250 mm. The diameter of the bolt holes in the longitudinal seams shall not exceed the bolt diameter by more than 3 mm except those in the plate corners. Bolt holes in circumferential seams, including plate corners, may be slotted with a width equal to the bolt diameter plus 10 mm. The minimum distance from the center of a hole to the edge of a plate shall be $1^3/_4$ times the diameter of the bolt. Holes shall be provided as required for connecting headwall anchors, bearings, and miscellaneous attachments.

6.4. *Special Plates*—Plates for forming skewed ends, beveled ends, or curved alignment shall be accurately cut to fit the order plans. Cut edges of plates shall be free of notches, gouges, or burrs and shall present a workmanlike finish. Legible identification shall be placed on each special plate to designate its proper position in the finished structure and referenced to the approved erection drawings.

6.5. *Extrusions*—Extrusions for longitudinal or circumferential structural reinforcing, if required, shall be as sized and located on the order plans, and fabricated from aluminum alloy 6061-T6. Extrusions for receiving angle on arches or other less critical structural members, if required, shall be as sized and located on the order plans, and shall be fabricated from aluminum alloy 6061-T6 or 6063-T6.

7. DIMENSIONS AND TOLERANCES

7.1. *Plate Thickness*—Plate thickness shall be as specified by the purchaser from the specified plate thickness listed in Table 4 (Note 3). For corrugated plate, the thickness shall be measured on the tangents of the corrugations.

Table 4—Plate Thickness[a]

Specified Thickness, mm	Min Thickness, mm
2.54	2.36
3.18	3.00
3.81	3.51
4.44	4.09
5.08	4.72
5.72	5.31
6.35	5.89

[a] Thickness is measured at any point on the plate not less than 10 mm from an edge and, if corrugated, on the tangents of corrugations.

Note 3—The purchaser should determine the required thickness according to the design criteria in *AASHTO LRFD Bridge Design Specifications* or other appropriate guidelines.

7.2. *Cross-Section Dimensions*—Cross-section dimensions, such as diameter, span and rise, and radius of curvature, shall be measured to the inside crest of corrugations. The average diameter of circular pipe, based on two measurements at 90 degrees to each other, shall not vary more than ±2 percent from the calculated inside diameter shown in Table 5. The span and rise of pipe arch, arch, underpass, and other noncircular structures shall be as specified within ±2 percent.

Note 4—The purchaser should consult the fabricator to determine the standard dimensions for the various types of structures other than circular structures.

Table 5—Diameter of Circular Pipe 230 by 65 mm Corrugation

Nominal Diameter Specified, mm	Calculated Inside Diameter, mm
1525	1490
1675	1645
1830	1805
1980	1955
2135	2115
2285	2265
2440	2425
2590	2580
2745	2735
2895	2890
3050	3050
3200	3200
3355	3360
3505	3515
3660	3670
3810	3825
3960	3980
4115	4135
4265	4290
4420	4445
4570	4600
4725	4750
4875	4910
5030	5070
5180	5225
5335	5380
5485	5535
5640	5695
5790	5845
5945	6005
6095	6160
6250	6315
6400	6470
6555	6630
6705	6780
6860	6940
7010	7090
7165	7250
7315	7405
7470	7560
7620	7715
7770	7870
7925	8025

8. WORKMANSHIP

8.1. Plates, fasteners, and accessories shall be of uniform quality consistent with good manufacturing and inspection practices.

9. SAMPLING AND TESTING

9.1. Sampling and testing of plate shall be according to ASTM B 209M. Sampling and testing of other materials shall be according to the specification referenced. The manufacturer shall make adequate tests and measurements to ensure that the material produced complies with this specification.

9.1.1. Test results including chemical composition and mechanical properties shall be maintained by the manufacturer for 7 years and shall be made available to the fabricator and purchaser upon request, for examination at the manufacturer's facility unless otherwise agreed upon.

9.2. The fabricator or the purchaser may make such tests as are necessary to determine the acceptability of the material or to verify the correctness of a certification.

9.3. Mechanical properties shall be determined on plate prior to corrugating or other fabricating, except tests may be made after fabrication by the purchaser for tensile and yield strengths.

10. REJECTION AND REHEARING

10.1. Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or fabricator promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or fabricator may make claim for a rehearing.

11. CERTIFICATION

11.1. When specified in the purchase order or contract, a manufacturer's certification shall be furnished to the purchaser of the plate (fabricator), or manufacturer's and fabricator's certification shall be furnished to the purchaser of the finished pipe, stating that samples representing each lot have been tested and inspected in accordance with this specification and the requirements have been met. When specified in the purchase order or contract, a report of the mechanical test results and the chemical composition limits shall be furnished.

Note 5—As the identity of the plate is not maintained from the original ingot production, if numerical results are required by the purchaser, tests should be performed on the finished plate.

12. PRODUCT MARKING

12.1. Each plate shall be identified by showing the following:

12.1.1. Name or trademark of plate manufacturer;

12.1.2. Name of fabricator, if other than the manufacturer;

12.1.3. Alloy and temper;

12.1.4. Specified thickness;

12.1.5. Identification symbols showing date of fabricating by a six-digit number indicating in order the year, month, and day of the month; and

12.1.6. AASHTO designation number.

12.2. The marking shall be so placed that when the structure is erected, the identification will appear on the inside.

12.3. The marking shall be applied to the plate by a permanent method, such as coining, in accordance with ASTM B 666M.

Standard Specification for

Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe

AASHTO Designation: M 242M/M 242-08[1]
ASTM Designation: C 655M-07[1] and C 655-07[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe

AASHTO Designation: M 242M/M 242-08[1]
ASTM Designation: C 655M-07[1] and C 655-07[1]

1. SCOPE

1.1 This specification covers reinforced concrete pipe designed for specific D-loads and intended to be used for the conveyance of sewage, industrial wastes, and storm water, and for the construction of culverts.

1.2 This specification is applicable for orders in either SI units (M 242M) or in inch-pound units (M 242). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 242.

Note 1—Experience has shown that the successful performance of this product depends upon the proper selection of the pipe strength, the type of bedding and backfill, the care that the installation conforms to the construction specifications, and provision for adequate inspection at the construction site. This specification does not include requirements for bedding, backfill, the relationship between field load conditions and the strength designation of pipe, or durability under unusual environmental conditions. These requirements should be included in the project specification.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 280, Concrete Pipe, Manhole Sections, or Tile

2.2 *ASTM Standards*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete
- E 105, Standard Practice for Probability Sampling of Materials
- MNL 7A, *Manual on Presentation of Data and Control Chart Analysis*
- STP 15-C, *Manual on Quality Control of Materials*

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. BASIS OF ACCEPTANCE

4.1 The acceptability of the pipe design shall be determined in accordance with Section 9. After the pipe design has been accepted, or if the pipe design has been accepted previously in accordance with Section 9, the owner may select and have applied the basis of acceptance described in either Section 4.1.1 or Section 4.1.2. Unless designated by the owner at the time of, or before placing an order, either basis of acceptance shall be permitted.

4.1.1 *Acceptance on the Basis of Pipe Load and Material Tests and Inspection of Manufactured Pipe for Defects*—Determine in accordance with Sections 5, 6, 8, and 10.

Note 2—It is necessary that samples be selected at random. For guidance, see ASTM E 105.

4.1.2 *Acceptance on the Basis of Concrete Compression and Materials Tests and Inspection of Manufactured Pipe for Defects*—Determine in accordance with Sections 5, 6, 8, and 11.

4.2 *Age for Acceptance*—Pipe shall be considered ready for acceptance when they conform to the requirements.

5. DESIGN AND MANUFACTURING DATA

5.1 The manufacturer shall provide the following information regarding the pipe unless waived by the owner:

5.1.1 Basis of acceptance, and

5.1.2 Pipe design strength.

5.1.3 *Physical Characteristics*:

5.1.3.1 Diameter, wall thickness, laying length, and joint details;

5.1.4 Design concrete strength, minimum f_c' equals 27.6 MPa [4000 psi]; and

5.1.5 Admixtures.

5.1.6 *Reinforcement*:

5.1.6.1 Type of reinforcement, applicable reinforcement specification, and grade; and

5.1.6.2 Placement, placement tolerances, diameter, spacing and cross-sectional area of circumferential, longitudinal, and special reinforcement.

5.1.7 Manufacturing and curing process.

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6. MATERIALS AND MANUFACTURE

6.1 *Materials*:

6.1.1 *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.1.2 *Cementitious Materials*:

6.1.2.1 *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash.

6.1.2.2 *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.1.2.3 *Ground Granulated Blast-Furnace Slag (GGBFS)—GGBFS shall conform to the requirements of Grade 100 or 120 of M 302.*

6.1.2.4 *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

(a) Portland cement only,
(b) Portland blast-furnace slag cement only,
(c) Slag modified portland cement only,
(d) Portland-pozzolan cement only,
(e) A combination of portland cement and fly ash,
(f) A combination of portland cement and ground granulated blast-furnace slag, or
(g) A combination of portland cement, ground granulated blast furnace slag (not to exceed 25 percent of the total cementious weight), and fly ash (not to exceed 25 percent of the total cementious weight).

6.1.3 *Aggregates*—Aggregates shall conform to the requirements of M 6 and M 80, except that the requirements for gradation shall not apply.

6.1.4 *Admixtures and Blends*—Admixtures and blends shall be allowed to be used unless prohibited by the owner.

6.1.5 *Steel Reinforcement*—Reinforcement shall consist of wire conforming to M 32M/M 32 or M 225M/M 222, or of wire fabric conforming to M 55M/M 55 or M 221M/M 221, or of bars of Grade 300 [40] steel conforming to M 31M/M 31.

6.2 *Manufacture*:

6.2.1 *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.1 and shall be added to the mix in a proportion not less than 280 kg/m^3 [470 lb/yd^3] unless mix designs with a lower cementitious material content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

6.2.2 *Reinforcement*:

6.2.2.1 *Placement*—Reinforcement shall be placed as indicated in Section 5.1.6.2, subject to the tolerances given in Sections 5.1.6.2 and 8.2.2. Minimum design protective cover of concrete over the circumferential reinforcement in the barrel of the pipe shall be 25 mm [1 in.] for wall thicknesses of 63 mm [$2^1/_2$ in.] or greater, and 19 mm [$^3/_4$ in.] for wall thicknesses less than 63 mm [$2^1/_2$ in.], subject to the tolerances given in Section 8.2.2.

6.2.2.2 *Splices*—The strength of the pipe shall not be adversely affected by the splice.

6.2.2.3 *Spacing*—The spacing center-to-center of adjacent rings of circumferential reinforcement in a cage shall not exceed 100 mm [4 in.] for pipe with a wall thickness up to and including 100 mm [4 in.] and shall not exceed the wall thickness or 150 mm [6 in.], whichever is smaller, for larger pipe.

6.2.3 *Joints*—The joints shall be of such design and the ends of the concrete pipe sections so formed that when the sections are laid together they will make a continuous line of pipe with a smooth interior free of appreciable irregularities in the flow line, all compatible with the permissible variations given in Section 8.

6.2.4 *Lift Holes*—When agreed upon by the owner, lift eyes or holes are permitted in each pipe for the purpose of handling.

6.3 *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers shall be allowed to be used, at the owner’s option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

7. PHYSICAL REQUIREMENTS

7.1 *Strength*—The design strength designation of the pipe shall be the D-load to produce the 0.3 mm [0.01 in.] crack when tested in accordance with T 280. The relationship of ultimate strength D-load to the design strength D-load shall be determined using a factor of 1.5 for design strength designations up to 100 N/m·mm [2000 lbf/ft·ft] of diameter, a factor varying in linear proportions from 1.5 to 1.25 for design strength designations from 100 N/m·mm [2000 lbf/ft·ft] through 150 N/m·mm [3000 lbf/ft·ft], and a factor of 1.25 for design strength designations in excess of 150 N/m·mm [3000 lbf/ft·ft].

Note 3—As used in this specification, the 0.3-mm [0.01-in.] crack is a test criterion for pipe tested in three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

Note 4—Ultimate strength of concrete pipe in the buried condition is dependent on varying soil bedding factors and varying failure modes and shall not necessarily have a relationship to the ultimate strength as defined under three-edge-bearing conditions.

7.2 *Test Equipment and Facilities*—The manufacturer shall furnish without charge all samples, facilities, and personnel necessary to carry out the tests required by this specification.

7.3 *Pipe Load Tests*—The tests for crushing strength, when required, shall be made in accordance with T 280. When alternative methods of load testing are specified, tests shall be made in accordance with the alternative requirements.

8. DIMENSIONS AND PERMISSIBLE VARIATIONS

8.1 *Standard Diameters*—Pipe shall be manufactured in the standard inside diameters listed in Table 1.

Note 5—Diameters other than those shown in Table 1 and diameters larger than 3600 mm [144 in.] are possibly available. When such sizes are required, the owner should contact the manufacturers in the area.

Table 1—Standard Designated Inside Diameters, mm [in.]

mm	[in.]	mm	[in.]	mm	[in.]	mm	[in.]	mm	[in.]	mm	[in.]	mm	[in.]
300	12	600	24	900	26	1500	60	2100	84	2700	108	3300	132
375	15	675	27	1050	42	1650	66	2250	90	2850	114	3450	138
450	18	750	30	1200	48	1800	72	2400	96	3000	120	3600	144
525	21	825	33	1350	54	1950	78	2500	102	3150	126		

8.2 *Design Tolerances*—Except as specified in this section, all permissible design tolerances shall be given in Section 5.

8.2.1 *Internal Diameters*—The permissible variations in the internal diameter are as prescribed in Table 2. These diameter requirements are based on the average of four diameter measurements at a distance of 12-in. from the end of the bell or spigot of the pipe. Diameter verification shall be made on the number of pipe selected for test per Section 11.

Table 2—Permissible Variation in Internal Diameter

Designated Diameter of Pipe		Permissible Variation, Internal Diameter of Pipe			
		Minimum		Maximum	
mm	[in.]	mm	[in.]	mm	[in.]
300	12	300	$11^{3}/_{4}$	310	$12^{1}/_{4}$
375	15	375	$14^{23}/_{32}$	390	$15^{9}/_{32}$
450	18	450	$17^{11}/_{16}$	465	$18^{5}/_{16}$
525	21	525	$20^{21}/_{32}$	545	$21^{11}/_{32}$
600	24	600	$23^{5}/_{8}$	620	$24^{3}/_{8}$
675	27	675	$26^{5}/_{8}$	695	$27^{3}/_{8}$
750	30	750	$29^{5}/_{8}$	775	$30^{3}/_{8}$
825	33	825	$32^{5}/_{8}$	850	$33^{3}/_{8}$
900	36	900	$35^{5}/_{8}$	925	$36^{3}/_{8}$
1050	42	1050	$41^{9}/_{16}$	1080	$42^{7}/_{16}$
1200	48	1200	$47^{1}/_{2}$	1230	$48^{1}/_{2}$
1350	54	1350	$53^{7}/_{16}$	1385	$54^{9}/_{16}$
1500	60	1500	$59^{3}/_{8}$	1540	$60^{5}/_{8}$
1650	66	1650	$65^{5}/_{16}$	1695	$66^{11}/_{16}$
1800	72	1800	$71^{1}/_{4}$	1850	$72^{3}/_{4}$
1950	78	1950	$77^{1}/_{4}$	2000	$78^{3}/_{4}$
2100	84	2100	$83^{3}/_{16}$	2155	$84^{13}/_{16}$
2250	90	2250	$89^{1}/_{8}$	2310	$90^{7}/_{8}$
2400	96	2400	$95^{1}/_{16}$	2465	$96^{15}/_{16}$
2550	102	2550	101	2620	103
2700	108	2700	$106^{15}/_{16}$	2770	$109^{1}/_{16}$
2850	114	2850	$112^{7}/_{8}$	2925	$115^{1}/_{8}$
3000	120	3000	$118^{13}/_{16}$	3080	$121^{3}/_{16}$
3150	126	3150	$124^{3}/_{4}$	3235	$127^{1}/_{4}$
3300	132	3300	$130^{11}/_{16}$	3390	$133^{5}/_{16}$
3450	138	3450	$136^{5}/_{8}$	3540	$139^{3}/_{8}$
3600	144	3600	$142^{9}/_{16}$	3695	$145^{7}/_{16}$

8.2.2 *Reinforcement Placement Tolerances*—The maximum variation in the nominal position of the reinforcement shall be ±10 percent of the wall thickness or ±16 mm [±$^{5}/_{8}$ in.], whichever is greater. Pipe having variations in the position of the reinforcement exceeding those specified above shall be accepted if the three-edge-bearing strength requirements obtained on a representative sample are met. In no case, however, shall the cover over the circumferential reinforcement be less than 16 mm [$^{5}/_{8}$ in.].

8.2.3 *Length of Two Opposite Sides*—Variations in the laying length of two opposite sides of pipe shall not be more than 6 mm [$^{1}/_{4}$ in.] for all sizes through 600 mm [24-in.] internal diameter, and not more than 10 mm/m [$^{1}/_{8}$ in./ft] of internal diameter for all larger sizes, with a maximum of 16 mm [$^{5}/_{8}$ in.] in any pipe through 2100 mm [84-in.] internal diameter, and a maximum of 19 mm [$^{3}/_{4}$ in.] for 2250 mm [90-in.] internal diameter or larger, except where beveled-end pipe for laying on curves is specified by the owner.

8.2.4 *Length of Pipe*—The underrun in length of a section of pipe shall not be more than 10 mm/m [$^{1}/_{8}$ in./ft] with a maximum of 13 mm [$^{1}/_{2}$ in.] in any length of pipe.

8.2.5 *Wall Thickness Tolerances*—The wall thickness shall not be less than the nominal specified in the design given in Section 5.1.3.1 by more than 5 percent or 5 mm [$^{3}/_{16}$ in.], whichever is greater.

A wall thickness more than that required in the design is not a cause for rejection except that such pipe shall not be used for the tests required in Section 7.3.

9. ACCEPTANCE OF DESIGN

9.1 *Acceptance by Tests of Specimens*—Three to five representative specimens, or special test pipe that are shorter than standard production pipe, as agreed upon by the owner and manufacturer, shall be tested to the 0.3 mm [0.01 in.] crack and to ultimate strength and the results recorded. Compute the values in Sections 9.1.1 and 9.1.2 for both the 0.3 mm [0.01 in.] crack and the ultimate strength.

9.1.1 Compute the estimated standard deviation, *s*, by Equation 1 or Equation 2, which yield identical values.

$$s = \sqrt{[\Sigma\left(X_i - \overline{X}\right)^2]\Big/(n-1)} \tag{1}$$

$$s = \sqrt{[\Sigma X_i^2 - \left(\Sigma X_i\right)^2\big/n]\Big/(n-1)} \tag{2}$$

where:

X_i = observed value of the load to produce the 0.3 mm [0.01 in.] crack (and the load to develop the ultimate strength)

$\overline{X}$ = average (arithmetic mean) of the values of x_i, and

n = number of observed values.

9.1.2 Compute the minimum allowable arithmetic mean, $\overline{X}_s$, by Equation 3. In Equation 3, the value of the estimated standard deviation, *s*, shall be as calculated by Equations 1 or 2 or equal to 0.07*L*, whichever is greater.

$$\overline{X}_s = L + 1.07s \tag{3}$$

where:

L = specification limit (specified D-load).

9.1.3 The pipe design shall be acceptable if the arithmetic mean $\overline{X}$ for the 0.3 mm [0.01 in.] crack and ultimate strength is equal to or greater than the computed values of $\overline{X}_s$, and if all the tested specimens meet or exceed the specification limit.

9.2 *Alternative Acceptance Method*—The manufacturer shall be allowed to request approval of designs based on empirical evaluations of the strength of the pipe, including, but not limited to, designs based on interpolation between designs approved in accordance with Section 9.1, or designs evaluated on the basis of tests other than the three-edge-bearing test method. Acceptance of design tests need not be performed for each contract or order.

10. ACCEPTANCE OF PIPE BY LOAD TESTING

10.1 *Lot Sampling*—When the acceptance is to be in accordance with Section 4.1.1, randomly select from the lot a sample of the size listed in Table 3 and test each specimen to the design strength. When all specimen test strengths are greater than the minimum design strength D-load, the lot shall be accepted. When one or more specimen test strengths are less than the minimum design strength D-load, the values for $\overline{X}$ and *s* shall be computed and *s* shall be substituted into the applicable equation given in Table 3. When the arithmetic mean $\overline{X}$ is equal to or greater than the computed value of $\overline{X}_s$, the lot of pipe shall be acceptable. When the arithmetic mean $\overline{X}$ is less than the computed value of $\overline{X}_s$, the lot of pipe shall be rejected for that design strength D-load strength.

Table 3—Sample Size

Lot Size	Sample Size	Equation	Equation Number
0 to 300	3	$\overline{X}_S = L + 1.08s$	*(4)*
301 to 500	4	$\overline{X}_S = L + 1.09s$	*(5)*
501 to 800	5	$\overline{X}_S = L + 1.10s$	*(6)*
801 to 1300	7	$\overline{X}_S = L + 1.16s$	*(7)*

10.2 *Use of Design Test Pipe*—When the pipe tested in Section 9 were selected at random from a production lot, the test data may be used in the acceptance analysis of that lot.

10.3 *Use of Pipe Tested to 0.3mm [0.01 in.] Crack*—Pipe that have been tested only to the formation of the 0.3mm [0.01 in.] crack and that meet the design strength requirements shall be acceptable for use. All pipe that test less than the design strength shall be removed from the lot and marked so that they will not be shipped.

11. ACCEPTANCE OF PIPE BY CONCRETE COMPRESSION TESTING

11.1 *Type of Specimen*—Compression tests for determining concrete compressive strength shall be allowed to be made on either concrete cylinders or on cores drilled from the pipe. Pipe that fails to meet the strength requirements as determined by the selected test type shall not be retested using one of the other test types without approval of the owner.

11.2 *Compression Testing of Cylinders*:

11.2.1 *Cylinder Production*—Cylinders shall be prepared in accordance with the Cylinder Strength Test Method of T 280.

11.2.2 *Number of Cylinders*—Prepare not fewer than five test cylinders from each concrete mix used within a group (one day’s production) of pipe sections.

11.2.3 *Acceptability on the Basis of Cylinder Test Results*:

11.2.3.1 When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength of concrete in the group of pipe sections shall be accepted.

11.2.3.2 When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the design concrete strength, then the group shall be accepted.

11.2.3.3 The group of pipe shall be acceptable only when the compressive strength of the cylinders tested conforms to the acceptance criteria stated in Section 11.2.3.1 or Section 11.2.3.2.

11.3 *Compression Testing of Cores*:

11.3.1 *Obtaining Cores*—Cores shall be obtained, prepared, and tested in accordance with the Core Strength Test Method of T 280.

11.3.2 *Number of Cores*—One core shall be cut from a pipe section selected at random from each day’s production run of a single concrete strength.

11.4 *Acceptability on the Basis of Core Test Results*:

11.4.1 When the compressive strengths of a core tested for a group of pipe sections is equal to or greater than the design concrete strength, the compressive strength of the concrete for the group is acceptable.

11.4.2 If the compressive strength of the core tested is less than the design concrete strength, two additional cores shall be taken from that pipe section and tested. The group of pipe represented by these core tests shall be considered acceptable if: (1) the average of three cores is equal to at least 85 percent of the required strength , and (2) no single core is less than 75 percent of the required strength.

11.4.3 If the compressive strength of the three cores does not meet the requirements of Section 11.4.2, the pipe section from which the cores were taken shall be rejected. Two pipe sections from the remainder of the group shall be selected at random and cored and tested for conformance with either Section 11.4.1 or Section 11.4.2. If both pipe sections meet the core strength requirements of Section 11.4.1 or Section 11.4.2, the remainder of the group shall be acceptable. If either or both pipe sections do not meet the strength test requirements, then the remainder of the group shall be either rejected or, at the option of the manufacturer, each pipe section of the remainder of the group shall be cored and accepted individually, and any of the pipe sections that have core strengths less than the requirements of Section 11.4.1 or Section 11.4.2 shall be rejected.

11.5 *Plugging Core Holes*—Core holes shall be plugged and sealed by the manufacturer in a manner such that the pipe section will meet all of the requirements of this specification. Pipe sections so plugged and sealed shall be considered satisfactory for use.

11.6 *Retests of Pipe*—When not more than 20 percent of the concrete specimens fail to pass the requirements of this specification, the manufacturer may cull the project stock and may eliminate whatever quantity of pipe is desired. The manufacturer shall mark those pipe so that they will not be shipped. The required tests shall be made on the balance of the order and the pipe shall be accepted if they conform to the requirements of this specification.

12. INSPECTION

12.1 The quality of materials, process of manufacture, and the finished pipe shall be subject to inspection by the owner.

13. REJECTION

13.1 Pipe shall be subject to rejection for failure to conform to any of the specification requirements. Individual sections of pipe are subject to rejection because of any of the following:

13.1.1 Fractures or cracks passing through the wall, except for a single-end crack that does not exceed the depth of the joint;

13.1.2 Defects that indicate mixing and molding not in compliance with Section 6.2;

13.1.3 The ends of the pipe are not normal to the walls and centerline of the pipe, within the limits of variations given in Section 8.2.3;

13.1.4 Damaged ends where such damage would prevent making a satisfactory joint; or

13.1.5 Surface defects that indicate honeycombed or open texture that would adversely affect the function of the pipe.

13.2 The exposure of the ends of longitudinals, stirrups, or spacers that have been used to position the cages during the placement of the concrete is not a cause for rejection.

14. DISPOSITION OF A REJECTED LOT

14.1 A lot of pipe which fails to meet the criteria for acceptability shall be allowed to be utilized in accordance with a procedure mutually agreed upon by the manufacturer and the owner. The procedure shall demonstrate improvement in the lot, statistically calculate a reduced D-load strength for the lot, or develop an acceptable disposition. The manufacturer shall bear all expenses incurred by the procedure.

15. REPAIRS

15.1 Pipe shall be repaired, if necessary, because of imperfections in manufacture, damage during handling, or pipes that have been cored for testing, and will be acceptable if, in the opinion of the owner, the repairs are sound and properly finished and cured and the repaired pipe conforms to the requirements of this specification.

16. CERTIFICATION

16.1 When agreed upon in writing by the owner and the manufacturer, a certification shall be made the basis of acceptance. This shall consist of a copy of the manufacturer's test report or a statement by the manufacturer, accompanied by a copy of the test results, that the pipe has been sampled, tested, and inspected in accordance with the provisions of Section 4. Each certification so furnished shall be signed by an authorized agent of the manufacturer.

17. PRODUCT MARKING

17.1 The following information shall be legibly marked on each section of pipe:

17.1.1 The pipe design strength shall be indicated by the 0.3 mm [0.01 in.] crack D-load designated in Section 5.1.2, followed by the capital letter D and specification designation;

17.1.2 Date of manufacture;

17.1.3 Name or trademark of the manufacturer;

17.1.4 Plant identification; and

17.1.5 One end of each section of pipe designed to be installed with a particular axis of orientation shall be clearly marked during the process of manufacturing or immediately thereafter on the inside and outside of opposite walls on the vertical axis or shall be designated by location of lift holes.

17.2 Markings shall be indented on the pipe section or painted thereon with waterproof paint.

18. KEYWORDS

18.1 *Concrete pipe*—reinforced; culvert; D-load; sewer pipe; storm drains; three-edge-bearing strength.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE CALCULATION

X1.1. As required by Section 10.1, the acceptability of a lot of 520 sections of 1350 mm [54 in.] designated inside diameter pipe will be determined in accordance with Section 4.1.1. The design strength (0.3 mm [0.01 in.] crack) D-load is specified as 62 N/linear m per mm [1250 lbf/linear ft per ft] of designated inside diameter (62 [1250] D pipe).

X1.2. From the lot, randomly select a sample of five specimens ($n = 5$) each 1.8 m [6 ft] long as shown in Table 2.

X1.3. Test the pipe and record the observed values of X_i, in kilonewtons [pounds-force], which produce the 0.3 mm [0.01 in.] crack: 213.51 [48,000], 144.57 [32,500], 191.27 [43,000], 200.17 [45,000], and 180.15 [40,500].

X1.4. *Example Computations*—choose the appropriate example for either SI or inch-pound units;

(a) In this example X_i, is in kilonewtons, convert the specification limit L (design strength D-load) to kilonewtons by multiplying the D-load times the designated inside diameter in millimeters times the pipe length in meters, or

$$L = 62 \times 1350 \times 1.8 = 150.66 \text{ kN}$$

(b) In this example X_i is in pounds-force, convert the specification limit L (design strength D-load) to pounds by multiplying the D-load times the designated inside diameter in feet times the pipe length in feet, or

$$L = 1250 \times \left({}^{54}\!/\!{}_{12}\right) \times 6 = 33{,}750 \text{ lbf}$$

X1.5. Since an observed value of the test loads (X_i = 144.57 kN [32,500 lbf]) is less than the specification limit (L =150.66 kN [33,750 lbf]), compliance with the acceptability criteria must be determined in accordance with Section 10.

X1.6. The following values for $\bar{X}$ and s must be computed (see Note 6 if computing values using inch-pound units):

$\bar{X}$ = average (arithmetic mean) of the observed values X_i, and

s = estimated standard deviation.

Note X1—The observed inch-pound values of pipe strengths in Table X1.2 are divided by 100 to simplify the computations in accordance with the recommendation made in Section 25 of ASTM STP 15-C, *Manual on Quality Control of Materials*. The effect is to reduce the size of the numbers so they can be computed more readily on a desk calculator.

X1.7. Calculate the values for $\bar{X}$ as follows: (See Table X1.1, for SI Values for $\bar{X}$, see Table X1.2 for inch-pound Values for $\bar{X}$.)

Table X1.1—SI Values for $\overline{X}$

213.51	45 586.52		
144.57	20 900.48	$(\Sigma X_i)^2 =$	$(929.67)^2$
191.27	36 584.21	$=$	864286.31
200.17	40 068.03	$\overline{X} =$	$(\Sigma X_i/n)$
180.15	32 454.02	$\overline{X} =$	(929.67/5)
$\Sigma X_i = 929.67$	$\Sigma X_i^2 = 175593.26$	$\overline{X} =$	185.93 kN

Table X1.2—Inch-Pound Values for $\overline{X}$

Values for $\overline{X}$			
480	230,400	$(\Sigma X_i)^2 =$	$(2090)^2$
325	105,625	$=$	4,368,100
430	184,900	$\overline{X} =$	$(\sum X_i/n)\times 100$
450	202,500	$\overline{X} =$	$(2090/5)\times 100$
405	164,025	$\overline{X} =$	41,800 lbf
$\Sigma X_i = 2090$	$\Sigma X_i^2 = 887,450$		

X1.8. The standard deviation, *s*, may be computed by either Equations 1 or 2. Since Equation 2 is a simpler form for computation, this will be used.

$$s = \sqrt{\left[\sum X_i^2 - \left(\sum X_i\right)^2 / n\right] \Big/ (n-1)}$$

(a) Example computation using SI units:

$$s = \sqrt{(175\ 593.26 - 864\ 286.31/5)/(5-1)}$$

$$s = \sqrt{684.0}$$

$$s = 26.15 \text{ kN}$$

(b) Example computation using inch-pound units;

$$s = \sqrt{(887,450) - (4,368,100/5)/(5-1)}$$

$$s = \sqrt{3458}$$

$s = 5.88$ Multiply by 100 to obtain total pounds-force:

$s = 58.8 \times 100$

$s = 5880$ lbf

X1.9. The required minimum allowable arithmetic mean $\bar{X}_s$ is computed by Equation 3:

(a) SI value computation

$$\bar{X}_s = L + 1.10s$$

$$\bar{X}_s = 150.66 + 1.10 \times 26.15$$

$$\bar{X}_s = 179.43 \text{ kN}$$

Since the actual $\bar{X}$ of 185.93 kN is greater than the required minimum allowable $\bar{X}_s$ of 179.43 kN, the lot of pipe is acceptable.

(b) Inch-pound value computation

$$\bar{X}_s = L + 1.10s$$

$$\bar{X}_s = 33750 + 1.10 \times 5880$$

$$\bar{X}_s = 40,218 \text{ lbf}$$

Since the actual $\bar{X}$ of 41,800 lbf is greater than the required minimum allowable $\bar{X}_s$ of 40,218 lbf, the lot of pipe is acceptable.

X1.10. ASTM MNL 7A (formerly STP 15-D), *Manual on Presentation of Data and Control Chart Analysis*, is a valuable source of information regarding statistical procedures and simplified computational methods.

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[1] Agrees with ASTM C 655M-07 and C 655-07 except that the use of synthetic fibers is at the option of the owner and the method of acceptance is changed per Sections 11.1, 11.2.2, 11.2.3.3, 11.4.2, and 11.4.3.

Standard Specification for

Field-Applied Coating of Corrugated Metal Structural Plate for Pipe, Pipe-Arches, and Arches

AASHTO Designation: M 243-96 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Field-Applied Coating of Corrugated Metal Structural Plate for Pipe, Pipe-Arches, and Arches

AASHTO Designation: M 243-96 (2008)

1. SCOPE

1.1. This specification covers field-applied asphaltic mastic coating of corrugated metal structural plate for pipe, pipe-arches, and arches to be used for the construction of metal culverts.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 167, Corrugated Steel Structural Plate, Zinc-Coated, for Field-Bolted Pipe, Pipe-Arches, and Arches
- M 219, Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches

3. DESCRIPTION

3.1. Corrugated metal structural plate for pipe, pipe-arches, and arches shall conform to the requirements of M 167 or M 219 and, in addition, shall be coated as hereinafter described.

3.2. Before applying coating material to metal surfaces, moisture, dirt, oil, unbonded or incompatible paint, grease, residual oils, alkalies, or other foreign matter must be removed from the surface to be coated.

COATING MATERIAL REQUIREMENTS

4. ASPHALT MASTIC

4.1. The material shall be uniformly applied to structural plate for pipe, pipe-arches, or arches in such a manner to attain (both inside and outside) a minimum thickness of 1.27 mm measured on the crest of the corrugations.

4.2. The asphalt mastic shall be furnished in any one of three consistencies depending on the type of application to be employed. In spraying consistency, the material shall be suitable for air gun spraying without the use of additional thinners at temperatures of 4.4ºC and above. In trowel grade consistency, the material shall be suitable for knife or trowel application. In brushing consistency, the material shall be suitable for application with an ordinary roofing brush.

4.3. The asphalt mastic shall be designed as a cold-applied membrane waterproofing for application to aluminum or steel to provide a protective coating with high resistance to corrosion and chemical fumes. It shall not be affected by freezing temperatures and will not flow in hot weather. It shall have high cohesive strength and, after application, readily harden into a tough elastic seal. The material shall be mixed until the mineral stabilizers and fillers are uniformly dispersed.

4.4. The material for coating shall be an asphalt having the following physical characteristics:

Asphalt Base—Oxidized petroleum asphalts

Solvent—Rapid drying petroleum solvents

Fillers—Mineral stabilizers and fillers

Consistency—Made in three consistencies—trowel, brush, and spraying

4.5. *Physical Properties*:

	Trowel Grade		Spraying Grade		Brushing Grade	
	Min	Max	Min	Max	Min	Max
Solids, percent by mass	63	68	61	66	60	65
Density, kg/L	1.04	1.07	0.99	1.11	0.98	1.02
Dry to touch, h		2		2		2
Dry hard		48		48		48

4.6. *Methods of Sampling and Testing*:

4.6.1. A representative sample of approximately 4 L shall be taken from each lot furnished.

4.6.2. *Physical Tests*:

4.6.2.1. *Solids Content*—Approximately a 9-g sample of material is weighed into an aluminum drying dish to an accuracy of 0.01 g. Sample is heated until constant mass is obtained (approximately 24 to 48 h) at 163 ± 3ºC cooled, reweighed, and percentage of solids calculated. Percent of solids is determined by dividing mass of material after heating by mass of material before heating × 100.

4.6.2.2. *Flow Properties at Elevated Temperatures*—A coating of the material is applied approximately 1.6 mm thick, on a degreased steel panel 0.61 mm thick. Parallel lines spaced 12.7 mm apart are scored horizontally across the width of the surface. After air drying for a period of 48 h, the panel shall be suspended in a vertical position in an oven at 66 ± 3ºC for 24 h. After removal of the panel, the surface of the coating is inspected for shifting or sagging of the lines. Any shifting or sagging of the lines shall be cause for rejection.

4.6.2.3. *Acid and Alkali Resistance*—A coating of the material prepared in accordance with Section 4.6.2.2 shall show no signs of attack when immersed for 24 h in each of the following solutions: 10 percent of hydrochloric acid, 10 percent of sulfuric acid, and 10 percent of sodium hydroxide. On removal of the mastic by solvent cleaning, the panel surface shall be free from any pitting or rusting.

4.6.2.4. *Pliability and Adherence Characteristics*—A coating of the material shall be prepared in accordance with Section 4.6.2.2. After air drying for a period of 48 h, followed by baking in an oven for 48 h at 104 ± 3ºC the material shall not crack or peel from the panel when bent at room temperature (22 ± 1ºC) 180 degrees over a 28.6-mm mandrel.

Standard Specification for

Corrugated Steel Pipe, Polymer-Precoated, for Sewers and Drains

AASHTO Designation: M 245-00 (2008)
ASTM Designation: A 762/A 762M-98

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Specification for

Corrugated Steel Pipe, Polymer-Precoated, for Sewers and Drains

AASHTO Designation: M 245-00 (2008)
ASTM Designation: A 762/A 762M-98

1. SCOPE

1.1. This specification covers polymer-precoated corrugated steel pipe intended for use for storm water drainage, underdrains, the construction of culverts, and similar uses. Pipe covered by this specification is not normally used for the conveyance of sanitary or industrial wastes. The steel sheet used in fabrication of the pipe has a polymer protective coating over a metallic coating of zinc (galvanizing), 55 aluminum-zinc alloy, or zinc-5 percent aluminum-Mischmetal alloy.

1.2. The polymer coating provides a degree of extra protection for the pipe against abrasion and corrosion as compared with metallic-coated pipe without polymer coating. Some severe environments may cause corrosion problems to accessory items such as rivets or coupling band hardware that does not have a polymer coating. Additional protection for polymer-precoated corrugated steel pipe can be provided by use of coatings applied after fabrication of the pipe as described in M 190.

1.3. This specification does not include requirements for bedding, backfill, or the relationship between earth cover load and sheet thickness of the pipe. Experience has shown that the successful performance of this product depends upon the proper selection of sheet thickness, type of bedding and backfill, controlled manufacture in the plant, and care in the installation. The installation procedure is described in the *AASHTO LRFD Bridge Construction Specifications*, Section 26.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 190, Bituminous-Coated Corrugated Metal Culvert Pipe and Pipe-Arches
- M 198, Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants
- M 218, Steel Sheet, Zinc-Coated (Galvanized), for Corrugated Steel Pipe
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 243, Field-Applied Coating of Corrugated Metal Structural Plate for Pipe, Pipe-Arches, and Arches
- M 246, Steel Sheet, Metallic-Coated and Polymer-Precoated, for Corrugated Steel Pipe
- M 289, Aluminum-Zinc Alloy Coated Sheet Steel for Corrugated Steel Pipe
- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

- T 249, Helical Lock Seam Corrugated Pipe
- *AASHTO LRFD Bridge Construction Specifications*
- *AASHTO LRFD Bridge Design Specifications*

2.2. *ASTM Standards*:

- A 493, Standard Specification for Stainless Steel Wire and Wire Rods for Cold Heading and Cold Forging
- A 780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- A 796/A 796M, Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications
- A 929/A 929M, Standard Specification for Sheet Steel, Metallic-Coated by the Hot-Dip Process for Corrugated Steel Pipe
- B 633, Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
- D 1005, Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers
- D 1056, Standard Specification for Flexible Cellular Materials—Sponge or Expanded Rubber
- F 568M, Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners (Metric)

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1. *fabricator*—the producer of the pipe.

3.2. *manufacturer*—the producer of the sheet.

3.3. *purchaser*—the purchaser of the finished product.

4. CLASSIFICATION

4.1. The corrugated steel pipe covered by this specification is classified as follows:

4.1.1. *Type I*—This pipe shall have a full circular cross section, with a single thickness of corrugated sheet, fabricated with annular (circumferential) or helical corrugations.

4.1.2. *Type IA*—This pipe shall have a full circular cross section with an outer shell of corrugated sheet fabricated with helical corrugations and an inner liner of smooth (uncorrugated) sheet attached to the shell at helical lock seams.

4.1.3. *Type IR*—This pipe shall have a full circular cross section with a single thickness of smooth sheet, fabricated with helical ribs projecting outwardly.

4.1.4. *Type II*—This pipe shall be a Type I pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.5. *Type IIA*—This pipe shall be a Type IA pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.6. *Type IIR*—This pipe shall be a Type IR pipe that has been reformed into a pipe-arch having an approximately flat bottom.

4.1.7. *Type III*—This pipe, intended for use as underdrains or for underground disposal of water, shall be a Type I pipe that has been perforated to permit the inflow or outflow of water.

4.1.8. *Type IIIA*—This pipe, intended for use as underdrains, shall consist of a semicircular cross section having a smooth (uncorrugated) bottom with a corrugated top shield.

4.2. Perforations in Type III pipe are included in two classes as described in Section 8.3.2.

5. ORDERING INFORMATION

5.1. Orders for material to this specification shall include the following information as necessary to adequately describe the desired product:

5.1.1. Name of material (polymer-coated corrugated steel pipe);

5.1.2. Grade of polymer coating indicating thickness on inside and outside (Section 6.1.1);

5.1.3. Type of metallic coating (zinc or aluminum-zinc alloy) (Section 6.1.2);

5.1.4. AASHTO designation and date of issue;

5.1.5. Type of pipe (Section 4.1);

5.1.6. Diameter of circular pipe (Table 8), or span and rise of pipe-arch section (Tables 10, 11, or 12);

5.1.7. Length, either total length or length of each piece and number of pieces;

5.1.8. Description of corrugations (Section 7.2);

5.1.9. Sheet thickness (Section 8.1.2);

5.1.10. For Type I and Type II pipe, the pipe fabrication method, whether with annular corrugations or helical corrugations (Section 7.1.1) (Note 1);

5.1.11. Coupling bands, number, and type (Section 9.1) if special type is required;

5.1.12. Gaskets for coupling bands, if required (Section 9.3);

5.1.13. For Type III pipe, class of perforations, if other than Class 1 (Section 8.3.2);

5.1.14. Certification, if required (Section 14.1); and

5.1.15. Special requirements.

Note 1—Pipe manufactured with annular corrugations may have an element of weakness in the longitudinal seams compared with pipe with helical corrugations. Therefore, consideration of the method of fabrication is important when pipe is installed under certain conditions of loading.

6. MATERIALS

6.1. *Steel Sheet for Pipe*—All pipe fabricated under this specification shall be formed from polymer-precoated sheet conforming to M 246.

6.1.1. The grade of coating shall be stated in the order, and the polymer coating thickness on both inside and outside of the pipe. The polymer coating is classified by grade corresponding to the thickness in micrometers on each side in SI units. (See Table 1.)

Table 1—Grade

Grade	Coating Thickness, μm
250/250	250/250

6.1.1.1. Any combination of polymer coating thickness or other than shown in Table 1 is subject to agreement between the manufacturer and purchaser or fabricator.

6.1.2. The polymer coating is applied to steel sheet having a metallic coating of zinc or aluminum-zinc alloy, as described in M 218, M 289, or ASTM A 929M. The type of metallic coating should be stated in the order, consistent with thickness availability as shown in Table 8. If the type of metallic coating is not stated, zinc-coated sheet conforming to M 218 shall be used. All pipe furnished on the order shall have the same metallic coating unless otherwise specified.

6.2. *Steel Sheet for Coupling Bands*—The sheet used in fabricating coupling bands shall conform to M 246 with the same polymer coating grade as that used for fabrication of the pipe furnished under the order, and having the same metallic coating.

6.2.1. As an alternate, the steel sheet for coupling bands shall conform to M 218, M 289, or ASTM A 929M (with the same metallic coating as the pipe), with the sheet having a bituminous coating according to M 190, except the thickness requirement shall not apply.

6.2.2. When specifically permitted by the purchaser, coupling bands shall be made of steel sheet conforming to the specification listed in Section 6.2.1 having the same metallic coating as the pipe, but without bituminous coating.

6.3. *Rivets*—The rivets used in riveted pipe shall be of the same material as the base metal specified for the corrugated sheets. They shall be thoroughly galvanized or sherardized. If bolts and nuts are substituted for rivets (Section 7.3.1), they shall meet the following requirements. (See Table 2.)

Table 2—Bolts and Nuts

	Bolts	Nuts
For pipe fabrication:		
For M 245 pipe	F 568, Class 8.8	M 291M, Class 12
For coupling bands:		
For M 245 pipe	F 568, Class 4.6	M 291M, Class 5

The bolts and nuts shall be hot-dip galvanized in conformance with M 232M/M 232, or be mechanically galvanized in conformance with M 298, Class 40.

6.3.1. When specified in the order, rivets used in riveted pipe to be installed in severely corrosive environments shall be made of stainless steel conforming to any of the S3xxxx designations in ASTM A 493. Stainless steel rivets may be substituted for those described in Section 6.3 at the fabricator's option.

Note 2—Some polymer-precoated pipe in a severe environment is reported to have failed due to corrosion of rivets conforming to Section 6.3, while the sheet was essentially unaffected. The use of stainless steel rivets is recommended to overcome such problems.

6.4. *Hardware for Coupling Bands*—Bolts and nuts for coupling bands shall conform to the following requirements. (See Table 2.) Bolts, nuts, and other threaded items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 8; or mechanical process as provided in M 298, Class 8. Other hardware items used with coupling bands shall be zinc coated by one of the following processes: hot-dip process as provided in M 232M/M 232; electroplating process as provided in ASTM B 633, Class Fe/Zn 25; or mechanical process as provided in M 298, Class 25.

6.5. *Gaskets*—If gaskets are used in couplings, they shall be a band of expanded rubber meeting the requirements of ASTM D 1056 for the "RE" closed cell grades, or O-rings meeting the requirements of M 198.

7. FABRICATION

7.1. *General Requirements*—Pipe shall be fabricated in full circular cross section except for Type IIIA, which is described in Section 8.4.

7.1.1. Type I pipe shall have annular corrugations with lap joints fastened with rivets or shall have helical corrugations with a continuous lock seam extending from end to end of each length of pipe. The type of fabrication used shall be the option of the fabricator unless otherwise specified.

7.1.2. Type IA pipe shall be fabricated with a smooth liner and helically corrugated shell integrally attached at helical lock seams extending from end to end of each length of pipe. The shell shall have corrugations of nominal 68- or 75-mm pitch.

7.1.3. Type IR pipe shall be fabricated with helical ribs projecting outward with a continuous lock seam extending from end to end of each length of pipe.

7.2. *Corrugations*—The corrugations shall be either annular or helical as provided in Section 7.1. The direction of the crests and valleys of helical corrugations shall not be less than 60 degrees from the axis of the pipe for pipe diameters larger than 500 mm and not less than 45 degrees from the axis for pipe diameters of 500 mm and smaller.

7.2.1. For Type I and IA pipe, corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 3 for the size indicated in the order, except if the depth measurement of one or more corrugations is less than the minimum depth in Table 3, the depth of all corrugations between adjacent seams shall be measured and the values of Table 4 for minimum average depth and minimum corrugation depth shall apply.

Note 3—Inspection frequently consists of measurement of the depth of one or a few corrugations. If such measurement indicates insufficient depth, application of the requirements in Table 4 provides for acceptance where greater depth of some corrugations compensates for lack of depth of others. These measurements would normally be made at one location between seams on a length of pipe.

Table 3—Corrugation Requirements for Types I, IA, II, IIA, and III Pipe

Nominal Size, mm	Max Pitch,[a] mm	Min Depth,[b] mm	Inside Radius[c]	
			Nominal, mm	Min, mm
38 × 6.5[d]	48	6	7	6.5
68 × 13	73	12	17	12
75 × 25	83	24	14	12
125 × 25	135	24	40	36

[a] Pitch is measured from crest to crest of corrugations, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests parallel to the axis of the pipe to the bottom of the intervening valley. If the depth measurement of one or more corrugations is less than the value indicated herein, the depth of all corrugations between seams shall be measured, and the requirements of Table 2 shall be applied. (See Section 7.2.1.)

[c] Minimum inside radius requirement does not apply to a corrugation containing a helical lock seam.

[d] The corrugation size of 38 × 6.5 mm is available only in helically corrugated pipe.

Table 4—Referee Requirements for Corrugation Depth[a]

Nominal size, mm	Diameter, mm	Min Average Depth, mm	Min Corrugation Depth, mm
38 × 6.5	All	6.1	5.0
68 × 13	300 through 525	12.1	10.0
68 × 13	Greater than 525	12.4	11.0
75 × 25	All	24.9	23.0
25 × 25	All	24.9	23.0

[a] See Section 7.2.1 for application of Table 2.

7.2.2. For Type IR pipe, the corrugations shall be essentially rectangular ribs projecting outward from the pipe wall. The dimensions and spacing of the ribs shall be in accordance with Table 5 for the size indicated on the order. For the 292-mm rib spacing, if the sheet between the ribs does not include a lock seam, a stiffener shall be included midway between the ribs. This stiffener shall have a nominal radius of 6.4 mm and a minimum height of 5.1 mm toward the outside of the pipe.

Note 4—The nominal dimensions and properties for smooth corrugations and for ribs are given in *AASHTO LRFD Bridge Design Specifications* and in ASTM A 796/A 796M.

Table 5—Rib Requirements for Types IR and IIR Pipe

Nominal Size, mm	Rib			Bottom Outside Radius, Min, mm	Bottom Outside Radius,[d] Max Avg, mm	Top Outside Radius, Min, mm	Top Outside Radius,[d] Max Avg, mm
	Width,[a] Min, mm	Depth,[b] Min, mm	Spacing,[c] Max, mm				
19 × 19 × 190	17	19	197	2.5	6.0	$2.5 + t$	$6.0 + t$
19 × 25 × 292	17	24	298	2.5	6.0	$2.5 + t$	$6.0 + t$

[a] Width is a dimension of the inside of the rib, but is measured on the outside of the pipe (outside of the rib) and shall meet or exceed the stated minimum width plus two times the wall thickness, that is, $2t + 17$ mm.

[b] Depth is an average of three ribs (one sheet width) measured from the inside by placing a straightedge across the open rib and measuring to the bottom of the rib.

[c] Spacing is an average of three ribs (one sheet width) measured center-to-center of the ribs at 90 degrees to the direction of the ribs.

[d] The average of the four rib radii (Top and Bottom) shall be within the minimum and maximum tolerances. The outside radius refers to the surface outside of the pipe.

7.3. *Riveted Seams*—The longitudinal seams shall be staggered to the extent that no more than three thicknesses of sheet are fastened by any rivet. Pipe to be reformed into pipe-arch shape shall have seams meeting the longitudinal seam requirement of Section 8.2.2.

Note 5—Fabrication of pipe without longitudinal seams in 120 degrees of arc, so that the pipe may be installed without longitudinal seams in the invert, is subject to negotiation between the purchaser and fabricator.

7.3.1. The size of rivets, number per corrugation, and width of lap at the longitudinal seam shall be as stated in Table 6, depending on sheet thickness, corrugation size, and diameter of pipe. For pipe with 25-mm deep corrugations, M 12 diameter bolts and nuts may be used in lieu of rivets on a one-for-one replacement ratio. Circumferential seams shall be riveted using rivets of the same size as for longitudinal seams and shall have a maximum rivet spacing of 150 mm, measured on centers, except that six rivets will be sufficient in 300-mm diameter pipe.

Table 6—Riveted Longitudinal Seams

Specified Sheet Thickness, mm	Nominal Corrugation Size		
	68 × 13 mm[a,d]	75 × 25 mm[b,e]	125 × 25 mm[c,e]
	Rivet Diameters, Min, mm		
1.32	8.0	—	—
1.63	8.0	9.5	9.5
2.01	8.0	9.5	9.5
2.77	9.5	11.0	11.0
3.51	9.5	11.0	11.0
4.27	9.5	11.0	11.0

[a] One rivet each valley for pipe diameters 900 mm and smaller. Two rivets each valley for pipe diameters 1000 mm and larger.

[b] Two rivets each valley for all pipe diameters.

[c] Two rivets each crest and valley for all pipe diameters.

[d] Minimum width of lap: 38 mm for pipe diameters 900 mm and smaller, and 75 mm for pipe diameters 1050 mm and larger.

[e] Minimum width of lap: 75 mm for pipe of all diameters.

7.3.2. All rivets shall be driven cold in such a manner that the sheets shall be drawn tightly together throughout the entire lap. The center of a rivet shall be no closer than twice its diameter from the edge of the sheet. All rivets shall have neat, workmanlike, and full hemispherical heads or heads of a form acceptable to the purchaser, shall be driven without bending, and shall completely fill the hole.

7.4. *Helical Lock Seams*—The lock seam for Type I pipe shall be formed in the tangent element of the corrugation profile with its center near the neutral axis of the corrugation profile. The lock seam for Type IA pipe shall be in the valley of the corrugation, shall be spaced not more than 760 mm apart, and shall be formed from both the liner and the shell in the same general manner as Type I helical lock seam pipe. The lock seam for Type IR pipe shall be formed in the flat zone of the pipe wall, midway between two ribs.

7.4.1. The edges of the sheets within the cross section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of –10 percent of lap width allowable. The lapped surfaces shall be in tight contact. The profile of the sheet shall include a retaining offset adjacent to the 180-degree fold (as described in T 249) of one sheet thickness on one side of the lock seam, or one-half sheet thickness on both sides of the lock seam, at the fabricator's option. There shall be no visible cracks in the metal, loss of metal-to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam.

7.4.2. Specimens cut from production pipe normal to and across the lock seam shall develop the tensile strength as provided in Table 7, when tested according to T 249. For Type IA pipe, the lock seam strength shall be as tabulated based on the thickness of the corrugated shell.

Table 7—Lock Seam Tensile Strength

Specified Sheet Thickness,[a] mm	Lock Seam Tensile Strength, per Unit Width, Min, kN/m
1.02	30
1.32	42
1.63	60
2.01	91
2.77	122
3.50	154
4.27	210

[a] For Type IA pipe, the thickness shall be that of the corrugated shell.

7.4.3. When the ends of helically corrugated lock seam pipe have been rerolled to form annular corrugations, either with or without a flanged end finish, the lock seam in the rerolled end shall not contain any visible cracks in the base metal and the tensile strength of the lock seam shall be not less than 60 percent of that required in Section 7.4.2.

7.5. *End Finish*:

7.5.1. To facilitate field jointing, the ends of the individual pipe sections with helical corrugations may be rerolled to form annular corrugations extending at least two corrugations from the pipe end, or to form an upturned flange meeting the requirements in Section 7.5.2, or both. The diameter of ends shall not exceed that of the pipe barrel by more than the depth of the corrugation. All types of pipe ends, whether rerolled or not, shall be matched in a joint such that the maximum difference in the diameter of abutting pipe ends is 13 mm.

7.5.1.1. When pipe with any size helical corrugation or rib is rerolled to form annular corrugations in the ends, the usual size of the annular corrugations is 68 by 13 mm.

7.5.2. If a flanged finish is used on the ends of individual pipe sections to facilitate field jointing, the flange shall be uniform in width, not less than 13 mm wide, and square to the longitudinal axis of the pipe.

7.5.3. The ends of all pipe that will form the inlet and outlet of culverts, fabricated of sheets having nominal thicknesses of 2.01 mm and less, shall be reinforced in a manner approved by the purchaser, when specified.

8. PIPE REQUIREMENTS

8.1. *Type I, Type IA, and Type IR Pipe*:

8.1.1. *Pipe Dimensions*—The nominal diameter of the pipe shall be as stated in the order, selected from the sizes listed in Table 8. The size of corrugations, which are standard for each size of pipe, are also shown in Table 8. The average inside diameter of circular pipe and pipe to be reformed into pipe-arches shall not vary more than 1 percent or 13 mm, whichever is greater, from the nominal diameter when measured on the inside crest of the corrugations. Alternately, for pipe having annular corrugations, conformance with the inside diameter requirement may be determined by measuring the outside circumference, for which minimum values are given in Table 8.

Note 6—The outside circumference of helically corrugated pipe is influenced by the corrugation size and the angle of the corrugations, affecting the number of corrugations crossed; therefore, no minimum circumferential measurement can be specified.

Table 8—Pipe Sizes

Nominal Inside Diameter, mm	Corrugation Sizes[a]					Min Outside Circumference,[b] mm
	38 × 6.5 mm	68 × 13 mm	75 × 25 mm	125 × 25 mm	Ribbed Pipe[c]	
100	X					284
150	X					441
200	X					598
250	X					755
300	X	X				912
375	X	X				1148
450	X	X			X	1383
525		X			X	1620
600		X			X	1854
675		X			X	2091
750		X			X	2483
825		X			X	2561
900		X	X	X	X	2797
1050		X	X	X	X	3269
1200		X	X	X	X	3739
1350		X	X	X	X	4209
1500		X	X	X	X	4675
1650		X	X	X	X	5142
1800		X	X	X	X	5609
1950		X	X	X	X	6075
2100		X	X	X	X	6542
2250			X	X	X	7008
2400			X	X	X	7475
2550			X	X	X	7941
2700			X	X	X	8408
2850			X	X		8874
3000			X	X		9341
3150			X	X		9807
3300			X	X		10274
3450			X	X		10740
3600			X	X		11207

[a] An "X" indicates standard corrugation sizes for each nominal diameter of pipe.

[b] Measured in valley of annular corrugations. Not applicable to helically corrugated pipe.

[c] Rib sizes 19 × 19 × 190 mm and 19 × 25 × 292 mm.

8.1.2. *Sheet Thickness*—Sheet thickness shall be specified by the purchaser from the specified sheet thicknesses listed in Table 9 (Notes 7 and 8). For Type IA pipe, the thickness of both the shell and the liner shall be given; the thickness of the corrugated shell shall not be less than 60 percent of the thickness of the equivalent Type I pipe; the liner shall have a nominal thickness of at least 1.02 mm; and the sum of the specified thicknesses of shell and liner shall equal or exceed the specified thickness of an equivalent pipe with corrugations identical to the shell according to the design criteria in *AASHTO LRFD Bridge Design Specifications*.

Note 7—The sheet thicknesses indicated in Table 9 are the thicknesses listed as available in M 246. The specified thickness is based on the thickness of the metallic-coated sheet, not including the thickness of polymer coating.

Note 8—The purchaser should determine the required thickness for each of the types of pipe described in Sections 4.1.1 through 4.1.6, according to the design criteria in *AASHTO LRFD Bridge Design Specifications*, Section 12, or other appropriate guidelines.

Table 9—Thickness of Metallic-Coated Steel Sheet[a]

Specified Thickness		Specification Designation	
mm	ASTM A 929M Zn-5A1 MM, Alloy Coated	M 218, Zinc-Coated	M 289, 55 Aluminum-Zinc Alloy Coated
1.02	X	X	X
1.32	X	X	X
1.63	X	X	X
2.01	X	X	X
2.77	X	X	X
3.51	X	X	X
4.27	X	X	

[a] An "X" indicates sheet thickness included in the applicable specifications which are referenced in M 246. The specified thickness is the thickness of the metallic-coated steel sheet and does not include the thickness of the polymer coating.

8.1.3. When specified by the purchaser, the finished pipe shall be factory elongated to the extent specified. The elongation shall be accomplished by the use of a mechanical apparatus that will produce a uniform deformation throughout the length of the section.

8.2. *Type II, IIA, and IIR Pipe*:

8.2.1. *Pipe-Arch Dimensions*—Pipe furnished as Type II, IIA, or IIR shall be made from Type I, IA, or IR pipe, respectively, and shall be reformed to provide a pipe-arch shape. All applicable requirements for Types I, IA, and IR pipe shall be met by finished Types II, IIA, and IIR pipe, respectively. Pipe-arches shall conform to the dimensional requirements of Tables 10, 11, or 12. All dimensions shall be measured from the inside crests of corrugations for Type II pipe or from the inside liner or surface for Types IIA or IIR pipe, respectively.

Table 10—Pipe Arch Requirements—68 × 13 mm Corrugations

Pipe-Arch Size, mm	Equivalent Dia, mm	Span,[a] mm	Rise,[a] mm	Min Corner Radius, mm	Max B,[b] mm
430 × 330	375	430	330	75	135
530 × 380	450	530	380	75	155
610 × 460	525	610	460	75	185
710 × 510	600	710	510	75	205
780 × 560	675	780	560	75	225
885 × 610	750	870	630	75	240
970 × 690	825	970	690	75	255
1060 × 740	900	1060	740	90	265
1240 × 840	1050	1240	840	100	290
1440 × 970	1200	1440	970	130	345
1620 × 1100	1350	1620	1100	155	380
1800 × 1200	1500	1800	1200	180	420
1950 × 1320	1650	1950	1320	205	460
2100 × 1450	1800	2100	1450	230	510

[a] A tolerance of 25 mm or 2 percent of equivalent diameter, whichever is greater, will be permissible in span and rise.

[b] B is defined as the vertical dimension from a horizontal line across the widest portion of the arch to the lowest portion of the base.

Table 11—Pipe-Arch Requirements—75 × 25 mm Corrugations

Pipe-Arch Size, mm	Equiv Dia, mm	Span,[a] mm	Rise,[a] mm	Min Corner Radius, mm
1010 × 790	900	1010 – 45	790 + 45	130
1160 × 920	1050	1160 – 55	920 + 55	155
1340 × 1050	1200	1340 – 60	1050 + 60	180
1520 × 1170	1350	1520 – 70	1170 + 70	205
1670 × 1300	1500	1670 – 75	1300 + 75	230
1850 × 1400	1650	1850 – 85	1400 + 85	305
2050 × 1500	1800	2050 – 95	1500 + 95	355
2200 × 1620	1950	2200 – 110	1620 + 110	355
2400 × 1720	2100	2400 – 120	1720 + 120	410
2600 × 1820	2250	2600 – 130	1820 + 130	410
2840 × 1920	2400	2840 – 145	1920 + 145	460
2970 × 2020	2550	2970 – 150	2020 + 150	460
3240 × 2120	2700	3240 – 165	2120 + 165	460
3470 × 2220	2850	3470 – 175	2220 + 175	460
3600 × 2320	3000	3600 – 180	2320 + 180	460

[a] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances, no tolerance in opposite direction.

Table 12—Pipe-Arch Requirements—19 × 19 mm and 19 × 25 × 292 mm Rib Corrugations

Pipe-Arch Size, mm	Equiv Dia, mm	Span,*a* mm	Rise,[a] mm	Min Corner Radius, mm
500 × 400	450	500 – 25	410 + 25	130
580 × 490	525	580 – 25	490 + 25	130
680 × 540	600	680 – 40	540 + 40	130
750 × 620	675	750 – 40	620 + 40	130
830 × 670	750	830 – 40	670 + 40	130
900 × 750	825	900 – 45	750 + 45	130
1010 × 790	900	1010 – 45	790 + 45	130
1160 × 920	1050	1160 – 55	920 + 55	155
1340 × 1050	1200	1340 – 60	1050 + 60	180
1520 × 1170	1350	1520 – 70	1170 + 70	205
1670 × 1300	1500	1670 – 75	1300 + 75	230
1850 × 1400	1650	1850 – 85	1400 + 85	305
2050 × 1500	1800	2050 – 95	1500 + 95	355

[a] Negative and positive numbers listed with span and rise dimensions are negative and positive tolerances, no tolerance in opposite direction.

8.2.2. *Longitudinal Seams*—Longitudinal seams of riveted pipe arches shall not be placed in the corner radius.

8.2.3. Reforming Type IR into Type IIR pipe shall be done in a manner that avoids damage to the external ribs.

8.3. *Type III Pipe*:

8.3.1. Type III pipe shall have a full circular cross section and shall conform to the requirements for Type I pipe and, in addition, shall contain perforations conforming to one of the classes described in Section 8.3.2.

8.3.2. *Perforations*—The perforations shall conform to the requirements for Class 1, unless otherwise specified in the order. Class 1 perforations are for pipe intended to be used for subsurface drainage. Class 2 perforations are for pipe intended to be used for subsurface disposal of water, but pipe containing Class 2 perforations may also be used for subsurface drainage.

8.3.2.1. *Class 1 Perforations*—The perforations shall be approximately circular and cleanly cut; shall have nominal diameters of not less than 4.8 mm nor greater than 9.5 mm, and shall be arranged in rows parallel to the axis of the pipe. The perforations shall be located on the inside crests or along the neutral axis of the corrugations, with one perforation in each row for each corrugation. Pipe connected by couplings or bands may be unperforated within 100 mm of each end of each length of pipe. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the centerlines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the centerlines of the uppermost rows above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 13.

Note 9—Pipe with Class 1 perforations is generally available in diameters from 100 to 525 mm inclusive, although perforated pipe in larger sizes may be obtained.

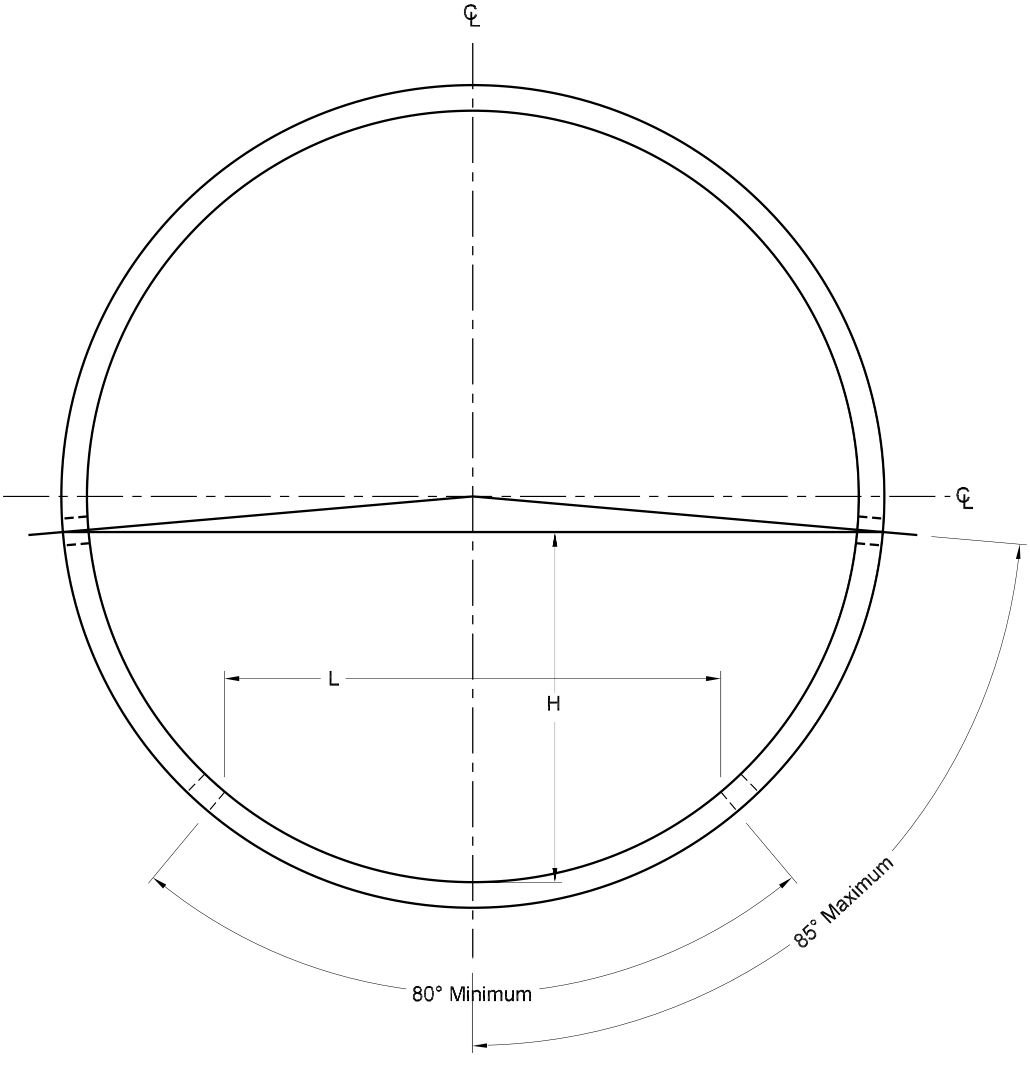

Figure 1—Requirements for Perforations

Table 13—Rows of Perforations, Height *H* of the Centerline of the Uppermost Rows above the Invert, and Chord Length *L* of the Unperforated Segment, for Class 1 Perforations

Internal Diameter of Pipe, mm	Rows of Perforations[a]	*H*, Max,[b] mm	*L*, Min,[b] mm
100	2	46	64
150	4	69	96
200	4	92	128
250	4	115	160
300	6[c]	138	192
375	6[c]	172	240
450	6[c]	207	288
525	6	241	338
600 and larger	8	(d)	(d)

[a] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and fabricator. Note that the number of perforations per unit length in each row (and inlet area) is dependent on the corrugation pitch.

[b] See Figure 1 for location of dimensions *H* and *L*.

[c] Minimum of four rows permitted in pipe with 38 × 6.5 mm corrugations.

[d] H(max) = 0.46D; L(min) = 0.64D, where D = internal diameter of pipe, millimeters or inches, as appropriate.

8.3.2.2. *Class 2 Perforations*—The perforations shall be circular holes with nominal diameters of 8.0 to 9.5 mm or slots with nominal width of 4.8 to 8.0 mm and not to exceed 13 mm in length. The perforations shall be uniformly spaced around the full periphery of the pipe. The perforations shall provide an opening area of not less than 230 square centimeters per square meter of pipe surface based on nominal diameter and length of pipe.

Note 10—323 perforations, 9.5-mm diameter, per square meter satisfies this requirement.

8.4. *Type IIIA Pipe*:

8.4.1. Type IIIA pipe shall be fabricated of an unperforated semicircular bottom section with a top shield of corrugated steel, both of nominal 1.32-mm thickness or greater. The smooth semicircular bottom section shall be approximately 120 mm in diameter and shall have a continuous lip extending outward along each side; the corrugated top shield shall be approximately 160 mm wide including a 19 mm sloping overhang on each side and shall be secured to the lip of the bottom section by integral tabs spaced at about 90 mm center-to-center. The top shield shall have corrugations approximately 22 mm center-to-center and approximately 8.0-mm depth.

9. COUPLING BANDS

9.1. *Types of Coupling Bands*—Field joints for each type of corrugated steel pipe shall maintain pipe alignment during construction and prevent infiltration of fill material during the life of the installation. Coupling bands may be of the following types:

9.1.1. *Coupling bands may be of the following types*:

9.1.1.1. Bands with annular corrugations;

9.1.1.2. Bands with helical corrugations;

9.1.1.3. Bands with projections (dimples);

9.1.1.4. Channel bands for upturned flanges, with or without annular corrugations;

9.1.1.5. Flat bands; and

9.1.1.6. Smooth sleeve-type couplers.

9.1.2. Except as provided in Sections 9.1.1 through 9.1.4, the type of coupling furnished shall be at the option of the fabricator unless the type is specified in the order.

Note 11—Bands are classified according to their ability to resist shear, moment, and tensile forces as described in *AASHTO LRFD Bridge Construction Specifications*, Section 26, and identified as "standard joints" and "special joints." The first four types of bands listed in Section 9.1, and meeting the requirements of Section 9.2, are expected to meet the requirements for "standard joints." Some may also be able to meet the requirements for "special joints," but such capability should be determined by analysis or test.

9.1.3. Coupling bands with annular corrugations shall be used only with pipe with annular corrugations, or helical pipe in which the ends have been rerolled to form annular corrugations. The corrugations in the band shall have the same dimensions as the corrugations in the pipe end, or may be of a special design to engage only the first or second corrugation from the end of each pipe. The band may also include a U-shaped channel to accommodate upturned flanges on the pipe.

9.1.4. Coupling bands with helical corrugations shall be used only with pipe with helically corrugated ends. The corrugations in the bands shall be designed to properly mesh with the corrugations in the pipe.

9.1.5. Coupling bands with projections (dimples) may be used with pipe with either annular or helical corrugations. The bands shall be formed with the projections in annular rows with one projection for each corrugation of helical pipe. Bands 265 or 300 mm wide shall have two annular rows of projections, and bands 415 or 560 mm wide shall have four annular rows of projections.

9.1.6. Channel bands may be used only with pipe having upturned flanges on the pipe ends.

9.1.7. Smooth sleeve-type couplers and flat bands may be used only with Type III and IIIA pipe of 300-mm diameter or smaller.

9.2. *Requirements*—Coupling bands shall be fabricated to lap on an equal portion of each of the pipe sections to be connected. The ends of the bands shall lap or be fabricated to form a tightly closed joint upon installation. Coupling band thickness shall conform to the requirements in Table 14, based on the sheet thickness of the pipe to be connected except as provided in Sections 9.2.1 and 9.2.2. The bandwidth shall be not less than as shown in Table 15. The bands shall be connected in a manner approved by the purchaser with suitable galvanized devices, such as angles or integrally or separately formed and attached flanges, bolted with zinc-coated bolts; bars and straps; wedge lock and straps; or lugs. Coupling bands shall be fastened with the following size of bolts:

- Pipe diameters 450 mm and less—M10 diameter;
- Pipe diameters 525 mm and greater—M12 diameter;
- Type IIIA pipe—M8 diameter.

Table 14—Coupling Band Thickness

Nominal Pipe Thickness, mm	Nominal Coupling Band Thickness, Min, mm
2.77 and thinner	1.32
3.51	1.63
4.27	2.01

Table 15—Coupling Bandwidth Requirements

		Coupling Bandwidth, Min		
Nominal Corrugation Size,[a] mm	Nominal Pipe Inside Diameter,[b] mm	Annular Corrugated Bands, mm	Helically Corrugated Bands, mm	Bands with Projections, mm
38 × 6.5	100 to 450	285	180	285
68 × 13	300 to 900	180	300	285
	1050 to 1800	285	300	285
	1950 to 2100[c]	285	300	415
75 × 25	900 to 1800	300	350	285
	1950 to 3600	300	350	415
125 × 25	900 to 1800	500	560	300
	1950 to 3600	500	560	560

[a] For helically corrugated pipe with rerolled ends, the nominal corrugation size refers to the dimensions of the end corrugations in the pipe.

[b] Equivalent diameter for Type II, IIA, and IIR pipe.

[c] Diameters through 3600 mm for annular corrugated bands used on rerolled ends of helically corrugated pipe.

9.2.1. If flanges are provided on the pipe ends, the coupling may also be made by interlocking the flanges with a preformed channel band or other band incorporating a locking channel not less than 19 mm in width. The depth of the channel shall be not less than 13 mm. The channel band shall have a minimum nominal thickness of 2.01 mm.

9.2.2. Smooth sleeve-type couplings and flat bands shall be steel having a nominal thickness of not less than 1.02 mm or, as an option, may be a plastic sleeve to provide equivalent strength. The coupling shall be close-fitting to hold the pipe firmly in alignment without the use of sealing compounds or gaskets. The coupling or flat band shall contain a device so that the band or coupling will lap equally on the two pipes being joined. The overall length of the coupling shall be equal to or greater than the nominal diameter of the pipe.

9.3. *Gaskets*—Where infiltration or exfiltration is a concern, the couplings may be required to have gaskets. The closed-cell expanded rubber gaskets shall be a continuous band, approximately 180 mm wide and approximately 9.5 mm thick. Rubber O-ring gaskets shall be 20-mm diameter for pipe diameters of 900 mm or smaller, and 22-mm diameter for larger pipe diameters, having 13-mm deep end corrugations. Rubber O-ring gaskets shall be 35-mm diameter for pipe having 25-mm deep end corrugations.

Note 12—Riveted pipe is not watertight, having small openings at the intersection of longitudinal and circumferential seams. Therefore, this type of fabrication should not be used where watertightness is a concern unless the pipe is bituminous coated or lined prior to installation.

9.4. Other types of coupling bands or fastening devices, which are as equally effective as those described, and which comply with the joint performance criteria of *AASHTO LRFD Bridge Construction Specifications*, Section 26 may be used when approved by the purchaser.

10. WORKMANSHIP

10.1. The completed pipe shall show careful, finished workmanship in all particulars. Pipe that has been damaged, either during fabrication or in shipping, may be rejected unless repairs are made that are satisfactory to the purchaser. Among others, the following defects shall be considered as constituting poor workmanship:

- Variation from a straight centerline;
- Elliptical shape in pipe intended to be round;
- Dents or bends in the metal;
- Polymer coating or metallic coating that has been bruised, broken, disbonded, or otherwise damaged;
- Lack of rigidity;
- Illegible markings on the steel sheet;
- Ragged or diagonal sheared edges;
- Uneven laps in riveted pipe;
- Loose, unevenly lined, or unevenly spaced rivets;
- Loosely formed lock seams.

11. REPAIR OF DAMAGED COATINGS

11.1. Pipe on which either the polymer coating or the underlying metallic coating has been damaged in fabrication or handling shall be repaired. Damage to the metallic coating shall be repaired as described in Sections 11.2 through 11.4. Damage to the polymer coating shall be repaired as described in Section 11.5. The repair shall be done so that the completed pipe shall show careful finished workmanship in all particulars. Pipe which, in the opinion of the purchaser, has not been cleaned or coated satisfactorily may be rejected. If the purchaser so elects, the repair shall be done in his presence.

11.2. Damage to the metallic coating shall be repaired as provided in ASTM A 780 (Note 13) except as described herein. The damaged area shall be cleaned to bright metal by blast cleaning, power disk sanding, or wire brushing. The cleaned area shall extend at least 13 mm into the undamaged section of the coating. The cleaned area shall be coated within 24 hours and before any rusting or soiling.

Note 13—While ASTM A 780 specifically refers to repair of damaged zinc coatings, the same procedures are applicable to repair of aluminum-zinc alloy coatings except as described in this section.

11.3. *Zinc-Rich Paint Coating*—Zinc-rich paint shall be applied to a dry film thickness of at least 0.13 mm over the damaged section and surrounding cleaned area. Zinc-rich paint shall be used for repair of damage to both zinc and aluminum-zinc alloy coatings.

11.4. *Metallizing Coating*—The damaged area shall be cleaned as described in Section 11.2, except it shall be cleaned to the near-white condition. The repair coating applied to the cleaned section shall have a thickness of not less than 0.13 mm over the damaged section and shall taper off to zero thickness at the edges of the cleaned undamaged section.

11.4.1. Where zinc coating is to be metallized, it shall be done with zinc wire containing not less than 99.98 percent zinc.

11.4.2. Where aluminum-zinc alloy coating is to be metallized, it shall be done using zinc wire containing not less than 99.98 percent zinc, aluminum wire containing not less than 99 percent aluminum, or an alloy wire of 55 percent aluminum and 45 percent zinc by mass.

11.5. Areas of damaged polymer coating shall be repaired with a polymer coating similar to and compatible with respect to durability, adhesion, and appearance of the original polymer coating.

11.5.1. Polymer coating damaged during shipping or installation may be repaired using materials as described in Section 11.5 or by the application of a protective coating material conforming to M 243.

12. INSPECTION

12.1. The purchaser or his representative shall have free access to the fabricating plant for inspection, and every facility shall be extended to him for this purpose. This inspection shall include an examination of the pipe for the items in Section 10.1 and the specific requirements of this specification applicable to the type of pipe and method of fabrication.

12.2. On a random basis, samples may be taken for chemical analysis and metallic and polymer coating measurements for check purposes. These samples will be secured from fabricated pipe or from sheets or coils of the material used in fabrication of the pipe. The mass of metallic coating shall be determined in accordance with T 65M/T 65 for zinc and the dilute hydrochloric acid method of T 65M/T 65 for aluminum-zinc alloy. The thickness of polymer coating shall be measured according to ASTM D 1005.

13. REJECTION

13.1. Pipe that fails to conform to the specific requirements of this specification, or that shows poor workmanship, may be rejected. This requirement applies not only to the individual pipe, but to any shipment as a whole in which a substantial number of pipes are defective. If the average deficiency in length of any shipment of pipe is greater than 1 percent, the shipment may be rejected.

14. CERTIFICATION

14.1. When specified in the purchase order or contract, a manufacturer’s or fabricator’s certification, or both, shall be furnished to the purchaser stating that samples representing each lot have been tested and inspected in accordance with this specification and have been found to meet the requirements for the material described in the order. When specified in the order, a report of the test results shall be furnished.

Standard Specification for

Steel Sheet, Metallic-Coated and Polymer-Precoated, for Corrugated Steel Pipe

AASHTO Designation: M 246-05
ASTM Designation: A 742/A 742M-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Sheet, Metallic-Coated and Polymer-Precoated, for Corrugated Steel Pipe

AASHTO Designation: M 246-05
ASTM Designation: A 742/A 742M-03

1. SCOPE

1.1. This specification covers polymer-precoated steel sheet for corrugated steel pipe (CSP), which is coated after metallic coating on continuous lines by coil coating (roller coating or laminating) processes. The metallic coating is either zinc or aluminum-zinc alloy. Sheet for this purpose is furnished flat in coils, flat in cut lengths, or corrugated in cut lengths, all being protected by a mill-applied polymer coating on one or both sides.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 218, Steel Sheet, Zinc-Coated (Galvanized), for Corrugated Steel Pipe
- M 289, Aluminum-Zinc Alloy Coated Sheet Steel for Corrugated Steel Pipe

2.2. *ASTM Standards*:

- A 916M, Zinc-5 Percent Aluminum-MM Alloy Coated Steel Pipe
- D 543, Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
- D 658, Standard Test Method for Abrasion Resistance of Organic Coatings by Air Blast Abrasive (Withdrawn 1996)
- D 1005, Standard Test Method for Measurement by Dry Film Thickness of Organic Coatings Using Micrometers
- D 2794, Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
- G 22, Standard Practice for Determining Resistance of Plastics to Bacteria (Withdrawn 2001)
- G 23, Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials (Withdrawn 2000)
- G 62, Standard Test Methods for Holiday Detection in Pipeline Coatings

3. CLASSIFICATION

3.1. The polymer coating is classified by grade corresponding to the thickness micrometers on each side in SI units, and the thickness in mils on each side in inch-pound units. (See Table 1.)

Table 1—Polymer Coating

Grade	Coating Thickness, μm
250/250	250/250

3.2. Any combination of polymer coating thickness other than shown in Table 1 is subject to agreement between the manufacturer and purchaser or fabricator.

4. TERMINOLOGY

4.1. In this specification, *manufacturer* refers to the producer of the sheet, *fabricator* refers to the producer of the pipe, and *purchaser* refers to the purchaser of the finished pipe.

5. ORDERING INFORMATION

5.1. The polymer-precoated sheet covered by this specification shall be ordered only to the specified thicknesses listed in Table 2. The specified thickness is based on the thickness of the metallic-coated steel sheet, not including the thickness of the polymer coating.

Table 2—Thicknesses of Metallic-Coated Steel Plate

Specified Thickness		Specification Designation		
mm	in.	M 218, Zinc-Coated	M 289, 55% Aluminum-Zinc Alloy Coated	A 916M, Zn-5 Al-MM Alloy Coated
1.02	0.040	X	X	X
1.32	0.052	X	X	X
1.63	0.064	X	X	X
2.01	0.079	X	X	X
2.77	0.109	X	X	X
3.51	0.138	X	X	X
4.27	0.168	X		X

Note: An "X" indicates sheet thickness included in the applicable specification.

5.2. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product:

5.2.1. Name of material (polymer-precoated steel sheet for CSP);

5.2.2. Type of metallic coating (Section 6.1);

5.2.3. AASHTO designation number and date of issue;

5.2.4. Corrugation size, if corrugated (Section 6.3);

5.2.5. Substrate dimensions (specified thickness; width, either flat or overall corrugated; and length, if cut length);

5.2.6. Grade of polymer coating (Section 3) indicating thickness on each side;

5.2.7. Coil size requirements (specify maximum outside diameter (OD), acceptable inside diameter (ID), and maximum mass);

5.2.8. Certification, if required (Section 11.1); and

5.2.9. Special requirements.

Note 1—Typical ordering descriptions are as follows: Polymer-precoated steel sheet, aluminum-zinc alloy coated for CSP, conforming to M 246-____, 2.77 by 700 mm by coil, with Grade 250 polymer coating (0.25 mm); coil 1200 mm max OD, 600 mm ID, 10000 kg max coil mass. [Polymer-precoated steel sheet, zinc-coated for CSP, conforming to M 246-____.]

6. GENERAL REQUIREMENTS

6.1. The metallic-coated steel substrate shall conform to all applicable requirements of the specification listed below for the kind of metallic coating specified. If the type of metallic coating is not stated in the order, zinc-coated sheet as described in Section 6.1.1 shall be furnished.

6.1.1. *Zinc Coating*—Zinc-coated steel sheet shall conform to the requirements of M 218.

6.1.2. *Aluminum-Zinc Alloy Coating 55*—Aluminum-zinc alloy coated steel sheet shall conform to the requirements of M 289 and zinc-5 aluminum-MM alloy coated steel sheets shall conform to the requirements of ASTM A 916M.

6.1.3. The steel sheet shall be thoroughly cleaned of any chromate pretreatment or other passivation using a multi-brush cleaning process. All traces of the caustic cleaning solution shall be immediately rinsed from the sheet following caustic cleaning. After drying, the steel sheet shall be treated with chromic acid solution and heat-cured prior to application of the polymer film. The deposited chromium content shall range from 135 to 190 mg/m^2.

6.2. The polymer coating shall be a film coating composed of at least 85 percent ethylene acrylic acid copolymer and be capable of being applied to the sheet specified in Section 6.1. After application, the polymer coating shall be free of holes, tears, and discontinuities, and shall be sufficiently flexible so that it will withstand the corrugating, forming, and lock-seaming operations, and punching of holes for rivets or perforations.

6.3. If the polymer-coated sheet is to be furnished with corrugations, the corrugations shall conform to the requirements stated in the appropriate specification listed in Section 6.1.

7. REQUIREMENTS FOR POLYMER COATINGS

7.1. *Adhesion*—There shall be no spalling or cracking of the coating when tested in accordance with Section 9.1. There shall be no disbonding of the coating at the cut to be made as described in Section 9.1.

7.2. *Impact*—There shall be no break in the polymer coating when tested in accordance with Section 9.2.

7.3. *Thickness of Coating*—The thickness of the polymer coating shall meet the requirements of Section 3, or as specified in the purchase order, when tested in accordance with Section 9.3.

7.4. *Holidays*—The polymer coating on the steel shall be substantially free of holidays when tested in accordance with Section 9.4. An average of 22 holidays per square meter of actual surface area on the test specimen shall be permitted.

Note 2—Holidays are pinholes or voids in the polymer coating that are not visually discernible.

7.5. *Abrasion Resistance*—The average abrasion coefficient, when tested in accordance with Section 9.5, shall be a minimum of 3.9 (expressed in g/μm of thickness).

7.6. *Imperviousness*—There shall be no loosening or separation of the polymer coating from the metallic-coated steel substrate when tested in accordance with Section 9.6.

7.7. *Freeze–Thaw Resistance*—The specimen shall withstand 100 freeze–thaw cycles, as described in Section 9.7, without spalling, disbonding, or other detrimental effects.

7.8. *Weatherability*—The specimens shall withstand 1000 hours of weathering with no observable delamination or cracking, when tested in accordance with Section 9.8.

7.9. *Resistance to Microbial Attack*—There shall be no effect of microbial attack of the polymer coating when tested in accordance with Section 9.9.

Note 3—Tests 7.1 through 7.4 are suggested as quality control tests. When these tests are used for quality control, they may be run at room temperature only. Tests 7.5 through 7.9 are suggested as qualifying tests. However, the purchaser may use any of the tests listed to verify compliance.

8. SAMPLING AND TESTING

8.1. The manufacturer shall make tests and measurements adequate to ensure that the material produced complies with this specification.

8.1.1. Test results to show compliance with this specification shall be retained by the manufacturer for 7 years and shall be made available to the fabricator and purchaser upon request.

8.2. The purchaser of the sheet (fabricator), or purchaser of the pipe made from the sheet, may make such tests as are deemed necessary to determine the acceptability of the material or to verify the correctness of a certification.

8.3. Flat samples of polymer-precoated steel shall be taken by the manufacturer from each coil or in accordance with the sampling procedure as mutually agreed between manufacturer and purchaser. Each sample shall be at least 600 mm long by the coil width and shall carry an identification to relate it to the coil from which it was taken.

9. TEST METHODS FOR POLYMER COATINGS

9.1. *Adhesion*:

9.1.1. *Scope*—This procedure is to measure the adhesion of the polymer coating to the metallic-coated substrate.

9.1.2. *Significance and Use*—This test indicates the ability of the polymer to withstand forces in fabrication and use tending to disbond the coating from the substrate.

9.1.3. *Procedure*—Cut a 50 by 200 mm coupon from the sample of precoated steel. Bend the coupon 180 degrees over a 12.5-mm diameter mandrel. The surface with the polymer coating to be tested shall be on the outside of the bend. After making the bend, make a cut through the polymer coating along an element on the outside of the bend to check for polymer coating adhesion. Perform this test at –18ºC, 25ºC, and 50ºC ± 1ºC. Check for spalling or cracking of the polymer coating, or for disbonding from the metallic-coated substrate.

9.1.4. *Precision and Bias*—No statement is made about either the precision or the bias of the procedure for measuring adhesion since the result merely states whether there is conformance to the criteria for success specified in the procedure.

9.2. *Impact*:

9.2.1. *Scope*—This procedure is to measure the ability of the polymer coating to withstand impact.

9.2.2. *Significance and Use*—This test provides a measure of the ability of the polymer coating to resist damage by impact, to which it may be subjected in service, in order to determine brittleness of the polymer coating.

9.2.3. *Procedure*—Cut a 150 by 150 mm coupon from the sample of precoated steel to be used for fabrication of the pipe. Direct impact the coating with an energy of 4.0 J using an impact tester[1] with a 15.88-mm diameter punch and with the specimen set on a 16.26-mm diameter punch die. Test at approximately 25ºC (Note 4). Check for breaks in the polymer coating.

Note 4—This test procedure is described in detail in ASTM D 2794.

9.2.4. *Precision and Bias*—No statement is made about either the precision or the bias of the procedure for measuring impact resistance since the result merely states whether there is conformance to the criteria for success specified in the procedure.

9.3. *Thickness of Coating*—Measure polymer coating thickness in accordance with ASTM D 1005.

9.4. *Holidays*—Test a specimen that is at least 300 mm long and the full coil width in accordance with ASTM G 62, Method A, using a nominal voltage of 67.5 volts.

9.5. *Abrasion Resistance*—Determine the abrasion coefficient in accordance with ASTM D 658 except use a silicon carbide grain passing a 106-µm sieve and retained on a 90-µm sieve, and an air test pressure of 33.25 kPa (250 mm Hg).

9.5.1. The modifications to the procedure in ASTM D 658 are not expected to have an effect on the precision and bias as indicated in ASTM D 658.

9.6. *Imperviousness*—Test the polymer coating for imperviousness to chemical reagents in accordance with the applicable sections of ASTM D 543 using a 10 percent solution of sodium chloride, a 10 percent solution of sodium hydroxide, and a 30 percent solution of sulfuric acid. Hold each reagent in a separate confined area of the polymer-precoated sheet for a period of 48 hours. Avoid excessive evaporation of the test solutions.

9.7. *Freeze–Thaw Resistance*:

9.7.1. *Scope*—This procedure is to evaluate the ability of the polymer coating to resist freeze–thaw cycling.

9.7.2. *Significance and Use*—As pipe fabricated from polymer-coated steel sheet will be exposed to freeze-thaw action while saturated, the procedure will measure ability to withstand such action without damage to the polymer coating.

9.7.3. *Procedure*—Cut a minimum of three 150 by 150 mm coupons from the sample of precoated metal. Immerse the coupons in water at room temperature for 2 weeks and then subject them to freeze–thaw cycling. One (1) cycle shall consist of 8 hours at –18ºC followed immediately by immersion in water at room temperature for 16 hours. Cycle time may be interrupted over weekends and holidays, but the specimens shall be maintained in water at room temperature, and such interruptions should be noted. Make observations during the cycling and note any visible changes in the coating, such as spalling, disbonding, etc. After 100 cycles, make a final examination of the effects as a result of freezing and thawing.

9.7.4. *Precision and Bias*—No statement is made about either the precision or the bias of the procedure for measuring freeze–thaw resistance since the result merely states whether there is conformance to the criteria for success specified in the procedure.

9.8. *Weatherability*—Subject coupons of the precoated metal to accelerated weathering in accordance with ASTM G 23 using the specimen spray arrangement for Type E, Single Open-Flame Sunshine Carbon-Arc Lamp Apparatus. Test conditions shall consist of a 2-hour cycle including 18 minutes of water spray and a maximum temperature of 60ºC.

9.9. *Resistance to Microbial Attack*—Subject test specimens of the polymer coating to conditions described in ASTM G 22, Procedure B. There shall be no visible effects of bacterial attack on the polymer coating after the prescribed incubation period (21 days minimum).

10. REJECTION

10.1. Material tested by the purchaser and found not conforming to this specification may be rejected.

11. CERTIFICATION

11.1. When specified in the purchase order or contract, a manufacturer's certification shall be furnished to the purchaser of the sheet (fabricator) or to the purchaser of the finished pipe stating that samples representing each lot have been tested and inspected in accordance with this specification and the requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished. The results of tests suggested in Section 7 as qualifying tests may be typical results rather than results of tests on the specific lot of material.

12. MARKING

12.1. Each 0.6 to 1.5 m of sheet in coils or cut lengths shall be identified by marking as follows:

12.1.1. Name of sheet producer,

12.1.2. Brand name,

12.1.3. Specified thickness of metallic-coated sheet,

12.1.4. Type of metallic coating,

12.1.5. Type or thickness of polymer coating,

12.1.6. Identification symbols relating to a specific heat number and coating lot number, and

12.1.7. AASHTO designation number.

12.2. The brand shall be removed, obliterated, or the sheet rebranded "Non-Specification" on each 0.6 to 1.5 m of material in a coating lot or heat for which control tests, as prescribed herein, show nonconformance to this specification, or where the metallic-coated steel substrate shows nonconformance to the appropriate sheet specification.

COMMENTARY (NOT PART OF THE SPECIFICATION)

C1. PRINCIPAL CHANGES IN THIS REVISION RECORDED FOR THE CONVENIENCE OF THE USER

C1.1. Aluminum-coated steel sheet has been deleted as an acceptable material since it is not produced with polymer coating.

C1.2. The classification, based on polymer coating thickness, has been changed from arbitrary Types A, B, and C to Grades with the numbers expressing the polymer thickness (Section 3).

C1.3. The polymer coating thickness requirement has been clarified (Section 7.3).

C1.4. Test methods contained in the specification have been revised to add scope, significance and use, and precision statements as required by ASTM (Sections 9.1, 9.2, 9.7). Clarifying details have been added in Sections 9.4 and 9.8.

C1.5. The certification provisions have been revised in accordance with the Form and Style for ASTM Standards.

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[1] The Gardner-Impact Tester, Variable, Model IG 1120, available from Pacific Scientific Company, Gardner/Neotec Instrument Division, 2431 Linden Lane, Silver Spring, MD 20910, has been found suitable for this purpose.

Standard Specification for

Corrugated Polyethylene Drainage Pipe

AASHTO Designation: M 252-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Corrugated Polyethylene Drainage Pipe

AASHTO Designation: M 252-09

1. SCOPE

1.1. This specification covers the requirements and methods of test for corrugated polyethylene (PE) pipe, couplings and fittings for use in subsurface drainage systems, storm sewers, and in surface drainage (culverts), where soil support is given to the pipe's flexible walls in all applications.

1.1.1. Nominal sizes of 75 to 250 mm (3 to 10 in.) are included.

1.1.2. Materials, dimensions, pipe stiffness, environmental stress-crack resistance, perforations, joining systems, and forms of marking are specified.

Note 1—When PE pipe is to be used in locations where the ends may be exposed, consideration should be given to combustibility of the PE and the deteriorating effects of prolonged exposure to ultraviolet radiation.

1.2. *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. customary units are shown in parentheses, and may not be exact equivalents.

1.3. The following precautionary caveat pertains only to the test method portion, Section 9.3 of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests

2.2. *ASTM Standards*:

- D 618, Standard Practice for Conditioning Plastics for Testing
- D 883, Standard Terminology of Terms Relating to Plastics
- D 1693, Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics
- D 2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D 2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D 3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- D 4218, Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
- D 4218, Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique

- ■ F 412, Standard Terminology Relating to Plastic Piping Systems

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3. TERMINOLOGY

3.1. The terminology used in this standard is in accordance with the definitions given in ASTM D 883 and ASTM F 412 unless otherwise specified.

3.2. *crack*—Any break or split that extends through the wall.

3.3. *crease*—An irrecoverable indentation; generally associated with wall buckling.

3.4. *reworked material*—A plastic from a processor's own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D 883).

4. CLASSIFICATION

4.1. The corrugated PE pipe covered by this specification is classified as follows:

4.1.1. *Type C*—This pipe shall have a full circular cross section, with a corrugated surface both inside and outside. Corrugations may be either annular or helical.

4.1.1.1. *Type CP*—This pipe shall be Type C with Class 2 perforations.

4.1.2. *Type S*—This pipe shall have a full circular cross section, with an outer corrugated pipe wall and a smooth inner liner. Corrugations may be either annular or helical. Type S pipe is not available in nominal sizes of less than 100 mm (4 in.).

4.1.2.1. *Type SP*—This pipe shall be Type S with either Class 1 or Class 2 perforations.

4.2. Class 1 and Class 2 perforations are as described in Sections 7.4.1 and 7.4.2.

5. ORDERING INFORMATION

5.1. Orders using this specification shall include the following information as necessary to adequately describe the desired product:

5.1.1. AASHTO designation and year of issue;

5.1.2. Type of pipe (Section 4.1);

5.1.3. Diameter and length required, either total length or length of each piece and number of pieces;

Note 2—Type C and CP pipe less than 200 mm (8 in.) in diameter may be supplied coiled; coiling of Type C and CP pipe 200 mm (8 in.) or greater is not recommended; Type S and SP pipe is not supplied in coils.

5.1.4. Number of couplings;

5.1.5. For Type SP pipe, class of perforations (Class 2 is furnished if not specified) (Section 7.4); and

5.1.6. Certification, if desired (Section 12.1).

6. MATERIALS

6.1. *Basic Materials*:

6.1.1. *Extruded Pipe and Blow Molded Fittings*—Pipe and fittings shall be made of virgin PE resin compounds meeting the requirements of ASTM D 3350 and cell classification 424420C, except that the carbon black content shall not exceed 5 percent. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.2. *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE resins meeting the requirements of ASTM D 3350 and cell classification 213320C, except that the carbon black content shall not exceed 5 percent. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.3. *Injection Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE resins meeting the requirements of ASTM D 3350 and cell classification 314420C, except that the carbon black content shall not exceed 5 percent. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.2. *Reworked Material*—In lieu of virgin PE, clean reworked material may be used, provided that it meets the cell class requirements as described in Section 6.1.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. The ends of the pipe shall be cut squarely and cleanly so as not to adversely affect joining or connecting.

7.1.1. *Visible Defects*—Cracks, creases, unpigmented or nonuniformly pigmented pipe are not permissible.

7.1.2. *Inner Liner*—For Type S and SP pipe, the inner liner shall be fused to the outer corrugated wall at all internal corrugation crests.

7.2. *Pipe Dimensions*:

7.2.1. *Nominal Size*—The nominal size for the pipe and fittings is based on the nominal inside diameter of the pipe. Nominal diameters shall be sized for Type C and CP pipe in not less than 25-mm (1 in.) increments from 75 to 250 mm (3 to 10 in.). Nominal sizes shall be sized for Type S and SP pipe in not less than 50-mm (2 in.) increments from 100 to 250 mm (4 to 10 in.).

7.2.2. *Inner Liner*—For Type S and SP pipe, the inner liner shall have a minimum thickness of 0.5 mm (0.02 in.) for pipe of 100 mm (4 in.) and 150 mm (6 in.) nominal size and a minimum thickness of 0.6 mm (0.025 in.) for pipe of 200 mm (8 in.) and 250 mm (10 in.) nominal size, when measured in accordance with Section 9.5.4.

7.2.3. *Inside Diameter Tolerances*—The tolerance on the specified inside diameter shall be +4.5, –1.5 percent when measured in accordance with Section 9.5.1.

7.2.4. *Length*—Corrugated PE pipe is an extruded product and may be sold in any length agreeable to the user. Lengths shall not be less than 99 percent of the stated quantity when measured in accordance with Section 9.5.2.

7.3. *Fitting and Coupling Dimensions*:

7.3.1. The maximum allowable gap between fitting or coupling and pipe shall not exceed 3 mm (0.1 in.) unless otherwise specified.

7.3.2. All fittings and couplings shall be within an overall length dimensional tolerance of ±12 mm (0.5 in.) of the manufacturer's specified dimensions.

7.4. *Perforations*—When perforated pipe is specified, the perforations shall conform to the requirements of Class 2, unless otherwise specified in the order. Class 1 perforations are for pipe intended to be used for subsurface drainage or combination storm and underdrain. Class 2 perforations are for pipe intended to be used for subsurface drainage only. The perforations shall be cleanly cut so as not to restrict the inflow of water. Where circular perforations are preferred, the drill shall not penetrate the side walls of the corrugations. Pipe connected by couplings or bands may be unperforated within 100 mm (4 in.) of each end of each length of pipe.

Note 3—Pipe ordered under Class 1 perforations has no requirement as to inlet area because it specifies size, number, and location of holes. Alternate perforation patterns should be agreed to between the purchaser and manufacturer.

7.4.1. *Class 1 Perforations*—The perforations shall be approximately circular and shall have nominal diameters of not more than 5 mm (0.2 in.) for 100- and 150-mm (4- and 6-in.) diameter pipe and not greater than 10 mm (0.4 in.) for 200- and 250-mm (8- and 10-in.) diameter pipe. The holes shall be arranged in rows parallel to the axis of the pipe. The location of the perforations shall be in the valley of the outside corrugation and in each corrugation. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of the lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance of the centerlines of the uppermost rows above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 1. All measurements shall be made in accordance with Section 9.5.3.

Table 1—Rows of Perforations, Height *H* of the Centerline of the Uppermost Rows above the Invert, and Chord Length *L* of Unperforated Segment, for Class 1 Perforations

Nominal Diameter, mm (in.)	Rows of Perforations[a]	*H*, Max,[b,] mm (in.)	*L*, Min,[b] mm (in.)
75 (3)	2	35 (1.4)	50 (2)
100 (4)	2	45 (1.75)	65 (2.5)
150 (6)	4	70 (2.75)	95 (3.75)
200 (8)	4	94 (3.7)	130 (5.1)
250 (10)	4	120 (4.7)	160 (6.3)

[a] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and manufacture. Note that the number of perforations per meter in each row (and inlet area) is dependent on the corrugation pitch.

[b] See Figure 1 for location of dimensions *H* and *L*.

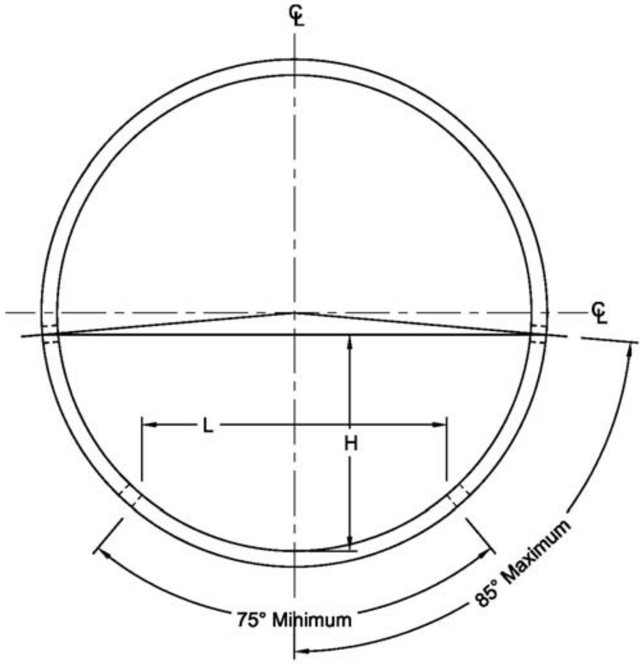

Figure 1—Requirements for Perforations

7.4.2. *Class 2 Perforations*—Circular and slotted perforations shall conform to the maximum dimensions as shown in Table 2. Perforations shall be placed in the outside valleys of the corrugations. The water inlet area shall be a minimum of 20 cm^2/m (1 $in.^2$/ft) of pipe. All measurements shall be made in accordance with Section 9.5.3.

Table 2—Maximum Perforation Dimensions

Nominal Pipe Diameter, mm (in.)	Drilled Hole Diameter, mm (in.)	Slotted Holes	
		Width, mm (in.)	Length, mm (in.)
75 (3)	4.75 (0.19)	3 (0.12)	25 (1)
100 (4)	4.75 (0.19)	3 (0.12)	25 (1)
150 (6)	4.75 (0.19)	3 (0.12)	25 (1)
200 (8)	6.25 (0.25)	3 (0.12)	30 (1.2)
250 (10)	8.00 (0.3)	3 (0.12)	30 (1.2)

7.5. *Pipe Stiffness*—Type C pipe, as described in Section 4.1.1, shall have a minimum pipe stiffness (PS) of 240 kPa (35 psi) at 5 percent deflection; and Type S pipe, as described in Section 4.1.2, shall have a minimum PS of 340 kPa (50 psi) at 5 percent deflection when tested in accordance with Section 9.1. The pipe tested shall contain perforations, if specified.

7.6. *Pipe Flattening*—There shall be no evidence of wall buckling, cracking, splitting, delamination, or decrease or downward deviation in the load-deflection curve when the pipe is tested in accordance with Section 9.2.

7.7. *Environmental Stress Cracking*—There shall be no cracking of the pipe when tested in accordance with Section 9.3.

7.8. *Brittleness*—There shall be no cracking of the pipe wall when tested in accordance with Section 9.4 except as specified in Sections 7.8.1 and 7.8.2.

Note 4—The brittleness test is similar to that described in ASTM F 405.

7.8.1. Cracks with a maximum chord length of 10 mm (0.4 in.) that originate at a perforation or at either end of the sample shall not be cause for rejection.

7.8.2. Splitting along a seam or mold parting line is not caused by brittleness and should be evaluated as a workmanship defect as described in Section 7.1.1 if no split exceeds 50 mm (2 in.) in chord length.

7.9. *Fitting and Coupling Requirements*:

7.9.1. The fittings and couplings shall not reduce or impair the overall integrity or function of the pipe line.

7.9.2. Common corrugated fittings include reducers, tees, wyes, and end caps.

Note 5—Only fittings and couplings supplied or recommended by the pipe manufacturer should be used.

7.9.3. Fittings and couplings shall not reduce the inside diameter of the pipe being joined by more than 5 percent of the nominal inside diameter. Reducer fittings shall not reduce the cross-sectional area of the smaller size.

7.9.4. Pipe connected by in-line couplers shall not separate when tested in accordance with Section 9.6.1.

7.9.5. The coupling shall not crack or crease when tested in accordance with Section 9.6.2.

7.9.6. The design of the couplers shall be such that when connected with the pipe, the axis of the assembly will be level and true when tested in accordance with Section 9.6.3.

8. CONDITIONING

8.1. *Conditioning*—Condition the specimen prior to test at 23 ± 2ºC (73.4 ± 3.6°F) for not less than 24 hours in accordance with Procedure A in ASTM D 618 for those tests where conditioning is required, and unless otherwise specified.

8.2. *Conditions*—Conduct the test in a laboratory temperature of 23 ± 2ºC (73.4 ± 3.6°F) unless otherwise specified herein.

9. TEST METHODS

9.1. *Pipe Stiffness*—Select a pipe specimen and test for PS as described in ASTM D 2412, with the following exceptions.

9.1.1. The test specimen shall be 300 ± 10 mm (12 ± 0.4 in.) long, cut to include full corrugations.

9.1.2. Locate the specimen in the loading machine with an imaginary line connecting the two seams formed by the corrugation mold (end view) parallel to the loading plates. The specimen must lie flat on the plate within 1 mm (0.04 in.) and may be straightened by hand bending at room temperature to accomplish this.

9.1.3. The deflection indicator shall be readable and accurate to ±0.03 mm (0.001 in.).

9.1.4. The residual curvature found in corrugated pipe, especially that furnished in coils, frequently results in an erratic load-deflection curve. When this occurs, the beginning point for deflection measurements shall be at a load of 20 ± 5 newtons (4.5 ± 1 lbf). This point shall be considered as the origin of the load-deflection curve.

Note 6—The parallel plates must exceed the length of the test specimen as specified above.

Note 7—Additional pipe specimens may be tested at other orientations for PS and flattening if desired.

9.2. *Pipe Flattening*—Flatten the pipe specimen from Section 9.1 until the vertical inside diameter is reduced by 20 percent. The rate of loading shall be the same as in Section 9.1. The specimen shall fail if wall buckling, cracking, splitting, or delamination is observed with the unaided eye or if there is a decrease or downward deviation in load-deflection curve at 20 percent or less deflection. The load-deflection curve shall be carried beyond 20 percent deflection so that the shape of the curve at 20 percent deflection can be determined.

9.3. *Environmental Stress Cracking*—Test sections of the pipe for environmental stress cracking in accordance with ASTM D 1693, except for the following modification:

9.3.1. Two specimens shall be tested.

9.3.2. Each specimen shall consist of a 90-degree arc length of pipe without perforations as shown in Figure 2.

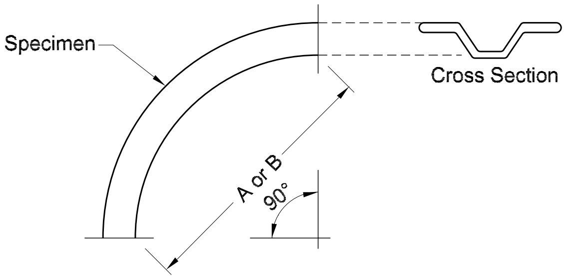

Figure 2—Specimen Configuration for Environmental Stress Cracking

9.3.3. Bend the specimens to shorten the inside chord length 20 ± 1 percent and retain in this position using a suitable holding device. Determine the arc chord dimension (B) of the specimen under test as follows:

$$B = 0.8A \qquad (1)$$

where:

A = the inside chord dimension before bending, and

B = the same dimension taken after bending. (See Figure 2.)

9.3.4. Place the bent specimen in a container of suitable size and cover completely with the preheated wetting agent 100 percent "Igepal CO-630," a trade name for nonylphenoxy poly (ethyleneoxy) ethanol, at 50ºC ± 2ºC (122°F ± 3.6°F). Maintain this temperature for 24 hours, and then remove the sample and inspect immediately. For recommended practices on using specific chemicals to test plastic pipe, refer to R 16.

9.4. *Brittleness*—Test two samples of pipe at an impact of 45 joules (35 ft-lbf) between two flat parallel plates using the apparatus depicted in Figure 3.

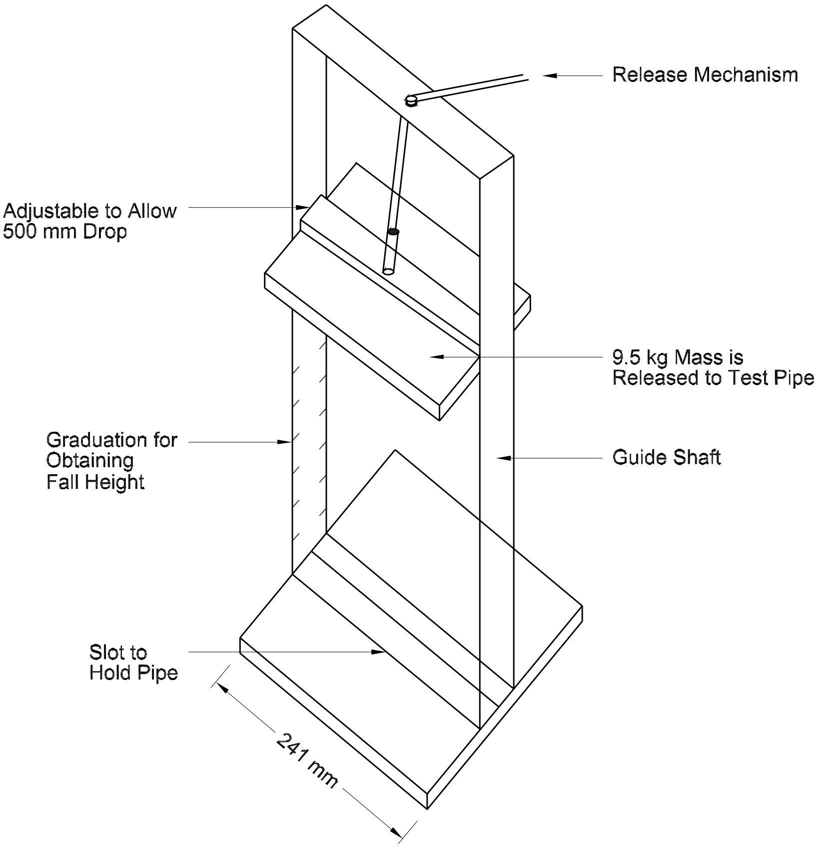

Figure 3—Brittleness Test Device

9.4.1. Cut the sample specimens 150 mm (6 in.) long from one continuous length.

9.4.2. Condition specimens at –4ºC ± 2ºC (25°F ± 3.6°F) for a minimum of 1 hour.

9.4.3. Set the 9.5-kg (20 lb) top plate for a free fall of 500 mm (20 in.) to the uppermost surface of the specimen.

9.4.4. Locate the specimen on the bottom plate with the plane of the corrugated seams parallel to the plate.

9.4.5. Drop the upper plate and impact test the specimen within 30 seconds of removal from the conditioning environment.

9.4.6. Remove and inspect in accordance with the requirements of Section 7.8.

9.5. *Pipe Dimensions*:

9.5.1. *Inside Diameter*—Measure the inside diameter of two sections of pipe with a tapered plug in accordance with ASTM D 2122. Alternatively, measure the inside diameter of two sections, with a suitable device accurate to ±0.2 mm (0.008 in.) the mold part-line and 90 degrees to it, and average the measurements.

9.5.2. *Length*—Measure pipe with any suitable device accurate to 0.2 percent. Make all measurements on the pipe while it is stress-free and at rest on a flat surface in a straight line. The length measurements may be taken at ambient temperature.

9.5.3. *Perforations*—Measure dimensions of perforations on a straight specimen with no external forces applied. Make linear measurements with instruments accurate to 0.2 mm (0.008 in.).

9.5.4. *Inner Liner*—Measure the thickness of the inner liner with a digital micrometer or ultrasonic thickness gauge in accordance with ASTM D 2122.

9.6. *Couplings*:

9.6.1. *Joint Integrity*—This test is limited to Type C and Type CP pipe supplied in coils. Assemble couplings to appropriate pipe in accordance with the manufacturer’s recommendations. Use pipe samples at least 150 mm (6 in.) in length. Vertically suspend two pipe lengths connected by the joint couplings along their longitudinal axis. Then hang a tare mass from the lower end of the assembled pipe specimen for 3 minutes. Apply the test mass gently. Verify that the joint will support a mass along the pipe axis equal to 0.090 kg/mm (60 lb/ft) of the nominal inside diameter, without separating. Test two coupling of each type.

9.6.2. *Strength*—Assemble each coupling to the appropriate pipe in accordance with the manufacturer’s recommendations. Use pipe samples at least 150 mm (6 in.) in length. Load the connected pipe and coupling between parallel plates at the rate of 12.5 mm/minute (0.5 in./min) until the vertical inside diameter is reduced by at least 20 percent of the nominal diameter of the coupling. Inspect for damage while at the specified deflection and after load removal, and report the results of this inspection.

9.6.3. *Alignment*—Assure that the assembly or joint is correct and complete; if the pipe is bent, it should be hand-straightened prior to performing this test. Lay the assembly or joint on a flat surface and verify that it will accommodate straight-line flow.

10. INSPECTION AND RETEST

10.1. *Inspection*—Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

10.2. *Retest and Rejection*—If any failure to conform to these specifications occurs, the pipe or fittings or couplings may be retested to establish conformity in accordance with agreement between the purchaser and seller. Individual results, not averages, constitute failure.

11. MARKING

11.1. All pipe shall be clearly marked at intervals of not more than 3.5 m (10 ft), and fittings and couplings shall be clearly marked, as follows:

11.1.1. Manufacturer’s name or trademark,

11.1.2. Nominal size,

11.1.3. The specification designation AASHTO M 252,

11.1.4. The plant designation code, and

11.1.5. The date of manufacture or an appropriate code. If a date code is used, a durable manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

Note 8—A durable sticker is one that is substantial enough to remain in place and be legible through installation of the pipe.

12. QUALITY ASSURANCE

12.1. A manufacturer’s certification that the product was manufactured, tested, and supplied in accordance with this specification shall be signed by a person authorized by the manufacturer.

Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers

AASHTO Designation: M 259-98 (2006)[1]
ASTM Designation: C 789-95a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers

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1. SCOPE

1.1. This specification covers single-cell precast reinforced concrete box sections intended to be used for the construction of culverts and for the conveyance of storm water, industrial wastes, and sewage.

1.2. A complete metric companion to M 259 has been developed—M 259M; therefore, no metric equivalents are presented in this specification.

Note 1—This specification is primarily a manufacturing and purchasing specification. However, standard designs are included and the criteria used to develop these designs are given in the Appendices. The successful performance of this product depends upon the proper selection of the box section, bedding, and backfill, and care that the installation conforms to the construction specifications. The owner of the precast reinforced concrete box sections specified herein is cautioned that the loading conditions and the field requirements must properly correlate with the box section specified and that inspection at the construction site must be provided.

Note 2—AASHTO M 273 is to be used for box sections with less than 2 ft of cover subjected to highway loading.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 154, Air-Entraining Admixtures for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 273, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

- T 280, Concrete Pipe, Manhole Sections, or Tile
- *Standard Specifications for Highway Bridges*

2.2. *ASTM Standards*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. DEFINITIONS

3.1. *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. TYPES

4.1. Precast reinforced concrete box sections manufactured in accordance with this specification shall be of three types identified in Tables 1, 2, and 3, and shall be designated by type, span, rise, and design earth cover.

5. BASIS OF ACCEPTANCE

5.1. Acceptability of the box sections produced in accordance with Section 7 shall be determined by the results of the concrete compressive strength tests described in Section 10, by the material requirements described in Section 6, and by inspection of the finished box sections.

5.2. Box sections shall be considered ready for acceptance when they conform to the requirements of this specification.

6. MATERIALS

6.1. *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water in which steel has been embedded in such a manner that the steel and concrete act together.

6.2. *Cementitious Materials*:

6.2.1. *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash and shall not exceed 25 percent by weight.

6.2.2. *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3. *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.3.1. Portland cement only,

6.2.3.2. Portland blast-furnace slag cement only,

Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a]

Design Earth Cover, ft[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3 ft by 2 ft by 4 in.[c]					
2	17	0.19	0.20	0.21	0.10[d]
3	15	0.10	0.11	0.11	0.10[d]
4 to 8	15	0.10[d]	0.10[d]	0.10[d]	0.10[d]
10	15	0.10[d]	0.11	0.11	0.10[d]
12	14	0.10[d]	0.13	0.13	0.10[d]
14	14	0.11	0.14	0.14	0.10[d]
16	14	0.12	0.16	0.16	0.10[d]
18	14	0.13	0.17	0.18	0.10[d]
20	14	0.14	0.19	0.19	0.10[d]
3 ft by 3 ft by 4 in.[c]					
2	27	0.15	0.24	0.25	0.10[d]
3	20	0.10	0.13	0.14	0.10[d]
4 to 6	17	0.10[d]	0.10[d]	0.10[d]	0.10[d]
8	15	0.10[d]	0.11	0.11	0.10[d]
10	15	0.10[d]	0.12	0.13	0.10[d]
12	15	0.10[d]	0.14	0.14	0.10[d]
14	15	0.10[d]	0.15	0.16	0.10[d]
16	15	0.10[d]	0.17	0.18	0.10[d]
18	15	0.10[d]	0.19	0.19	0.10[d]
20	15	0.11	0.21	0.21	0.10[d]
4 ft by 2 ft by 5 in.[c]					
2	19	0.26	0.22	0.20	0.12[d]
3	18	0.15	0.13	0.13	0.12[d]
4 to 8	18	0.12[d]	0.12[d]	0.12[d]	0.12[d]
10	17	0.13	0.13	0.14	0.12[d]
12	17	0.15	0.15	0.15	0.12[d]
14	17	0.17	0.17	0.17	0.12[d]
16	17	0.19	0.19	0.19	0.12[d]
18	17	0.21	0.21	0.21	0.12[d]
4 ft by 3 ft by 5 in.[c]					
2	22	0.21	0.27	0.24	0.12[d]
3	19	0.13	0.16	0.16	0.12[d]
4	18	0.12[d]	0.13	0.13	0.12[d]
5	18	0.12[d]	0.12[d]	0.13	0.12[d]
6	17	0.12[d]	0.12[d]	0.13	0.12[d]
8	17	0.12[d]	0.14	0.14	0.12[d]
10	17	0.12[d]	0.15	0.16	0.12[d]
12	17	0.12[d]	0.17	0.18	0.12[d]
14	17	0.13	0.20	0.20	0.12[d]
16	17	0.15	0.22	0.22	0.12[d]
18	17	0.16	0.24	0.24	0.12[d]
4 ft by 4 ft by 5 in.[c]					
2	34	0.18	0.30	0.28	0.12[d]
3	24	0.12[d]	0.18	0.18	0.12[d]
4	21	0.12[d]	0.14	0.15	0.12[d]
5	20	0.12[d]	0.13	0.14	0.12[d]
6	19	0.12[d]	0.14	0.14	0.12[d]
8	18	0.12[d]	0.15	0.15	0.12[d]
10	18	0.12[d]	0.16	0.17	0.12[d]
12	18	0.12[d]	0.19	0.19	0.12[d]
14	18	0.12[d]	0.21	0.21	0.12[d]
16	18	0.12[d]	0.23	0.24	0.12[d]
18	17	0.14	0.25	0.26	0.12[d]
5 ft by 3 ft by 6 in.[c]					
2	23	0.26	0.28	0.23	0.14[d]
3	21	0.17	0.18	0.18	0.14[d]
4	21	0.14[d]	0.15	0.15	0.14[d]
5	20	0.14[d]	0.14[d]	0.15	0.14[d]
6	20	0.14[d]	0.15	0.15	0.14[d]
8	20	0.14[d]	0.16	0.16	0.14[d]
10	20	0.15	0.18	0.19	0.14[d]
12	20	0.17	0.20	0.21	0.14[d]
14	20	0.19	0.23	0.23	0.14[d]
16	19	0.21	0.26	0.26	0.14[d]
18	19	0.23	0.28	0.29	0.14[d]
5 ft by 4 ft by 6 in.[c]					
2	28	0.23	0.32	0.27	0.14[d]
3	23	0.15	0.20	0.21	0.14[d]
4 to 6	22	0.14[d]	0.16	0.17	0.14[d]
8	20	0.14[d]	0.17	0.18	0.14[d]
10	20	0.14[d]	0.20	0.21	0.14[d]
12	20	0.14[d]	0.22	0.23	0.14[d]
14	20	0.16	0.25	0.26	0.14[d]
16	19	0.18	0.28	0.29	0.14[d]
18	19	0.20	0.31	0.31	0.14[d]
5 ft by 5 ft by 6 in.[c]					
2	41	0.20	0.35	0.29	0.14[d]
3	29	0.14[d]	0.22	0.23	0.14[d]
4	25	0.14[d]	0.18	0.19	0.14[d]
5	24	0.14[d]	0.17	0.18	0.14[d]
6	22	0.14[d]	0.17	0.18	0.14[d]
8	22	0.14[d]	0.18	0.19	0.14[d]
10	21	0.14[d]	0.21	0.22	0.14[d]
12	21	0.14[d]	0.23	0.24	0.14[d]
14	21	0.14[d]	0.26	0.27	0.14[d]
16	21	0.16	029	0.30	0.14[d]
18	20	0.17	0.32	0.33	0.14[d]
6 ft by 3 ft by 7 in.[c]					
2	29	0.30	0.29	0.22	0.17[d]
3	24	0.21	0.19	0.18	0.17[d]
4	24	0.18	0.17[d]	0.17[d]	0.17[d]
5	24	0.17[d]	0.17[d]	0.17[d]	0.17[d]
6	23	0.17[d]	0.17[d]	0.17[d]	0.17[d]
8	23	0.17[d]	0.18	0.18	0.17[d]
10	23	0.20	0.20	0.21	0.17[d]
12	23	0.23	0.23	0.24	0.17[d]
14	23	0.26	0.26	0.26	0.17[d]
16	23	0.28	029	0.29	0.17[d]
18	23	0.31	0.32	0.32	0.17[d]

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Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		6 ft by 4 ft by 7 in.[c]			
2	28	0.26	0.33	0.26	0.17[d]
3	25	0.18	0.22	0.21	0.17[d]
4	24	0.17[d]	0.19	0.19	0.17[d]
5	23	0.17[d]	0.18	0.19	0.17[d]
6	23	0.17[d]	0.18	0.19	0.17[d]
8	23	0.17[d]	0.20	0.21	0.17[d]
10	22	0.18	0.23	0.24	0.17[d]
12	22	0.20	0.26	0.26	0.17[d]
14	22	0.22	0.29	0.30	0.17[d]
16	22	0.24	0.32	0.33	0.17[d]
18	22	0.27	0.35	0.36	0.17[d]
		6 ft by 5 ft by 7 in.[c]			
2	33	0.24	0.36	0.29	0.17[d]
3	27	0.17[d]	0.24	0.23	0.17[d]
4 to 6	25	0.17[d]	0.20	0.21	0.17[d]
8	23	0.17[d]	0.21	0.22	0.17[d]
10	23	0.17[d]	0.24	0.25	0.17[d]
12	23	0.17[d]	0.27	0.29	0.17[d]
14	23	0.19	0.31	0.32	0.17[d]
16	22	0.21	0.34	0.35	0.17[d]
18	22	0.23	0.37	0.39	0.17[d]
		6 ft by 6 ft by 7 in.[c]			
2	48	0.22	0.39	0.31	0.17[d]
3	33	0.17[d]	0.26	0.25	0.17[d]
4	29	0.17[d]	0.22	0.23	0.17[d]
5	27	0.17[d]	0.21	0.22	0.17[d]
6	26	0.17[d]	0.21	0.22	0.17[d]
8	25	0.17[d]	0.22	0.24	0.17[d]
10	24	0.17[d]	0.25	0.27	0.17[d]
12	24	0.17[d]	0.28	0.30	0.17[d]
14	24	0.17[d]	0.32	0.33	0.17[d]
16	24	0.19	0.35	0.37	0.17[d]
18	23	0.21	0.38	0.40	0.17[d]
		7 ft by 4 ft by 8 in.[c]			
2	32	0.30	0.34	0.25	0.19[d]
3	27	0.21	0.23	0.21	0.19[d]
4	27	0.19[d]	0.20	0.20	0.19[d]
5	26	0.19[d]	0.20	0.21	0.19[d]
6	26	0.19[d]	0.20	0.21	0.19[d]
8	26	0.20	0.22	0.23	0.19[d]
10	25	0.23	0.25	0.26	0.19[d]
12	25	0.25	0.29	0.29	0.19[d]
14	25	0.28	0.32	0.33	0.19[d]
16	25	0.31	0.36	0.36	0.19[d]
18	25	0.34	0.39	0.40	0.19[d]
		7 ft by 5 ft by 8 in.[c]			
2	32	0.27	0.37	0.28	0.19[d]
3	28	0.19[d]	0.26	0.23	0.19[d]
4 to 6	27	0.19[d]	0.22	0.23	0.19[d]
8	26	0.19[d]	0.24	0.25	0.19[d]
10	25	0.20	0.27	0.29	0.19[d]
12	25	0.22	0.31	0.32	0.19[d]
14	25	0.25	0.35	0.36	0.19[d]
16	25	0.27	0.38	0.40	0.19[d]
18	25	0.30	0.42	0.43	0.19[d]
		7 ft by 6 ft by 8 in.[c]			
2	38	0.24	0.39	0.31	0.19[d]
3	31	0.19[d]	0.27	0.26	0.19[d]
4	29	0.19[d]	0.24	0.25	0.19[d]
5	28	0.19[d]	0.23	0.25	0.19[d]
6	27	0.19[d]	0.24	0.25	0.19[d]
8	26	0.19[d]	0.26	0.27	0.19[d]
10	26	0.19[d]	0.29	0.30	0.19[d]
12	26	0.20	0.33	0.34	0.19[d]
14	25	0.22	0.36	0.38	0.19[d]
16	25	0.25	0.40	0.42	0.19[d]
18	25	0.27	0.44	0.46	0.19[d]
		7 ft by 7 ft by 8 in.[c]			
2	55	0.22	0.42	0.33	0.19[d]
3	38	0.19[d]	0.29	0.27	0.19[d]
4 to 6	33	0.19[d]	0.25	0.27	0.19[d]
8	28	0.19[d]	0.27	0.29	0.19[d]
10	27	0.19[d]	0.30	0.32	0.19[d]
12	27	0.19[d]	0.34	0.36	0.19[d]
14	27	0.21	0.37	0.39	0.19[d]
16	27	0.23	0.41	0.43	0.19[d]
		8 ft by 4 ft by 8 in.[c]			
2	34	0.37	0.40	0.29	0.19[d]
3	31	0.27	0.28	0.24	0.19[d]
4	28	0.25	0.25	0.24	0.19[d]
5	28	0.26	0.25	0.26	0.19[d]
6	28	0.26	0.26	0.26	0.19[d]
8	27	0.28	0.28	0.29	0.19[d]
10	27	0.32	0.32	0.33	0.19[d]
12	27	0.36	0.36	0.37	0.19[d]
14	27	0.40	0.41	0.42	0.19[d]
		8 ft by 5 ft by 8 in.[c]			
2	35	0.34	0.43	0.32	0.19[d]
3	31	0.25	0.31	0.27	0.19[d]
4	28	0.23	0.27	0.27	0.19[d]
5	28	0.24	0.27	0.29	0.19[d]
6	27	0.24	0.28	0.29	0.19[d]
8	27	0.26	0.30	0.32	0.19[d]
10	27	0.29	0.35	0.36	0.19[d]
12	27	0.32	0.39	0.41	0.19[d]
		8 ft by 6 ft by 8 in.[c]			
2	36	0.31	0.46	0.35	0.19[d]
3	31	0.23	0.33	0.29	0.19[d]
4	30	0.22	0.29	0.29	0.19[d]
5	29	0.23	0.29	0.31	0.19[d]
6	28	0.22	0.30	0.31	0.19[d]
8	27	0.24	0.32	0.34	0.19[d]
10	27	0.27	0.37	0.39	0.19[d]
12	27	0.30	0.42	0.43	0.19[d]

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Table 1— Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		8 ft by 7 ft by 8 in.[c]			
2	41	0.28	0.49	0.38	0.19[d]
3	35	0.22	0.35	0.32	0.19[d]
4	32	0.20	0.31	0.31	0.19[d]
5	31	0.21	0.31	0.33	0.19[d]
6	30	0.21	0.31	0.34	0.19[d]
8	29	0.22	0.34	0.36	0.19[d]
10	28	0.25	0.38	0.41	0.19[d]
12	28	0.28	0.43	0.46	0.19[d]
		8 ft by 8 ft by 8 in.[c]			
2	61	0.26	0.51	0.40	0.19[d]
3	41	0.20	0.37	0.34	0.19[d]
4	36	0.19[d]	0.32	0.33	0.19[d]
5	34	0.20	0.32	0.35	0.19[d]
6	32	0.20	0.33	0.36	0.19[d]
8	31	0.21	0.35	0.38	0.19[d]
10	30	0.23	0.40	0.43	0.19[d]
12	29	0.26	0.44	0.48	0.19[d]
		9 ft by 5 ft by 9 in.[c]			
2	38	0.36	0.43	0.31	0.22[d]
3	34	0.28	0.32	0.27	0.22[d]
4	31	0.26	0.28	0.27	0.22[d]
5	31	0.28	0.29	0.29	0.22[d]
6	30	0.29	0.30	0.31	0.22[d]
8	30	0.30	0.32	0.34	0.22[d]
10	30	0.34	0.37	0.39	0.22[d]
12	30	0.38	0.42	0.43	0.22[d]
14	29	0.43	0.47	0.48	0.22[d]
		9 ft by 6 ft by 9 in.[c]			
2	38	0.33	0.46	0.34	0.22[d]
3	34	0.26	0.34	0.29	0.22[d]
4	32	0.24	0.31	0.29	0.22[d]
5	31	0.26	0.31	0.32	0.22[d]
6	30	0.27	0.32	0.34	0.22[d]
8	30	0.28	0.35	0.37	0.22[d]
10	30	0.31	0.40	0.41	0.22[d]
12	29	0.35	0.45	0.47	0.22[d]
		9 ft by 7 ft by 9 in.[c]			
2	41	0.30	0.49	0.37	0.22[d]
3	36	0.24	0.36	0.32	0.22[d]
4	33	0.23	0.32	0.32	0.22[d]
5	32	0.24	0.33	0.34	0.22[d]
6	31	0.25	0.34	0.36	0.22[d]
8	31	0.26	0.37	0.39	0.22[d]
10	30	0.29	0.42	0.44	0.22[d]
12	30	0.33	0.47	0.49	0.22[d]
		9 ft by 8 ft by 9 in.[c]			
2	46	0.28	0.51	0.39	0.22[d]
3	39	0.23	0.38	0.34	0.22[d]
4	36	0.22[d]	0.34	0.34	0.22[d]
5	34	0.23	0.35	0.37	0.22[d]
6	33	0.24	0.35	0.38	0.22[d]
8	32	0.25	0.38	0.41	0.22[d]
10	31	0.28	0.43	0.46	0.22[d]
12	31	0.31	0.49	0.52	0.22[d]
		9 ft by 9 ft by 9 in.[c]			
2	68	0.27	0.54	0.42	0.22[d]
3	45	0.22[d]	0.40	0.36	0.22[d]
4	41	0.22[d]	0.36	0.36	0.22[d]
5	38	0.22[d]	0.36	0.39	0.22[d]
6	36	0.23	0.37	0.40	0.22[d]
8	34	0.24	0.40	0.43	0.22[d]
10	33	0.26	0.45	0.48	0.22[d]
12	33	0.29	0.50	0.54	0.22[d]
		10 ft by 5 ft by 10 in.[c]			
2	41	0.38	0.43	0.31	0.24[d]
3	38	0.30	0.32	0.27	0.24[d]
4	35	0.29	0.30	0.28	0.24[d]
5	34	0.31	0.30	0.30	0.24[d]
6	33	0.33	0.32	0.33	0.24[d]
8	33	0.35	0.35	0.36	0.24[d]
10	33	0.40	0.40	0.41	0.24[d]
12	33	0.45	0.45	0.46	0.24[d]
14	33	0.50	0.50	0.51	0.214[d]
		10 ft by 6 ft by 10 in.[c]			
2	41	0.35	0.46	0.34	0.24[d]
3	37	0.29	0.35	0.30	0.24[d]
4	34	0.27	0.32	0.30	0.24[d]
5	33	0.29	0.33	0.33	0.24[d]
6	33	0.31	0.34	0.36	0.24[d]
8	33	0.33	0.37	0.39	0.24[d]
10	32	0.37	0.42	0.44	0.24[d]
12	32	0.41	0.48	0.50	0.24[d]
14	32	0.46	0.53	0.55	0.24[d]
		10 ft by 7 ft by 10 in.[c]			
2	42	0.32	0.49	0.36	0.24[d]
3	38	0.27	0.37	0.32	0.24[d]
4	35	0.26	0.34	0.32	0.24[d]
5	34	0.27	0.35	0.35	0.24[d]
6	34	0.29	0.36	0.38	0.24[d]
8	33	0.31	0.39	0.42	0.24[d]
10	33	0.34	0.45	0.47	0.24[d]
12	32	0.38	0.50	0.52	0.24[d]
		10 ft by 8 ft by 10 in.[c]			
2	45	0.31	0.52	0.39	0.24[d]
3	40	0.26	0.39	0.34	0.24[d]
4	37	0.25	0.36	0.35	0.24[d]
5	36	0.26	0.37	0.38	0.24[d]
6	35	0.27	0.38	0.41	0.24[d]
8	34	0.29	0.41	0.44	0.24[d]
10	33	0.32	0.47	0.50	0.24[d]
12	33	0.36	0.52	0.55	0.24[d]

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Table 1— Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
10 ft by 9 ft by 10 in.[c]					
2	51	0.29	0.54	0.42	0.24[d]
3	44	0.24[d]	0.41	0.37	0.24[d]
4	40	0.24[d]	0.37	0.37	0.24[d]
5	38	0.25	0.38	0.40	0.24[d]
6	37	0.26	0.40	0.43	0.24[d]
8	36	0.28	0.43	0.46	0.24[d]
10	35	0.31	0.48	0.52	0.24[d]
12	34	0.34	0.54	0.58	0.24[d]
10 ft by 10 ft by 10 in.[c]					
2	75	0.29	0.56	0.44	0.24[d]
3	50	0.24[d]	0.43	0.39	0.24[d]
4	45	0.24[d]	0.39	0.39	0.24[d]
5	42	0.24[d]	0.40	0.42	0.24[d]
6	40	0.25	0.41	0.45	0.24[d]
8	38	0.27	0.44	0.48	0.24[d]
10	37	0.30	0.50	0.54	0.24[d]
12	36	0.33	0.55	0.60	0.24[d]
11 ft by 4 ft by 11 in.[c]					
2	45	0.44	0.40	0.27	0.26[d]
3	43	0.35	0.30	0.26[d]	0.26[d]
4	42	0.35	0.28	0.26[d]	0.26[d]
5	39	0.37	0.29	0.28	0.26[d]
6	38	0.39	0.30	0.30	0.26[d]
8	38	0.43	0.33	0.34	0.26[d]
10	37	0.49	0.38	0.39	0.26[d]
12	37	0.55	0.43	0.44	0.26[d]
14	37	0.62	0.48	0.49	0.26[d]
16	37	0.69	0.54	0.54	0.26[d]
11 ft by 6 ft by 11 in.[c]					
2	44	0.37	0.46	0.33	0.26[d]
3	41	0.31	0.35	0.30	0.26[d]
4	38	0.30	0.33	0.30	0.26[d]
5	36	0.32	0.34	0.33	0.26[d]
6	36	0.34	0.35	0.36	0.26[d]
8	36	0.37	0.39	0.41	0.26[d]
10	35	0.42	0.44	0.46	0.26[d]
12	35	0.46	0.50	0.52	0.26[d]
14	35	0.52	0.56	0.58	0.26[d]
16	35	0.57	0.62	0.64	0.26[d]
11 ft by 8 ft by 11 in.[c]					
2	46	0.33	0.51	0.38	0.26[d]
3	41	0.28	0.39	0.34	0.26[d]
4	39	0.27	0.36	0.35	0.26[d]
5	37	0.29	0.38	0.38	0.26[d]
6	37	0.30	0.39	0.41	0.26[d]
8	36	0.33	0.43	0.46	0.26[d]
10	36	0.37	0.48	0.51	0.26[d]
12	35	0.41	0.54	0.57	0.26[d]
14	35	0.45	0.61	0.64	0.26[d]
11 ft by 10 ft by 11 in.[c]					
2	56	0.30	0.55	0.43	0.26[d]
3	48	0.26[d]	0.42	0.38	0.26[d]
4	44	0.26[d]	0.39	0.38	0.26[d]
5	42	0.26[d]	0.40	0.42	0.26[d]
6	40	0.28	0.42	0.45	0.26[d]
8	39	0.30	0.45	0.49	0.26[d]
10	38	0.34	0.51	0.55	0.26[d]
12	37	0.37	0.57	0.62	0.26[d]
14	37	0.41	0.64	0.68	0.26[d]
11 ft by 11 ft by 11 in.[c]					
2	82	0.30	0.57	0.45	0.26[d]
3	55	0.26[d]	0.44	0.40	0.26[d]
4	48	0.26[d]	0.41	0.40	0.26[d]
5	46	0.26[d]	0.42	0.43	0.26[d]
6	44	0.27	0.43	0.47	0.26[d]
8	41	0.29	0.46	0.51	0.26[d]
10	40	0.33	0.52	0.57	0.26[d]
12	39	0.36	0.58	0.63	0.26[d]
14	39	0.40	0.64	0.70	0.26[d]
12 ft by 4 ft by 12 in.[c]					
2	50	0.46	0.41	0.29[d]	0.29[d]
3	47	0.38	0.31	0.29[d]	0.29[d]
4	45	0.38	0.29[d]	0.29[d]	0.29[d]
5	43	0.41	0.30	0.29[d]	0.29[d]
6	42	0.43	0.31	0.31	0.29[d]
8	41	0.49	0.35	0.36	0.29[d]
10	41	0.55	0.40	0.41	0.29[d]
12	41	0.62	0.45	0.46	0.29[d]
14	41	0.70	0.50	0.51	0.29[d]
16	41	0.78	0.55	0.57	0.29[d]
12 ft by 6 ft by 12 in.[c]					
2	47	0.39	0.47	0.33	0.29[d]
3	44	0.33	0.36	0.30	0.29[d]
4	41	0.33	0.34	0.31	0.29[d]
5	39	0.35	0.35	0.34	0.29[d]
6	39	0.38	0.37	0.37	0.29[d]
8	39	0.42	0.41	0.43	0.29[d]
10	39	0.47	0.47	0.49	0.29[d]
12	38	0.53	0.53	0.55	0.29[d]
14	38	0.59	0.59	0.61	0.29[d]
16	38	0.65	0.65	0.67	0.29[d]
12 ft by 8 ft by 12 in.[c]					
2	48	0.35	0.52	0.38	0.29[d]
3	44	0.31	0.40	0.35	0.29[d]
4	41	0.30	0.38	0.36	0.29[d]
5	40	0.32	0.39	0.39	0.29[d]
6	39	0.34	0.41	0.42	0.29[d]
8	39	0.38	0.46	0.48	0.29[d]
10	38	0.42	0.52	0.55	0.29[d]
12	38	0.46	0.58	0.61	0.29[d]
14	38	0.52	0.65	0.68	0.29[d]

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Table 1— Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions^a *(Continued)*

Design Earth Cover, ft^a	M, Min in.	Circumferential Reinforcement Areas^b			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		12 ft by 10 ft by 12 in.^{c}			
2	55	0.33	0.56	0.43	0.29^d
3	48	0.29^d	0.44	0.39	0.29^d
4	44	0.29^d	0.41	0.40	0.29^d
5	43	0.29^d	0.43	0.43	0.29^d
6	42	0.32	0.44	0.47	0.29^d
8	40	0.35	0.49	0.53	0.29^d
10	40	0.38	0.55	0.59	0.29^d
12	39	0.42	0.61	0.66	0.29^d
14	39	0.47	0.68	0.73	0.29^d
		12 ft by 12 ft by 12 in.^{c}			
2	89	0.32	0.60	0.48	0.29^d
3	60	0.29^d	0.47	0.43	0.29^d
4	53	0.29^d	0.44	0.43	0.29^d
5	50	0.29^d	0.45	0.47	0.29^d
6	48	0.29^d	0.47	0.50	0.29^d
8	45	0.33	0.51	0.57	0.29^d
10	44	0.36	0.57	0.63	0.29^d
12	43	0.40	0.64	0.70	0.29^d
14	42	0.44	0.70	0.77	0.29^d

[a] The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see Section 7.2.

[b] Design steel area in square inches per linear foot of box section at those locations that are indicated on the typical section included in Appendix X1.

[c] The box section designation, for example, 3 ft by 2 ft by 2 in. indicates (interior horizontal span in feet) by (interior vertical rise in feet) by (wall and slab thickness in inches).

[d] Minimum practical steel area is specified.

Notes:

1. Design earth covers and reinforcement areas are based on the weight of a column of earth over the width of the box section as defined in Appendix X1. See Appendix X2 for modification to reinforcement areas for other earth load conditions.
2. Concrete design strength, 5000 psi.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions^a

Design Earth Cover, ft^a	M, Min in.	Circumferential Reinforcement Areas^b			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		3 ft by 2 ft by 4 in.^{c}			
2	17	0.19	0.20	0.21	0.10^d
3	15	0.10^d	0.11	0.11	0.10^d
4 to 8	15	0.10^d	0.10^d	0.10^d	0.10^d
10	14	0.10^d	0.11	0.12	0.10^d
12	14	0.10^d	0.13	0.13	0.10^d
14	14	0.10^d	0.14	0.14	0.10^d
16	14	0.12	0.16	0.16	0.10^d
18	14	0.13	0.18	0.18	0.10^d
20	14	0.15	0.19	0.19	0.10^d
		3 ft by 3 ft by 4 in.^{c}			
2	27	0.15	0.24	0.25	0.10^d
3	20	0.10^d	0.13	0.14	0.10^d
4 to 6	18	0.10^d	0.10^d	0.11	0.10^d
8	15	0.10^d	0.11	0.12	0.10^d
10	15	0.10^d	0.13	0.13	0.10^d
12	15	0.10^d	0.14	0.14	0.10^d
14	15	0.10^d	0.15	0.16	0.10^d
16	15	0.10^d	0.17	0.18	0.10^d
18	15	0.10^d	0.19	0.20	0.10^d
20	15	0.11	0.21	0.21	0.10^d
		4 ft by 2 ft by 5 in.^{c}			
2	19	0.26	0.22	0.20	0.12^d
3	18	0.15	0.13	0.13	0.12^d
4 to 6	18	0.12^d	0.12^d	0.12^d	0.12^d
8	17	0.13	0.12^d	0.12^d	0.12^d
10	17	0.14	0.14	0.14	0.12^d
12	17	0.15	0.15	0.15	0.12^d
14	17	0.17	0.17	0.17	0.12^d
16	17	0.19	0.19	0.19	0.12^d
18	17	0.21	0.21	0.21	0.12^d
		4 ft by 3 ft by 5 in.^{c}			
2	22	0.21	0.27	0.24	0.12^d
3	19	0.13	0.16	0.16	0.12^d
4	18	0.12^d	0.13	0.13	0.12^d
5	18	0.12^d	0.12^d	0.13	0.12^d
6	17	0.12^d	0.13	0.13	0.12^d
8	17	0.12^d	0.14	0.15	0.12^d
10	17	0.12^d	0.16	0.16	0.12^d
12	17	0.12^d	0.18	0.18	0.12^d
14	17	0.13	0.20	0.20	0.12^d
16	17	0.15	0.22	0.23	0.12^d
18	17	0.16	0.24	0.25	0.12^d
		4 ft by 4 ft by 5 in.^{c}			
2	34	0.18	0.30	0.28	0.12^d
3	24	0.12^d	0.18	0.18	0.12^d
4	21	0.12^d	0.14	0.15	0.12^d
5	20	0.12^d	0.14	0.14	0.12^d
6	19	0.12^d	0.14	0.15	0.12^d
8	18	0.12^d	0.15	0.16	0.12^d
10	18	0.12^d	0.17	0.18	0.12^d
12	18	0.12^d	0.19	0.19	0.12^d
14	18	0.12^d	0.21	0.21	0.12^d
16	18	0.13	0.23	0.29	0.12^d
18	17	0.14	0.26	0.26	0.12^d

Continued on next page.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft.[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
5 ft by 3 ft by 6 in.[c]					
2	23	0.26	0.28	0.24	0.14[d]
3	21	0.17	0.18	0.18	0.14[d]
4	21	0.14[d]	0.15	0.15	0.14[d]
5	20	0.14[d]	0.14[d]	0.15	0.14[d]
6	20	0.14[d]	0.15	0.15	0.14[d]
8	20	0.14[d]	0.17	0.17	0.14[d]
10	20	0.16	0.18	0.19	0.14[d]
12	20	0.17	0.21	0.21	0.14[d]
14	20	0.19	0.23	0.23	0.14[d]
16	19	0.22	0.26	0.26	0.14[d]
18	19	0.24	0.29	0.29	0.14[d]
5 ft by 4 ft by 6 in.[c]					
2	28	0.23	0.32	0.27	0.14[d]
3	23	0.15	0.20	0.21	0.14[d]
4	22	0.14[d]	0.16	0.17	0.14[d]
5	21	0.14[d]	0.16	0.17	0.14[d]
6	21	0.14[d]	0.17	0.17	0.14[d]
8	20	0.14[d]	0.18	0.19	0.14[d]
10	20	0.14[d]	0.20	0.21	0.14[d]
12	20	0.15	0.23	0.23	0.14[d]
14	20	0.16	0.25	0.26	0.14[d]
16	19	0.18	0.28	0.29	0.14[d]
18	19	0.20	0.31	0.32	0.14[d]
5 ft by 5 ft by 6 in.[c]					
2	41	0.20	0.35	0.30	0.14[d]
3	29	0.14[d]	0.22	0.23	0.14[d]
4	25	0.14[d]	0.18	0.19	0.14[d]
5	24	0.14[d]	0.17	0.18	0.14[d]
6	22	0.14[d]	0.18	0.19	0.14[d]
8	22	0.14[d]	0.19	0.20	0.14[d]
10	21	0.14[d]	0.21	0.22	0.14[d]
12	21	0.14[d]	0.24	0.25	0.14[d]
14	21	0.14[d]	0.26	0.27	0.14[d]
16	21	0.16	0.29	0.31	0.14[d]
18	20	0.18	0.32	0.33	0.14[d]
6 ft by 3 ft by 7 in.[c]					
2	29	0.31	0.29	0.27	0.17[d]
3	24	0.21	0.19	0.18	0.17[d]
4	24	0.18	0.17[d]	0.17[d]	0.17[d]
5	24	0.17[d]	0.17[d]	0.17[d]	0.17[d]
6	23	0.18	0.17[d]	0.17[d]	0.17[d]
8	23	0.19	0.19	0.19	0.17[d]
10	23	0.21	0.21	0.21	0.17[d]
12	23	0.23	0.23	0.24	0.17[d]
14	23	0.26	0.26	0.26	0.17[d]
16	23	0.29	0.29	0.30	0.17[d]
18	23	0.32	0.32	0.33	0.17[d]
6 ft by 4 ft by 7 in.[c]					
2	23	0.27	0.33	0.31	0.17[d]
3	21	0.18	0.22	0.21	0.17[d]
4	21	0.17[d]	0.19	0.19	0.17[d]
5	20	0.17[d]	0.18	0.19	0.17[d]
6	20	0.17[d]	0.19	0.20	0.17[d]
8	20	0.17[d]	0.21	0.22	0.17[d]
10	22	0.18	0.23	0.24	0.17[d]
12	22	0.20	0.26	0.27	0.17[d]
14	22	0.22	0.29	0.30	0.17[d]
16	22	0.25	0.32	0.33	0.17[d]
18	22	0.27	0.36	0.37	0.17[d]
6 ft by 5 ft by 7 in.[c]					
2	33	0.25	0.36	0.34	0.17[d]
3	27	0.17[d]	0.24	0.23	0.17[d]
4	25	0.17[d]	0.20	0.21	0.17[d]
5	24	0.17[d]	0.20	0.21	0.17[d]
6	24	0.17[d]	0.21	0.22	0.17[d]
8	23	0.17[d]	0.22	0.23	0.17[d]
10	23	0.17[d]	0.25	0.26	0.17[d]
12	23	0.18	0.28	0.29	0.17[d]
14	23	0.19	0.31	0.32	0.17[d]
16	22	0.22	0.34	0.36	0.17[d]
18	22	0.24	0.38	0.39	0.17[d]
6 ft by 6 ft by 7 in.[c]					
2	48	0.23	0.39	0.37	0.17[d]
3	33	0.17[d]	0.26	0.26	0.17[d]
4	29	0.17[d]	0.22	0.23	0.17[d]
5	27	0.17[d]	0.21	0.23	0.17[d]
6	26	0.17[d]	0.22	0.23	0.17[d]
8	25	0.17[d]	0.23	0.25	0.17[d]
10	24	0.17[d]	0.26	0.27	0.17[d]
12	24	0.17[d]	0.29	0.30	0.17[d]
14	24	0.17[d]	0.32	0.33	0.17[d]
16	24	0.20	0.36	0.37	0.17[d]
18	23	0.21	0.39	0.41	0.17[d]
7 ft by 4 ft by 8 in.[c]					
2	32	0.34	0.34	0.33	0.19[d]
3	27	0.23	0.23	0.23	0.19[d]
4	27	0.20	0.20	0.21	0.19[d]
5	26	0.20	0.20	0.21	0.19[d]
6	26	0.20	0.21	0.22	0.19[d]
8	26	0.21	0.23	0.24	0.19[d]
10	25	0.23	0.26	0.27	0.19[d]
12	25	0.25	0.29	0.30	0.19[d]
14	25	0.28	0.32	0.33	0.19[d]
16	25	0.32	0.36	0.37	0.19[d]
18	25	0.35	0.40	0.41	0.19[d]
7 ft by 5 ft by 8 in.[c]					
2	34	0.31	0.37	0.37	0.19[d]
3	28	0.21	0.26	0.26	0.19[d]
4	27	0.19[d]	0.22	0.23	0.19[d]
5	26	0.19[d]	0.22	0.23	0.19[d]
6	26	0.19[d]	0.23	0.24	0.19[d]
8	26	0.19[d]	0.25	0.26	0.19[d]
10	25	0.21	0.28	0.29	0.19[d]
12	25	0.23	0.31	0.32	0.19[d]
14	25	0.25	0.35	0.36	0.19[d]
16	25	0.28	0.39	0.40	0.19[d]
18	25	0.31	0.43	0.44	0.19[d]

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Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		7 ft by 6 ft by 8 in.[c]			
2	38	0.28	0.39	0.40	0.19[d]
3	31	0.19[d]	0.27	0.28	0.19[d]
4	29	0.19[d]	0.24	0.25	0.19[d]
5	28	0.19[d]	0.24	0.25	0.19[d]
6	27	0.19[d]	0.24	0.26	0.19[d]
8	26	0.19[d]	0.27	0.28	0.19[d]
10	26	0.19[d]	0.30	0.31	0.19[d]
12	26	0.21	0.33	0.34	0.19[d]
14	25	0.22	0.36	0.38	0.19[d]
16	25	0.25	0.41	0.42	0.19[d]
		7 ft by 7 ft by 8 in.[c]			
2	55	0.26	0.42	0.43	0.19[d]
3	38	0.19[d]	0.29	0.30	0.19[d]
4	33	0.19[d]	0.25	0.27	0.19[d]
5	31	0.19[d]	0.25	0.27	0.19[d]
6	30	0.19[d]	0.26	0.28	0.19[d]
8	28	0.19[d]	0.28	0.30	0.19[d]
10	27	0.19[d]	0.31	0.33	0.19[d]
12	27	0.19[d]	0.34	0.36	0.19[d]
14	27	0.21	0.37	0.40	0.19[d]
16	27	0.23	0.42	0.44	0.19[d]
		8 ft by 4 ft by 8 in.[c]			
2	34	0.43	0.40	0.38	0.19[d]
3	31	0.31	0.28	0.29	0.19[d]
4	28	0.27	0.25	0.26	0.19[d]
5	28	0.27	0.25	0.26	0.19[d]
6	28	0.27	0.26	0.27	0.19[d]
8	27	0.30	0.29	0.30	0.19[d]
10	27	0.33	0.33	0.34	0.19[d]
12	27	0.36	0.36	0.37	0.19[d]
		8 ft by 5 ft by 8 in.[c]			
2	35	0.38	0.43	0.42	0.19[d]
3	31	0.29	0.31	0.32	0.19[d]
4	28	0.25	0.27	0.28	0.19[d]
5	28	0.25	0.28	0.29	0.19[d]
6	27	0.25	0.29	0.30	0.19[d]
8	27	0.27	0.32	0.33	0.19[d]
10	27	0.30	0.35	0.37	0.19[d]
12	27	0.33	0.40	0.41	0.19[d]
		8 ft by 6 ft by 8 in.[c]			
2	36	0.35	0.47	0.46	0.19[d]
3	31	0.27	0.33	0.35	0.19[d]
4	30	0.23	0.29	0.31	0.19[d]
5	29	0.23	0.30	0.31	0.19[d]
6	28	0.23	0.31	0.32	0.19[d]
8	27	0.25	0.34	0.35	0.19[d]
10	27	0.27	0.38	0.39	0.19[d]
12	27	0.30	0.42	0.44	0.19[d]
		8 ft by 7 ft by 8 in.[c]			
2	41	0.33	0.50	0.49	0.19[d]
3	35	0.25	0.35	0.38	0.19[d]
4	32	0.22	0.31	0.33	0.19[d]
5	31	0.22	0.31	0.34	0.19[d]
6	30	0.22	0.32	0.35	0.19[d]
8	29	0.23	0.35	0.38	0.19[d]
10	28	0.25	0.39	0.42	0.19[d]
12	28	0.28	0.44	0.46	0.19[d]
		8 ft by 8 ft by 8 in.[c]			
2	61	0.31	0.53	0.52	0.19[d]
3	41	0.24	0.37	0.40	0.19[d]
4	36	0.21	0.33	0.35	0.19[d]
5	34	0.20	0.33	0.36	0.19[d]
6	32	0.21	0.34	0.37	0.19[d]
8	31	0.22	0.37	0.40	0.19[d]
10	30	0.24	0.41	0.43	0.19[d]
12	29	0.26	0.45	0.48	0.19[d]
		9 ft by 5 ft by 9 in.[c]			
2	38	0.43	0.45	0.41	0.22[d]
3	34	0.33	0.33	0.33	0.22[d]
4	31	0.29	0.29	0.30	0.22[d]
5	31	0.29	0.30	0.31	0.22[d]
6	30	0.30	0.31	0.32	0.22[d]
8	30	0.32	0.34	0.35	0.22[d]
10	30	0.35	0.38	0.39	0.22[d]
12	30	0.39	0.42	0.44	0.22[d]
		9 ft by 6 ft by 9 in.[c]			
2	38	0.40	0.48	0.45	0.22[d]
3	34	0.30	0.35	0.36	0.22[d]
4	32	0.27	0.31	0.33	0.22[d]
5	31	0.27	0.32	0.34	0.22[d]
6	30	0.28	0.33	0.35	0.22[d]
8	30	0.29	0.36	0.38	0.22[d]
10	30	0.32	0.40	0.42	0.22[d]
12	29	0.36	0.45	0.47	0.22[d]
		9 ft by 7 ft by 9 in.[c]			
2	41	0.37	0.52	0.48	0.22[d]
3	36	0.29	0.38	0.39	0.22[d]
4	33	0.26	0.33	0.36	0.22[d]
5	32	0.26	0.34	0.36	0.22[d]
6	31	0.26	0.35	0.37	0.22[d]
8	31	0.28	0.38	0.41	0.22[d]
10	30	0.30	0.42	0.45	0.22[d]
12	30	0.33	0.47	0.50	0.22[d]
		9 ft by 8 ft by 9 in.[c]			
2	46	0.35	0.54	0.51	0.22[d]
3	39	0.27	0.40	0.42	0.22[d]
4	36	0.24	0.35	0.38	0.22[d]
5	34	0.24	0.36	0.38	0.22[d]
6	33	0.25	0.37	0.39	0.22[d]
8	32	0.26	0.40	0.43	0.22[d]
10	31	0.28	0.44	0.47	0.22[d]
12	31	0.31	0.49	0.52	0.22[d]

Continued on next page.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
9 ft by 9 ft by 9 in.[c]					
2	68	0.33	0.57	0.55	0.22[d]
3	45	0.26	0.42	0.44	0.22[d]
4	41	0.23	0.37	0.40	0.22[d]
5	38	0.23	0.37	0.40	0.22[d]
6	36	0.23	0.38	0.42	0.22[d]
8	34	0.25	0.41	0.45	0.22[d]
10	33	0.27	0.45	0.49	0.22[d]
12	33	0.30	0.50	0.54	0.22[d]
10 ft by 5 ft by 10 in.[c]					
2	41	0.47	0.46	0.40	0.24[d]
3	38	0.36	0.34	0.33	0.24[d]
4	35	0.34	0.31	0.32	0.24[d]
5	34	0.34	0.32	0.33	0.24[d]
6	33	0.34	0.33	0.34	0.24[d]
8	33	0.37	0.36	0.37	0.24[d]
10	33	0.41	0.40	0.42	0.24[d]
12	33	0.45	0.45	0.46	0.24[d]
10 ft by 6 ft by 10 in.[c]					
2	41	0.44	0.49	0.44	0.24[d]
3	37	0.34	0.37	0.36	0.24[d]
4	34	0.31	0.33	0.35	0.24[d]
5	33	0.31	0.34	0.36	0.24[d]
6	33	0.32	0.35	0.37	0.24[d]
8	33	0.34	0.39	0.41	0.24[d]
10	32	0.38	0.43	0.45	0.24[d]
12	32	0.41	0.48	0.50	0.24[d]
10 ft by 7 ft by 10 in.[c]					
2	42	0.41	0.53	0.47	0.24[d]
3	38	0.32	0.39	0.39	0.24[d]
4	35	0.30	0.36	0.38	0.24[d]
5	34	0.30	0.36	0.38	0.24[d]
6	34	0.30	0.37	0.40	0.24[d]
8	33	0.32	0.41	0.43	0.24[d]
10	33	0.35	0.46	0.48	0.24[d]
12	32	0.39	0.51	0.53	0.24[d]
10 ft by 8 ft by 10 in.[c]					
2	45	0.38	0.56	0.51	0.24[d]
3	40	0.30	0.41	0.42	0.24[d]
4	37	0.28	0.38	0.40	0.24[d]
5	36	0.28	0.38	0.41	0.24[d]
6	35	0.29	0.39	0.42	0.24[d]
8	34	0.31	0.43	0.46	0.24[d]
10	33	0.33	0.48	0.51	0.24[d]
12	33	0.36	0.53	0.56	0.24[d]
10 ft by 9 ft by 10 in.[c]					
2	51	0.36	0.59	0.54	0.24[d]
3	42	0.29	0.44	0.45	0.24[d]
4	40	0.27	0.39	0.43	0.24[d]
5	38	0.27	0.40	0.43	0.24[d]
6	37	0.27	0.41	0.44	0.24[d]
8	35	0.29	0.45	0.48	0.24[d]
10	35	0.32	0.49	0.53	0.24[d]
12	34	0.35	0.54	0.58	0.24[d]
10 ft by 10 ft by 10 in.[c]					
2	75	0.35	0.61	0.57	0.24[d]
3	50	0.28	0.46	0.47	0.24[d]
4	45	0.26	0.41	0.45	0.24[d]
5	42	0.26	0.41	0.46	0.24[d]
6	40	0.26	0.43	0.47	0.24[d]
8	38	0.28	0.46	0.50	0.24[d]
10	37	0.30	0.51	0.55	0.24[d]
12	31	0.33	0.56	0.60	0.24[d]
11 ft by 4 ft by 11 in.[c]					
2	45	0.54	0.43	0.35	0.26[d]
3	43	0.43	0.32	0.30	0.26[d]
4	41	0.40	0.29	0.30	0.26[d]
5	39	0.41	0.30	0.31	0.26[d]
6	38	0.42	0.31	0.32	0.26[d]
8	38	0.45	0.34	0.36	0.26[d]
10	37	0.51	0.39	0.40	0.26[d]
12	37	0.57	0.44	0.45	0.26[d]
14	37	0.64	0.49	0.50	0.26[d]
16	37	0.71	0.54	0.55	0.26[d]
11 ft by 6 ft by 11 in.[c]					
2	44	0.46	0.50	0.43	0.26[d]
3	41	0.37	0.38	0.36	0.26[d]
4	38	0.35	0.35	0.35	0.26[d]
5	36	0.36	0.36	0.37	0.26[d]
6	36	0.36	0.37	0.39	0.26[d]
8	36	0.39	0.40	0.42	0.26[d]
10	35	0.43	0.46	0.47	0.26[d]
12	35	0.48	0.51	0.53	0.26[d]
14	35	0.53	0.57	0.59	0.26[d]
11 ft by 8 ft by 11 in.[c]					
2	46	0.41	0.56	0.49	0.26[d]
3	41	0.33	0.42	0.41	0.26[d]
4	39	0.31	0.39	0.40	0.26[d]
5	37	0.32	0.40	0.42	0.26[d]
6	37	0.33	0.41	0.44	0.26[d]
8	36	0.35	0.45	0.47	0.26[d]
10	36	0.38	0.50	0.53	0.26[d]
12	35	0.42	0.56	0.59	0.26[d]
14	35	0.46	0.62	0.65	0.26[d]
11 ft by 10 ft by 11 in.[c]					
2	56	0.37	0.62	0.55	0.26[d]
3	48	0.30	0.46	0.46	0.26[d]
4	44	0.29	0.42	0.45	0.26[d]
5	42	0.30	0.43	0.47	0.26[d]
6	40	0.30	0.44	0.48	0.26[d]
8	39	0.32	0.47	0.52	0.26[d]
10	38	0.35	0.53	0.57	0.26[d]
12	37	0.38	0.59	0.63	0.26[d]
14	37	0.42	0.65	0.70	0.26[d]

Continued on next page.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		11 ft by 11 ft by 11 in.[c]			
2	82	0.36	0.64	0.58	0.26[d]
3	55	0.29	0.48	0.48	0.26[d]
4	49	0.28	0.43	0.47	0.26[d]
5	46	0.29	0.44	0.49	0.26[d]
6	44	0.29	0.45	0.50	0.26[d]
8	41	0.31	0.49	0.53	0.26[d]
10	40	0.34	0.54	0.59	0.26[d]
12	39	0.37	0.60	0.65	0.26[d]
14	39	0.41	0.66	0.71	0.26[d]
		12 ft by 4 ft by 12 in.[c]			
2	50	0.58	0.44	0.35	0.29[d]
3	47	0.46	0.33	0.30	0.29[d]
4	45	0.43	0.31	0.30	0.29[d]
5	43	0.46	0.32	0.33	0.29[d]
6	42	0.47	0.33	0.34	0.29[d]
8	41	0.51	0.36	0.37	0.29[d]
10	41	0.57	0.41	0.42	0.29[d]
12	41	0.64	0.46	0.47	0.29[d]
14	41	0.72	0.51	0.52	0.29[d]
16	41	0.80	0.56	0.58	0.29[d]
		12 ft by 6 ft by 12 in.[c]			
2	47	0.50	0.51	0.42	0.29[d]
3	44	0.40	0.39	0.36	0.29[d]
4	41	0.38	0.36	0.36	0.29[d]
5	42	0.40	0.38	0.39	0.29[d]
6	39	0.41	0.39	0.41	0.29[d]
8	39	0.44	0.43	0.45	0.29[d]
10	39	0.49	0.48	0.50	0.29[d]
12	38	0.55	0.54	0.56	0.29[d]
14	38	0.61	0.60	0.62	0.29[d]

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		12 ft by 8 ft by 12 in.[c]			
2	49	0.45	0.58	0.49	0.29[d]
3	44	0.36	0.44	0.42	0.29[d]
4	41	0.34	0.41	0.41	0.29[d]
5	40	0.36	0.42	0.45	0.29[d]
6	39	0.37	0.43	0.46	0.29[d]
8	39	0.39	0.47	0.50	0.29[d]
10	38	0.44	0.53	0.56	0.29[d]
12	38	0.48	0.60	0.63	0.29[d]
14	38	0.66	0.69	0.69	0.29[d]
		12 ft by 10 ft by 12 in.[c]			
2	55	0.41	0.63	0.55	0.29[d]
3	48	0.33	0.48	0.47	0.29[d]
4	44	0.32	0.44	0.46	0.29[d]
5	43	0.34	0.46	0.49	0.29[d]
6	42	0.34	0.47	0.51	0.29[d]
8	40	0.36	0.51	0.55	0.29[d]
10	40	0.40	0.57	0.61	0.29[d]
12	39	0.44	0.63	0.68	0.29[d]
14	39	0.48	0.70	0.75	0.29[d]
		12 ft by 12 ft by 12 in.[c]			
2	89	0.38	0.68	0.60	0.29[d]
3	60	0.31	0.51	0.51	0.29[d]
4	53	0.30	0.47	0.50	0.29[d]
5	50	0.32	0.48	0.54	0.29[d]
6	48	0.32	0.50	0.55	0.29[d]
8	45	0.34	0.53	0.59	0.29[d]
10	44	0.37	0.59	0.65	0.29[d]
12	43	0.41	0.66	0.72	0.29[d]
14	42	0.45	0.72	0.79	0.29[d]

[a] The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see Section 7.2.

[b] Design steel area in square inches per linear foot of box section at those locations that are indicated on the typical section included in Appendix X1.

[c] The box section designation, for example, 3 ft by 2 ft by 2 in. indicates (interior horizontal span in feet) by (interior vertical rise in feet) by (wall and slab thickness in inches).

[d] Minimum practical steel area is specified.

Notes:

1. Design earth covers and reinforcement areas are based on the weight of a column of earth over the width of the box section as defined in Appendix X1. See Appendix X2 for modification to reinforcement areas for other earth load conditions.
2. Concrete design strength, 5000 psi.

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a]

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		3 ft by 2 ft by 4 in.[c]			
0 to 10	14	0.10[d]	0.10[d]	0.10[d]	0.10[d]
12	14	0.10[d]	0.10	0.11	0.10[d]
14	14	0.10[d]	0.12	0.12	0.10[d]
16	14	0.10[d]	0.14	0.14	0.10[d]
18	14	0.11	0.16	0.16	0.10[d]
20	14	0.13	0.17	0.18	0.10[d]
22	14	0.14	0.19	0.19	0.10[d]

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		3 ft by 3 ft by 4 in.[c]			
0 to 10	15	0.10[d]	0.10[d]	0.10[d]	0.10[d]
12	14	0.10[d]	0.11	0.12	0.10[d]
14	14	0.10[d]	0.13	0.13	0.10[d]
16	14	0.10[d]	0.15	0.15	0.10[d]
18	14	0.10[d]	0.17	0.17	0.10[d]
20	14	0.10[d]	0.19	0.19	0.10[d]

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Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
4 ft by 2 ft by 5 in.[c]					
0 to 10	18	0.12^{d}	0.12^{d}	0.12^{d}	0.12^{d}
12	17	0.12^{d}	0.13	0.13	0.12^{d}
14	17	0.14	0.15	0.15	0.12^{d}
16	17	0.16	0.17	0.17	0.12^{d}
18	17	0.18	0.19	0.19	0.12^{d}
20	17	0.21	0.21	0.21	0.12^{d}
4 ft by 3 ft by 5 in.[c]					
0 to 8	17	0.12^{d}	0.12^{d}	0.12^{d}	0.12^{d}
10	17	0.12^{d}	0.12^{d}	0.13	0.12^{d}
12	17	0.12^{d}	0.14	0.15	0.12^{d}
14	17	0.12^{d}	0.17	0.17	0.12^{d}
16	17	0.12^{d}	0.19	0.20	0.12^{d}
18	17	0.14	0.22	0.22	0.12^{d}
20	17	0.16	0.24	0.25	0.12^{d}
4 ft by 4 ft by 5 in.[c]					
0 to 8	18	0.12^{d}	0.12	0.12	0.12^{d}
10	17	0.12^{d}	0.13	0.13	0.12^{d}
12	17	0.12^{d}	0.15	0.16	0.12^{d}
14	17	0.12^{d}	0.18	0.18	0.12^{d}
16	17	0.12^{d}	0.20	0.21	0.12^{d}
18	17	0.12^{d}	0.23	0.23	0.12^{d}
20	17	0.13	0.25	0.26	0.12^{d}
5 ft by 3 ft by 6 in.[c]					
0 to 8	20	0.14^{d}	0.14^{d}	0.14^{d}	0.14^{d}
10	19	0.14^{d}	0.14^{d}	0.15	0.14^{d}
12	19	0.14^{d}	0.17	0.18	0.14^{d}
14	19	0.16	0.20	0.20	0.14^{d}
16	19	0.18	0.23	0.23	0.14^{d}
18	19	0.21	0.25	0.26	0.14^{d}
20	19	0.23	0.28	0.29	0.14^{d}
5 ft by 4 ft by 6 in.[c]					
0 to 8	20	0.14^{d}	0.14^{d}	0.14^{d}	0.14^{d}
10	19	0.14^{d}	0.16	0.16	0.14^{d}
12	19	0.14^{d}	0.17	0.19	0.14^{d}
14	19	0.14^{d}	0.22	0.22	0.14^{d}
16	19	0.15	0.25	0.25	0.14^{d}
18	19	0.17	0.28	0.28	0.14^{d}
20	19	0.19	0.31	0.31	0.14^{d}
5 ft by 5 ft by 6 in.[c]					
0 to 8	22	0.14^{d}	0.14^{d}	0.14^{d}	0.14^{d}
10	21	0.14^{d}	0.16	0.17	0.14^{d}
12	20	0.14^{d}	0.19	0.20	0.14^{d}
14	20	0.14^{d}	0.22	0.23	0.14^{d}
16	20	0.14^{d}	0.25	0.26	0.14^{d}
18	20	0.15	0.28	0.30	0.14^{d}
20	20	0.17	0.32	0.33	0.14^{d}
6 ft by 3 ft by 7 in.[c]					
0 to 10	23	0.17^{d}	0.17^{d}	0.17^{d}	0.17^{d}
12	23	0.18	0.19	0.20	0.17^{d}
14	23	0.21	0.23	0.23	0.17^{d}
16	23	0.24	0.26	0.26	0.17^{d}
18	23	0.28	0.29	0.29	0.17^{d}
20	23	0.31	0.32	0.33	0.17^{d}
6 ft by 4 ft by 7 in.[c]					
0 to 8	23	0.17^{d}	0.17^{d}	0.17^{d}	0.17^{d}
10	22	0.17^{d}	0.18	0.19	0.17^{d}
12	22	0.17^{d}	0.21	0.22	0.17^{d}
14	22	0.18	0.25	0.26	0.17^{d}
16	22	0.21	0.28	0.29	0.17^{d}
18	22	0.23	0.32	0.33	0.17^{d}
20	22	0.26	0.35	0.36	0.17^{d}
6 ft by 5 ft by 7 in.[c]					
0 to 8	23	0.17^{d}	0.17^{d}	0.17^{d}	0.17^{d}
10	21	0.17^{d}	0.19	0.20	0.17^{d}
12	21	0.17^{d}	0.23	0.24	0.17^{d}
14	21	0.17^{d}	0.26	0.27	0.17^{d}
16	21	0.18	0.30	0.31	0.17^{d}
18	21	0.20	0.34	0.35	0.17^{d}
20	21	0.23	0.37	0.39	0.17^{d}
6 ft by 6 ft by 7 in.[c]					
0 to 6	26	0.17^{d}	0.17^{d}	0.17^{d}	0.17^{d}
8	24	0.17^{d}	0.17^{d}	0.18	0.17^{d}
10	24	0.17^{d}	0.20	0.21	0.17^{d}
12	24	0.17^{d}	0.23	0.25	0.17^{d}
14	23	0.17^{d}	0.27	0.29	0.17^{d}
16	23	0.17^{d}	0.31	0.32	0.17^{d}
18	23	0.18	0.34	0.36	0.17^{d}
7 ft by 4 ft by 8 in.[c]					
0 to 8	26	0.19^{d}	0.19^{d}	0.19^{d}	0.19^{d}
10	25	0.19^{d}	0.20	0.21	0.19^{d}
12	25	0.20	0.24	0.25	0.19^{d}
14	25	0.23^{d}	0.28	0.29	0.19^{d}
16	25	0.27	0.32	0.33	0.19^{d}
18	25	0.30	0.36	0.36	0.19^{d}
20	25	0.34	0.40	0.40	0.19^{d}
7 ft by 5 ft by 8 in.[c]					
0 to 8	26	0.19^{d}	0.19	0.19	0.19^{d}
10	25	0.19^{d}	0.22	0.23	0.19^{d}
12	25	0.19^{d}	0.26	0.27	0.19^{d}
14	25	0.21	0.30	0.31	0.19^{d}
16	25	0.23	0.34	0.35	0.19^{d}
18	25	0.26	0.38	0.39	0.19^{d}
7 ft by 6 ft by 8 in.[c]					
0 to 6	27	0.19^{d}	0.19^{d}	0.19^{d}	0.19^{d}
8	26	0.19^{d}	0.19^{d}	0.20	0.19^{d}
10	25	0.19^{d}	0.23	0.24	0.19^{d}
12	25	0.19^{d}	0.27	0.29	0.19^{d}
14	25	0.19^{d}	0.31	0.33	0.19^{d}
16	25	0.21	0.35	0.37	0.19^{d}
18	25	0.24	0.40	0.41	0.19^{d}

Continued on next page

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
7 ft by 7 ft by 8 in.[c]					
0 to 6	30	0.19[d]	0.19[d]	0.19[d]	0.19[d]
8	27	0.19[d]	0.19[d]	0.21	0.19[d]
10	27	0.19[d]	0.24	0.25	0.19[d]
12	27	0.19[d]	0.28	0.30	0.19[d]
14	26	0.19[d]	0.32	0.34	0.19[d]
16	26	0.20	0.36	0.38	0.19[d]
18	26	0.22	0.41	0.43	0.19[d]
8 ft by 4 ft by 8 in.[c]					
0 to 6	28	0.19[d]	0.19[d]	0.19[d]	0.19[d]
8	27	0.20	0.21	0.22	0.19[d]
10	27	0.24	0.26	0.27	0.19[d]
12	27	0.29	0.30	0.31	0.19[d]
14	27	0.34	0.35	0.36	0.19[d]
8 ft by 5 ft by 8 in.[c]					
0 to 6	28	0.19[d]	0.19[d]	0.19[d]	0.19[d]
8	27	0.19[d]	0.23	0.24	0.19[d]
10	26	0.22	0.28	0.29	0.19[d]
12	26	0.26	0.33	0.34	0.19[d]
14	26	0.30	0.38	0.39	0.19[d]
8 ft by 6 ft by 8 in.[c]					
0 to 5	28	0.19[d]	0.19[d]	0.19[d]	0.19[d]
6	27	0.19[d]	0.19[d]	0.20	0.19[d]
8	27	0.19[d]	0.24	0.26	0.19[d]
10	27	0.20	0.29	0.31	0.19[d]
12	27	0.24	0.35	0.36	0.19[d]
14	27	0.28	0.40	0.42	0.19[d]
8 ft by 7 ft by 8 in.[c]					
0 to 5	30	0.19[d]	0.19[d]	0.19[d]	0.19[d]
6	28	0.19[d]	0.20	0.22	0.19[d]
8	27	0.19[d]	0.25	0.27	0.19[d]
10	27	0.19[d]	0.30	0.33	0.19[d]
12	27	0.22	0.36	0.38	0.19[d]
14	27	0.26	0.42	0.44	0.19[d]
8 ft by 8 ft by 8 in.[c]					
0 to 4	34	0.19[d]	0.19[d]	0.19[d]	0.19[d]
5	31	0.19[d]	0.19[d]	0.20	0.19[d]
6	30	0.19[d]	0.20	0.23	0.19[d]
8	30	0.19[d]	0.26	0.28	0.19[d]
10	29	0.19[d]	0.31	0.34	0.19[d]
12	29	0.21	0.37	0.40	0.19[d]
14	29	0.24	0.42	0.45	0.19[d]
9 ft by 5 ft by 9 in.[c]					
0 to 6	31	0.22[d]	0.22[d]	0.22[d]	0.22[d]
8	30	0.22[d]	0.24	0.26	0.22[d]
10	29	0.26	0.30	0.31	0.22[d]
12	29	0.31	0.35	0.37	0.22[d]
14	29	0.36	0.41	0.42	0.22[d]
9 ft by 6 ft by 9 in.[c]					
0 to 6	31	0.22[d]	0.22[d]	0.22[d]	0.22[d]
8	29	0.22[d]	0.26	0.28	0.22[d]
10	29	0.24	0.32	0.33	0.22[d]
12	29	0.28	0.38	0.39	0.22[d]
14	29	0.33	0.43	0.45	0.22[d]
9 ft by 7 ft by 9 in.[c]					
0 to 5	32	0.22[d]	0.22[d]	0.22[d]	0.22[d]
6	30	0.22[d]	0.22[d]	0.24	0.22[d]
8	30	0.22[d]	0.27	0.29	0.22[d]
10	30	0.23	0.33	0.35	0.22[d]
12	29	0.27	0.39	0.41	0.22[d]
14	29	0.31	0.45	0.48	0.22[d]
9 ft by 8 ft by 9 in.[c]					
0 to 5	34	0.22[d]	0.22[d]	0.22[d]	0.22[d]
6	32	0.22[d]	0.22[d]	0.25	0.22[d]
8	31	0.22[d]	0.28	0.31	0.22[d]
10	31	0.22[d]	0.34	0.37	0.22[d]
12	30	0.25	0.40	0.43	0.22[d]
14	30	0.29	0.47	0.50	0.22[d]
9 ft by 9 ft by 9 in.[c]					
0 to 4	38	0.22[d]	0.22[d]	0.22[d]	0.22[d]
5	35	0.22[d]	0.22[d]	0.23	0.22[d]
6	34	0.22[d]	0.23	0.26	0.22[d]
8	33	0.22[d]	0.29	0.32	0.22[d]
10	33	0.22[d]	0.35	0.39	0.22[d]
12	32	0.24	0.41	0.45	0.22[d]
14	32	0.27	0.48	0.51	0.22[d]
10 ft by 5 ft by 10 in.[c]					
0 to 6	34	0.24[d]	0.24[d]	0.24[d]	0.24[d]
8	33	0.25	0.26	0.27	0.24[d]
10	33	0.31	0.32	0.33	0.24[d]
12	33	0.36	0.38	0.39	0.24[d]
14	32	0.42	0.44	0.45	0.24[d]
16	32	0.48	0.44	0.51	0.24[d]
10 ft by 6 ft by 10 in.[c]					
0 to 6	34	0.24[d]	0.24[d]	0.24[d]	0.24[d]
8	32	0.24[d]	0.28	0.30	0.24[d]
10	32	0.28	0.34	0.36	0.24[d]
12	32	0.33	0.40	0.42	0.24[d]
14	32	0.39	0.46	0.48	0.24[d]
10 ft by 7 ft by 10 in.[c]					
0 to 5	34	0.24[d]	0.24[d]	0.24[d]	0.24[d]
6	33	0.24[d]	0.24[d]	0.25	0.24[d]
8	32	0.24[d]	0.30	0.32	0.24[d]
10	32	0.26	0.36	0.38	0.24[d]
12	32	0.31	0.42	0.45	0.24[d]
14	32	0.36	0.49	0.51	0.24[d]
10 ft by 8 ft by 10 in.[c]					
0 to 5	36	0.24[d]	0.24[d]	0.24[d]	0.24[d]
6	34	0.24[d]	0.24[d]	0.27	0.24[d]
8	33	0.24[d]	0.31	0.33	0.24[d]
10	33	0.25	0.37	0.40	0.24[d]
12	32	0.29	0.44	0.47	0.24[d]
14	32	0.34	0.51	0.54	0.24[d]

Continued on next page.

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	*M*, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
		10 ft by 9 ft by 10 in.[c]			
0 to 4	38	0.24[d]	0.24[d]	0.24[d]	0.24[d]
5	36	0.24[d]	0.24[d]	0.25	0.24[d]
6	35	0.24[d]	0.25	0.29	0.24[d]
8	34	0.24[d]	0.32	0.35	0.24[d]
10	34	0.24[d]	0.38	0.42	0.24[d]
12	33	0.28	0.45	0.49	0.24[d]
14	33	0.32	0.52	0.56	0.24[d]
		10 ft by 10 ft by 10 in.[c]			
0 to 4	43	0.24[d]	0.24[d]	0.24[d]	0.24[d]
5	38	0.24[d]	0.24[d]	0.27	0.24[d]
6	37	0.24[d]	0.26	0.30	0.24[d]
8	36	0.24[d]	0.33	0.37	0.24[d]
10	36	0.24[d]	0.39	0.44	0.24[d]
12	35	0.27	0.46	0.50	0.24[d]
14	35	0.31	0.53	0.57	0.24[d]
		11 ft by 4 ft by 11 in.[c]			
0 to 2	38	0.26[d]	0.26[d]	0.26[d]	0.26[d]
3	38	0.26[d]	0.26[d]	0.26[d]	0.26[d]
4	38	0.26[d]	0.26[d]	0.26[d]	0.26[d]
5	37	0.26[d]	0.26[d]	0.26[d]	0.26[d]
6	37	0.26[d]	0.26[d]	0.26[d]	0.26[d]
8	37	0.31	0.26[d]	0.26[d]	0.26[d]
10	37	0.37	0.31	0.32	0.26[d]
12	37	0.45	0.36	0.37	0.26[d]
14	37	0.52	0.42	0.43	0.26[d]
16	37	0.60	0.47	0.48	0.26[d]
18	37	0.68	0.53	0.54	0.26[d]
		11 ft by 6 ft by 11 in.[c]			
0 to 2	36	0.26[d]	0.26[d]	0.26[d]	0.26[d]
3	36	0.26[d]	0.26[d]	0.26[d]	0.26[d]
4	36	0.26[d]	0.26[d]	0.26[d]	0.26[d]
5	36	0.26[d]	0.26[d]	0.26[d]	0.26[d]
6	35	0.26[d]	0.26[d]	0.26[d]	0.26[d]
8	35	0.27	0.29	0.31	0.26[d]
10	35	0.32	0.36	0.37	0.26[d]
12	35	0.38	0.42	0.44	0.26[d]
14	35	0.44	0.48	0.50	0.26[d]
16	35	0.50	0.55	0.57	0.26[d]
18	35	0.56	0.62	0.64	0.26[d]
		11 ft by 8 ft by 11 in.[c]			
0 to 2	38	0.26[d]	0.26[d]	0.26[d]	0.26[d]
3	37	0.26[d]	0.26[d]	0.26[d]	0.26[d]
4	36	0.26[d]	0.26[d]	0.26[d]	0.26[d]
5	36	0.26[d]	0.26[d]	0.26[d]	0.26[d]
6	35	0.26[d]	0.26[d]	0.28	0.26[d]
8	35	0.26[d]	0.32	0.34	0.26[d]
10	35	0.28	0.39	0.41	0.26[d]
12	35	0.33	0.46	0.48	0.26[d]
14	35	0.38	0.53	0.55	0.26[d]
16	35	0.43	0.60	0.65	0.26[d]
		11 ft by 10 ft by 11 in.[c]			
0 to 2	42	0.26[d]	0.26[d]	0.26[d]	0.26[d]
3	41	0.26[d]	0.26[d]	0.26[d]	0.26[d]
4	40	0.26[d]	0.26[d]	0.26[d]	0.26[d]
5	39	0.26[d]	0.26[d]	0.27	0.26[d]
6	39	0.26[d]	0.27	0.30	0.26[d]
8	38	0.26[d]	0.33	0.37	0.26[d]
10	37	0.26[d]	0.40	0.44	0.26[d]
12	37	0.30	0.47	0.52	0.26[d]
14	36	0.35	0.55	0.59	0.26[d]
16	36	0.39	0.62	0.66	0.26[d]
		11 ft by 11 ft by 11 in.[c]			
0 to 2	47	0.26[d]	0.26[d]	0.26[d]	0.26[d]
3	44	0.26[d]	0.26[d]	0.26[d]	0.26[d]
4	43	0.26[d]	0.26[d]	0.26[d]	0.26[d]
5	42	0.26[d]	0.26[d]	0.28	0.26[d]
6	41	0.26[d]	0.27	0.32	0.26[d]
8	40	0.26[d]	0.34	0.39	0.26[d]
10	39	0.26[d]	0.41	0.46	0.26[d]
12	39	0.29	0.48	0.53	0.26[d]
14	38	0.34	0.55	0.60	0.26[d]
16	38	0.38	0.62	0.68	0.26[d]
		12 ft by 4 ft by 12 in.[c]			
0 to 2	42	0.29[d]	0.29[d]	0.29[d]	0.29[d]
3	42	0.29[d]	0.29[d]	0.29[d]	0.29[d]
4	41	0.29[d]	0.29[d]	0.29[d]	0.29[d]
5	41	0.29[d]	0.29[d]	0.29[d]	0.29[d]
6	41	0.29[d]	0.29[d]	0.29[d]	0.29[d]
8	41	0.35	0.29[d]	0.29[d]	0.29[d]
10	41	0.43	0.32	0.33	0.29[d]
12	41	0.51	0.38	0.39	0.29[d]
14	41	0.59	0.44	0.45	0.29[d]
16	41	0.68	0.50	0.51	0.29[d]
18	41	0.77	0.56	0.57	0.29[d]
		12 ft by 6 ft by 12 in.[c]			
0 to 2	40	0.29[d]	0.29[d]	0.29[d]	0.29[d]
3	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
4	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
5	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
6	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
8	38	0.30	0.31	0.33	0.29[d]
10	38	0.37	0.38	0.39	0.29[d]
12	38	0.43	0.44	0.46	0.29[d]
14	38	0.50	0.51	0.53	0.29[d]
16	38	0.57	0.58	0.60	0.29[d]
18	38	0.64	0.65	0.67	0.29[d]
		12 ft by 8 ft by 12 in.[c]			
0 to 2	40	0.29[d]	0.29[d]	0.29[d]	0.29[d]
3	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
4	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
5	39	0.29[d]	0.29[d]	0.29[d]	0.29[d]
6	38	0.29[d]	0.29[d]	0.30	0.29[d]
8	38	0.29[d]	0.34	0.37	0.29[d]
10	38	0.32	0.41	0.44	0.29[d]
12	37	0.38	0.49	0.52	0.29[d]
14	37	0.43	0.56	0.59	0.29[d]
16	37	0.49	0.64	0.67	0.29[d]

Continued on next page.

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]				Design Earth Cover, ft[a]	M, Min in.	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}			A_{s1}	A_{s2}	A_{s3}	A_{s4}
12 ft by 10 ft by 12 in.[c]						12 ft by 12 ft by 12 in.[c]					
0 to 2	43	0.29[d]	0.29[d]	0.29[d]	0.29[d]	0 to 2	52	0.29[d]	0.29[d]	0.29[d]	0.29[d]
3	42	0.29[d]	0.29[d]	0.29[d]	0.29[d]	3	49	0.29[d]	0.29[d]	0.29[d]	0.29[d]
4	41	0.29[d]	0.29[d]	0.29[d]	0.29[d]	4	46	0.29[d]	0.29[d]	0.29[d]	0.29[d]
5	41	0.29[d]	0.29[d]	0.29[d]	0.29[d]	5	45	0.29[d]	0.29[d]	0.32	0.29[d]
6	40	0.29[d]	0.29[d]	0.33	0.29[d]	6	45	0.29[d]	0.30	0.35	0.29[d]
8	39	0.29[d]	0.36	0.40	0.29[d]	8	43	0.29[d]	0.38	0.43	0.29[d]
10	39	0.30	0.44	0.48	0.29[d]	10	43	0.29[d]	0.45	0.50	0.29[d]
12	39	0.34	0.51	0.55	0.29[d]	12	42	0.33	0.53	0.58	0.29[d]
14	38	0.39	0.59	0.63	0.29[d]	14	41	0.37	0.60	0.66	0.29[d]
16	38	0.45	0.67	0.71	0.29[d]	16	41	0.42	0.68	0.75	0.29[d]

[a] The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see Section 7.2.

[b] Design steel area in square inches per linear foot of box section at those locations that are indicated on the typical section included in Appendix X1.

[c] The box section designation, for example, 3 ft by 2 ft by 2 in. indicates (Interior Horizontal Span in feet) by (interior vertical rise in feet) by (wall and slab thickness in inches).

[d] Minimum practical steel area is specified.

Notes:
1. Design earth covers and reinforcement areas are based on the weight of a column of earth over the width of the box section as defined in Appendix X1. See Appendix X2 for modification to reinforcement areas for other earth load conditions.
2. Concrete design strength, 5000 psi.

6.2.3.3. Portland-pozzolan cement only, and

6.2.3.4. A combination of portland cement and fly ash wherein the proportion of fly ash is between 5 and 25 percent by weight of total cementitious materials (portland cement plus fly ash).

6.3. *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirements for gradation shall not apply.

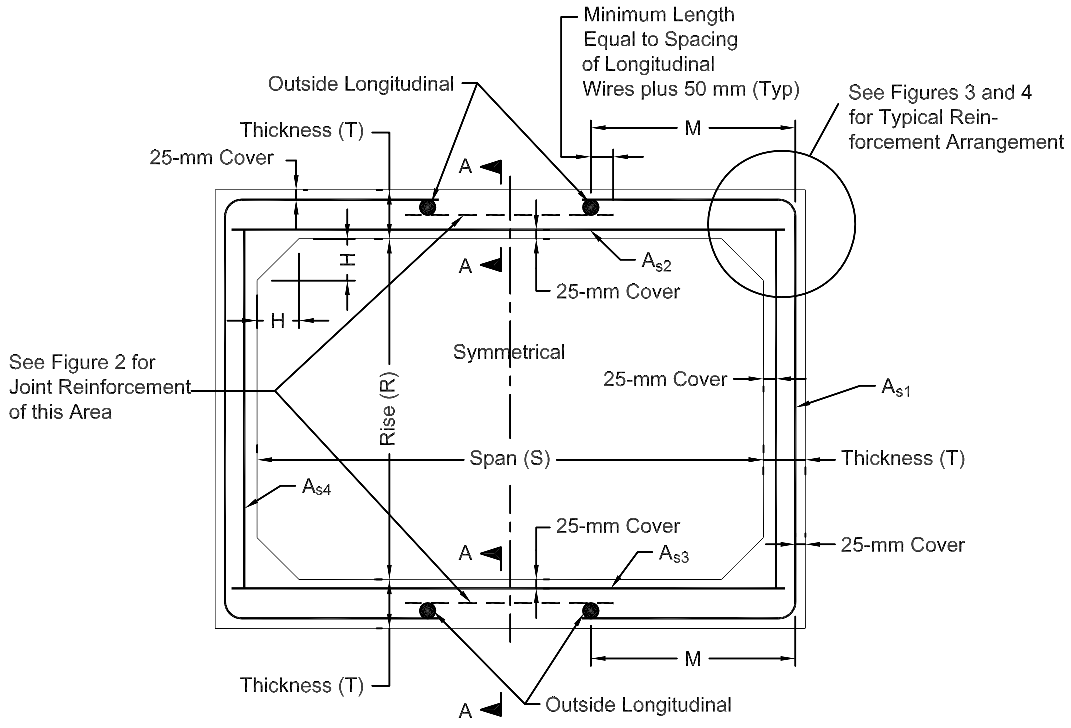
6.4. *Admixtures and Blends*—Admixtures and blends may be used with the approval of the owner.

6.5. *Steel Reinforcement*—Reinforcement shall consist of welded wire fabric conforming to M 55M/M 55 or M 221M/M 221.

6.6. *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers may be used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

7. DESIGN

7.1. *Design Tables*—The box section dimensions, compressive strength of the concrete, and reinforcement details shall be as prescribed in Tables 1, 2, or 3 and Figures 1, 2, and 3, subject to the provisions of Section 11. Table 1 sections are designed for combined earth dead load and AASHTO HS20 live load conditions. Table 2 sections are designed for combined earth dead load and Interstate live load conditions when the Interstate live loading exceeds the HS20 live loading. Table 3 sections are designed for earth dead load conditions only. Criteria used to develop Tables 1, 2, and 3 are given in Appendix X1. For modifications to the designs shown in Tables 1, 2, and 3 due to anticipated earth and surcharge loads different from those used to develop the tables, see Appendix X2.



Notes: 1. The dimension *M* is the total of the theoretical cutoff length plus the required anchorage.
2. The haunch dimension *H* is equal to the thickness *T*.

Figure 1—Typical Box Section

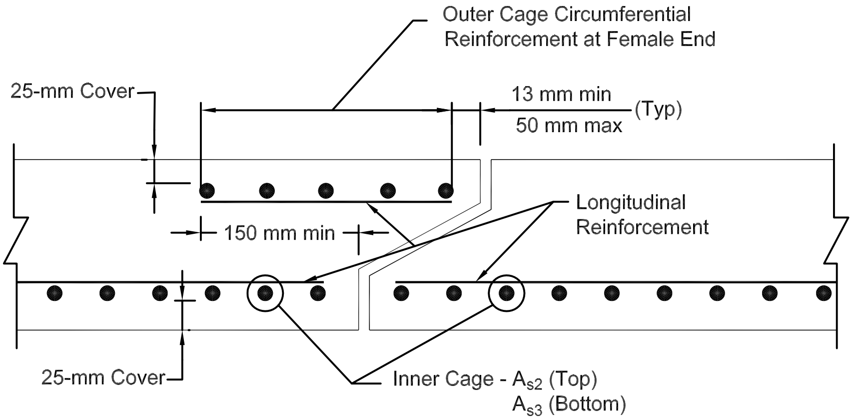


Figure 2—Section A-A Top and Bottom Slab Joint Reinforcement

7.2. *Modified and Special Designs*—The manufacturer may request approval by the owner of modified designs that differ from the designs in Section 7; or special designs for sizes and loads other than those shown in Tables 1, 2, and 3.

Note 3—The tabular designs in this specification were prepared according to AASHTO's *Standard Specifications for Highway Bridges*, 1973 Edition. The current AASHTO *Standard Specifications for Highway Bridges* allows concrete shear stress criteria that differ from the

1973 criteria. The use of current AASHTO concrete shear stress criteria shall be acceptable by this specification for modified or special designs.

7.3. *Placement of Reinforcement*—The cover of concrete over the circumferential reinforcement shall be 1 in., subject to the provisions of Section 11. The inside circumferential reinforcement shall extend into the male portion of the joint and the outside circumferential reinforcement shall extend into the female portion of the joint. The clear distance of the end circumferential wires shall be not less than $^1/_2$ in. or more than 2 in. from the ends of the box section. Reinforcement shall be assembled utilizing any combination of single or multiple layers of welded-wire fabric. A common reinforcement unit may be utilized for both A_{s2} (or A_{s3}) and A_{s4}, with the largest area requirement governing, bending the reinforcement 90 degrees at the corners and waiving the extension requirements of Figure 3. See Figure 4. The welded-wire fabric shall be composed of circumferential and longitudinal wires meeting the spacing requirements of Section 7.4 and shall contain sufficient longitudinal wires extending through the box section to maintain the shape and position of reinforcement. The exposure of the ends of longitudinals, stirrups, and spacers used to position the reinforcement shall not be a cause for rejection.

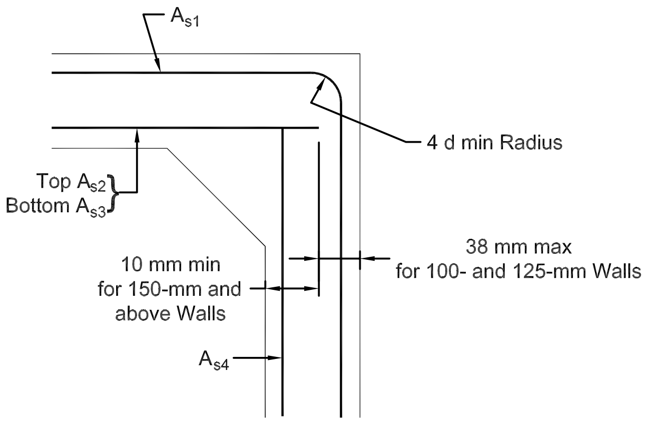


Figure 3—Detail Inner Reinforcement

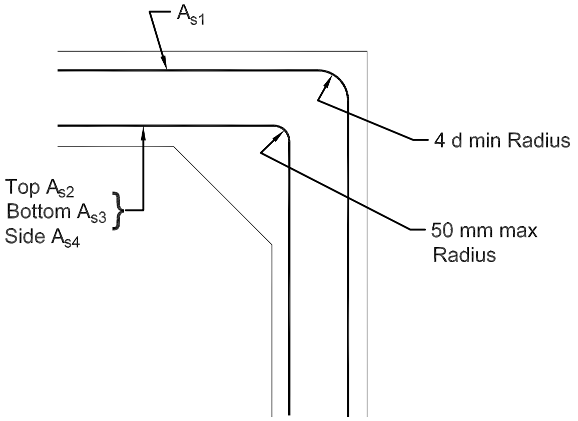


Figure 4—Detail Option

7.4. *Laps, Welds, and Spacing*—Splices in the circumferential reinforcement shall be made by lapping. The overlap measured between the outermost longitudinal wires of each fabric sheet shall not be less than the spacing of the longitudinal wires plus 2 in. If A_{s1} is extended and connected, welded splices shall be allowed in the connection. A_{s4} may be lapped and welded at any location or connected by welding at the corners to A_{s2} and A_{s3}. The spacing center-to-center of the circumferential wires shall not be less than 2 in. nor more than 4 in. The spacing center-to-center of the longitudinal wires shall not be more than 8 in.

8. JOINTS

8.1. The precast reinforced concrete box sections shall be produced with male and female ends. The ends shall be of such design and the ends of the box sections so formed that the sections can be laid together to make a continuous line of box sections compatible with the permissible variations given in Section 11.

8.2. Outer cage circumferential reinforcement as shown in Figures 1 and 2 shall be placed in the top and bottom slabs at the female portion of the joint when A_{s1} is not continuous over the span. The minimum area of such reinforcement in square inches per linear foot of box section length shall be the same as the areas specified for A_{s4} in Tables 1, 2, and 3.

9. MANUFACTURE

9.1. *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by weight. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 470 lb/yd^3 unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

9.2. *Curing*—The box sections shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength in 28 days or less. Any one of the following methods of curing or combinations thereof may be used:

9.2.1. *Steam Curing*—The box sections may be low pressure, steam cured by a system that will maintain a moist atmosphere.

9.2.2. *Water Curing*—The box sections may be water cured by any method that will keep the sections moist.

9.2.3. *Membrane Curing*—A sealing membrane conforming to the requirements of M 148 may be applied and shall be left intact until the required concrete compressive strength is attained. The concrete temperature at the time of application shall be within 10ºF of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

9.3. *Forms*—The forms used in manufacture shall be sufficiently rigid and accurate to maintain the box section dimensions within the permissible variations given in Section 11. All casting surfaces shall be of smooth nonporous material.

9.4. *Handling*—Handling devices or holes shall be permitted in each box section for the purpose of handling and laying.

10. PHYSICAL REQUIREMENTS

10.1. *Type of Specimen*—Compression tests for determining concrete compressive strength may be made on either concrete cylinders or on cores drilled from the boxed section.

10.2. *Compression Testing of Cylinders*:

10.2.1. *Cylinder Production*—Cylinders shall be prepared in accordance with the Cylinder Strength Test Method of T 280.

10.2.2. *Number of Cylinders*—Prepare not fewer than five test cylinders from a group (1 day's production of each concrete strength) of box sections.

10.2.3. *Acceptability on the Basis of Cylinder Test Results*:

10.2.3.1. When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength in the group of box sections shall be accepted.

10.2.3.2. When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the design concrete strength, then the compressive strength of the concrete in the group of box sections shall be accepted.

10.2.3.3. When the compressive strength of the cylinders tested does not conform to the acceptance criteria stated in Section 10.2.3.1 or Section 10.2.3.2, the acceptability of the group shall be determined in accordance with the provisions of Section 10.2.

10.3. *Compression Testing of Cores*:

10.3.1. *Obtaining Cores*—Cores shall be obtained and prepared in accordance with the Core Strength Test Method of T 280.

10.3.2. *Number of Cores*—One core shall be taken from a box section selected at random from each group of 15 box sections of a single size or fraction of such a group from each continuous production run.

10.4. *Acceptability on the Basis of Core Test Results*:

10.4.1. When the compressive strengths of cores tested for a group of box sections is equal to or greater than the design concrete strength, the compressive strength of the concrete for the group is acceptable.

10.4.2. If the compressive strength of the core tested is less than the design concrete strength, the box section from which that core was taken may be re-cored. If the compressive strength of the re-core is equal to or greater than the design concrete compressive strength, the compressive strength of the concrete for the group is acceptable.

10.4.3. If the compressive strength of the re-core is less than the design concrete strength, the box section from which the core was taken shall be rejected. Two box sections from the remainder of the group shall be selected at random and one core shall be taken from each box section. If the compressive strength of both cores is equal to or greater than the design concrete compressive strength, the concrete compressive strength of the remainder of the group shall be acceptable. If the compressive strength of either of the two cores tested is less than the design concrete compressive strength, then the remainder of the group shall be either rejected or, at the option of the manufacturer, each box section of the remainder of the group shall be cored and accepted individually, and any of the box sections that have a core with less than the design concrete compressive strength shall be rejected.

10.5. *Plugging Core Holes*—The core holes shall be plugged and sealed by the manufacturer in a manner such that the box section will meet all of the test requirements of this specification. Box sections so sealed shall be considered satisfactory for use.

10.6. *Test Equipment*—Every manufacturer furnishing box sections under this specification shall furnish all facilities and personnel necessary to carry out the tests required.

11. PERMISSIBLE VARIATIONS

11.1. *Internal Dimensions*—The internal dimensions shall not vary more than one percent from the design dimensions. The haunch dimensions shall not vary more than $^1/_4$ in. from the design dimensions.

11.2. *Slab and Wall Thickness*—The slab and wall thickness shall not be less than that shown in the design by more than 5 percent or $^3/_{16}$ in., whichever is greater. A thickness more than that required in the design shall not be a cause for rejection.

11.3. *Length of Opposite Surfaces*—Variations in laying lengths of two opposite surfaces of the box section shall not be more than $^1/_8$ in./ft of internal span, with a maximum of $^5/_8$ in. for all sizes through 7-ft internal span, and a maximum of $^3/_4$ in. for internal spans greater than 7 ft, except where beveled ends for laying on curves are specified by the owner.

11.4. *Length of Section*—The underrun in length of a section shall not be more than $^1/_8$ in./ft of length with a maximum of $^1/_2$ in. in any box section.

11.5. *Position of Reinforcement*—The maximum variation in the position of the reinforcement for 5 in. or less slab and wall thicknesses shall be $\pm^3/_8$ in., and for greater than 5-in. slab and wall thicknesses shall be $\pm^1/_2$ in. In no case, however, shall the cover over the reinforcement be less than $^5/_8$ in., as measured to the internal surface or the external surface. The preceding minimum cover limitation does not apply at the mating surfaces of the joint.

11.6. *Area of Reinforcement*—The areas of steel reinforcement shall be the design steel areas as shown in Tables 1, 2, or 3. Steel areas greater than those required shall not be cause for rejection. The permissible variation in diameter of any wire in finished fabric shall conform to the tolerances prescribed for the wire before fabrication by either M 32M/M 32 or M 225M/M 225 as applicable.

12. REPAIRS

12.1. Box sections may be repaired, if necessary, because of imperfections in manufacture or handling damage and will be acceptable if, in the opinion of the owner, the repaired box section conforms to the requirements of this specification.

13. INSPECTION

13.1. The quality of materials, the process of manufacture, and the finished box sections shall be subject to inspection by the owner.

14. REJECTION

14.1. Box sections shall be subject to rejection if it fails to conform to any of the specification requirements. Individual box sections may be rejected because of any of the following:

14.1.1. Fractures or cracks passing through the wall, except for a single-end crack that does not exceed the depth of the joint.

14.1.2. Defects that indicate mixing and molding, not in compliance with Section 9.1, or honeycombed or open texture that would adversely affect the function of the box sections.

14.1.3. The ends of the box sections are not normal to the walls and centerline of the box section, within the limits of variations given in Section 11, except where beveled ends are specified.

14.1.4. Damaged ends, where such damage would prevent making a satisfactory joint.

15. MARKING

15.1. The following information shall be clearly marked on each box section by indentation, waterproof paint, or other approved means:

15.1.1. Box section span, rise, table number, maximum and minimum design earth cover, and specification designation;

15.1.2. Date of manufacture;

15.1.3. Name or trademark of the manufacturer; and

15.1.4. Each section shall be clearly marked by indentation on either the inner or outer surface during the process of manufacture so that the location of the top will be evident immediately after the forms are stripped. In addition, the word “top” shall be lettered with waterproof paint on the inside top surface.

16. KEYWORDS

16.1. Concrete box—precast; culvert.

APPENDIXES

(Nonmandatory Information)

X1. DESIGN CRITERIA USED TO DEVELOP TABLES 1, 2, AND 3

X1.1. *Bedding and Backfill Assumptions*:

X1.1.1. The bedding is assumed to provide a slightly yielding, uniformly distributed support over the bottom width of the box section.

X1.1.2. The design earth covers and reinforcement areas are based on the weight of a column of earth over the width of the box section.

X1.1.3. Refer to Appendix X2 for other bedding and backfill conditions.

X1.2. *Criteria for Loads*:

X1.2.1. Design loads are based on the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges*, Thirteenth Edition.

X1.2.2. Live loads for designs given in Table 1 are H20 truck wheel loads as defined in the AASHTO specifications. Live loads for designs given in Table 2 are either the H20 truck wheel loads, or interstate truck wheel loads as defined in U.S. Department of Commerce, Bureau of Public Roads Circular Memorandum 22-40, 22 April 1957, depending upon which produces the more severe design strength requirements. Distribution of truck wheel loads through earth fills is in accordance with Article 1.3.3 of the AASHTO specifications. Earth cover loads for designs given in Tables 1, 2, and 3 are the weight of a column of earth of a width equal to the outside width dimension of the box section and a height equal to the depth of earth cover over the top of the section. This earth load is recommended in Article 1.2.2 (A) of the AASHTO Bridge Specifications for the normal case of box culverts on “yielding” subgrade. The AASHTO specifications define an “unyielding” subgrade as “rock or piles” and require the use of the Iowa formulas for this case. See Appendix X2 for a method to modify the designs given in Tables 1, 2, and 3 when the anticipated earth load, or earth load plus uniformly distributed surface surcharge load, is greater (or less) than the weight of the column of earth directly above the out-to-out width of the box sections.

X1.2.3. Article 1.2.2 of the AASHTO specification allows the design of buried structures, such as box section culverts, for 70 percent of the weight of earth directly above the out-to-out width of structures. On the other hand, the Marston-Spangler theory of earth loads on buried pipe gives a total earth load greater than the weight of the column of earth directly over the structure for most “positive projecting” culverts, and less than the weight of the column of earth over the structure for “trench type” installations, “negative projecting” culverts, and “induced trench” culverts. In view of the number of different installation conditions that may be encountered and the use of higher reinforcing steel stresses associated with the ultimate strength design method (Section X1.2), the 30 percent reduction in weight of supported earth load permitted in Article 1.2.2 of the AASHTO specification is not utilized for the tabulated designs, and a method of modifying designs for anticipated earth loads that differs from the above described “standard earth load” is given in Appendix X2.

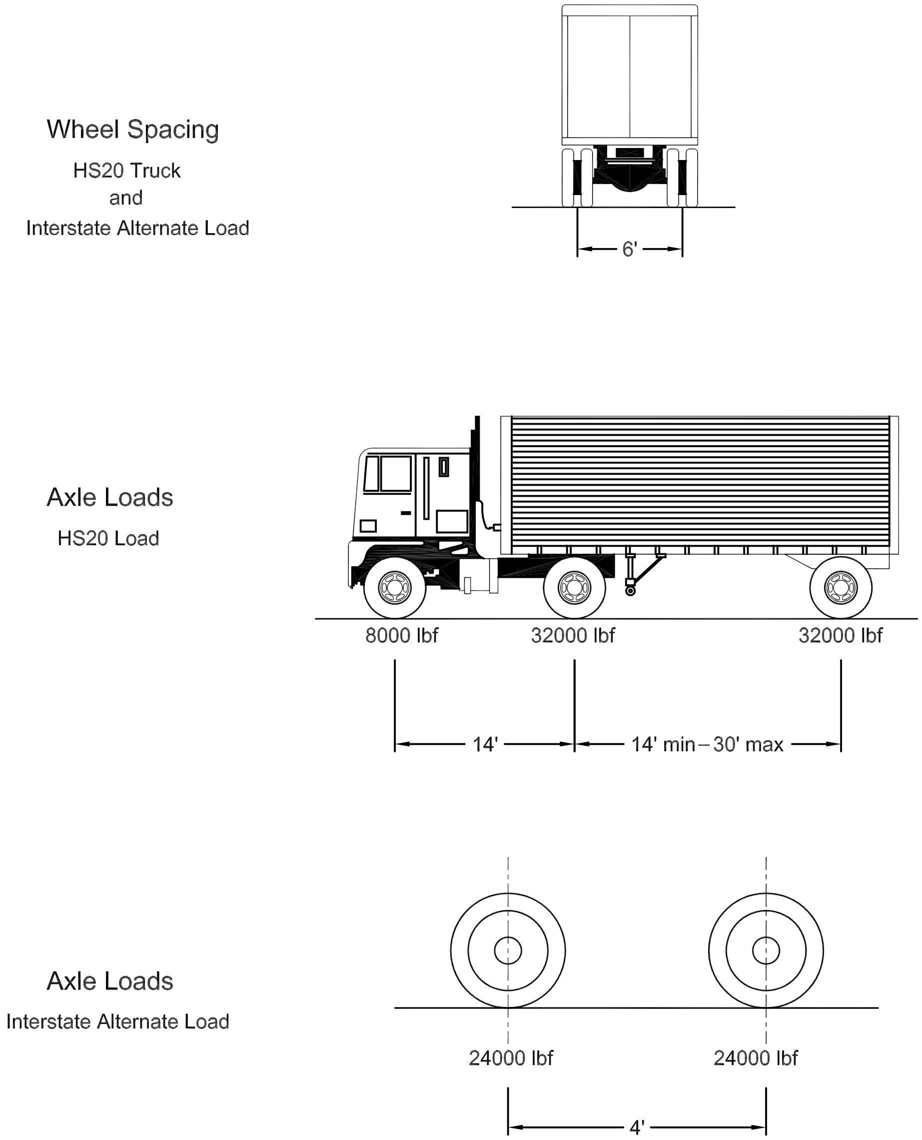


Figure X1.1—Axle Loads for Box Section Standard Designs

X1.2.4. Lateral earth pressure from weight of earth above and adjacent to a box section is taken as a minimum of 0.25 times vertical pressure, and an additional 0.25 times vertical pressure is added when determining steel areas only when areas are increased by such increased lateral pressure. For Tables 1 and 2, additional lateral pressure in lbf/ft^2 from approaching truck wheel loads is taken as 700 divided by depth of earth cover in feet and is added when determining steel areas only at sections where area is increased by increased lateral pressure.

X1.3. *Methods of Analysis*:

X1.3.1. The structural effects of the loads described in Section X1.2 are evaluated based on the elastic method of structural analysis. Design moments, shears, and thrusts are determined by computer analysis using the stiffness matrix method, and design is based on maximum stress resultants at critical sections caused by the most severe combination of design loads.

X1.4. *Method of Design*:

X1.4.1. Design heights of earth cover, wall thicknesses, and reinforcing steel areas are determined based on the elastic method structural analysis and the ultimate strength method of reinforced concrete design given in the 1971 ACI Building Code (ACI 318-71).[2] Steel areas are governed by ultimate flexural strength. The steel areas and the size and spacing of circumferential wires are proportioned to limit the maximum crack width to 0.01 in. under design load conditions. Evaluation of crack control with the welded wire fabric reinforcement specified for the tabulated designs is based on the results of research by Lloyd, Rejali, and Kesler[3] at the University of Illinois, and is significantly more conservative than the crack control provisions given in ACI 318-71. This is because it is recognized that approximations that were used to simplify the ACI crack control provisions can result in unconservative designs for thin elements such as slabs. Standard designs do not cover installations that must resist significant external water pressure. Furthermore, installations that are subject to high external water pressure may require vertical reinforcement for the inside face of the side walls. Lloyd, Rejali, and Kesler suggest that crack control equations developed for deformed bar reinforcement may also be used for both welded smooth wire fabric and deformed wire fabric reinforcement.

X1.4.2. Note that some box section designs shown in the tables have steel area requirements designated by "D" as minimum practical steel area. For such designs, the steel areas calculated for support of design loads are less than the minimum steel area that is specified for slabs in AASHTO Specification, 0.002 bt, and thus, the minimum reinforcement areas are shown in the tables.

X1.4.3. For specific criteria used in Tables 1, 2, and 3, refer to Table X1.1.

Table X1.1—Update on AASHTO Bridge Specification Edition Impact (variable with depth) (see AASHTO Bridge Specifications, 1977)

Material Properties:	
Welded wire fabric, minimum specified yield stress	65000 psi
Concrete, minimum specified compressive strength	5000 psi
Soil Data:	
Unit weight	120 lbf/ft^3
Ratio of lateral to vertical pressure from weight of earth	0.25 min to 0.50 max
Additional lateral pressure from approaching truck wheels	700 ÷ H, lbf/ft^2 where H =earth cover, ft
External water table	below box section invert
Effective weight coefficient	1.0
—	
Uniform internal pressure	0.0
Depth of water in box section	equal to inside height
External ground water pressure	0.0
Structural Arrangement:	
Concrete cover over steel	1.0 in.
Slab thickness	$^1/_{12}$ times inside span plus 1.0 in. up to 7-ft span—$^1/_{12}$ inside span above 7-ft span
Side Wall thickness	equal to slab thickness
Haunch dimensions	vertical and horizontal dimensions both equal to slab thickness
Minimum reinforcing inside face slabs and side walls, outside face side walls and corners of slabs	0.002 bt
The structural arrangement and details are shown in Figure 1	

[a] See ACI 318-71, Section 9.2.1(c).

X1.4.4. The maximum height of earth cover shown in the tables is determined by the shear strength of the box section without the use of special shear reinforcement, as given in Sections 11.2.1, 11.2.2, and 11.4.1 of ACI 318-71, and by the "standard weight" of the column of earth directly above the box section. See Table X1.2 for the maximum loads that can be carried on the standard box sections. These loads can be used to determine maximum earth cover heights when the anticipated weight of earth supported by the section is greater than (or less than) the above "standard weight" of earth cover.

Table X1.2—Design Information for Revising Tabulated Reinforcing Steel Areas

	Change in Reinforcing Steel Area per 1000 lbf/ft Change in Total Weight on Box Section				Change in Reinforcing Steel Area per 1000 lbf/ft Change in Total Weight on Box Section		
Culvert Size	ΔA_{s1}, in.^{2}/ft	ΔA_{s2} ΔA_{s3}, in.^{2}/ft	Maximum W, lbf/ft[a]	Culvert Size	ΔA_{s1}, in.^{2}/ft	ΔA_{s2} ΔA_{s3}, in.^{2}/ft	Maximum W, lbf/ft[a]
3 ft by 2 ft by 4 in.	0.018	0.023	9500	9 ft by 5 ft by 9 in.	0.022	0.025	20300
3 ft by 3 ft by 4 in.	0.013	0.028	9400	9 ft by 6 ft by 9 in.	0.020	0.027	20100
4 ft by 2 ft by 5 in.	0.021	0.020	12200	9 ft by 7 ft by 9 in.	0.018	0.029	19800
4 ft by 3 ft by 5 in.	0.016	0.025	12100	9 ft by 8 ft by 9 in.	0.016	0.030	19600
4 ft by 4 ft by 5 in.	0.013	0.028	12000	9 ft by 9 ft by 9 in.	0.015	0.031	19400
5 ft by 3 ft by 6 in.	0.019	0.022	14800	10 ft by 5 ft by 10 in.	0.022	0.023	22800
5 ft by 4 ft by 6 in.	0.015	0.025	14700	10 ft by 6 ft by 10 in.	0.020	0.025	22500
5 ft by 5 ft by 6 in.	0.012	0.028	14500	10 ft by 7 ft by 10 in.	0.019	0.027	22300
6 ft by 3 ft by 7 in.	0.020	0.020	17500	10 ft by 9 ft by 10 in.	0.017	0.028	22100
6 ft by 4 ft by 7 in.	0.017	0.023	17300	10 ft by 9 ft by 10 in.	0.015	0.030	21800
6 ft by 5 ft by 7 in.	0.013	0.020	17100	10 ft by 10 ft by 10 in.	0.014	0.031	21600
6 ft by 6 ft by 7 in.	0.013	0.028	16900	11 ft by 4 ft by 11 in.	0.024	0.020	25300
7 ft by 5 ft by 8 in.	0.019	0.022	19800	11 ft by 6 ft by 11 in.	0.021	0.023	24900
7 ft by 5 ft by 8 in.	0.016	0.024	19600	11 ft by 9 ft by 11 in.	0.018	0.026	24500
7 ft by 6 ft by 8 in.	0.014	0.026	19400	11 ft by 10 ft by 11 in.	0.015	0.029	24000
7 ft by 7 ft by 8 in.	0.013	0.028	19300	11 ft by 11 ft by 11 in.	0.013	0.030	23800
8 ft by 4 ft by 8 in.	0.024	0.024	18000	12 ft by 4 ft by 12 in.	0.025	0.018	27800
8 ft by 5 ft by 8 in.	0.021	0.027	17800	12 ft by 6 ft by 12 in.	0.022	0.021	27400
8 ft by 6 ft by 8 in.	0.018	0.029	17600	12 ft by 8 ft by 12 in.	0.019	0.024	27000
8 ft by 7 ft by 8 in.	0.016	0.030	17400	12 ft by 10 ft by 12 in.	0.016	0.027	26500
8 ft by 8 ft by 8 in.	0.015	0.032	17200	12 ft by 12 ft by 12 in.	0.013	0.030	26200

[a] Maximum allowable total weight on box section as governed by shear strength of box section without stirrups.

X1.5. *Multiple-Cell Installations*:

X1.5.1. The designs given herein are for single cell precast reinforced concrete box sections. The units may be used in parallel for multicell installations if means of positive lateral bearing by continuous contact between the sides of adjacent boxes are provided. Compacted earth fill, granular backfill, or grouting between the units are considered means of providing such positive bearing.

X2. MODIFICATION OF “STANDARD” BOX SECTION DESIGNS FOR EARTH LOADS DIFFERENT FROM THE “STANDARD” EARTH LOAD

X2.1. The heights of cover given in Tables 1, 2, and 3 are based on a “standard weight of earth fill” equal to the weight of a column of earth with a unit weight of 120 lb/ft^3 and a width equal to the out-to-out width of the box section. For some installations, the design engineer may determine that for a given height of cover, the weight of earth to be supported by the box section is more or less than the above “standard weight of earth fill” used to develop the designs given in the tables.

X2.1.1. For example, the Marston-Spangler theory for loads on buried structures indicates that the weight of earth that must be supported by most “positive projecting” conduits is greater than the weight of a column of earth directly over the conduit, while the weight of earth that must be supported by “trench-type” conduits, “negative-projecting” conduits, and “induced-trench” conduits is less than the weight of earth over the conduits. Also, the designer may wish to use a unit weight of earth more or less than the 120 lb/ft^3 used in the “standard weight,” or may wish to include a particular uniformly distributed surface surcharge loading.

X2.2. Incremental reinforcing steel areas are given in Table X1.1 for each box section type. Where installation conditions warrant the use of a weight of earth more or less than the “standard weight,” the designer may utilize these incremental areas to modify the steel areas given in Tables 1, 2, or 3 for a particular height of cover. The maximum total weight of earth fill that may be supported over the out-to-out width of each standard box section size, as governed by shear strength without shear reinforcing, is also given in Table X1.2. Thus, for any weight of earth or surface surcharge, or both, a designer can use Tables 1, 2, 3, and X1.2, to determine the required area of reinforcing steel for various heights of earth cover, or the maximum height of earth cover without special shear reinforcing, for any of the standard box section sizes shown in these tables.

X2.3. The following design example illustrates how the previously mentioned tables may be used to obtain a suitable design for a box section to support an earth load that is greater than the “standard weight of earth” used to develop Tables 1, 2, and 3.

X2.3.1. *Example*:

X2.3.1.1. *Given*—A 6 ft by 6 ft by 7 in. Table 1 precast concrete box section under 14 ft of cover with 110 lb/ft^3 earth and an effective weight of earth supported by the section of 1.36 times the weight of the column of earth directly over the section instead of the standard 120 lb/ft^3 earth.

X2.3.1.2. *Find*—The required A_{s1}, A_{s2}, and A_{s3} circumferential reinforcement areas. In all cases A_{s4} is governed by the minimum steel areas as described in X1.4.2 and is not changed by increased vertical loads.

X2.3.2. *Solution*:

X2.3.2.1. Effective unit weight of soil = 110 × 1.36 = 150 lb/ft^3

X2.3.2.2. Determine change in total weight of earth on culvert in kps force/linear ft (1000 lbf):

$$W = H \times B \times w \qquad (X2.1)$$

where:

W = total weight of earth on culvert, kf/linear ft;
H = height of earth cover, ft;
B = outside span, ft;
w = unit weight of earth, kf/ft^3;
W_{120} = 14 × 7.167 × 0.120 = 12.040 kf/ft;
W_{150} = 14 × 7.167 × 0.150 = 15.051 kf/ft; and
W = $W_{150} - W_{120}$ = 3.011 kf/ft

X2.3.2.3. Determine the change in circumferential reinforcement areas. From Table 1, for a 6 ft by 6 ft by 7 in. section under 14 ft of cover A_{s1} = 0.17, A_{s2} = 0.32, and A_{s3} = 0.33 in.^{2}/ft. From Table X1.2, for a 6 ft by 6 ft by 7 in. section, the changes in reinforcing areas are for A_{s1} = 0.013, A_{s2} and A_{s3} = 0.02B in.^{2}/ft for each 1000 lbf/ft of load change. Therefore:

$$\Delta A_{s1} = 3.011 \times 0.013 = 0.039$$

$$\Delta A_{s2} = 3.011 \times 0.028 = 0.084$$

$$\Delta A_{s3} = 3.011 \times 0.028 = 0.084$$

Therefore, the correct reinforcement areas are as follows:

$$A_{s1} = 0.17 + 0.04 = 0.21 \text{ in.}^2/\text{ft}$$

$$A_{s2} = 0.32 + 0.08 = 0.40 \text{ in.}^2/\text{ft}$$

$$A_{s3} = 0.33 + 0.08 = 0.41 \text{ in.}^2/\text{ft}$$

X2.3.2.4. Determine if the total weight of earth on the culvert is less than the maximum as governed by the shear strength of culvert without stirrups.

From Table X1.2, the maximum allowable weight = 16 900 lbf/ft. From Section X2.3.2.2,

W_{150} = 15 051 lbf/ft

The approximate equivalent uniform load from an HS20 live-load at 14-ft burial depth is about 160 lbf/ft^2 or a total load of 1150 lbf/ft (160 × 7.167). Therefore, the total weight on the box section is 16 200 lbf/ft (15 050 + 1150), which is less than the maximum allowable; therefore, the design is satisfactory.

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[1] Standard designs and criteria used to develop designs included in this specification are under the jurisdiction of the AASHTO Subcommittee on Bridges and Structures.

[2] Available from the American Concrete Institute, P.O. Box 4754, Redford Station, Detroit, MI 48219.

[3] Lloyd, J. P., H. M. Rejali, and C. E. Kesler, "Crack Control in One-Way Slabs Reinforced with Deformed Welded Wire Fabric." *Journal of the American Concrete Institute Proceedings.* PACIA, Vol. 66, No. 5, May 1969.

Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers [Metric]

AASHTO Designation: M 259M-00 (2008)[1]
ASTM Designation: C 789M-98

American Association of State Highway and Transportation Officials
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Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers [Metric]

AASHTO Designation: M 259M-00 (2008)[1]
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1. SCOPE

1.1. This specification covers single-cell precast reinforced concrete box sections intended to be used for the construction of culverts and for the conveyance of storm water, industrial wastes, and sewage.

1.2. This specification is the metric counterpart of M 259.

Note 1—This specification is primarily a manufacturing and purchasing specification. However, standard designs are included and the criteria used to develop these designs are given in the Appendices. The successful performance of this product depends upon the proper selection of the box section, bedding, and backfill, and care that the installation conforms to the construction specifications. The owner of the precast reinforced concrete box sections specified herein is cautioned that the loading conditions and field requirements must properly correlate with the box section specified and that inspection at the construction site must be provided.

Note 2—AASHTO M 273M is to be used for box sections with less than 0.6 m of cover subjected to highway loading.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement
- M 262, Concrete Pipe and Related Products
- M 273M, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 0.6 m of Cover Subjected to Highway Loadings [Metric]
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- T 280, Concrete Pipe, Manhole Sections, or Tile
- *Standard Specifications for Highway Bridges*

2.2. *ASTM Standard*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete

2.3. *ACI Code*:

- ACI 318-71, Building Code

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. TYPES

4.1. Precast reinforced concrete box sections manufactured in accordance with this specification shall be of three types identified in Tables 1, 2, and 3, and shall be designated by type, span, rise, and design earth cover.

Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions^a

Design Earth Cover, m^a	M, Min, mm	Circumferential Reinforcement Areas^b			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
900 mm by 600 mm by 100 mm^c					
0.6	430	400	420	440	210^d
0.9	380	210	230	230	210^d
1.2 to 2.4	380	210^d	210^d	210^d	210^d
3.0	380	210^d	230	230	210^d
3.7	360	210^d	280	280	210^d
4.3	360	230	300	300	210^d
4.9	360	250	340	340	210^d
5.5	360	280	360	380	210^d
6.1	360	300	400	400	210^d
900 mm by 900 mm by 100 mm^c					
0.6	690	320	510	530	210^d
0.9	510	210^d	280	300	210^d
1.2 to 1.8	430	210^d	210^d	210^d	210^d
2.4	380	210^d	230	230	210^d
3.0	380	210^d	250	280	210^d
3.7	380	210^d	300	300	210^d
4.3	380	210^d	320	340	210^d
4.9	380	210^d	360	380	210^d
5.5	380	210^d	400	400	210^d
6.1	380	230	440	440	210^d
1200 mm by 600 mm by 125 mm^c					
0.6	480	550	470	420	250^d
0.9	460	320	280	280	250^d
1.2 to 2.4	460	250^d	250^d	250^d	250^d
3.0	430	280	280	300	250^d
3.7	430	320	320	320	250^d
4.3	430	360	360	360	250^d
4.9	430	400	400	400	250^d
5.5	430	440	440	440	250^d
1200 mm by 900 mm by 125 mm^c					
0.6	560	440	570	510	250^d
0.9	480	280	340	340	250^d
1.2	460	250^d	280	280	250^d
1.5	460	250^d	250^d	280	250^d
1.8	430	250^d	250^d	280	250^d
2.4	430	250^d	300	300	250^d
3.0	430	250^d	320	340	250^d
3.7	430	250^d	360	380	250^d
4.3	430	280	420	420	250^d
4.9	430	320	470	470	250^d
5.5	430	340	510	510	250^d
1200 mm by 1200 mm by 125 mm^c					
0.6	860	380	640	590	250^d
0.9	610	250^d	380	380	250^d
1.2	530	250^d	300	320	250^d
1.5	510	250^d	280	300	250^d
1.8	480	250^d	300	300	250^d
2.4	460	250^d	320	320	250^d
3.0	460	250^d	340	360	250^d
3.7	460	250^d	400	400	250^d
4.3	460	250^d	440	440	250^d
4.9	460	250^d	490	510	250^d
5.5	430	300	530	550	250^d
1500 mm by 900 mm by 150 mm^c					
0.6	580	760	590	490	300^d
0.9	530	360	380	380	300^d
1.2	530	300^d	320	320	300^d
1.5	510	300^d	300^d	320	300^d
1.8	510	300^d	320	320	300^d
2.4	510	300^d	340	340	300^d
3.0	510	320	380	400	300^d
3.7	510	360	420	440	300^d
4.3	510	400	490	490	300^d
4.9	480	440	550	550	300^d
5.5	480	490	590	610	300^d
1500 mm by 1200 mm by 150 mm^c					
0.6	710	490	680	570	300^d
0.9	580	320	420	440	300^d
1.2 to 1.8	560	300^d	340	360	300^d
2.4	510	300^d	360	380	300^d
3.0	510	300^d	420	440	300^d
3.7	510	300^d	470	490	300^d
4.3	510	340	530	550	300^d
4.9	480	380	590	610	300^d
5.5	480	420	660	660	300^d
1500 mm by 1500 mm by 150 mm^c					
0.6	1040	420	740	610	300^d
0.9	740	300^d	470	490	300^d
1.2	640	300^d	380	400	300^d
1.5	610	300^d	360	380	300^d
1.8	560	300^d	360	380	300^d
2.4	560	300^d	380	400	300^d
3.0	530	300^d	440	470	300^d

Continued on next page.

Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3.7	530	300[d]	490	510	300[d]
4.3	530	300[d]	550	570	300[d]
4.9	530	340	610	640	300[d]
5.5	510	360	680	700	300[d]
1800 mm by 900 mm by 175 mm[c]					
0.6	740	640	610	470	360[d]
0.9	610	440	400	380	360[d]
1.2	610	380	360[d]	360[d]	360[d]
1.5	610	360[d]	360[d]	360[d]	360[d]
1.8	580	360[d]	360[d]	360[d]	360[d]
2.4	580	360[d]	380	380	360[d]
3.0	580	420	420	440	360[d]
3.7	580	490	490	510	360[d]
4.3	580	550	550	550	360[d]
4.9	580	590	610	610	360[d]
5.5	580	660	680	680	360[d]
1800 mm by 1200 mm by 175 mm[c]					
0.6	710	550	700	550	360[d]
0.9	640	380	470	440	360[d]
1.2	610	360[d]	400	400	360[d]
1.5	580	360[d]	380	400	360[d]
1.8	580	360[d]	380	400	360[d]
2.4	580	360[d]	420	410	360[d]
3.0	560	380	490	510	360[d]
3.7	560	420	550	550	360[d]
4.3	560	470	610	640	360[d]
4.9	560	510	680	700	360[d]
5.5	560	570	740	760	360[d]
1800 mm by 1500 mm by 175 mm[c]					
0.6	840	510	760	610	360[d]
0.9	690	360[d]	510	490	360[d]
1.2 to 1.8	640	360[d]	420	440	360[d]
2.4	580	360[d]	440	470	360[d]
3.0	580	360[d]	510	530	360[d]
3.7	580	360[d]	570	610	360[d]
4.3	580	400	660	680	360[d]
4.9	560	440	720	740	360[d]
5.5	560	490	780	830	360[d]
1800 mm by 1800 mm by 175 mm[c]					
0.6	1200	470	830	660	360[d]
0.9	840	360[d]	550	530	360[d]
1.2	740	360[d]	470	490	360[d]
1.5	690	360[d]	440	470	360[d]
1.8	660	360[d]	440	470	360[d]
2.4	640	360[d]	470	510	360[d]
3.0	610	360[d]	530	570	360[d]
3.7	610	360[d]	590	640	360[d]
4.3	610	360[d]	680	700	360[d]
4.9	610	400	740	780	360[d]
5.5	580	440	800	850	360[d]
2100 mm by 1200 mm by 200 mm[c]					
0.6	810	640	720	530	400[d]
0.9	690	440	490	440	400[d]
1.2	690	400[d]	420	420	400[d]
1.5	660	400[d]	420	440	400[d]
1.8	660	400[d]	420	440	400[d]
2.4	660	420	470	490	400[d]
3.0	640	490	530	550	400[d]
3.7	640	530	610	610	400[d]
4.3	640	590	680	700	400[d]
4.9	640	660	760	760	400[d]
5.5	640	720	830	850	400[d]
2100 mm by 1500 mm by 200 mm[c]					
0.6	810	570	780	590	400[d]
0.9	710	400[d]	550	490	400[d]
1.2 to 1.8	690	400[d]	470	490	400[d]
2.4	660	400[d]	510	530	400[d]
3.0	640	420	570	610	400[d]
3.7	640	470	660	680	400[d]
4.3	640	530	740	760	400[d]
4.9	640	570	800	850	400[d]
5.5	640	640	890	910	400[d]
2100 mm by 1800 mm by 200 mm[c]					
0.6	970	510	830	660	400[d]
0.9	790	400[d]	570	550	400[d]
1.2	740	400[d]	510	530	400[d]
1.5	710	400[d]	490	530	400[d]
1.8	690	400[d]	510	530	400[d]
2.4	660	400[d]	550	570	400[d]
3.0	660	400[d]	610	640	400[d]
3.7	660	420	700	720	400[d]
4.3	640	470	760	800	400[d]
4.9	640	530	850	890	400[d]
5.5	640	570	930	970	400[d]
2100 mm by 2100 mm by 200 mm[c]					
0.6	1400	470	890	700	400[d]
0.9	970	400[d]	610	570	400[d]
1.2 to 1.8	840	400[d]	530	570	400[d]
2.4	710	400[d]	570	610	400[d]
3.0	690	400[d]	640	680	400[d]
3.7	690	400[d]	720	760	400[d]
4.3	690	440	780	830	400[d]
4.9	690	490	870	910	400[d]
2400 mm by 1200 mm by 200 mm[c]					
0.6	860	780	850	610	400[d]
0.9	790	570	590	510	400[d]
1.2	710	530	530	510	400[d]
1.5	710	550	530	550	400[d]
1.8	710	550	550	550	400[d]
2.4	690	590	590	610	400[d]
3.0	690	680	680	700	400[d]
3.7	690	760	760	780	400[d]
4.3	690	850	870	890	400[d]
2400 mm by 1500 mm by 200 mm[c]					
0.6	890	720	910	680	400[d]
0.9	790	530	660	570	400[d]
1.2	710	490	570	570	400[d]
1.5	710	510	570	610	400[d]

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Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions^a *(Continued)*

Design Earth Cover, m^a	M, Min, mm	Circumferential Reinforcement Areas^b			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
1.8	690	510	590	610	400^d
2.4	690	550	640	680	400^d
3.0	690	610	740	760	400^d
3.7	690	680	830	870	400^d
2400 mm by 1800 mm by 200 mm^c					
0.6	910	660	970	740	400^d
0.9	790	490	700	610	400^d
1.2	760	470	610	610	400^d
1.5	740	490	610	660	400^d
1.8	710	470	640	660	400^d
2.4	690	510	680	720	400^d
3.0	690	570	780	830	400^d
3.7	690	640	890	910	400^d
2400 mm by 2100 mm by 200 mm^c					
0.6	1040	590	1040	800	400^d
0.9	890	470	740	680	400^d
1.2	810	420	660	660	400^d
1.5	790	440	660	700	400^d
1.8	760	440	660	720	400^d
2.4	740	470	720	760	400^d
3.0	710	530	800	890	400^d
3.7	710	590	910	970	400^d
2400 mm by 2400 mm by 200 mm^c					
0.6	1550	550	1080	850	400^d
0.9	1040	420	780	720	400^d
1.2	910	400^d	680	700	400^d
1.5	860	420	680	740	400^d
1.8	810	420	700	760	400^d
2.4	790	440	740	800	400^d
3.0	760	490	850	910	400^d
3.7	740	550	930	1020	400^d
2700 mm by 1500 mm by 225 mm^c					
0.6	970	760	910	660	470^d
0.9	860	590	680	570	470^d
1.2	790	550	590	570	470^d
1.5	790	590	610	610	470^d
1.8	760	610	640	660	470^d
2.4	760	640	680	720	470^d
3.0	760	720	780	830	470^d
3.7	760	800	890	910	470^d
4.3	740	910	990	1020	470^d
2700 mm by 1800 mm by 225 mm^c					
0.6	970	700	970	720	470^d
0.9	860	550	720	610	470^d
1.2	810	510	660	610	470^d
1.5	790	550	660	680	470^d
1.8	760	570	680	720	470^d
2.4	760	590	740	780	470^d
3.0	760	660	850	870	470^d
3.7	740	740	950	990	470^d
2700 mm by 2100 mm by 225 mm^c					
0.6	1040	640	1040	780	470^d
0.9	910	510	760	680	470^d
1.2	840	490	680	680	470^d
1.5	810	510	700	720	470^d
1.8	790	530	720	760	470^d
2.4	790	550	780	830	470^d
3.0	760	610	890	930	470^d
3.7	760	700	990	1040	470^d
2700 mm by 2400 mm by 225 mm^c					
0.6	1170	590	1080	830	470^d
0.9	990	490	800	720	470^d
1.2	910	470^d	720	720	470^d
1.5	860	490	740	780	470^d
1.8	840	510	740	800	470^d
2.4	810	530	800	870	470^d
3.0	790	590	910	970	470^d
3.7	790	660	1040	1100	470^d
2700 mm by 2700 mm by 225 mm^c					
0.6	1730	570	1140	890	470^d
0.9	1140	470^d	850	760	470^d
1.2	1040	470^d	760	760	470^d
1.5	970	470^d	760	830	470^d
1.8	910	490	780	850	470^d
2.4	860	510	850	910	470^d
3.0	840	550	950	1020	470^d
3.7	840	610	1060	1140	470^d
3000 mm by 1500 mm by 250 mm^c					
0.6	1040	800	910	660	510^d
0.9	970	640	680	570	510^d
1.2	890	610	640	590	510^d
1.5	860	660	640	640	510^d
1.8	840	700	680	700	510^d
2.4	840	740	740	760	510^d
3.0	840	850	850	870	510^d
3.7	840	950	950	970	510^d
4.3	840	1060	1060	1080	510^d
3000 mm by 1800 mm by 250 mm^c					
0.6	1040	740	970	720	510^d
0.9	940	610	740	640	510^d
1.2	860	570	680	640	510^d
1.5	840	610	700	700	510^d
1.8	840	660	720	760	510^d
2.4	840	700	780	830	510^d
3.0	810	780	890	930	510^d
3.7	810	870	1020	1060	510^d
4.3	810	970	1120	1160	510^d
3000 mm by 2100 mm by 250 mm^c					
0.6	1070	680	1040	760	510^d
0.9	970	570	780	680	510^d
1.2	890	550	720	680	510^d
1.5	860	570	740	740	510^d
1.8	860	610	760	800	510^d
2.4	840	660	830	890	510^d
3.0	840	720	950	990	510^d
3.7	810	800	1060	1100	510^d

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Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3000 mm by 2400 mm by 250 mm[c]					
0.6	1140	660	1100	830	510^d
0.9	1020	550	830	720	510^d
1.2	940	530	760	740	510^d
1.5	910	550	780	800	510^d
1.8	890	570	800	870	510^d
2.4	860	610	870	930	510^d
3.0	840	680	990	1060	510^d
3.7	840	760	1100	1160	510^d
3000 mm by 2700 mm by 250 mm[c]					
0.6	1330	610	1140	890	510^d
0.9	1120	510^d	870	780	510^d
1.2	1020	510^d	780	780	510^d
1.5	970	530	800	850	510^d
1.8	940	550	850	910	510^d
2.4	910	590	910	970	510^d
3.0	890	660	1020	1100	510^d
3.7	860	720	1140	1230	510^d
3000 mm by 3000 mm by 250 mm[c]					
0.6	1900	610	1190	930	510^d
0.9	1270	510^d	910	830	510^d
1.2	1140	510^d	830	830	510^d
1.5	1070	510^d	850	890	510^d
1.8	1020	530	870	950	510^d
2.4	970	570	930	1020	510^d
3.0	940	640	1060	1140	510^d
3.7	910	700	1160	1270	510^d
3300 mm by 1200 mm by 275 mm[c]					
0.6	1140	930	850	570	550^d
0.9	1090	740	640	550^d	550^d
1.2	1070	740	590	550^d	550^d
1.5	990	780	610	590	550^d
1.8	970	830	640	640	550^d
2.4	970	910	700	720	550^d
3.0	940	1040	800	830	550^d
3.7	940	1160	910	930	550^d
4.3	940	1310	1020	1040	550^d
4.9	940	1460	1120	1140	550^d
3300 mm by 1800 mm by 275 mm[c]					
0.6	1120	780	970	700	550^d
0.9	1040	660	740	640	550^d
1.2	970	640	700	640	550^d
1.5	910	680	720	700	550^d
1.8	910	720	740	760	550^d
2.4	910	780	830	870	550^d
3.0	890	890	930	970	550^d
3.7	890	970	1060	1100	550^d
4.3	890	1100	1190	1230	550^d
4.9	890	1210	1310	1350	550^d
3300 mm by 2400 mm by 275 mm[c]					
0.6	1170	700	1080	800	550^d
0.9	1040	590	830	720	550^d
1.2	990	570	760	740	550^d
1.5	940	610	800	800	550^d
1.8	940	640	830	870	550^d
2.4	910	700	910	970	550^d
3.0	910	780	1020	1080	550^d
3.7	890	870	1140	1210	550^d
4.3	890	950	1290	1350	550^d
3300 mm by 3000 mm by 275 mm[c]					
0.6	1420	640	1160	910	550^d
0.9	1220	550^d	890	800	550^d
1.2	1120	550^d	830	800	550^d
1.5	1070	550^d	850	890	550^d
1.8	1020	590	890	950	550^d
2.4	990	640	950	1040	550^d
3.0	970	720	1080	1160	550^d
3.7	940	780	1210	1310	550^d
4.3	940	870	1350	1440	550^d
3300 mm by 3300 mm by 275 mm[c]					
0.6	2080	640	1210	950	550^d
0.9	1400	550^d	930	850	550^d
1.2	1220	550^d	870	850	550^d
1.5	1170	550^d	890	910	550^d
1.8	1120	570	910	990	550^d
2.4	1040	610	970	1080	550^d
3.0	1020	700	1100	1210	550^d
3.7	990	760	1230	1330	550^d
4.3	990	850	1350	1480	550^d
3600 mm by 1200 mm by 300 mm[c]					
0.6	1270	970	870	610^d	610^d
0.9	1190	800	660	610^d	610^d
1.2	1190	800	610^d	610^d	610^d
1.5	1140	870	640	610^d	610^d
1.8	1090	910	660	660	610^d
2.4	1070	1040	740	760	610^d
3.0	1040	1160	850	870	610^d
3.7	1040	1310	950	970	610^d
4.3	1040	1480	1060	1080	610^d
4.9	1040	1650	1160	1210	610^d
3600 mm by 1800 mm by 300 mm[c]					
0.6	1190	830	990	700	610^d
0.9	1120	700	760	640	610^d
1.2	1040	700	720	660	610^d
1.5	990	740	740	720	610^d
1.8	990	800	780	780	610^d
2.4	990	890	870	910	610^d
3.0	990	990	990	1040	610^d
3.7	970	1120	1120	1160	610^d
4.3	970	1250	1250	1290	610^d
4.9	970	1380	1380	1420	610^d
3600 mm by 2400 mm by 300 mm[c]					
0.6	1220	740	1100	800	610^d
0.9	1120	660	850	740	610^d
1.2	1040	640	800	760	610^d
1.5	1020	680	830	830	610^d
1.8	990	720	870	890	610^d
2.4	990	800	970	1020	610^d
3.0	970	890	1100	1160	610^d
3.7	970	970	1230	1290	610^d
4.3	970	1100	1380	1440	610^d

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Table 1—Design Requirements for Precast Concrete Box Sections Under Earth Dead and HS20 Live Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	*M*, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3600 mm by 3000 mm by 300 mm[c]					
0.6	1400	700	1190	910	610[d]
0.9	1220	610[d]	930	830	610[d]
1.2	1120	610[d]	870	850	610[d]
1.5	1090	610[d]	910	910	610[d]
1.8	1070	680	930	990	610[d]
2.4	1020	740	1040	1120	610[d]
3.0	1020	800	1160	1250	610[d]
3.7	990	890	1290	1400	610[d]
4.3	990	990	1440	1550	610[d]
3600 mm by 3600 mm by 300 mm[c]					
0.6	2260	680	1270	1020	610[d]
0.9	1520	610[d]	990	910	610[d]
1.2	1350	610[d]	930	910	610[d]
1.5	1270	610[d]	950	990	610[d]
1.8	1220	610[d]	990	1060	610[d]
2.4	1140	700	1080	1210	610[d]
3.0	1120	760	1210	1330	610[d]
3.7	1090	850	1350	1480	610[d]
4.3	1070	930	1480	1630	610[d]

[a] The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see Section 7.2.

[b] Design steel area in square millimeters per linear meter of box section at those locations that are indicated on the typical section included in Appendix X1.

[c] The box section designation, for example, 900 mm by 600 mm by 100 mm indicates (interior horizontal span, in millimeters) by (interior vertical rise, in millimeters) by (wall and slab thickness, in millimeters).

[d] Minimum practical steel area is specified.

Notes:
1. Design earth covers and reinforcement areas are based on the mass of a column of earth over the width of the box section as defined in Appendix X1. See Appendix X2 for modification to reinforcement areas for other earth load conditions.
2. Concrete design strength, 35 MPa.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a]

Design Earth Cover, m[a]	*M*, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
900 mm by 600 mm by 100 mm[c]					
0.6	430	400	420	440	210[d]
0.9	380	210[d]	230	230	210[d]
1.2 to 2.4	380	210[d]	210[d]	210[d]	210[d]
3.0	360	210[d]	230	250	210[d]
3.7	360	210[d]	280	280	210[d]
4.3	360	210[d]	300	300	210[d]
4.9	360	250	340	340	210[d]
5.5	360	280	380	380	210[d]
6.1	360	320	400	400	210[d]
900 mm by 900 mm by 100 mm[c]					
0.6	660	520	510	530	210[d]
0.9	510	210[d]	280	300	210[d]
1.2 to 1.8	460	210[d]	210[d]	230	210[d]
2.4	380	210[d]	230	250	210[d]
3.0	380	210[d]	280	280	210[d]
3.7	380	210[d]	300	300	210[d]
4.3	380	210[d]	320	340	210[d]
4.9	380	210[d]	360	380	210[d]
5.5	380	210[d]	400	420	210[d]
6.1	380	230	440	440	210[d]
1200 mm by 600 mm by 125 mm[c]					
0.6	480	550	470	420	250[d]
0.9	460	320	280	280	250[d]
1.2 to 1.8	460	250[d]	250[d]	250[d]	250[d]
2.4	430	280	250	250[d]	250[d]
3.0	430	300	300	300	250[d]
3.7	430	320	320	320	250[d]
4.3	430	360	360	360	250[d]
4.9	430	400	400	400	250[d]
5.5	430	440	440	440	250[d]
1200 mm by 900 mm by 125 mm[c]					
0.6	560	440	570	510	250[d]
0.9	480	280	340	340	250[d]
1.2	460	250[d]	280	280	250[d]
1.5	460	250[d]	250[d]	280	250[d]
1.8	430	250[d]	280	280	250[d]
2.4	430	250[d]	300	320	250[d]
3.0	430	250[d]	340	340	250[d]
3.7	430	250[d]	380	380	250[d]
4.3	430	280	420	420	250[d]
4.9	430	320	470	490	250[d]
5.5	430	340	510	530	250[d]
1200 mm by 1200 mm by 125 mm[c]					
0.6	860	380	640	590	250[d]
0.9	610	250[d]	380	380	250[d]
1.2	530	250[d]	300	320	250[d]
1.5	510	250[d]	300	300	250[d]
1.8	480	250[d]	300	320	250[d]
2.4	460	250[d]	320	340	250[d]
3.0	460	250[d]	360	380	250[d]
3.7	460	250[d]	400	400	250[d]
4.3	460	250[d]	440	440	250[d]
4.9	460	280	490	610	250[d]
5.5	430	300	550	550	250[d]

Continued on next page.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	*M*, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
1500 mm by 900 mm by 150 mm[c]					
0.6	580	550	590	510	300[d]
0.9	530	360	380	380	300[d]
1.2	530	300[d]	320	320	300[d]
1.5	510	300[d]	300[d]	320	300[d]
1.8	510	300[d]	320	320	300[d]
2.4	510	300[d]	360	360	300[d]
3.0	510	340	380	400	300[d]
3.7	510	360	440	440	300[d]
4.3	510	400	490	490	300[d]
4.9	480	470	550	550	300[d]
5.5	480	510	610	610	300[d]
1500 mm by 1200 mm by 150 mm[c]					
0.6	710	490	680	570	300[d]
0.9	580	320	420	440	300[d]
1.2	560	300[d]	340	360	300[d]
1.5	530	300[d]	340	360	300[d]
1.8	530	300[d]	360	360	300[d]
2.4	510	300[d]	380	400	300[d]
3.0	510	300[d]	420	440	300[d]
3.7	510	320	490	490	300[d]
4.3	510	340	530	550	300[d]
4.9	480	380	590	610	300[d]
5.5	480	420	660	680	300[d]
1500 mm by 1500 mm by 150 mm[c]					
0.6	1040	420	740	640	300[d]
0.9	740	300[d]	470	490	300[d]
1.2	640	300[d]	380	400	300[d]
1.5	610	300[d]	360	380	300[d]
1.8	560	300[d]	380	400	300[d]
2.4	560	300[d]	400	420	300[d]
3.0	530	300[d]	440	470	300[d]
3.7	530	300[d]	510	530	300[d]
4.3	530	300[d]	550	570	300[d]
4.9	530	340	610	660	300[d]
5.5	510	380	680	760	300[d]
1800 mm by 900 mm by 175 mm[c]					
0.6	740	660	610	570	360[d]
0.9	610	440	400	380	360[d]
1.2	610	380	360[d]	360[d]	360[d]
1.5	610	360[d]	360[d]	360[d]	360[d]
1.8	580	380	360[d]	360[d]	360[d]
2.4	580	400	400	400	360[d]
3.0	580	440	440	440	360[d]
3.7	580	490	490	510	360[d]
4.3	580	550	550	550	360[d]
4.9	580	610	610	640	360[d]
5.5	580	680	680	700	360[d]
1800 mm by 1200 mm by 175 mm[c]					
0.6	710	570	700	660	360[d]
0.9	640	380	470	440	360[d]
1.2	610	360[d]	400	400	360[d]
1.5	580	360[d]	380	400	360[d]
1.8	580	360[d]	400	420	360[d]
2.4	580	360[d]	440	470	360[d]
3.0	560	380	490	510	360[d]
3.7	560	420	550	570	360[d]
4.3	560	470	610	640	360[d]
4.9	560	530	680	700	360[d]
5.5	560	570	760	780	360[d]
1800 mm by 1500 mm by 175 mm[c]					
0.6	840	530	760	720	360[d]
0.9	690	360[d]	510	490	360[d]
1.2	640	360[d]	420	440	360[d]
1.5	610	360[d]	420	440	360[d]
1.8	610	360[d]	440	470	360[d]
2.4	580	360[d]	470	490	360[d]
3.0	580	360[d]	530	550	360[d]
3.7	580	380	590	610	360[d]
4.3	580	400	660	680	360[d]
4.9	560	470	720	760	360[d]
5.5	560	510	800	830	360[d]
1800 mm by 1800 mm by 175 mm[c]					
0.6	1220	490	830	780	360[d]
0.9	840	360[d]	550	550	360[d]
1.2	740	360[d]	470	490	360[d]
1.5	690	360[d]	440	490	360[d]
1.8	660	360[d]	470	490	360[d]
2.4	640	360[d]	490	530	360[d]
3.0	610	360[d]	550	570	360[d]
3.7	610	360[d]	610	640	360[d]
4.3	610	360[d]	680	700	360[d]
4.9	610	420	760	780	360[d]
5.5	580	440	830	870	360[d]
2100 mm by 1200 mm by 200 mm[c]					
0.6	810	720	720	700	400[d]
0.9	690	490	490	490	400[d]
1.2	690	420	420	440	400[d]
1.5	660	420	420	440	400[d]
1.8	660	420	440	470	400[d]
2.4	660	440	490	510	400[d]
3.0	640	490	550	570	400[d]
3.7	640	530	610	640	400[d]
4.3	640	590	680	700	400[d]
4.9	640	680	760	780	400[d]
5.5	640	740	850	870	400[d]
2100 mm by 1500 mm by 200 mm[c]					
0.6	860	660	780	780	400[d]
0.9	710	440	550	550	400[d]
1.2	690	400[d]	470	490	400[d]
1.5	660	400[d]	470	490	400[d]
1.8	660	400[d]	490	510	400[d]
2.4	660	400[d]	530	550	400[d]
3.0	640	440	590	610	400[d]
3.7	640	490	660	680	400[d]
4.3	640	530	740	760	400[d]
4.9	640	590	830	850	400[d]
5.5	640	660	910	930	400[d]

Continued on next page.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
2100 mm by 1800 mm by 200 mm[c]					
0.6	970	590	830	850	400[d]
0.9	790	400[d]	570	590	400[d]
1.2	740	400[d]	510	530	400[d]
1.5	710	400[d]	510	530	400[d]
1.8	690	400[d]	510	550	400[d]
2.4	660	400[d]	570	590	400[d]
3.0	660	400[d]	640	660	400[d]
3.7	660	440	700	720	400[d]
4.3	640	470	760	800	400[d]
4.9	640	530	870	890	400[d]
2100 mm by 2100 mm by 200 mm[c]					
0.6	1400	550	890	910	400[d]
0.9	970	400[d]	610	640	400[d]
1.2	840	400[d]	530	570	400[d]
1.5	790	400[d]	530	570	400[d]
1.8	760	400[d]	550	590	400[d]
2.4	710	400[d]	590	640	400[d]
3.0	690	400[d]	660	700	400[d]
3.7	690	400[d]	720	760	400[d]
4.3	690	440	780	850	400[d]
4.9	690	490	890	930	400[d]
2400 mm by 1200 mm by 200 mm[c]					
0.6	860	910	850	800	400[d]
0.9	790	660	590	610	400[d]
1.2	710	570	530	550	400[d]
1.5	710	570	530	550	400[d]
1.8	710	570	550	570	400[d]
2.4	690	640	610	640	400[d]
3.0	690	700	700	720	400[d]
3.7	690	760	760	780	400[d]
2400 mm by 1500 mm by 200 mm[c]					
0.6	890	800	910	890	400[d]
0.9	790	610	660	680	400[d]
1.2	710	530	570	590	400[d]
1.5	710	530	590	610	400[d]
1.8	690	530	610	640	400[d]
2.4	690	570	680	700	400[d]
3.0	690	640	740	780	400[d]
3.7	690	700	850	870	400[d]
2400 mm by 1800 mm by 200 mm[c]					
0.6	910	740	990	970	400[d]
0.9	790	570	700	740	400[d]
1.2	760	490	610	660	400[d]
1.5	740	490	640	660	400[d]
1.8	710	490	660	680	400[d]
2.4	690	530	720	740	400[d]
3.0	690	570	800	830	400[d]
3.7	690	640	890	930	400[d]
2400 mm by 2100 mm by 200 mm[c]					
0.6	1040	700	1060	1040	400[d]
0.9	890	530	740	800	400[d]
1.2	810	470	660	700	400[d]
1.5	790	470	660	720	400[d]
1.8	760	470	680	740	400[d]
2.4	740	490	740	800	400[d]
3.0	710	530	830	890	400[d]
3.7	710	590	930	970	400[d]
2400 mm by 2400 mm by 200 mm[c]					
0.6	1550	660	1120	1100	400[d]
0.9	1040	510	780	850	400[d]
1.2	910	440	700	740	400[d]
1.5	860	420	700	760	400[d]
1.8	810	440	720	780	400[d]
2.4	790	470	780	850	400[d]
3.0	760	510	870	910	400[d]
3.7	740	550	950	1020	400[d]
2700 mm by 1500 mm by 225 mm[c]					
0.6	970	910	950	870	470[d]
0.9	860	700	700	700	470[d]
1.2	790	610	610	640	470[d]
1.5	790	610	640	660	470[d]
1.8	760	640	660	680	470[d]
2.4	760	680	720	740	470[d]
3.0	760	740	800	840	470[d]
3.7	760	830	890	930	470[d]
2700 mm by 1800 mm by 225 mm[c]					
0.6	970	850	1020	950	470[d]
0.9	860	640	740	760	470[d]
1.2	810	570	660	700	470[d]
1.5	790	570	680	720	470[d]
1.8	760	590	700	740	470[d]
2.4	760	610	760	800	470[d]
3.0	760	680	850	890	470[d]
3.7	740	760	950	990	470[d]
2700 mm by 2100 mm by 225 mm[c]					
0.6	1040	780	1100	1020	470[d]
0.9	910	610	800	830	470[d]
1.2	840	550	700	760	470[d]
1.5	810	550	720	760	470[d]
1.8	790	550	740	780	470[d]
2.4	790	590	800	870	470[d]
3.0	760	640	890	950	470[d]
3.7	760	700	990	1060	470[d]
2700 mm by 2400 mm by 225 mm[c]					
0.6	1170	740	1140	1080	470[d]
0.9	990	570	850	890	470[d]
1.2	910	510	740	800	470[d]
1.5	860	510	760	800	470[d]
1.8	840	530	780	830	470[d]
2.4	810	550	850	910	470[d]
3.0	790	590	930	990	470[d]
3.7	790	660	1040	1100	470[d]
2700 mm by 2700 mm by 225 mm[c]					
0.6	1730	700	1210	1160	470[d]
0.9	1140	550	890	930	470[d]
1.2	1040	490	780	850	470[d]
1.5	970	490	780	850	470[d]

Continued on next page.

Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions^a *(Continued)*

Design Earth Cover, m^a	M, Min, mm	Circumferential Reinforcement Areas^b			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
1.8	910	490	800	890	470^d
2.4	860	530	870	950	470^d
3.0	840	570	950	1040	470^d
3.7	840	640	1060	1140	470^d
3000 mm by 1500 mm by 250 mm^c					
0.6	1040	990	970	850	510^d
0.9	970	760	720	700	510^d
1.2	890	720	660	680	510^d
1.5	860	720	680	700	510^d
1.8	840	720	700	720	510^d
2.4	840	780	760	780	510^d
3.0	840	870	850	890	510^d
3.7	840	950	950	970	510^d
3000 mm by 1800 mm by 250 mm^c					
0.6	1040	930	1040	930	510^d
0.9	940	720	780	760	510^d
1.2	860	660	700	740	510^d
1.5	840	660	720	760	510^d
1.8	840	680	740	780	510^d
2.4	840	720	830	870	510^d
3.0	810	800	910	950	510^d
3.7	810	870	1020	1060	510^d
3000 mm by 2100 mm by 250 mm^c					
0.6	1070	870	1120	990	510^d
0.9	970	680	830	830	510^d
1.2	890	640	760	800	510^d
1.5	860	640	760	800	510^d
1.8	860	640	780	850	510^d
2.4	840	700	870	910	510^d
3.0	840	700	970	1020	510^d
3.7	810	680	1080	1120	510^d
3000 mm by 2400 mm by 250 mm^c					
0.6	1140	800	1190	1080	510^d
0.9	1020	640	870	890	510^d
1.2	940	590	800	850	510^d
1.5	910	590	800	870	510^d
1.8	890	610	830	890	510^d
2.4	860	660	910	970	510^d
3.0	840	700	1020	1080	510^d
3.7	840	760	1120	1190	510^d
3000 mm by 2700 mm by 250 mm^c					
0.6	1330	760	1250	1140	510^d
0.9	1070	610	930	950	510^d
1.2	1020	570	830	910	510^d
1.5	970	570	850	910	510^d
1.8	940	570	870	930	510^d
2.4	890	610	950	1020	510^d
3.0	890	680	1040	1120	510^d
3.7	860	740	1140	1230	510^d
3000 mm by 3000 mm by 250 mm^c					
0.6	1900	740	1290	1210	510^d
0.9	1270	590	970	990	510^d
1.2	1140	550	870	950	510^d
1.5	1070	550	870	970	510^d

Design Earth Cover, m^a	M, Min, mm	Circumferential Reinforcement Areas^b			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
1.8	1020	550	910	990	510^d
2.4	970	590	970	1060	510^d
3.0	940	640	1080	1160	510^d
3.7	910	700	1190	1270	510^d
3300 mm by 1200 mm by 275 mm^c					
0.6	1140	1140	910	740	550^d
0.9	1090	910	680	640	550^d
1.2	1040	850	610	640	550^d
1.5	990	870	640	660	550^d
1.8	970	890	660	680	550^d
2.4	970	950	720	760	550^d
3.0	940	1080	830	850	550^d
3.7	940	1210	930	950	550^d
4.3	940	1350	1040	1060	550^d
4.9	940	1500	1140	1160	550^d
3300 mm by 1800 mm by 275 mm^c					
0.6	1120	970	1060	910	550^d
0.9	1040	780	800	760	550^d
1.2	970	740	740	740	550^d
1.5	910	760	760	780	550^d
1.8	910	760	780	830	550^d
2.4	910	830	850	890	550^d
3.0	890	910	970	990	550^d
3.7	890	1020	1080	1120	550^d
4.3	890	1120	1210	1250	550^d
3300 mm by 2400 mm by 275 mm^c					
0.6	1170	870	1190	1040	550^d
0.9	1040	700	890	870	550^d
1.2	990	660	830	850	550^d
1.5	940	680	850	890	550^d
1.8	940	700	870	930	550^d
2.4	910	740	950	990	550^d
3.0	910	800	1060	1120	550^d
3.7	890	890	1190	1250	550^d
4.3	890	970	1310	1380	550^d
3300 mm by 3000 mm by 275 mm^c					
0.6	1420	780	1310	1160	550^d
0.9	1220	640	970	970	550^d
1.2	1120	610	890	950	550^d
1.5	1070	640	910	990	550^d
1.8	1020	640	930	1020	550^d
2.4	990	680	990	1100	550^d
3.0	970	740	1120	1210	550^d
3.7	940	800	1250	1330	550^d
4.3	940	890	1380	1480	550^d
3300 mm by 3300 mm by 275 mm^c					
0.6	2080	760	1350	1230	550^d
0.9	1400	610	1020	1020	550^d
1.2	1240	590	910	990	550^d
1.5	1170	610	930	1040	550^d
1.8	1120	610	950	1060	550^d
2.4	1040	660	1040	1120	550^d
3.0	1020	720	1140	1250	550^d
3.7	990	780	1270	1380	550^d
4.3	990	870	1400	1500	550^d

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Table 2—Design Requirements for Precast Concrete Box Sections Under Earth Dead and Interstate Live Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3600 mm by 1200 mm by 300 mm[c]					
0.6	1270	1230	930	740	610[d]
0.9	1190	970	700	640	610[d]
1.2	1140	910	660	640	610[d]
1.5	1090	970	680	700	610[d]
1.8	1070	990	700	720	610[d]
2.4	1040	1080	760	780	610[d]
3.0	1040	1210	870	890	610[d]
3.7	1040	1350	970	990	610[d]
4.3	1040	1520	1080	1100	610[d]
4.9	1040	1690	1190	1230	610[d]
3600 mm by 1800 mm by 300 mm[c]					
0.6	1190	1060	1080	890	610[d]
0.9	1120	850	830	760	610[d]
1.2	1040	800	760	760	610[d]
1.5	990	850	800	830	610[d]
1.8	990	870	830	870	610[d]
2.4	990	930	910	950	610[d]
3.0	990	1040	1020	1060	610[d]
3.7	970	1160	1140	1190	610[d]
4.3	970	1290	1270	1310	610[d]
3600 mm by 2400 mm by 300 mm[c]					
0.6	1240	950	1230	1040	610[d]
0.9	1120	760	930	890	610[d]
1.2	1040	720	870	870	610[d]
1.5	1020	760	890	950	610[d]
1.8	990	780	910	970	610[d]
2.4	990	830	990	1060	610[d]
3.0	970	930	1120	1190	610[d]
3.7	970	1020	1270	1300	610[d]
4.3	970	1400	1460	1460	610[d]
3600 mm by 3000 mm by 300 mm[c]					
0.6	1400	870	1330	1160	610[d]
0.9	1220	700	1020	990	610[d]
1.2	1120	680	930	970	610[d]
1.5	1090	720	970	1040	610[d]
1.8	1070	720	990	1080	610[d]
2.4	1020	760	1080	1160	610[d]
3.0	1020	850	1210	1290	610[d]
3.7	990	930	1330	1440	610[d]
4.3	990	1020	1480	1590	610[d]
3600 mm by 3600 mm by 300 mm[c]					
0.6	2260	800	1440	1270	610[d]
0.9	1520	660	1080	1080	610[d]
1.2	1350	640	990	1060	610[d]
1.5	1270	680	1020	1140	610[d]
1.8	1220	680	1060	1160	610[d]
2.4	1140	720	1120	1250	610[d]
3.0	1120	780	1250	1380	610[d]
3.7	1090	870	1400	1520	610[d]
4.3	1070	950	1520	1670	610[d]

[a] The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see Section 7.2.

[b] Design steel area in square millimeters per linear meter of box section at those locations that are indicated on the typical section included in Appendix X1.

[c] The box section designation, for example, 900 mm by 600 mm by 100 mm indicates (interior horizontal span, in millimeters) by (interior vertical rise, in millimeters) by (wall and slab thickness, in millimeters).

[d] Minimum practical steel area is specified.

Notes:
1. Design earth covers and reinforcement areas are based on the mass of a column of earth over the width of the box section as defined in Appendix X1. See Appendix X2 for modification to reinforcement areas for other earth load conditions.
2. Concrete design strength, 35 MPa.

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a]

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
900 mm by 600 mm by 100 mm[c]					
0 to 3.0	360	210[d]	210[d]	210[d]	210[d]
3.7	360	210[d]	210[d]	230	210[d]
4.3	360	210[d]	250	250	210[d]
4.9	360	210[d]	300	300	210[d]
5.5	360	230	340	340	210[d]
6.1	360	280	360	380	210[d]
6.7	360	300	400	400	210[d]
900 mm by 900 mm by 100 mm[c]					
0 to 3.0	380	210[d]	210[d]	210[d]	210[d]
3.7	360	210[d]	230	250	210[d]
4.3	360	210[d]	280	280	210[d]
4.9	360	210[d]	320	320	210[d]
5.5	360	210[d]	360	360	210[d]
6.1	360	210[d]	400	400	210[d]
1200 mm by 600 mm by 125 mm[c]					
0 to 3.0	460	250[d]	250[d]	250[d]	250[d]
3.7	430	250[d]	280	280	250[d]
4.3	430	300	320	320	250[d]
4.9	430	340	360	360	250[d]
5.5	430	380	400	400	250[d]
6.1	430	440	440	440	250[d]

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Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	*M*, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
1200 mm by 900 mm by 125 mm[c]					
0 to 2.4	430	250[d]	250[d]	250[d]	250[d]
3.0	430	250[d]	250[d]	280	250[d]
3.7	430	250[d]	300	320	250[d]
4.3	430	250[d]	360	360	250[d]
4.9	430	250[d]	400	420	250[d]
5.5	430	300	470	470	250[d]
6.1	430	340	510	530	250[d]
1200 mm by 1200 mm by 125 mm[c]					
0 to 2.4	460	250[d]	250[d]	250[d]	250[d]
3.0	430	250[d]	280	280	250[d]
3.7	430	250[d]	320	340	250[d]
4.3	430	250[d]	380	380	250[d]
4.9	430	250[d]	420	440	250[d]
5.5	430	250[d]	490	490	250[d]
6.1	430	280	530	550	250[d]
1500 mm by 900 mm by 150 mm[c]					
0 to 2.4	510	300[d]	300[d]	300[d]	300[d]
3.0	480	300[d]	300[d]	320	300[d]
3.7	480	300[d]	360	380	300[d]
4.3	480	340	420	420	300[d]
4.9	480	380	490	490	300[d]
5.5	480	440	530	550	300[d]
6.1	480	490	590	610	300[d]
1500 mm by 1200 mm by 150 mm[c]					
0 to 2.4	510	300[d]	300[d]	300[d]	300[d]
3.0	480	300[d]	340	340	300[d]
3.7	480	300[d]	380	380	300[d]
4.3	480	300[d]	470	470	300[d]
4.9	480	320	530	530	300[d]
5.5	480	360	590	590	300[d]
6.1	480	400	660	660	300[d]
1500 mm by 1500 mm by 150 mm[c]					
0 to 2.4	560	300[d]	300[d]	300[d]	300[d]
3.0	530	300[d]	340	360	300[d]
3.7	510	300[d]	400	420	300[d]
4.3	510	300[d]	470	490	300[d]
4.9	510	300[d]	530	550	300[d]
5.5	510	320	590	640	300[d]
6.1	510	360	680	700	300[d]
1800 mm by 900 mm by 175 mm[c]					
0 to 3.0	580	360[d]	360[d]	360[d]	360[d]
3.7	580	380	400	420	360[d]
4.3	580	440	490	490	360[d]
4.9	580	510	550	550	360[d]
5.5	580	590	610	610	360[d]
6.1	580	660	680	700	360[d]
1800 mm by 1200 mm by 175 mm[c]					
0 to 2.4	580	360[d]	360[d]	360[d]	360[d]
3.0	560	360[d]	380	400	360[d]
3.7	560	360[d]	440	470	360[d]
4.3	560	380	530	550	360[d]
4.9	560	440	590	610	360[d]
5.5	560	490	680	700	360[d]
6.1	560	550	740	760	360[d]
1800 mm by 1500 mm by 175 mm[c]					
0 to 2.4	580	360[d]	360[d]	360[d]	360[d]
3.0	530	360[d]	400	420	360[d]
3.7	530	360[d]	490	510	360[d]
4.3	530	360[d]	550	570	360[d]
4.9	530	380	640	660	360[d]
5.5	530	420	720	740	360[d]
6.1	530	490	780	830	360[d]
1800 mm by 1800 mm by 175 mm[c]					
0 to 1.8	660	360[d]	360[d]	360[d]	360[d]
2.4	610	360[d]	360[d]	380	360[d]
3.0	610	360[d]	420	440	360[d]
3.7	610	360[d]	490	530	360[d]
4.3	580	360[d]	570	610	360[d]
4.9	580	360[d]	660	680	360[d]
5.5	580	380	720	760	360[d]
2100 mm by 1200 mm by 200 mm[c]					
0 to 2.4	660	400[d]	400[d]	400[d]	400[d]
3.0	640	400[d]	420	440	400[d]
3.7	640	420	510	530	400[d]
4.3	640	490	590	610	400[d]
4.9	640	570	680	700	400[d]
5.5	640	640	760	760	400[d]
6.1	640	720	850	850	400[d]
2100 mm by 1500 mm by 200 mm[c]					
0 to 2.4	660	400[d]	400[d]	400[d]	400[d]
3.0	640	400[d]	470	490	400[d]
3.7	640	400[d]	550	570	400[d]
4.3	640	440	640	660	400[d]
4.9	640	490	720	740	400[d]
5.5	640	550	800	830	400[d]
2100 mm by 1800 mm by 200 mm[c]					
0 to 1.8	690	400[d]	400[d]	400[d]	400[d]
2.4	660	400[d]	400[d]	420	400[d]
3.0	640	400[d]	490	510	400[d]
3.7	640	400[d]	570	610	400[d]
4.3	640	400[d]	660	700	400[d]
4.9	640	440	740	780	400[d]
5.5	640	510	850	870	400[d]
2100 mm by 2100 mm by 200 mm[c]					
0 to 1.8	760	400[d]	400[d]	400[d]	400[d]
2.4	690	400[d]	400[d]	440	400[d]
3.0	690	400[d]	510	530	400[d]
3.7	690	400[d]	590	640	400[d]
4.3	660	400[d]	680	720	400[d]
4.9	660	420	760	800	400[d]
5.5	660	470	870	910	400[d]
2400 mm by 1200 mm by 200 mm[c]					
0 to 1.8	710	400[d]	400[d]	400[d]	400[d]
2.4	690	420	440	470	400[d]

Continued on next page.

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3.0	690	510	550	570	400[d]
3.7	690	610	640	660	400[d]
4.3	690	720	740	760	400[d]
2400 mm by 1500 mm by 200 mm[c]					
0 to 1.8	710	400[d]	400[d]	400[d]	400[d]
2.4	690	400[d]	490	510	400[d]
3.0	660	470	590	610	400[d]
3.7	660	550	700	720	400[d]
4.3	660	640	800	830	400[d]
2400 mm by 1800 mm by 200 mm[c]					
0 to 1.5	710	400[d]	400[d]	400[d]	400[d]
1.8	690	400[d]	400[d]	420	400[d]
2.4	690	400[d]	510	550	400[d]
3.0	690	420	610	660	400[d]
3.7	690	510	740	760	400[d]
4.3	690	590	850	890	400[d]
2400 mm by 2100 mm by 200 mm[c]					
0 to 1.5	760	400[d]	400[d]	400[d]	400[d]
1.8	710	400[d]	420	470	400[d]
2.4	690	400[d]	530	570	400[d]
3.0	690	400[d]	640	700	400[d]
3.7	690	470	760	800	400[d]
4.3	690	550	890	930	400[d]
2400 mm by 2400 mm by 200 mm[c]					
0 to 1.2	860	400[d]	400[d]	400[d]	400[d]
1.5	790	400[d]	400[d]	420	400[d]
1.8	760	400[d]	420	490	400[d]
2.4	760	400[d]	550	590	400[d]
3.0	740	400[d]	660	720	400[d]
3.7	740	440	780	850	400[d]
4.3	740	510	890	950	400[d]
2700 mm by 1500 mm by 225 mm[c]					
0 to 1.8	790	470[d]	470[d]	470[d]	470[d]
2.4	760	470[d]	510	550	470[d]
3.0	740	550	640	660	470[d]
3.7	740	660	740	780	470[d]
4.3	740	760	870	890	470[d]
2700 mm by 1800 mm by 225 mm[c]					
0 to 1.8	790	470[d]	470[d]	470[d]	470[d]
2.4	740	470[d]	550	590	470[d]
3.0	740	510	680	700	470[d]
3.7	740	590	800	830	470[d]
4.3	740	700	910	950	470[d]
2700 mm by 2100 mm by 225 mm[c]					
0 to 1.5	810	470[d]	470[d]	470[d]	470[d]
1.8	760	470[d]	470[d]	510	470[d]
2.4	760	470[d]	570	610	470[d]
3.0	760	490	700	740	470[d]
3.7	740	570	830	870	470[d]
4.3	740	660	950	1020	470[d]
2700 mm by 2400 mm by 225 mm[c]					
0 to 1.5	860	470[d]	470[d]	470[d]	470[d]
1.8	810	470[d]	470[d]	530	470[d]
2.4	790	470[d]	590	660	470[d]
3.0	790	470[d]	720	780	470[d]
3.7	760	530	850	910	470[d]
4.3	760	610	990	1060	470[d]
2700 mm by 2700 mm by 225 mm[c]					
0 to 1.2	970	470[d]	470[d]	470[d]	470[d]
1.5	890	470[d]	470[d]	490	470[d]
1.8	860	470[d]	490	550	470[d]
2.4	840	470[d]	610	680	470[d]
3.0	840	470[d]	740	830	470[d]
3.7	810	510	870	950	470[d]
4.3	810	570	1020	1080	
3000 mm by 1500 mm by 250 mm[c]					
0 to 1.8	860	510[d]	510[d]	510[d]	510[d]
2.4	840	530	550	570	510[d]
3.0	840	660	680	700	510[d]
3.7	840	760	800	830	510[d]
4.3	810	890	930	9500	510[d]
4.9	810	1020	930	1080	510[d]
3000 mm by 1800 mm by 250 mm[c]					
0 to 1.8	860	510[d]	510[d]	510[d]	510[d]
2.4	810	510[d]	590	640	510[d]
3.0	810	590	720	760	510[d]
3.7	810	700	850	890	510[d]
4.3	810	830	970	1020	510[d]
3000 mm by 2100 mm by 250 mm[c]					
0 to 1.5	910	510[d]	510[d]	510[d]	510[d]
1.8	860	510[d]	510[d]	570	510[d]
2.4	840	510[d]	660	700	510[d]
3.0	840	530	780	850	510[d]
3.7	810	610	930	990	510[d]
4.3	810	720	1080	1140	510[d]
3000 mm by 2400 mm by 250 mm[c]					
0 to 1.5	910	510[d]	510[d]	510[d]	510[d]
1.5	860	510[d]	510[d]	530	510[d]
2.4	840	510[d]	660	700	510[d]
3.0	840	530	780	850	510[d]
3.7	810	610	930	990	510[d]
4.3	810	720	1080	1140	510[d]
3000 mm by 2700 mm by 250 mm[c]					
0 to 1.2	970	510[d]	510[d]	510[d]	510[d]
1.5	910	510[d]	510[d]	530	510[d]
1.8	890	510[d]	530	610	510[d]
2.4	860	510[d]	680	740	510[d]
3.0	860	510[d]	800	890	510[d]
3.7	840	590	950	1040	510[d]
4.3	840	680	1100	1190	510[d]

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Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	M, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}
3000 mm by 3000 mm by 250 mm[c]					
0 to 1.2	1090	510[d]	510[d]	510[d]	510[d]
1.5	970	510[d]	510[d]	570	510[d]
1.8	940	510[d]	550	640	510[d]
2.4	910	510[d]	700	780	510[d]
3.0	910	510[d]	830	930	510[d]
3.7	890	570	970	1060	510[d]
4.3	890	660	1120	1210	510[d]
3300 mm by 1200 mm by 275 mm[c]					
0.6	970	550[d]	550[d]	550[d]	550[d]
0.9	970	550[d]	550[d]	550[d]	550[d]
1.2	970	550[d]	550[d]	550[d]	550[d]
1.5	970	550[d]	550[d]	550[d]	550[d]
1.8	940	550[d]	550[d]	550[d]	550[d]
2.4	940	660	550[d]	550[d]	550[d]
3.0	940	780	660	680	550[d]
3.7	940	950	760	780	550[d]
4.3	940	1100	890	910	550[d]
4.9	940	1270	990	1020	550[d]
5.5	940	1440	1120	1140	550[d]
3300 mm by 1800 mm by 275 mm[c]					
0.6	910	550[d]	550[d]	550[d]	550[d]
0.9	910	550[d]	550[d]	550[d]	550[d]
1.2	910	550[d]	550[d]	550[d]	550[d]
1.5	910	550[d]	550[d]	550[d]	550[d]
1.8	890	550[d]	550[d]	550[d]	550[d]
2.4	890	570	610	660	550[d]
3.0	890	680	760	780	550[d]
3.7	890	800	890	930	550[d]
4.3	890	930	1020	1060	550[d]
4.9	890	1060	1160	1210	550[d]
5.5	890	1190	1310	1350	550[d]
3300 mm by 2400 mm by 275 mm[c]					
0.6	970	550[d]	550[d]	550[d]	550[d]
0.9	940	550[d]	550[d]	550[d]	550[d]
1.2	910	550[d]	550[d]	550[d]	550[d]
1.5	910	550[d]	550[d]	550[d]	550[d]
1.8	910	550[d]	550[d]	590	550[d]
2.4	890	550[d]	680	720	550[d]
3.0	890	590	830	870	550[d]
3.7	890	700	970	1020	550[d]
4.3	890	800	1020	1160	550[d]
4.9	890	910	1270	1280	550[d]
3300 mm by 3000 mm by 275 mm[c]					
0.6	1070	550[d]	550[d]	550[d]	550[d]
0.9	1040	550[d]	550[d]	550[d]	550[d]
1.2	1020	550[d]	550[d]	550[d]	550[d]
1.5	990	550[d]	550[d]	570	550[d]
1.8	990	550[d]	570	640	550[d]
2.4	970	550[d]	700	780	550[d]
3.0	940	550[d]	850	930	550[d]
3.7	940	640	990	1100	550[d]
4.3	910	740	1160	1250	550[d]
4.9	910	830	1310	1400	550[d]
3300 mm by 3300 mm by 275 mm[c]					
0.6	1190	550[d]	550[d]	550[d]	550[d]
0.9	1120	550[d]	550[d]	550[d]	550[d]
1.2	1090	550[d]	550[d]	550[d]	550[d]
1.5	1070	550[d]	550[d]	590	550[d]
1.8	1040	550[d]	570	680	550[d]
2.4	1020	550[d]	720	830	550[d]
3.0	990	550[d]	870	970	550[d]
3.7	990	610	1020	1120	550[d]
4.3	970	720	1160	1270	550[d]
4.9	970	800	1310	1440	550[d]
3600 mm by 1200 mm by 300 mm[c]					
0.6	1070	610[d]	610[d]	610[d]	610[d]
0.9	1070	610[d]	610[d]	610[d]	610[d]
1.2	1040	610[d]	610[d]	610[d]	610[d]
1.5	1040	610[d]	610[d]	610[d]	610[d]
1.8	1040	610[d]	610[d]	610[d]	610[d]
2.4	1040	740	610[d]	610[d]	610[d]
3.0	1040	910	680	700	610[d]
3.7	1040	1080	800	830	610[d]
4.3	1040	1250	930	950	610[d]
4.9	1040	1440	1060	1080	610[d]
5.5	1040	1630	1190	1210	610[d]
3600 mm by 1800 mm by 300 mm[c]					
0.6	1020	610[d]	610[d]	610[d]	610[d]
0.9	990	610[d]	610[d]	610[d]	610[d]
1.2	990	610[d]	610[d]	610[d]	610[d]
1.5	990	610[d]	610[d]	610[d]	610[d]
1.8	990	610[d]	610[d]	610[d]	610[d]
2.4	970	640	660	700	610[d]
3.0	970	780	800	830	610[d]
3.7	970	910	930	970	610[d]
4.3	970	1060	1080	1120	610[d]
4.9	970	1210	1230	1270	610[d]
5.5	970	1350	1380	1420	610[d]
3600 mm by 2400 mm by 300 mm[c]					
0.6	1020	610[d]	610[d]	610[d]	610[d]
0.9	990	610[d]	610[d]	610[d]	610[d]
1.2	990	610[d]	610[d]	610[d]	610[d]
1.5	990	610[d]	610[d]	610[d]	610[d]
1.8	970	610[d]	610[d]	640	610[d]
2.4	970	610[d]	720	780	610[d]
3.0	970	680	870	930	610[d]
3.7	940	800	1040	1100	610[d]
4.3	940	910	1190	1250	610[d]
4.9	940	1040	1350	1420	610[d]
3600 mm by 3000 mm by 300 mm[c]					
0.6	1090	610[d]	610[d]	610[d]	610[d]
0.9	1070	610[d]	610[d]	610[d]	610[d]
1.2	1040	610[d]	610[d]	610[d]	610[d]
1.5	1040	610[d]	610[d]	610[d]	610[d]
1.8	1020	610[d]	610[d]	700	610[d]
2.4	990	610[d]	760	850	610[d]
3.0	990	640	930	1020	610[d]

Continued on next page.

Table 3—Design Requirements for Precast Concrete Box Sections Under Earth Dead Load Conditions[a] *(Continued)*

Design Earth Cover, m[a]	*M*, Min, mm	Circumferential Reinforcement Areas[b]				Design Earth Cover, m[a]	*M*, Min, mm	Circumferential Reinforcement Areas[b]			
		A_{s1}	A_{s2}	A_{s3}	A_{s4}			A_{s1}	A_{s2}	A_{s3}	A_{s4}
3.7	990	720	1080	1160	610[d]	1.5	1140	610[d]	610[d]	680	610[d]
4.3	970	830	1250	1330	610[d]	1.8	1140	610[d]	640	740	610[d]
4.9	970	950	1420	1500	610[d]	2.4	1090	610[d]	800	910	610[d]
3600 mm by 3600 mm by 300 mm[c]						3.0	1090	610[d]	950	1060	610[d]
0.6	1320	610[d]	610[d]	610[d]	610[d]	3.7	1070	700	1120	1230	610[d]
0.9	1240	610[d]	610[d]	610[d]	610[d]	4.3	1040	780	1270	1400	610[d]
1.2	1170	610[d]	610[d]	610[d]	610[d]	4.9	1040	890	1440	1590	610[d]

[a] The design earth cover indicated is the height of fill above the top of the box section. Design requirements are based on the material and soil properties, loading data, and typical section as included in Appendix X1. For alternative or special designs, see Section 7.2.

[b] Design steel area in square millimeters per linear meter of box section at those locations that are indicated on the typical section included in Appendix X1.

[c] The box section designation, for example, 900 mm by 600 mm by 100 mm indicates (interior horizontal span, in millimeters) by (interior vertical rise, in millimeters) by (wall and slab thickness, in millimeters).

[d] Minimum practical steel area is specified.

Notes:
1. Design earth covers and reinforcement areas are based on the mass of a column of earth over the width of the box section as defined in Appendix X1. See Appendix X2 for modification to reinforcement areas for other earth load conditions.
2. Concrete design strength, 35 MPa.

5. BASIS OF ACCEPTANCE

5.1. Acceptability of the box sections produced in accordance with Section 7 shall be determined by the results of the concrete compressive strength tests described in Section 10, by the material requirements described in Section 6, and by inspection of the finished box sections.

5.2. Box sections shall be considered ready for acceptance when they conform to the requirements of this specification.

6. MATERIALS

6.1.1. *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water in which steel has been embedded in such a manner that the steel and concrete act together.

6.2. *Cementitious Materials*:

6.2.1. *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash and shall not exceed 25 percent by mass.

6.2.2. *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3. *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in the concrete shall be one of the following:

6.2.3.1. Portland cement only.

6.2.3.2. Portland blast-furnace slag cement only.

6.2.3.3. Portland-pozzolan cement only.

6.2.3.4. A combination of portland cement and fly ash wherein the proportion of fly ash is between 5 and 25 percent by mass of total cementitious materials (portland cement plus fly ash).

6.3. *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirements for gradation shall not apply.

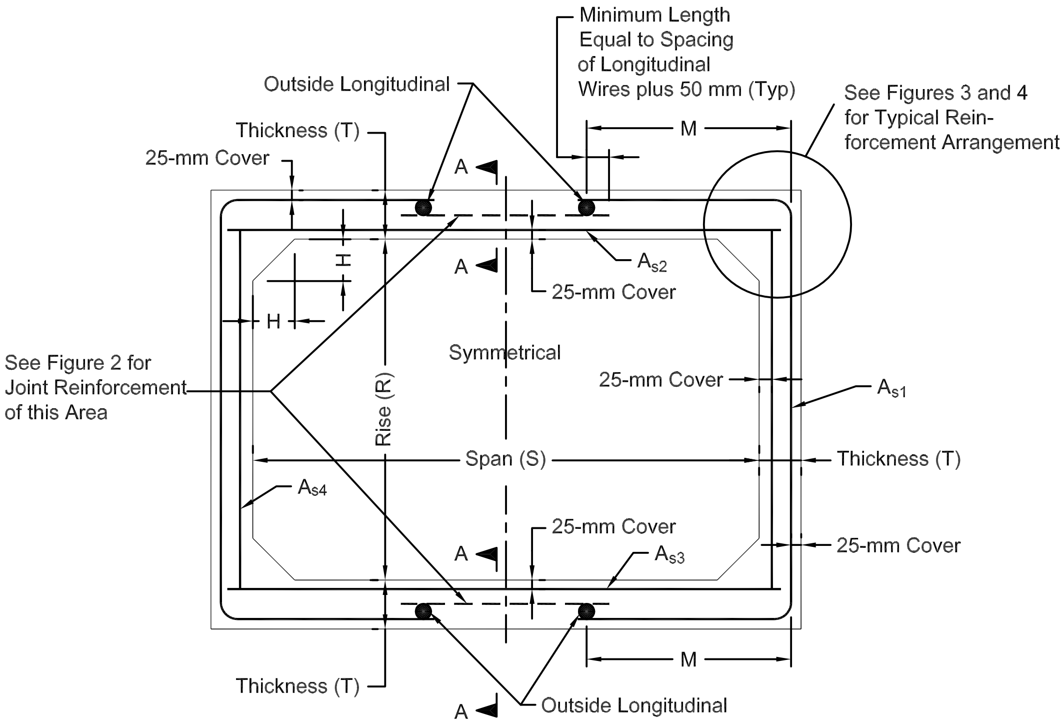
6.4. *Admixtures and Blends*—Admixtures and blends may be used with the approval of the owner.

6.5. *Steel Reinforcement*—Reinforcement shall consist of welded wire fabric conforming to M 55M/M 55 or M 221M/M 221.

6.6. *Synthetic Fibers*—Collated fibrillated virgin polypropylene fibers may be used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

7. DESIGN

7.1. *Design Tables*—The box section dimensions, compressive strength of the concrete, and reinforcement details shall be as prescribed in Tables 1, 2, or 3 and Figures 1, 2, and 3, subject to the provisions of Section 11. Table 1 sections are designed for combined earth dead load and AASHTO HS20 live load conditions. Table 2 sections are designed for combined earth dead load and Interstate live load conditions when the Interstate live loading exceeds the HS20 live loading. Table 3 sections are designed for earth dead load conditions only. Criteria used to develop Tables 1, 2, and 3 are given in Appendix X1. For modifications to the designs shown in Tables 1, 2, and 3 due to anticipated earth and surcharge loads different from those used to develop the tables, see Appendix X2.



Notes: 1. The dimension *M* is the total of the theoretical cutoff length plus the required anchorage.
2. The haunch dimension *H* is equal to the thickness *T*.

Figure 1—Typical Box Section

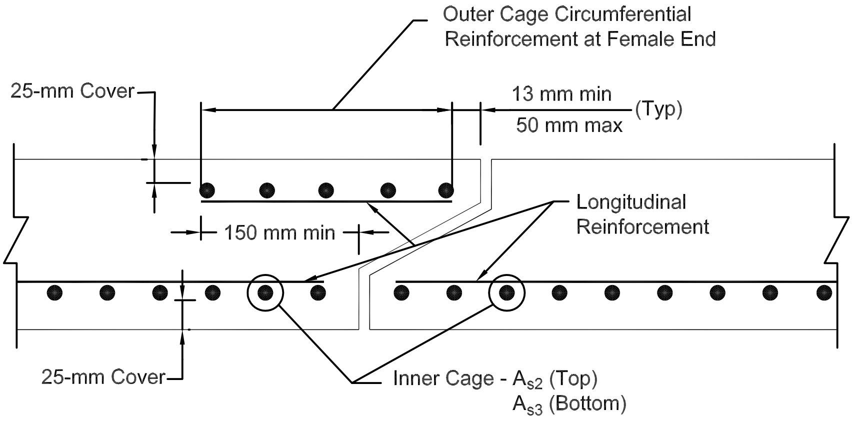


Figure 2—Section A-A Top and Bottom Slab Joint Reinforcement

7.2. *Modified and Special Designs*—The manufacturer may request approval by the owner of modified designs that differ from the designs in Section 7, or special designs for sizes and loads other than those shown in Tables 1, 2, and 3.

Note 3—The tabular designs in this specification were prepared according to AASHTO *Standard Specifications for Highway Bridges*, 1973 Edition. The current AASHTO *Standard Specifications for Highway Bridges* allows concrete shear stress criteria that differ from the 1973 criteria. The use of current AASHTO concrete shear stress criteria shall be acceptable by this specification for modified or special designs.

7.3. *Placement of Reinforcement*—The cover of concrete over the circumferential reinforcement shall be 25 mm, subject to the provisions of Section 11. The inside circumferential reinforcement shall extend into the male portion of the joint and the outside circumferential reinforcement shall extend into the female portion of the joint. The clear distance of the end circumferential wires shall be not less than 13 mm or more than 50 mm from the ends of the box section. Reinforcement shall be assembled utilizing any combination of single or multiple layers of welded-wire fabric. A common reinforcement unit may be utilized for both A_{s2} (or A_{s3}) and A_{s4}, with the largest area requirement governing, bending the reinforcement 90 degrees at the corners and waiving the extension requirements of Figure 3. (See Figure 4.) The welded-wire fabric shall be composed of circumferential and longitudinal wires meeting the spacing requirements of Section 7.4 and shall contain sufficient longitudinal wires extending through the box section to maintain the shape and position of reinforcement. The exposure of the ends of longitudinals, stirrups, and spacers used to position the reinforcement shall not be a cause for rejection.

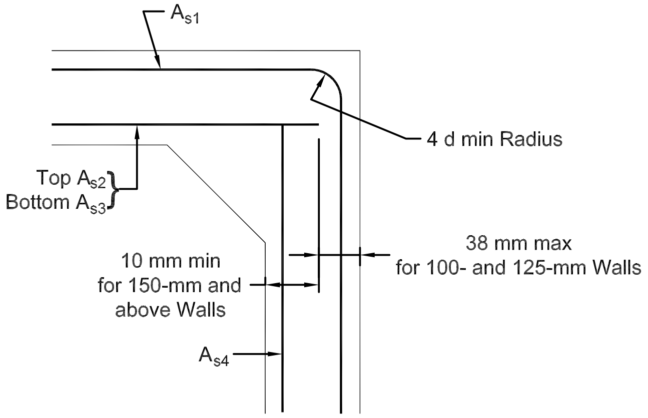


Figure 3—Detail Inner Reinforcement

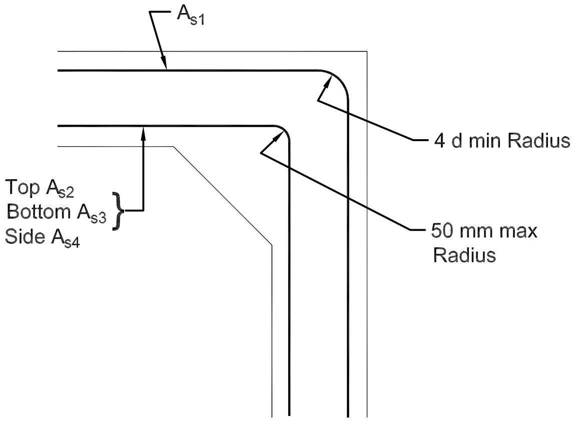


Figure 4—Detail Option

7.4. *Laps, Welds, and Spacing*—Splices in the circumferential reinforcement shall be made by lapping. The overlap measured between the outermost longitudinal wires of each fabric sheet shall not be less than the spacing of the longitudinal wires plus 50 mm. If A_{s1} is extended and connected, welded splices shall be allowed in the connection. A_{s4} may be lapped and welded at any location or connected by welding at the corners to A_{s2} and A_{s3}. The spacing center-to-center of the circumferential wires shall not be less than 50 mm nor more than 100 mm. The spacing center-to-center of the longitudinal wires shall not be more than 200 mm.

8. JOINTS

8.1. The precast reinforced concrete box sections shall be produced with male and female ends. The ends shall be of such design and the ends of the box sections so formed that the sections can be laid together to make a continuous line of box sections compatible with the permissible variations given in Section 11.

8.2. Outer cage circumferential reinforcement as shown in Figures 1 and 2 shall be placed in the top and bottom slabs at the female portion of the joint when A_{s1} is not continuous over the span. The minimum area of such reinforcement in square millimeters per linear meter of box section length shall be the same as the areas specified for A_{s4} in Tables 1, 2, and 3.

9. MANUFACTURE

9.1. *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this specification.

9.2. *Curing*—The box sections shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength in 28 days or less. Any one of the following methods of curing or combinations thereof may be used:

9.2.1. *Steam Curing*—The box sections may be low pressure, steam cured by a system that will maintain a moist atmosphere.

9.2.2. *Water Curing*—The box sections may be water cured by any method that will keep the sections moist.

9.2.3. *Membrane Curing*—A sealing membrane conforming to the requirements of M 148 may be applied and shall be left intact until the required concrete compressive strength is attained. The concrete temperature at the time of application shall be within 6ºC of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

9.3. *Forms*—The forms used in manufacture shall be sufficiently rigid and accurate to maintain the box section dimensions within the permissible variations given in Section 11. All casting surfaces shall be of smooth nonporous material.

9.4. *Handling*—Handling devices or holes shall be permitted in each box section for the purpose of handling and laying.

10. PHYSICAL REQUIREMENTS

10.1. *Type of Specimen*—Compression tests for determining concrete compressive strength may be made on either concrete cylinders or on cores drilled from the boxed section.

10.2. *Compression Testing of Cylinders*:

10.2.1. *Cylinder Production*—Cylinders shall be prepared in accordance with the Cylinder Strength Test Method of T 280.

10.2.2. *Number of Cylinders*—Prepare not fewer than five test cylinders from a group (1 day's production of each concrete strength) of box sections.

10.2.3. *Acceptability on the Basis of Cylinder Test Results*:

10.2.3.1. When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength in the group of box sections shall be accepted.

10.2.3.2. When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the design concrete strength, then the compressive strength of the concrete in the group of box sections shall be accepted.

10.2.3.3. When the compressive strength of the cylinders tested does not conform to the acceptance criteria stated in Sections 10.2.3.1 or 10.2.3.2, the acceptability of the group shall be determined in accordance with the provisions of Section 10.2.

10.3. *Compression Testing of Cores*:

10.3.1. *Obtaining Cores*—Cores shall be obtained and prepared in accordance with the Core Strength Test Method of T 280.

10.3.2. *Number of Cores*—One core shall be taken from a box section selected at random from each group of 15 box sections of a single size or fraction of such a group from each continuous production run.

10.4. *Acceptability on the Basis of Core Test Results*:

10.4.1. When the compressive strengths of cores tested for a group of box sections is equal to or greater than the design concrete strength, the compressive strength of the concrete for the group is acceptable.

10.4.2. If the compressive strength of the core tested is less than the design concrete strength, the box section from which that core was taken may be re-cored. If the compressive strength of the re-core is equal to or greater than the design concrete compressive strength, the compressive strength of the concrete for the group is acceptable.

10.4.3. If the compressive strength of the re-core is less than the design concrete strength, the box section from which the core was taken shall be rejected. Two box sections from the remainder of the group shall be selected at random and one core shall be taken from each box section. If the compressive strength of both cores is equal to or greater than the design concrete compressive strength, the concrete compressive strength of the remainder of the group shall be acceptable. If the compressive strength of either of the two cores tested is less than the design concrete compressive strength, then the remainder of the group shall be either rejected or, at the option of the manufacturer, each box section of the remainder of the group shall be cored and accepted individually, and any of the box sections that have a core with less than the design concrete compressive strength shall be rejected.

10.5. *Plugging Core Holes*—The core holes shall be plugged and sealed by the manufacturer in a manner such that the box section will meet all of the test requirements of this specification. Box sections so sealed shall be considered as satisfactory for use.

10.6. *Test Equipment*—Every manufacturer furnishing box sections under this specification shall furnish all facilities and personnel necessary to carry out the tests required.

11. PERMISSIBLE VARIATIONS

11.1. *Internal Dimensions*—The box culvert manufacturer shall establish the rise and span of the existing equipment to the nearest millimeter and verify that it is within the limits given in Table 4. The internal dimensions shall not vary more than 1 percent from the manufacturer's established metric size.

Table 4—Permissible Variation in Internal Size (Span or Rise)

Designated Size, mm	Permissible Variation, Internal Size, mm	
	Min	Max
600	600	620
900	900	920
1200	1200	1230
1500	1500	1540
1800	1810	1850
2100	2110	2160
2400	2410	2460
2700	2710	2770
3000	3020	3080
3300	3320	3390
3600	3620	3690

11.2. *Slab and Wall Thickness*—The slab and wall thickness shall not be less than that shown in the design by more than 5 percent or 5 mm, whichever is greater. A thickness more than that required in the design shall not be a cause for rejection.

11.3. *Length of Opposite Surfaces*—Variations in laying lengths of two opposite surfaces of the box section shall not be more than 10 mm/m of internal span, with a maximum of 16 mm for all sizes through 2100-mm internal span, and a maximum of 19 mm for internal spans greater than 2100 mm, except where beveled ends for laying on curves are specified by the owner.

11.4. *Length of Section*—The underrun in length of a section shall not be more than 10 mm/m of length with a maximum of 13 mm in any box section.

11.5. *Position of Reinforcement*—The maximum variation in the position of the reinforcement for 130 mm or less slab and wall thicknesses shall be ±10 mm and for greater than 130-mm slab and wall thicknesses shall be ±13 mm. In no case, however, shall the cover over the reinforcement be less than 16 mm, as measured to the internal surface or the external surface. The preceding minimum cover limitation does not apply at the mating surfaces of the joint.

11.6. *Area of Reinforcement*—The areas of steel reinforcement shall be the design steel areas as shown in Tables 1, 2, or 3. Steel areas greater than those required shall not be cause for rejection. The permissible variation in diameter of any wire in finished fabric shall conform to the tolerances prescribed for the wire before fabrication by either M 32M/M 32 or M 225M/M 225 as applicable.

12. REPAIRS

12.1. Box sections may be repaired, if necessary, because of imperfections in manufacture or handling damage and will be acceptable if, in the opinion of the owner, the repaired box section conforms to the requirements of this specification.

13. INSPECTION

13.1. The quality of materials, the process of manufacture, and the finished box sections shall be subject to inspection by the owner.

14. REJECTION

14.1. Box sections shall be subject to rejection if it fails to conform to any of the specification requirements. Individual box sections may be rejected because of any of the following:

14.1.1. Fractures or cracks passing through the wall, except for a single end crack that does not exceed the depth of the joint.

14.1.2. Defects that indicate mixing and molding, not in compliance with Section 9.1, or honeycombed or open texture that would adversely affect the function of the box sections.

14.1.3. The ends of the box sections are not normal to the walls and centerline of the box section, within the limits of variations given in Section 11, except where beveled ends are specified.

14.1.4. Damaged ends, where such damage would prevent making a satisfactory joint.

15. MARKING

15.1. The following information shall be clearly marked on each box section by indentation, waterproof paint, or other approved means:

15.1.1. Box section span, rise, table number, maximum and minimum design earth cover, and specification designation;

15.1.2. Date of manufacture;

15.1.3. Name or trademark of the manufacturer; and

15.1.4. Each section shall be clearly marked by indentation on either the inner or outer surface during the process of manufacture so that the location of the top will be evident immediately after the forms are stripped. In addition, the word “top” shall be lettered with waterproof paint on the inside top surface.

16. KEYWORDS

16.1. Concrete box—precast; culvert.

APPENDIX

(Nonmandatory Information)

X1. DESIGN CRITERIA USED TO DEVELOP TABLES 1, 2, AND 3

X1.1. *Bedding and Backfill Assumptions*:

X1.1.1. The bedding is assumed to provide a slightly yielding, uniformly distributed support over the bottom width of the box section.

X1.1.2. The design earth covers and reinforcement areas are based on the mass of a column of earth over the width of the box section.

X1.1.3. Refer to Appendix X2 for other bedding and backfill conditions.

X1.2. *Criteria for Loads*:

X1.2.1. Design loads are based on the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges*, Thirteenth Edition, 1973.

X1.2.2. Live loads for designs given in Table 1 are H20 truck wheel loads as defined in the AASHTO specifications. Live loads for designs given in Table 2 are either the H20 truck wheel loads, or interstate truck wheel loads as defined in U.S. Department of Commerce, Bureau of Public Roads Circular Memorandum 22-40, 22 April 1957, depending upon whichever produces the more severe design strength requirements. Distribution of truck wheel loads through earth fills is in accordance with Article 1.3.3 in the AASHTO specifications. Earth cover loads for designs given in Tables 1, 2, and 3 are the mass of a column of earth of a width equal to the outside width dimension of the box section and a height equal to the depth of earth cover over the top of the section. This earth load is recommended in Article 1.2.2 (A) of the AASHTO Bridge Specifications for the normal case of box culverts on “yielding” subgrade. The AASHTO specifications define an “unyielding” subgrade as “rock or piles” and requires the use of the Iowa formulas for this case. See Appendix X2 for a method to modify the designs given in Tables 1, 2, and 3 when the anticipated earth load, or earth load plus uniformly distributed surface surcharge load, is greater (or less) than the mass of the column of earth directly above the out-to-out width of the box sections.

X1.2.3. Article 1.2.2 of the AASHTO specification allows the design of buried structures, such as box section culverts, for 70 percent of the mass of earth directly above the out-to-out width of structure. On the other hand, the Marston-Spangler theory of earth loads on buried pipe gives a total earth load greater than the mass of the column of earth directly over the structure for most “positive projecting” culverts, and less than the mass of the column of earth over the structure for “trench type” installations, “negative projecting” culverts, and “induced trench” culverts. In view of the number of different installation conditions that may be encountered and the use of higher reinforcing steel stresses associated with the ultimate strength design method (see Section X1.2), the 30 percent reduction in mass of supported earth load permitted in Article 1.2.2 of the AASHTO specification is not utilized for the tabulated designs, and a method of modifying designs for anticipated earth loads that differ from the above described "standard earth load" is given in Appendix X2.

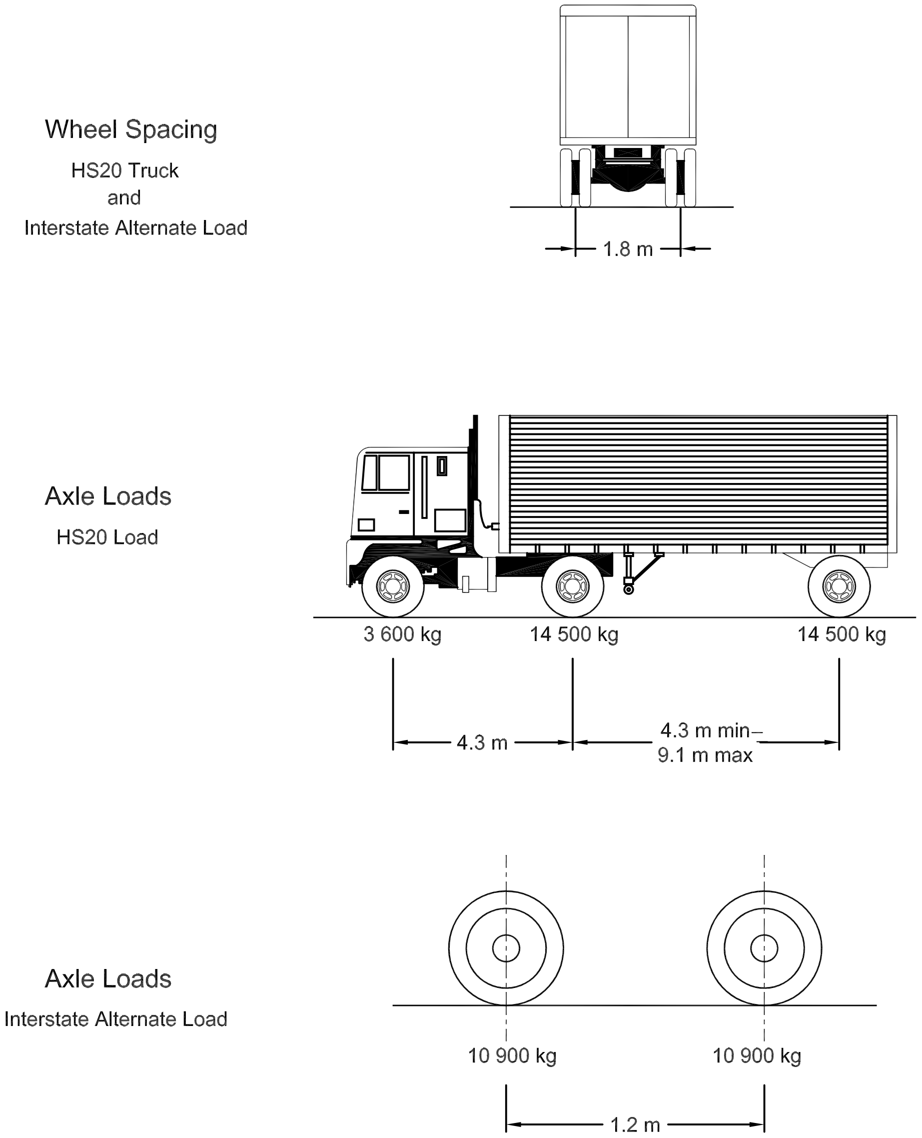


Figure X1.1—Axle Loads for Box Section Standard Designs

X1.2.4. Lateral earth pressure from mass of earth above and adjacent to a box section is taken as a minimum of 0.25 times vertical pressure, and an additional 0.25 times vertical pressure is added when determining steel areas only when areas are increased by such increased lateral pressure. For Tables 1 and 2, additional lateral pressure in pascals per square meter from approaching truck wheel loads is taken as 15 divided by depth of earth cover in meters and is added when determining steel areas only at sections where area is increased by lateral pressure.

X1.3. *Methods of Analysis*:

X1.3.1. The structural effects of the loads described in Section X1.2 are evaluated based on the elastic method of structural analysis. Design moments, shears, and thrusts are determined by computer analysis using the stiffness matrix method, and design is based on maximum stress resultants at critical sections caused by the most severe combination of design loads.

X1.4. *Method of Design*:

X1.4.1. Design heights of earth cover, wall thicknesses, and reinforcing steel areas are determined based on the elastic method of structural analysis and the ultimate strength method of reinforced concrete design given in the 1971 ACI Building Code (ACI 318-71).[2] Steel areas are governed by ultimate flexural strength. The steel areas and the size and spacing of circumferential wires are proportioned to limit the maximum crack width to 0.3 mm under design load conditions. Evaluation of crack control with the welded wire fabric reinforcement specified for the tabulated designs is based on the results of research by Lloyd, Rejali, and Kesler[3] at the University of Illinois, and is significantly more conservative than the crack control provisions given in ACI 318-71. This is because it is recognized that approximations that were used to simplify the ACI crack control provisions can result in unconservative designs for thin elements such as slabs. Standard designs do not cover installations that must resist significant external water pressure. Furthermore, installations that are subject to high external water pressure may require vertical reinforcement for the inside face of the side walls. Lloyd, Rejali, and Kesler suggest that crack control equations developed for deformed bar reinforcement may also be used for both welded smooth wire fabric and deformed wire fabric reinforcement.

X1.4.2. Note that some box section designs shown in the tables have steel area requirements designated by "D" as minimum practical steel area. For such designs, the steel areas calculated for support of design loads are less than the minimum steel area that is specified for slabs in AASHTO Specification, 0.002 bt, and thus, the minimum reinforcement areas are shown in the tables.

X1.4.3. For specific criteria used in Tables 1, 2, and 3, refer to Table X1.1.

X1.4.4. The maximum height of earth cover shown in the tables is determined by the shear strength of the box section without the use of special shear reinforcement, as given in Sections 11.2.1, 11.2.2, and 11.4.1 of ACI 318-71, and by the "standard mass" of the column of earth directly above the box section. See Table X1.2 for the maximum loads that can be carried on the standard box sections. These loads can be used to determine maximum earth cover heights, when the anticipated mass of earth supported by the section is greater than (or less than) the above "standard mass" of earth cover.

X1.5. *Multiple-Cell Installations*:

X1.5.1. The designs given herein are for single cell precast reinforced concrete box sections. The units may be used in parallel for multicell installations if means of positive lateral bearing by continuous contact between the sides of adjacent boxes are provided. Compacted earth fill, granular backfill, or grouting between the units are considered means of providing such positive bearing.

Table X1.1—Specific Criteria Used for Tables 1, 2, and 3

Material Properties:	
Welded wire fabric, minimum specified yield stress	445 MPa
Concrete, minimum specified compressive strength	35 MPa
Soil Data:	
Unit mass	1920 kg/m^3
Ratio of lateral to vertical pressure from mass of earth	0.25 min to 0.50 max
Additional lateral pressure from approaching truck wheels	33.5 ÷ H, kPa where H = earth cover, m
External water table	below box section invert
Effective mass coefficient	1.0
Capacity Reduction Factors (from ACI 318-71):	
Shear	0.85
Axial compression combined with bending[a]	0.70 to 0.90
Loading Data:	
Load factor—dead load	1.5
Load factor—live load	2.2
Truck axle load: H20 (Table 1)	14500 kg
Interstate (Table 2)	2 @ 10900 kg
None (Table 3)	—
Loading Data:	
Impact (variable with depth) (See AASHTO Bridge Specifications, 1969	0 to 20 percent
Uniform internal pressure	0.0
Depth of water in box section	equal to inside height
External groundwater pressure	0.0
Structural Arrangement:	
Concrete cover over steel	25 mm
Slab thickness	$^{1}/_{12}$ times inside span plus 25 mm up to 2100-mm span—$^{1}/_{12}$ inside span above 2100-mm span
Side wall thickness	equal to slab thickness
Haunch dimensions	vertical and horizontal dimensions both equal to slab thickness
Minimum reinforcing inside face slabs and side walls, outside face side walls and corners of slabs	0.002 bt
The structural arrangement and details are shown in Figure 1	

Table X1.2—Design Information for Revising Tabulated Reinforcing Steel

Box Section Designated Span × Rise × Wall Thickness, mm	Change in Reinforcing Steel Area per kg/m, Change in Total Mass on Box Section		Maximum W, kg/m[a]	Box Section Designated Span × Rise × Wall Thickness, mm	Change in Reinforcing Steel Area per kg/m, Change in Total Mass on Box Section		Maximum W, kg/m[a]
	ΔA_{s1} mm^2/m	ΔA_{s2} ΔA_{s3} mm^2/m			ΔA_{s1} mm^2/m	ΔA_{s2} ΔA_{s3} mm^2/m	
900 by 600 by 100	0.026	0.033	14100	2400 by 1200 by 200	0.034	0.034	26800
900 by 900 by 100	0.018	0.040	14000	2400 by 1500 by 200	0.030	0.038	26500
1200 by 600 by 125	0.030	0.028	18200	2400 by 1800 by 200	0.026	0.041	26200
1200 by 900 by 125	0.023	0.036	18000	2400 by 2100 by 200	0.023	0.043	2900
1200 by 1200 by 125	0.018	0.040	17900	2400 by 2400 by 200	0.021	0.046	25600
1500 by 900 by 150	0.027	0.031	22000	2700 by 1500 by 225	0.031	0.036	30200
1500 by 1200 by 150	0.021	0.036	21900	2700 by 1800 by 225	0.028	0.038	29900
1500 by 1500 by 150	0.017	0.040	21600	2700 by 2100 by 225	0.026	0.041	29500
1800 by 900 by 175	0.028	0.028	26000	2700 by 2400 by 225	0.023	0.043	29200
1800 by 1200 by 175	0.024	0.033	25700	2700 by 2700 by 225	0.021	0.044	28900
1800 by 1500 by 175	0.021	0.037	25400	3000 by 1500 by 250	0.031	0.033	33900
1800 by 1800 by 175	0.018	0.040	25200	3000 by 1800 by 250	0.028	0.036	33500
2100 by 1200 by 200	0.027	0.031	29500	3000 by 2100 by 250	0.027	0.038	33200
2100 by 1500 by 200	0.023	0.034	29200	3000 by 2400 by 250	0.024	0.040	32900
2100 by 1800 by 200	0.020	0.037	28900	3000 by 2700 by 250	0.021	0.043	32400
2100 by 2100 by 200	0.018	0.040	28700	3000 by 3000 by 250	0.020	0.044	32100

[a] Maximum allowable total mass on box section as governed by shear strength of box section without stirrups.

X2. MODIFICATION OF “STANDARD’’ BOX SECTION DESIGNS FOR EARTH LOADS DIFFERENT FROM THE “STANDARD” EARTH LOAD

X2.1. The heights of cover given in Tables 1, 2, and 3 are based on a “standard mass of earth fill” equal to the mass of a column of earth with a unit mass of 1920 kg/m^3 and a width equal to the out-to-out width of the box section. For some installations, the design engineer may determine that for a given height of cover, the mass of earth to be supported by the box section is more or less than the above “standard mass of earth fill” used to develop the designs given in the tables.

X2.1.1. For example, the Marston-Spangler theory for loads on buried structures indicates that the mass of earth that must be supported by most “positive projecting” conduits is greater than the mass of a column of earth directly over the conduit, while the mass of earth that must be supported by “trench-type” conduits, “negative-projecting” conduits, and “induced-trench” conduits is less than the mass of earth over the conduits. Also, the designer may wish to use a unit mass of earth more or less than the 1920 kg/m^3 used in the “standard mass,” or may wish to include a particular uniformly distributed surface surcharge loading.

X2.2. Incremental reinforcing steel areas are given in Table X1.2 for each box section type. Where installation conditions warrant the use of a mass of earth more or less than the “standard mass,” the designer may utilize these incremental areas to modify the steel areas given in Tables 1, 2, or 3 for a particular height of cover. The maximum total mass of earth fill that may be supported over the out-to-out width of each standard box section size, as governed by shear strength without shear reinforcing, is also given in Table X1.2. Thus, for any mass of earth or surface surcharge, or both, a designer can use Tables 1, 2, 3, and X1.2, to determine the required area of reinforcing steel for various heights of earth cover, or the maximum height of earth cover without special shear reinforcing, for any of the standard box section sizes shown in these tables.

X2.3. The following design example illustrates how the previously mentioned tables may be used to obtain a suitable design for a box section to support an earth load that is greater than the "standard mass of earth" used to develop Tables 1, 2, and 3.

X2.3.1. *Example*:

X2.3.1.1. *Given*—A 1800 by 1800 by 175 mm. Table 1 precast concrete box section under 4.3 m of cover with 1760 kg/m^3 earth and an effective mass of earth supported by the section of 1.36 times the mass of the column of earth directly over the section instead of the standard 1920 kg/m^3 earth.

X2.3.1.2. *Find*—The required A_{s1}, A_{s2}, and A_{s3} circumferential reinforcement areas. In all cases A_{s4} is governed by the minimum steel areas as described in X1.4.2 and is not changed by increased vertical loads.

X2.3.2. *Solution*:

X2.3.2.1. Effective unit mass of soil = 1760 + 1.36 = 2400 kg/m^3

X2.3.2.2. Determine change in total mass of earth on culvert in kilograms per linear meter:

$$W = H \times B \times w \tag{X2.1}$$

where:

W = total mass of earth on culvert, kg/linear m;

H = height of earth cover, m;

B = outside span, m;

w = unit weight of earth, kg/m^3;

W_{1920} = $4.3 \times 2.2 \times 1920 = 18200$ kg/m;

W_{2400} = $4.3 \times 2.2 \times 2400 = 22700$ kg/m;

W = $W_{2400} - W_{1920} = 4500$ kg/m.

X2.3.2.3. Determine the change in circumferential reinforcement areas. From Table 1, for an 1800 by 1800 by 175 mm section under 4.3 m of cover, A_{s1} = 360, A_{s2} = 680, and A_{s3} = 700 mm^2/m. From Table 6, for an 1800 by 1800 by 175 mm section, the changes in reinforcing areas are A_{s1} = 0.018; A_{s2} and A_{s3} = 0.040 mm^2/m for each kilogram per meter of load change. Therefore:

$$\Delta A_{s1} = 4500 \times 0.018 = 81$$

$$\Delta A_{s2} = 4500 \times 0.040 = 180$$

$$\Delta A_{s3} = 4500 \times 0.040 = 180$$

Therefore, the correct reinforcement areas are as follows:

$$A_{s1} = 360 + 81 = 441 \text{ mm}^2/\text{m}$$

$$A_{s2} = 680 + 180 = 860 \text{ mm}^2/\text{m}$$

$$A_{s3} = 700 + 180 = 880 \text{ mm}^2/\text{m}$$

X2.3.2.4. Determine if the total mass of earth on the culvert is less than maximum as governed by the shear strength of culvert without stirrups.

From Table 6, the maximum allowable mass = 25 200 kg/m. From Section X2.3.2.2,

$$W_{2400} = 22\,700 \text{ kg/m}$$

The approximate equivalent uniform load from an HS20 live load at 4.3-m burial depth is about 780 kg/m^2 or a total load 1720 kg/m (780 × 2.2). Therefore, the total mass on the box section is 24 400 kg/m (22 700 + 1720), which is less than the maximum allowable; therefore, the design is satisfactory.

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[1] Standard designs and criteria used to develop designs included in this specification are under the jurisdiction of the AASHTO Subcommittee on Bridges and Structures. Agrees with ASTM C 507-98 except that the use of synthetic fibers will be at the owner's option.

[2] Available from the American Concrete Institute, P.O. Box 4754, Redford Station, Detroit, MI 48219.

[3] Lloyd, J. P., H. M. Rejali, and C. E. Kesler, "Crack Control in One-Way Slabs Reinforced with Deformed Welded Wire Fabric." *Journal of the American Concrete Institute Proceedings.* PACIA, Vol. 66, No. 5, May 1969.

Standard Definitions of Terms Relating to Concrete Pipe and Related Products

AASHTO Designation: M 262-10[1]
ASTM Designation: C 822-08b

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Definitions of Terms Relating to

Concrete Pipe and Related Products

AASHTO Designation: M 262-10[1]
ASTM Designation: C 822-08b

1. TERMINOLOGY

1.1 *absorption*—the increase in mass of concrete resulting from the penetration of water into the concrete.

1.2 *absorption test*—a test made to determine the absorption of concrete.

1.3 *admixture*—a material other than water, aggregates, and cement used as an ingredient of concrete and added to the batch immediately before or during its mixture.

1.4 *annular space*—the space between the inner surface of the female end and the outer surface of the male end of an assembled pipe joint.

1.5 *bell*—see *female end of pipe.*

1.6 *blend*—a combining of various cementitious materials.

1.7 *box section*—a concrete pipe with a rectangular cross section.

1.8 *box section bottom slab*—lower horizontal portion of a box section in the installed condition (M 259, M 273).

1.9 *box section top slab*—upper horizontal portion of a box section in the installed condition (M 259, M 273).

1.10 *box section wall*—vertical sides of a box section in the installed condition (M 259, M 273).

1.11 *cage*—an assembled unit of steel reinforcement consisting of circumferential and longitudinal bars or wires.

1.12 *circular reinforcement*—a circular-shaped line of reinforcement.

1.13 *circumferential reinforcement*—reinforcement that is approximately perpendicular to the longitudinal axis of the concrete pipe, box, or structure.

1.14 *combined sewer*—a pipeline intended to convey sewage and storm water.

1.15 *compressive strength*—the maximum resistance of a concrete specimen to axial compressive loading; or the specified resistance used in design calculations.

1.16 *compression test*—a test made on a concrete specimen to determine the compressive strength.

1.17 *concrete*—a homogeneous mixture of portland cement, fine aggregate, coarse aggregate, and water. The mixture may also contain admixtures or other cementitious materials or both.

1.18 *core*—a cylinder of concrete obtained from concrete by means of a core drill.

1.19 *crown*—the top or highest point of the internal surface of the transverse cross section of a pipe.

1.20 *culvert*—a pipeline intended to convey water under a highway, railroad, canal, or similar facility.

1.21 *cylinder (test)*—a cast cylindrical specimen of concrete.

1.22 *designated size*—the dimensional name for a particular size that may or may not be equal to or related to the dimensions used for design purposes or dimensions of the manufactured product.

1.23 *design strength*—the minimum acceptable 0.3-mm (0.01-in.) crack D-load.

1.24 *D-load*—the supporting strength of a pipe loaded under three-edge-bearing test conditions expressed in newtons per linear meter per millimeter of inside diameter or horizontal span (pounds per linear foot per foot of inside diameter or horizontal span).

1.25 *D-load, 0.3-mm (0.01-in.) crack*—the maximum three-edge-bearing test load supported by a concrete pipe before a crack having a width of 0.3 mm (0.01 in.) occurs, measured at close intervals, throughout a continuous length of 300 mm (1 ft) or more measured parallel to the longitudinal axis of pipe barrel expressed as D-load.

1.26 *D-load ultimate (Du)*—the maximum three-edge-bearing test load supported by a pipe, expressed as D-load.

1.27 *distribution reinforcement*—reinforcement, typically running 90 degrees to the main or circumferential reinforcement, intended to disperse concentrated loads to larger areas of a structural member.

1.28 *drain tile*—pipe for collecting and conveying surface and subsurface water from an area.

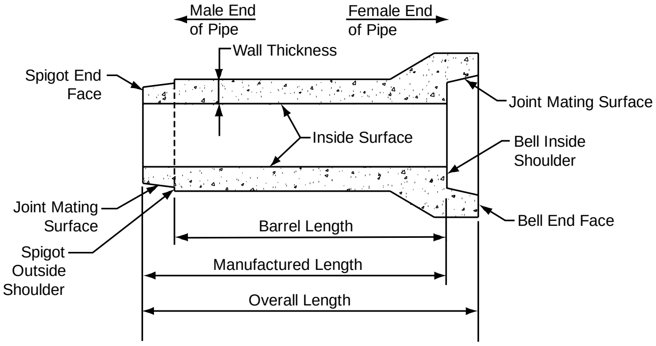
1.29 *elliptical reinforcement*—a line of reinforcement in the approximate shape of an ellipse.

1.30 *exfiltration*—the volume of pipeline flow leaving a sewer and its connections into the soil from pipe, joints, connections, and appurtenances.

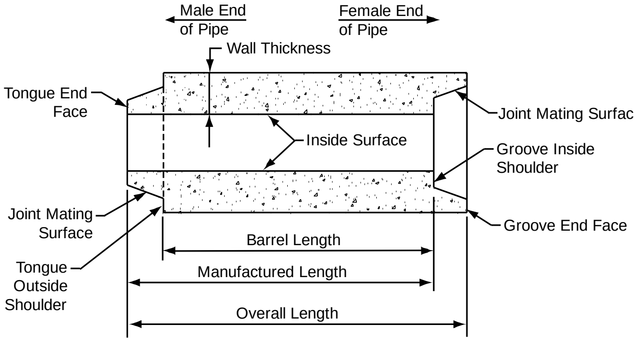
1.31 *external load-crushing strength test*—a test of the pipe in which external crushing forces are exerted in specified directions and locations on a specified length of pipe.

1.32 *external sealing bands*—flexible wrappings that are applied to the outside of a concrete pipe, box section, or manhole section joint intended to control the movement of fluids or solids through the joint.

1.33 *female end of pipe (bell, socket, groove, modified groove)*—that portion of the end of the pipe, regardless of its shape or dimensions, that overlaps a portion of the end of the adjoining pipe.



Bell and Spigot Pipe



Tongue and Groove Pipe

Notes:
1. This is a schematic drawing that only defines nomenclatures and cannot be used for joint designs.
2. Laying length is not shown and shall be as recommended by the pipe manufacturer when developing a pipe layout for field installations.
3. The length of the pipe used in the calculations for three-edge-bearing strength test results is defined as laying length in the Calculations section of T 280 and may not equal field laying length.

Figure 1—Pipe Nomenclature

1.34 *flow line*—a line formed by the inverts of pipe.

1.35 *gradation*—the distribution of particles of granular material among standard sizes usually expressed in terms of cumulative percentages larger or smaller than each of a series of sieve openings.

1.36 *grade rings*—precast concrete rings used for vertical adjustment at the top of a manhole to set manhole casting to proper grade.

1.37 *groove*—see *female end of pipe*.

1.38 *handling reinforcement*—reinforcement intended to reduce the risk of collapse of the pipe or section during handling or storage prior to and during final placement.

1.39 *hydrostatic pressure*—the pressure exerted by water at rest.

1.40 *hydrostatic test*—a test of the ability of a pipe or its joint to withstand internal hydrostatic pressure.

1.41 *infiltration*—the volume of groundwater entering a sewer and its connections from the soil through pipe, joints, connections, or appurtenances.

1.42 *inflow*—the volume of any kind of water entering a sewer and its connections from outside sources not including those sources described under "infiltration."

1.43 *installed length*—final length, along the centerline, of a pipe or box section in place including the longitudinal joint separation between the section and the last section placed.

1.44 *invert*—the bottom or lowest point of the internal surface of the transverse cross section of a pipe.

1.45 *irrigation pipe*—pipe intended for the distribution of irrigation water by pumping or gravity.

1.46 *joint*—a connection of two pipe, manhole, or box section ends, made either with or without the use of additional parts or materials, or both.

1.47 *joint angular deflection*—change in alignment commencing in the joint caused by opening or closing one side of the joint.

1.48 *joint at normal (design) closure*—position of the joint when closed to the manufacturer's recommended inside longitudinal separation without joint angular deflection.

1.49 *joint in off-center position*—with the joint at normal or design closure, without joint angular deflection, when the spigot or bell has been moved in a radial direction. The maximum off-center position occurs when the outer surface of the spigot and the inner surface of the bell are in contact.

1.50 *joint leakage test*—test procedure, utilizing water pressure, air pressure or a vacuum, intended to determine the acceptability of an individual joint relative to leakage.

1.51 *joint leakage test apparatus*—sealing device used to isolate a single joint so that the joint can be tested for leakage. See *joint leakage test.*

1.52 *joint reinforcement*—reinforcement, in or near the joint, intended to enhance the structural characteristics of the joint area of a concrete pipe or box section.

1.53 *joint shear test*—a proof-of-design test procedure to determine minimum shear strength of a joint.

1.54 *layer of reinforcement*—circumferential reinforcement that is one bar or wire in thickness.

1.55 *laying length*—pipe section centerline dimension used for preparing pipeline layout plans. The length as measured from a point on a pipe to an identical point of an adjacent pipe of an installed pipeline.

1.56 *lift hole*—a small hole cast or drilled in the wall of the pipe or section for inserting a bolt, loop of cable or other device used in handling the pipe or section.

1.57 *line of reinforcement*—circumferential reinforcement comprised of one or more layers.

1.58 *longitudinal reinforcement*—reinforcement, in a concrete pipe or box section, running parallel to the intended flow.

1.59 *lot*—an assemblage of concrete pipe, all being of like size, material, and strength designation, manufactured by the same process. The lot size may differ from the quantity designated in the contract or order.

1.60 *low-pressure air test*—testing procedure, utilizing compressed air, intended to determine the acceptability of a pipe section, joint, or pipeline.

1.61 *male end of pipe (spigot, tongue, modified tongue)*—that portion of the end of the pipe, regardless of its shape or dimensions, that is overlapped by a portion of the end of the adjoining pipe.

1.62 *manhole*—a precast concrete structure for vertical access to a pipeline or other closed structure.

1.63 *manhole base*—a concrete slab foundation and the bottom manhole riser section or a bottom manhole riser section with a connected concrete slab.

1.64 *manhole base section*—precast concrete slab foundation and the bottom manhole rise section, or the bottom riser section with precast monolithic or integral slab. A monolithic base section is cast as a single unit. An integral base section is made into a single unit by interconnecting precast manhole components such as a riser section and base slab.

1.65 *manhole reducer section*—a concrete pipe section used as a transition between different-diameter manhole riser sections

1.66 *manhole riser section*—a concrete pipe section used to construct a manhole exclusive of the base, reducers, and top section.

1.67 *manhole top*—the concrete slab top or conical top used to reduce the manhole riser diameter to that of the desired access hole.

1.68 *manufactured length*—the length from spigot/tongue end face to bell/groove inside shoulder.

1.69 *manufacturer*—the group, corporation, partnership, or individual that manufactures or supplies a product.

1.70 *mat reinforcement*—see *quadrant mat.*

1.71 *material tests*—the quality and property tests of component materials.

1.72 *modified design*—a concrete pipe design changed from a standard design.

1.73 *modified groove*—see *female end of pipe*.

1.74 *modified tongue*—see *male end of pipe*.

1.75 *negative air pressure (vacuum) test*—test procedure utilizing air at a pressure less than atmospheric pressure, intended to determine the acceptability of a pipe section or multiple pipe sections, or an installed pipeline or manhole before or after backfill.

1.76 *nonreinforced pipe*—concrete pipe designed without reinforcement.

1.77 *O-ring gasket*—a solid gasket of circular cross section.

1.78 *overall length*—the length from the spigot/tongue end face to bell/groove end face.

1.79 *owner*—the public agency or authority, group, corporation, partnership, or individual that specifies products or services for use on a project that it presently or eventually will own or administrate.

1.80 *permeability*—that property that permits movement of a liquid through the pores and interstices of the concrete.

1.81 *permeability test*—a test to determine the movement of a liquid through concrete under a hydraulic or pressure gradient.

1.82 *pipe*—a tube or elongated hollow concrete structure intended to transmit flow between locations.

1.83 *pipe diameter*—the inside diameter of a concrete pipe.

1.84 *pipe section*—a single pipe.

1.85 *pipeline*—pipe sections joined together.

1.86 *plant tests*—the quality assurance tests performed prior to delivery as a basis of acceptance.

1.87 *preformed flexible joint sealant*—pliable material, formed into a defined cross section, that is applied to the surface of a pipe, box section, or manhole section joint, intended to control the movement of fluids or solids through the joint.

1.88 *quadrant mat*—additional tension zone circumferential reinforcement secured to a layer of reinforcement in the concrete pipe wall.

1.89 *reinforced concrete pipe*—a pipe structure comprised of concrete and steel reinforcement. Such reinforcement is composed of steel wire, welded wire fabric, or bars, of known strength, formed into a cage and positioned in the concrete wall in a specific location in such a manner that the two materials act together to resist stresses.

1.90 *reinforcement*—steel in the form of continuous wire, welded wire fabric, or bars embedded in concrete in such a manner that the above referenced concrete and steel act together to resist stresses.

1.91 *resilient connector*—a flexible connection for joining pipe to structures capable of being deformed and deflected without rupture or leakage.

1.92 *rubber gasket*—rubber formed and used as a seal in concrete pipe joints.

1.93 *sample*—the number of specimens drawn from a lot.

1.94 *sewage (wastewater)*—the spent water of a community that is a combination of liquid and water-carried wastes.

1.95 *sewer*—a pipeline intended to convey sewage.

1.96 *special design*—a concrete pipe design for sizes, loads, or service conditions not covered by a standard design.

1.97 *specimen*—an individual unit on which a test can be made.

1.98 *spigot*—see *male end of pipe*.

1.99 *splice (reinforcement)*—junction of two sections of parallel reinforcement intended to provide continuity and to transfer forces between the two sections.

1.100 *springline*—the points on the internal surface of the transverse cross section of a pipe intersected by the line of maximum horizontal dimension; or in box sections, the mid-height of the internal vertical wall.

1.101 *standard design*—a published and proven concrete pipe design.

1.102 *storm drain*—a pipeline intended to convey storm water.

1.103 *storm sewer*—a pipeline intended to convey storm water.

1.104 *stormwater*—precipitation run-off.

1.105 *three-edge-bearing method*—a method for applying the load to a pipe in an external load-crushing strength test.

1.106 *tongue*—see *male end of pipe*.

1.107 *ultimate strength*—the maximum three-edge-bearing test load supported by a pipe.

1.108 *wall (pipe)*—the structural element composed of concrete or concrete and steel between the inside and outside surfaces of a concrete pipe.

1.109 *watertight*—will restrain the passage of water to not exceed a specified limit.

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[1] Agrees with ASTM C 822-08b except for the definition of "admixture."

Standard Specification for

Acrylonitrile-Butadiene-Styrene (ABS) and Poly(Vinyl Chloride) (PVC) Composite Sewer Piping

AASHTO Designation: M 264-03 (2007)
ASTM Designation: D 2680-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Acrylonitrile-Butadiene-Styrene (ABS) and Poly(Vinyl Chloride) (PVC) Composite Sewer Piping

AASHTO Designation: M 264-03 (2007)
ASTM Designation: D 2680-01

AASHTO M 264-03 (2007) is identical to ASTM D 2680-01 except for the following provisions:

1. Add the following to Section 2.1 of ASTM D 2680-01:
   - D 883, Standard Terminology Relating to Plastics
2. Replace the first sentence of Section 3.1.1 of ASTM D 2680-01 with the following:

   Definitions are in accordance with ASTM D 883 and F 412 and abbreviations are in accordance with ASTM D 1600, unless otherwise indicated.
3. Replace the first sentence of Section 5.2.2 of ASTM D 2680-01 with the following:

   The thermoplastic material shall be a rigid PVC plastic and shall meet or exceed the requirements of ASTM D 4396, for a minimum cell classification of 11432.

Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings

AASHTO Designation: M 273-00 (2008)[1]
ASTM Designation: C 850-95a

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Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings

AASHTO Designation: M 273-00 (2008)[1]
ASTM Designation: C 850-95a

1. SCOPE

1.1. This specification covers single-cell, precast reinforced concrete box sections with less than 2 ft of cover subjected to highway loadings and intended to be used for the construction of culverts and for the conveyance of storm water, industrial wastes, and sewage.

1.2. A complete metric companion to M 273 has been developed—M 273M; therefore, no metric equivalents are presented in this specification.

Note 1—This specification is primarily a manufacturing and purchasing specification. However, standard designs are included and the criteria used to develop these designs are given in Appendix X1. The successful performance of this product depends upon the proper selection of the box section, bedding, backfill, controlled manufacture in the plant, and care that the installation conforms to the construction specifications. The owner of the precast reinforced concrete box sections specified herein is cautioned that the loading conditions and the field requirements must be correlated with the box sections specified and that inspection at the construction site must be provided.

Note 2—AASHTO M 259 is to be used for box sections subjected to highway loading with 2 ft or more earth cover, or subjected to dead load only.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement

- M 259, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 280, Concrete Pipe, Manhole Sections, or Tile
- *Standard Specifications for Highway Bridges*

2.2. *ASTM Standard*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. TYPES

4.1. Precast reinforced concrete box sections manufactured in accordance with this specification shall be of the types identified in Tables 1 and 2, and shall be designated by type, span, and rise.

5. BASIS OF ACCEPTANCE

5.1. Acceptability of the box sections produced in accordance with Section 7 shall be determined by the results of the concrete compressive strength tests described in Section 10, by the material requirements described in Section 6, and by inspection of the finished box sections.

5.2. Box sections shall be considered ready for acceptance when they conform to the requirements of this specification.

6. MATERIALS

6.1. *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.2. *Cementitious Materials*:

6.2.1. *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash and shall not exceed 25 percent by weight.

Table 1—Design Requirements for Precast Reinforced Concrete Box Sections with Less Than 2 ft of Cover Subjected to HS20 Loading[a]

Box Section	Thickness, in.			Circumferential Reinforcement Areas[c]						Distribution Reinforcement Areas[d]	
$S \times R$, ft[b]	Top Slab	Bottom Slab	Wall	A_{s1}	A_{s2}	A_{s3}	A_{s4}	A_{s7}	A_{s8}	A_{s5}	A_{s6}
3 × 2	7	6	4	0.17	0.34	0.20	0.13[e]	0.17[e]	0.14[e]	0.17[e]	0.17[e]
3 × 3	7	6	4	0.13[e]	0.36	0.22	0.13[e]	0.17[e]	0.14[e]	0.18	0.17[e]
4 × 2	$7^1/_2$	6	5	0.21	0.37	0.20	0.13[e]	0.18[e]	0.14[e]	0.18[e]	0.18[e]
4 × 3	$7^1/_2$	6	5	0.18	0.41	0.23	0.13[e]	0.18[e]	0.14[e]	0.20	0.18[e]
4 × 4	$7^1/_2$	6	5	0.16	0.43	0.24	0.13[e]	0.18[e]	0.14[e]	0.21	0.18[e]
5 × 3	8	7	6	0.22	0.41	0.22	0.14[e]	0.19[e]	0.17[e]	0.19[e]	0.19[e]
5 × 4	8	7	6	0.19	0.44	0.24	0.14[e]	0.19[e]	0.17[e]	0.21	0.19[e]
5 × 5	8	7	6	0.16	0.46	0.26	0.14[e]	0.19[e]	0.17[e]	0.22	0.19[e]
6 × 3	8	7	7	0.30	0.42	0.21	0.17[e]	0.19[e]	0.17[e]	0.19[e]	0.19[e]
6 × 4	8	7	7	0.59	0.46	0.24	0.17[e]	0.19[e]	0.17[e]	0.20	0.19[e]
6 × 5	8	7	7	0.23	0.48	0.26	0.17[e]	0.19[e]	0.17[e]	0.21	0.19[e]
6 × 6	8	7	7	0.20	0.51	0.29	0.17[e]	0.19[e]	0.17[e]	0.22	0.19[e]
7 × 4	8	8	8	0.32	0.45	0.24	0.19[e]	0.19[e]	0.19[e]	0.19[e]	0.19[e]
7 × 5	8	8	8	0.29	0.48	0.27	0.19[e]	0.20	0.19[e]	0.19[e]	0.19[e]
7 × 6	8	8	8	0.27	0.51	0.29	0.19[e]	0.20	0.19[e]	0.20	0.19[e]
7 × 7	8	8	8	0.25	0.53	0.32	0.19[e]	0.23	0.19[e]	0.21	0.19[e]
8 × 4	8	8	8	0.37	0.51	0.27	0.19[e]	0.19[e]	0.19[e]	0.19[e]	0.19[e]
8 × 5	8	8	8	0.34	0.53	0.30	0.19[e]	0.19[e]	0.19[e]	0.20	0.19[e]
8 × 6	8	8	8	0.32	0.56	0.33	0.19[e]	0.25	0.19[e]	0.21	0.19[e]
8 × 7	8	8	8	0.30	0.58	0.35	0.19[e]	0.27	0.22	0.22	0.19[e]
8 × 8	8	8	8	0.28	0.60	0.38	0.23	0.29	0.26	0.22	0.19[e]
9 × 5	9	9	9	0.34	0.50	0.29	0.22[e]	0.22[e]	0.22[e]	0.22[e]	0.22[e]
9 × 6	9	9	9	0.32	0.53	0.32	0.22[e]	0.22[e]	0.22[e]	0.22[e]	0.22[e]
9 × 7	9	9	9	0.30	0.55	0.35	0.22[e]	0.25	0.22[e]	0.22[e]	0.22[e]
9 × 8	9	9	9	0.28	0.57	0.38	0.22[e]	0.27	0.24	0.22[e]	0.22[e]
9 × 9	9	9	9	0.27	0.58	0.41	0.25	0.30	0.28	0.22[e]	0.22[e]
10 × 5	10	10	10	0.34	0.48	0.29	0.24[e]	0.24[e]	0.24[e]	0.24[e]	0.24[e]
10 × 6	10	10	10	0.32	0.50	0.32	0.24[e]	0.24[e]	0.24[e]	0.24[e]	0.24[e]
10 × 7	10	10	10	0.31	0.52	0.35	0.24[e]	0.24[e]	0.24[e]	0.24[e]	0.24[e]
10 × 8	10	10	10	0.29	0.54	0.38	0.24[e]	0.26	0.24[e]	0.24[e]	0.24[e]
10 × 9	10	10	10	0.27	0.55	0.40	0.24[e]	0.28	0.26	0.24[e]	0.24[e]
10 × 10	10	10	10	0.27	0.57	0.43	0.27	0.32	0.31	0.24[e]	0.24[e]
11 × 4	11	11	11	0.38	0.44	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]
11 × 6	11	11	11	0.33	0.48	0.32	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]
11 × 8	11	11	11	0.29	0.51	0.38	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]
11 × 10	11	11	11	0.28	0.54	0.43	0.26[e]	0.29	0.29	0.26[e]	0.26[e]
11× 11	11	11	11	0.28	0.56	0.46	0.30	0.34	0.34	0.26[e]	0.26[e]
12 × 4	12	12	12	0.40	0.42	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 6	12	12	12	0.35	0.46	0.32	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 8	12	12	12	0.31	0.49	0.38	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 10	12	12	12	0.29[e]	0.53	0.43	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 12	12	12	12	0.29[e]	0.57	0.50	0.33	0.36	0.37	0.29[e]	0.29[e]

[a] Design requirements are based on maximum effects resulting from cover conditions ranging from 0 to 2 ft and the material and soil properties and loading data shown in Appendix X1. For modified or special designs, see Section 7.2.

[b] The box section designation, for example 3 by 2, indicates interior horizontal span, in feet, by interior vertical rise, in feet.

[c] Design reinforcement areas in square inches per linear foot of box section length at those locations as shown in Figure 1.

[d] Design reinforcement areas in square inches per linear foot of box section width at those locations as shown in Figure 1.

[e] Minimum reinforcement area is specified.

Notes:
1. Reinforcement areas are based on the weight of a column of earth over the width of the box section plus live loads as defined in Appendix X1.
2. Concrete design strength, 5000 psi.

Table 2—Design Requirements for Precast Reinforced Concrete Box Sections with Less Than 2 ft of Cover Subjected to Interstate Loading[a]

Box Section	Thickness, in.			Circumferential Reinforcement Areas[c]						Distribution Reinforcement Areas[d]	
$S \times R$, ft[b]	Top Slab	Bottom Slab	Wall	A_{s1}	A_{s2}	A_{s3}	A_{s4}	A_{s7}	A_{s8}	A_{s5}	A_{s6}
3 × 2	7	6	4	0.17	0.34	0.20	0.13[e]	0.17[e]	0.14[e]	0.17[e]	0.17[e]
3 × 3	7	6	4	0.13[e]	0.36	0.22	0.13[e]	0.17[e]	0.14[e]	0.18	0.17[e]
4 × 2	7½	6	5	0.21	0.38	0.20	0.13[e]	0.18[e]	0.14[e]	0.19	0.18[e]
4 × 3	7½	6	5	0.19	0.41	0.23	0.13[e]	0.18[e]	0.14[e]	0.21	0.18[e]
4 × 4	7½	6	5	0.18	0.43	0.25	0.13[e]	0.18[e]	0.14[e]	0.22	0.18[e]
5 × 3	8	7	6	0.26	0.41	0.28	0.14[e]	0.19[e]	0.17[e]	0.19[e]	0.19[e]
5 × 4	8	7	6	0.23	0.44	0.31	0.14[e]	0.19[e]	0.17[e]	0.21	0.19[e]
5 × 5	8	7	6	0.21	0.46	0.34	0.14[e]	0.19[e]	0.17[e]	0.22	0.19[e]
6 × 3	8	7	7	0.33	0.42	0.28	0.17[e]	0.19[e]	0.17[e]	0.19[e]	0.19[e]
6 × 4	8	7	7	0.29	0.46	0.32	0.17[e]	0.19[e]	0.17[e]	0.20	0.19[e]
6 × 5	8	7	7	0.27	0.48	0.34	0.17[e]	0.19[e]	0.17[e]	0.21	0.19[e]
6 × 6	8	7	7	0.25	0.51	0.37	0.17[e]	0.19[e]	0.17[e]	0.22	0.19[e]
7 × 4	8	8	8	0.33	0.45	0.31	0.19[e]	0.19[e]	0.19[e]	0.19[e]	0.19[e]
7 × 5	8	8	8	0.30	0.48	0.34	0.19[e]	0.20	0.19[e]	0.19[e]	0.19[e]
7 × 6	8	8	8	0.28	0.51	0.37	0.19[e]	0.20	0.19[e]	0.20	0.19[e]
7 × 7	8	8	8	0.26	0.53	0.39	0.19[e]	0.23	0.19[e]	0.21	0.19[e]
8 × 4	8	8	8	0.43	0.51	0.34	0.19[e]	0.19[e]	0.19[e]	0.19[e]	0.19[e]
8 × 5	8	8	8	0.39	0.53	0.38	0.19[e]	0.19[e]	0.19[e]	0.20	0.19[e]
8 × 6	8	8	8	0.36	0.56	0.41	0.19[e]	0.25	0.19[e]	0.21	0.19[e]
8 × 7	8	8	8	0.34	0.58	0.45	0.19[e]	0.27	0.22	0.22	0.19[e]
8 × 8	8	8	8	0.31	0.60	0.48	0.23	0.29	0.26	0.22	0.19[e]
9 × 5	9	9	9	0.42	0.50	0.37	0.22[e]	0.22[e]	0.22[e]	0.22[e]	0.22[e]
9 × 6	9	9	9	0.39	0.53	0.40	0.22[e]	0.22[e]	0.22[e]	0.22[e]	0.22[e]
9 × 7	9	9	9	0.37	0.55	0.44	0.22[e]	0.25	0.22[e]	0.22[e]	0.22[e]
9 × 8	9	9	9	0.34	0.57	0.47	0.22[e]	0.27[e]	0.24	0.22[e]	0.22[e]
9 × 9	9	9	9	0.32	0.58	0.50	0.25	0.30	0.28	0.22[e]	0.22[e]
10 × 5	10	10	10	0.44	0.48	0.36	0.24[e]	0.24[e]	0.24[e]	0.24[e]	0.24[e]
10 × 6	10	10	10	0.41	0.50	0.40	0.24[e]	0.24[e]	0.24[e]	0.24[e]	0.24[e]
10 × 7	10	10	10	0.39	0.52	0.43	0.24[e]	0.24[e]	0.24[e]	0.24[e]	0.24[e]
10 × 8	10	10	10	0.36	0.54	0.46	0.24[e]	0.26	0.24[e]	0.24[e]	0.24[e]
10 × 9	10	10	10	0.34	0.55	0.50	0.24[e]	0.28	0.26	0.24[e]	0.24[e]
10 × 10	10	10	10	0.33	0.57	0.53	0.27	0.32	0.31	0.24[e]	0.24[e]
11 × 4	11	11	11	0.49	0.44	0.32	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]
11 × 6	11	11	11	0.43	0.48	0.40	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]
11 × 8	11	11	11	0.38	0.51	0.46	0.26[e]	0.26[e]	0.26[e]	0.26[e]	0.26[e]
11 × 10	11	11	11	0.35	0.54	0.53	0.26[e]	0.29	0.29	0.26[e]	0.26[e]
11 × 11	11	11	11	0.34	0.57	0.56	0.30	0.34	0.34	0.26[e]	0.26[e]
12 × 4	12	12	12	0.50	0.42	0.32	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 6	12	12	12	0.44	0.46	0.39	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 8	12	12	12	0.40	0.50	0.46	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 10	12	12	12	0.36	0.56	0.53	0.29[e]	0.29[e]	0.29[e]	0.29[e]	0.29[e]
12 × 12	12	12	12	0.35	0.61	0.60	0.33	0.36	0.37	0.29[e]	0.29[e]

[a] Design requirements are based on maximum effects resulting from cover conditions ranging from 0 to 2 ft and the material and soil properties and loading data shown in Appendix X1. For modified or special designs, see Section 7.2.

[b] The box section designation, for example 3 by 2, indicates interior horizontal span, in feet, by interior vertical rise, in feet.

[c] Design reinforcement areas in square inches per linear foot of box section length at those locations as shown in Figure 1.

[d] Design reinforcement areas in square inches per linear foot of box section width at those locations as shown in Figure 1.

[e] Minimum reinforcement area is specified.

Notes:
1. Reinforcement areas are based on the weight of a column of earth over the width of the box section plus live loads as defined in Appendix X1.
2. Concrete design strength 5000 psi.

6.2.2. *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3. *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in concrete shall be one of the following:

6.2.3.1. Portland cement only,

6.2.3.2. Portland blast-furnace slag cement only,

6.2.3.3. Portland-pozzolan cement only, and

6.2.3.4. A combination of portland cement and fly ash wherein the proportion of fly ash is between 5 and 25 percent by weight of total cementitious material (portland cement plus fly ash).

6.3. *Aggregates*—Aggregates shall conform to M 6 and M 80 except that the requirements for gradation shall not apply.

6.4. *Admixtures and Blends*—Admixtures and blends may be used with the approval of the owner.

6.5. *Steel Reinforcement*—Reinforcement shall consist of welded wire fabric conforming to M 55M/M 55 or M 221M/M 221. Longitudinal distribution reinforcement may consist of welded wire fabric or deformed billet-steel bars conforming to M 31M/M 31, Grade 60.

6.6. *Synthetic Fibers*—Polypropylene fibers may be used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

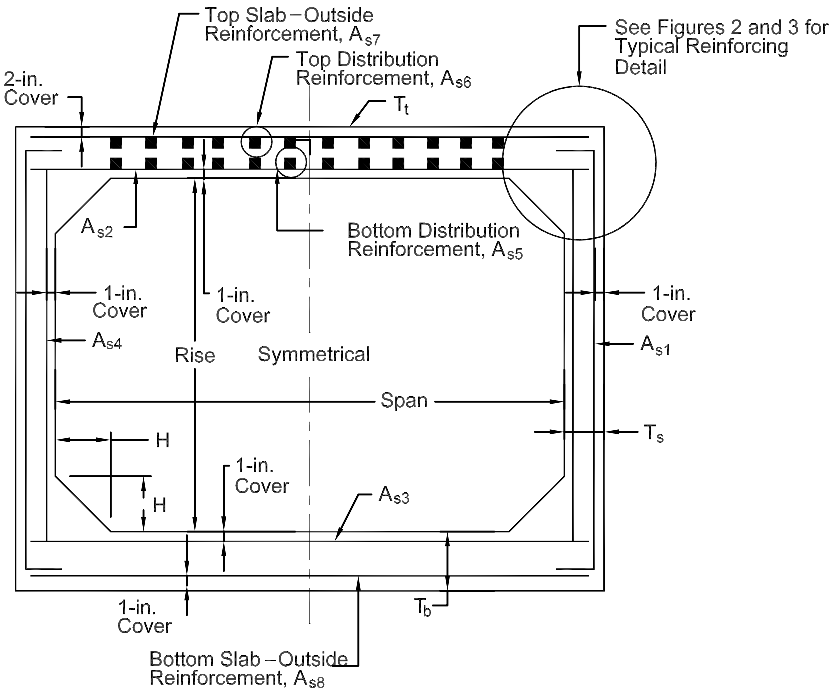
7. DESIGN

7.1. *Design Tables*—The box section dimensions, compressive strength of the concrete, and reinforcement details shall be as prescribed in Tables 1 or 2 and Figures 1 and 2, subject to the provisions of Section 11. Table 1 sections are designed for a cover range from 0 to 2 ft plus AASHTO HS20 live load conditions. Table 2 sections are designed for a cover range from 0 to 2 ft plus Interstate live load conditions. Criteria used to develop Tables 1 and 2 are given in the Appendix X1.

7.2. *Modified and Special Designs*—The manufacturer may request approval by the owner of modified designs that differ from the designs in Section 7.1; or special designs for sizes and loads other than those shown in Tables 1 and 2.

7.3. *Placement of Reinforcement*—The cover of concrete over the circumferential reinforcement shall be 1 in. except in the outside top of the top slab where it shall be 2 in., subject to the provisions of Section 11. The inside circumferential and longitudinal reinforcement shall extend into the male portion of the joint and the outside circumferential and longitudinal reinforcement shall extend into the female portion of the joint. The clear distance of the end circumferential wires shall be not less than $^1/_2$ in. or more than 2 in. from the ends of the box section. Reinforcement shall be assembled utilizing any combination of single or multiple layers of welded-wire fabric. Common reinforcement units may be utilized for both A_{s2} (or A_{s3}) and A_{s4}, and also for both A_{s7} (or A_{s8}) and A_{s1}, with the largest area requirement of each combination governing, bending the reinforcement

90 degrees at the corners, and waiving the extension requirements of Figure 2. See Figure 3. The welded-wire fabric shall be composed of circumferential and longitudinal wires meeting the spacing requirements of Section 7.4 and shall contain sufficient longitudinal wires extending through the box section to maintain the shape and position of reinforcement. Longitudinal distribution reinforcement may be welded-wire fabric or deformed billet-steel bars and shall meet the spacing requirements of Section 7.4. The ends of the longitudinal distribution reinforcement shall be not more than 2 in. from the ends of the box section. The exposure of the ends of longitudinals, stirrups, and spacers used to position the reinforcement shall not be a cause for rejection.



Note: The haunch dimension *H* is equal to the thickness T_s.

Figure 1—Typical Box Section

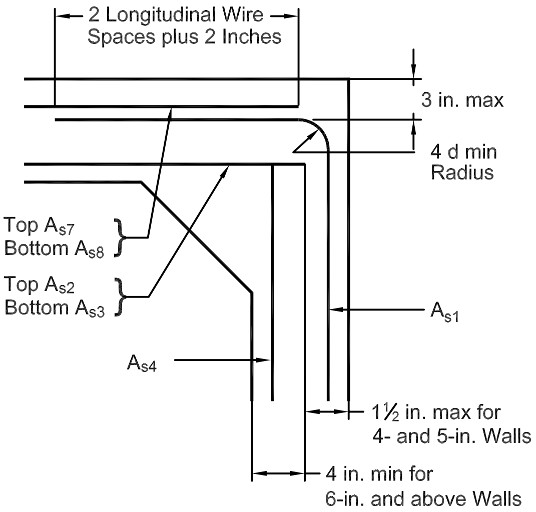


Figure 2—Detail Reinforcement Arrangement

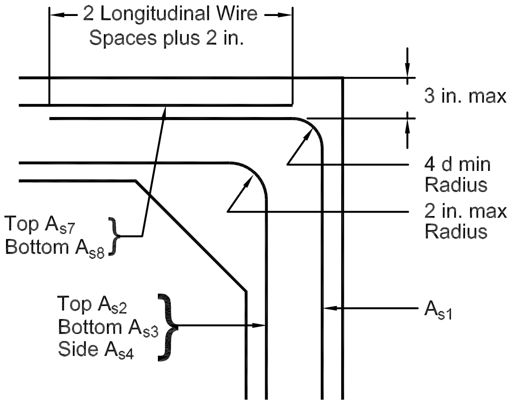


Figure 3—Detail Option

7.4. *Laps, Welds, and Spacing*—Splices in the circumferential reinforcement shall be made by lapping. The overlap measured between the outermost longitudinal wires of each fabric sheet shall be not less than the spacing of the longitudinal wires plus 2 in. A_{s1} shall be lapped with A_{s7} and A_{s8} as shown in Figure 2 or Figure 3 and may be connected by welding. A_{s4} may be lapped and welded at any location or connected by welding the corners to A_{s2} and A_{s3}. The spacing center-to-center of the circumferential wires shall not be less than 2 in. nor more than 4 in. The spacing center to center of the longitudinal wires shall not be more than 8 in. The spacing center-to-center of the longitudinal distribution wires or bars for either line of reinforcing in the top slab shall not be more than 8 in.

8. JOINTS

8.1. The precast reinforced concrete box sections shall be produced with male and female ends. The ends shall be of such design and the ends of the box sections so formed that the sections can be laid together to make a continuous line of box sections compatible with the permissible variations given in Section 11.

9. MANUFACTURE

9.1. *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by weight. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 470 lb/yd^3, unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this standard.

9.2. *Curing*—The box sections shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength in 28 days or less. Any one of the following methods of curing or combinations thereof may be used:

9.2.1. *Steam Curing*—The box sections may be low pressure, steam cured by a system that will maintain a moist atmosphere.

9.2.2. *Water Curing*—The box sections may be water cured by any method that will keep the section moist.

9.2.3. *Membrane Curing*—A sealing membrane conforming to the requirements of M 148 may be applied and shall be left intact until the required concrete compressive strength is attained. The concrete temperature at the time of the application shall be within ±10ºF of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

9.3. *Forms*—The forms used in manufacture shall be sufficiently rigid and accurate to maintain the box section dimensions within the permissible variations given in Section 11. All casting surfaces shall be of smooth, nonporous material.

9.4. *Handling*—Handling devices or holes shall be permitted in each box section for the purpose of handling and laying.

10. PHYSICAL REQUIREMENTS

10.1. *Type of Specimen*—Compression tests for determining concrete compressive strength may be made on either concrete cylinders or on cores drilled from the boxed section. (See T 22.)

10.2. *Compression Testing of Cylinders*:

10.2.1. *Cylinder Production*—Cylinders shall be prepared in accordance with the Cylinder Strength Test Method of T 280.

10.2.2. *Number of Cylinders*—Prepare not fewer than five test cylinders from a group (1 day's production of each concrete strength) of box sections.

10.2.3. *Acceptability on the Basis of Cylinder Test Results*:

10.2.3.1. When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength in the group of box sections shall be accepted.

10.2.3.2. When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the design concrete strength, then the compressive strength of the concrete in the group of box sections shall be accepted.

10.2.3.3. When the compressive strength of the cylinders tested does not conform to the acceptance criteria stated in Section 10.2.3.1 or Section 10.2.3.2, the acceptability of the group shall be determined in accordance with the provisions of Section 10.2.

10.3. *Compression Testing of Cores*:

10.3.1. *Obtaining Cores*—Cores shall be obtained and prepared in accordance with the Core Strength Test Method of T 280.

10.3.2. *Number of Cores*—One core shall be taken from a box section selected at random from each group of 15 box sections of a single size or fraction of such a group from each continuous production run.

10.4. *Acceptability on the Basis of Core Test Results*:

10.4.1. When the compressive strengths of cores tested for a group of box sections is equal to or greater than the design concrete strength, the compressive strength of the concrete for the group is acceptable.

10.4.2. If the compressive strength of the core tested is less than the design concrete strength, the box section from which that core was taken may be re-cored. If the compressive strength of the re-core is equal to or greater than the design concrete compressive strength, the compressive strength of the concrete for the group is acceptable.

10.4.3. If the compressive strength of the re-core is less than the design concrete strength, the box section from which the core was taken shall be rejected. Two box sections from the remainder of the group shall be selected at random and one core shall be taken from each box section. If the compressive strength of both cores is equal to or greater than the design concrete compressive strength, the concrete compressive strength of the remainder of the group shall be acceptable. If the compressive strength of either of the two cores tested is less than the design concrete compressive strength, then the remainder of the group shall be either rejected or, at the option of the manufacturer, each box section of the remainder of the group shall be cored and accepted individually, and any of the box sections that have a core with less than the design concrete compressive strength shall be rejected.

10.5. *Plugging Core Holes*—The core holes shall be plugged and sealed by the manufacturer in a manner such that the box section will meet all of the test requirements of this specification. Box sections so sealed shall be considered satisfactory for use.

10.6. *Test Equipment*—Every manufacturer furnishing box sections under this specification shall furnish all facilities and personnel necessary to carry out the test required.

11. PERMISSIBLE VARIATIONS

11.1. *Internal Dimensions*—The internal dimensions shall vary not more than 1 percent from the design dimensions. The haunch dimensions shall vary not more than $^1/_4$ in. from the design dimensions.

11.2. *Slab and Wall Thickness*—The slab and wall thickness shall not be less than that shown in the design by more than 5 percent or $^3/_{16}$ in., whichever is greater. A thickness more than that required in the design shall not be cause for rejection.

11.3. *Length of Opposite Surfaces*—Variations in laying lengths of two opposite surfaces of the box section shall not be more than $^1/_8$ in./ft of span with a maximum of $^5/_8$ in. for all sizes through 7-ft internal span, and a maximum of $^3/_4$ in. for internal spans greater than 7 ft, except where beveled ends for laying on curves are specified by the owner.

11.4. *Length of Section*—The underrun in length of a section shall not be more than $^1/_8$ in./ft of length with a maximum of $^1/_2$ in. any box section.

11.5. *Position of Reinforcement*—The maximum variation in the position of the reinforcement for 5 in. or less wall thicknesses shall be $\pm^3/_8$ in., and for greater than 5-in. slab and wall thicknesses shall be $\pm^1/_2$ in. In no case, however, shall the cover over the reinforcement be less than $^5/_8$ in., as measured to the internal surface or the external surface of the box section except the cover over the reinforcement for the external surface of the top slab shall not be less than $1^5/_8$ in. The preceding minimum cover limitation does not apply at the mating surfaces of the joint.

11.6. *Area of Reinforcement*—The areas of steel reinforcement shall be the design steel areas as shown in Tables 1 and 2. Steel areas greater than those required shall not be cause for rejection. The permissible variation in diameter of any reinforcement shall conform to the tolerances prescribed in the AASHTO specification for that type of reinforcement.

12. REPAIRS

12.1. Box sections may be repaired, if necessary, because of imperfections in manufacture or handling damage and will be acceptable if, in the opinion of the owner, the repaired box section conforms to the requirements of this specification.

13. INSPECTION

13.1. The quality of materials, the process of manufacture, and the finished box sections shall be subject to inspection by the owner.

14. REJECTION

14.1. Box sections shall be subject to rejection if it fails to conform to any of the specification requirements. Individual box sections may be rejected because of any of the following:

14.1.1. Fractures or cracks passing through the wall, except for a single-end crack that does not exceed the depth of the joint;

14.1.2. Defects that indicate mixing and molding, not in compliance with Section 9.1, or honeycombed or open texture, that would adversely affect the function of the box;

14.1.3. The ends of the box sections are not normal to the walls and centerline of the box section, within the limits of variations given in Section 11, except where beveled ends are specified; and

14.1.4. Damaged ends, where such damage would prevent making a satisfactory joint.

15. PRODUCT MARKING

15.1. The following information shall be legibly marked on each box section by indentation, waterproof paint, or other approved means:

15.1.1. Box section span, rise, table number, and specification designation,

15.1.2. Date of manufacture,

15.1.3. Name or trademark of the manufacturer,

15.1.4. Identification of the plant, and

15.1.5. Each section shall be clearly marked by indentation on either the inner or outer surface during the process of manufacture so that the location of the top will be evident immediately after the forms are stripped. In addition, the word "top" shall be lettered with waterproof paint on the inside top surface.

16. KEYWORDS

16.1. Concrete box—precast; culvert; sewer pipe; storm drain.

APPENDIX

(Nonmandatory Information)

X1. DESIGN CRITERIA USED TO DEVELOP TABLES 1 AND 2

X1.1. *Bedding and Backfill Assumptions*:

X1.1.1. The bedding is assumed to provide a slightly yielding, uniformly distributed support over the bottom width of the box section.

X1.1.2. The cover over the top of the box section may vary from 0 to 2 ft.

X1.2. *Criteria for Loads*:

X1.2.1. Design loads are based on the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges*.

X1.2.2. Live loads for designs given in Table 1 are HS20 loadings as defined in the AASHTO specifications. Live loads for designs given in Table 2 are interstate loadings as defined in U.S. Department of Commerce, Bureau of Public Roads Circular Memorandum 22-40, 22 April 1957. Impact allowances are in accordance with AASHTO specifications. Wheel loads are distributed over a width of [48 + 0.06 × (span minus one haunch)], in inches, perpendicular to the span by use of longitudinal distribution reinforcement in top and bottom of top slab. Loads are spread parallel to span over a length equal to (8 + 1.75 H cover) in inches. Cover loads for designs given in Tables 1 and 2 are the mass of a column of earth of a width equal to the outside width dimension of the box section and a height equal to the depth of cover over the top of the section.

X1.2.3. Lateral earth pressure from mass of earth above and adjacent to a box section is taken as a minimum of 0.25 times vertical pressure, and an additional 0.25 times vertical pressure is added in determining reinforcement areas only when areas are increased by such increased lateral pressure. Additional lateral pressure in lbf/ft^2 from approaching wheel loads is taken as 700 divided by depth to surface in feet, or 800 where depth to surface is less than 1 ft, and is added when determining reinforcement areas only at sections where areas are increased by increased lateral pressure.

X1.3. *Method of Analysis*:

X1.3.1. The structural effects of the loads described in Section X1.2 are evaluated based on the elastic method of structural analysis. Design moments, shears, and thrusts are determined by computer analysis using the stiffness matrix method, and design is based on maximum stress resultants at critical sections caused by the most severe combination of design loads.

X1.4. *Method of Design*:

X1.4.1. Box section design is based on load factor design provisions given in AASHTO's *Standard Specifications for Highway Bridges*. The load factor for dead load is increased from 1.3 to 1.5 for consistency with M 259. Reinforcement areas are governed by either service live load fatigue stress limitation of 21 000 lbf/in.^{2}, or service total load stress limitation of 36 000 lbf/in.^{2}, or ultimate total load yield stress limitation of 60 000 lbf/in.^{2} Crack width is controlled by limiting maximum spacing of circumferential reinforcement (welded wire fabric) to 4 in. and longitudinal distribution reinforcement (welded wire fabric or deformed grade 60 bars) to 8 in. Longitudinal distribution reinforcement called for in Tables 1 and 2 for top slab inside face is in accordance with distribution reinforcement formulas given in AASHTO specification for bridge decks. Longitudinal distribution reinforcement is also required in the top of the top slab, when wheel loads are adjacent to joints that provide only shear connections between box section units. These requirements were determined by evaluating analyses with loads in various positions on and near the edge of slabs having various length-to-width ratios and various conditions of edge restraint.

X1.4.2. Some box section designs shown in Tables 1 and 2 have reinforcement area requirements designated by "E" as minimum reinforcement area. For such cases, the reinforcement areas calculated for support of design loads are less than the minimum area that is specified in AASHTO bridge specifications, 0.002 Ag or 0.125 in.^{2}/ft whichever is greater.

X1.4.3. For specific criteria used to develop Tables 1 and 2, refer to Table X1.1.

X1.4.4. The top and bottom slab and sidewall thicknesses given in Tables 1 and 2 either conform to the dimensions used in M 259 or provide the minimum thickness required because of shear requirements given in the AASHTO bridge specification. The effective width of top or bottom slab for distribution of shear stress resulting from wheel loads is the same width used for determining maximum bending moments per unit of box section length.

X1.4.5. Haunch dimensions are the values used in M 259 and are the same as the sidewall thickness as shown in Tables 1 and 2.

Table X1.1—Specific Criteria Used to Develop Tables 1 and 2

Material Properties:	
Welded wire fabric, (circumferential or longitudinal distribution reinforcement), specified yield stress	60 000 psi
Deformed bars (longitudinal distribution reinforcement) specified yield stress	60 000 psi
Length of box section resisting truck wheel load	48 + 0.06 (span minus haunches), in.
Length of wheel bearing area parallel to slab span	(8 + 1.75H) in.
Concrete, minimum specified compressive strength	5000 psi
Soil Data:	
Unit weight	120 lb/ft^3
Ratio of lateral to vertical pressure from weight of earth	0.25 min to 0.50 max
External water table	below box section invert
Effective weight coefficient for soil load	1.0
Capacity Reduction Factors:	
Shear	0.85
Axial compression combined with bending	0.70 to 0.90
Loading Data:	
Load factor—dead load	1.5
Load factor—live load	2.2
Truck axle load:	
HS20 (Table 1)	32 000 lbf (See Figure 4.)
Interstate (Table 2)	2 @ 24 000 lbf each (See Figure 4.)
Lateral earth pressure from approaching wheel	800 lbf/ft^2 to 1 ft earth cover; 700/H lbf/ft^2 where H is depth of earth cover, ft, when depth exceeds 1 ft
Impact (variable with depth) see AASHTO Bridge Specifications, 1977	30 percent to 20 percent
Uniform internal pressure	0.0
Depth of water in box section external groundwater pressure	Equal to inside height 0.0
Structural Arrangements:	
Concrete cover over steel:	
Top of top slab	2 in.
All other surfaces	1 in.
Slab thickness	See Tables 1 and 2.
Side wall thickness	See Tables 1 and 2.
Haunch dimensions	Vertical and horizontal dimensions both equal to side wall thickness.
Minimum reinforcement	0.002 Ag or 0.125 in.^{2}/ft, whichever is greater
The structural arrangement and details are shown in Figures 1 and 2.	

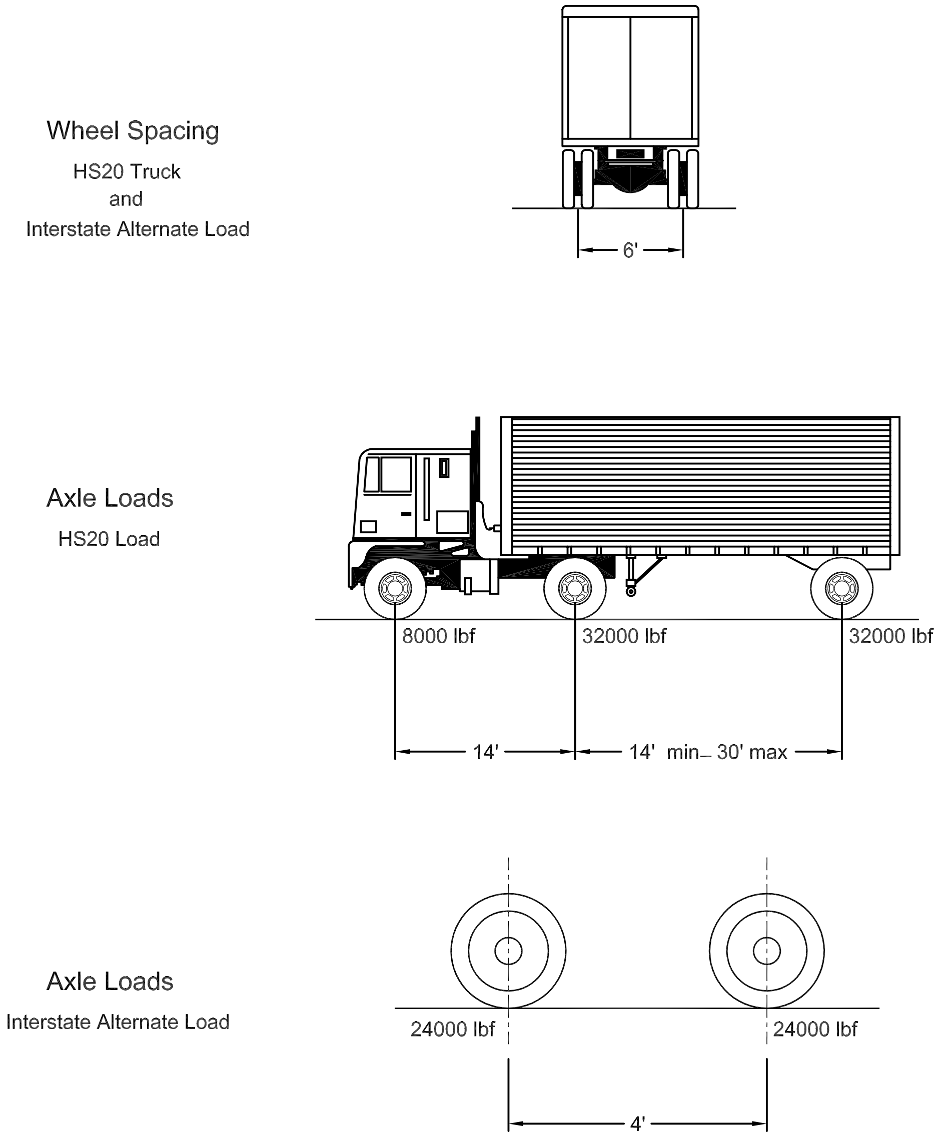


Figure X1.1—Axle Loads for Box Section Standard Designs

X1.5. *Multiple-Cell Installations*:

X1.5.1. The designs given herein are for single cell precast reinforced concrete box sections. The units may be used in parallel for multicell installations if means of positive lateral bearing by continuous contact between the sides of adjacent boxes are provided. Compacted earth fill, granular backfill, or grouting between the units are considered means of providing such positive bearing.

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[1] Standard Designs and Criteria used to develop the designs that are included in this specification are under the jurisdiction of the AASHTO Subcommittee on Bridges and Structures. Agrees with ASTM C 850-95a except that the use of synthetic fibers will be at the owner’s option.

Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 0.6 m of Cover Subjected to Highway Loadings [Metric]

AASHTO Designation: M 273M-00 (2008)[1]
ASTM Designation: C 850M-98

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Standard Specification for

Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 0.6 m of Cover Subjected to Highway Loadings [Metric]

AASHTO Designation: M 273M-00 (2008)[1]
ASTM Designation: C 850M-98

1. SCOPE

1.1. This specification covers single-cell, precast reinforced concrete box sections with less than 0.6 m of cover subjected to highway loadings and intended to be used for the construction of culverts and for the conveyance of storm water, industrial wastes, and sewage.

1.2. This metric specification is equivalent to M 273 and is compatible in technical content.

Note 1—This specification is primarily a manufacturing and purchasing specification. However, standard designs are included and the criteria used to develop these designs are given in Appendix X1. The successful performance of this product depends upon the proper selection of the box section, bedding, backfill, controlled manufacture in the plant, and care that the installation conforms to the construction specifications. The owner of the precast reinforced concrete box sections specified herein is cautioned that the loading conditions and the field requirements must be correlated with the box sections specified and inspection must be provided at the construction site.

Note 2—AASHTO M 259M is to be used for box sections subjected to highway loading with 0.6 m or more earth cover, or subjected to dead load only.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 148, Liquid Membrane-Forming Compounds for Curing Concrete (Discontinued)
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 240, Blended Hydraulic Cement

- M 259M, Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers [Metric]
- M 262, Concrete Pipe and Related Products
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 280, Concrete Pipe, Manhole Sections, or Tile
- *Standard Specifications for Highway Bridges*

2.2. *ASTM Standard*:

- C 1116, Standard Specification for Fiber-Reinforced Concrete

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms relating to concrete pipe, see M 262.

4. TYPES

4.1. Precast reinforced concrete box sections manufactured in accordance with this specification shall be of the types identified in Tables 1 and 2, and shall be designated by type, span, and rise.

Table 1—Design Requirements for Precast Reinforced Concrete Box Sections with Less Than 0.6 m of Cover Subjected to HS20 Loading[a]

	Thickness, mm			Circumferential Reinforcement Areas[c]						Distribution Reinforcement Areas[d]	
Box Section $S \times R$, mm[b]	Top Slab	Bottom Slab	Wall	A_{s1}	A_{s2}	A_{s3}	A_{s4}	A_{s7}	A_{s8}	A_{s5}	A_{s6}
900 × 600	175	150	100	360	720	420	280[e]	360[e]	300[e]	360[e]	360[e]
900 × 900	175	150	100	280[e]	760	470	280[e]	360[e]	300[e]	380[e]	360[e]
1200 × 600	190	150	125	440	780	420	280[e]	380[e]	300[e]	380[e]	380[e]
1200 × 900	190	150	125	380	870	490[e]	280[e]	380[e]	300[e]	420[e]	380[e]
1200 × 1200	190	150	125	340	910	510	280[e]	380[e]	300[e]	440[e]	380[e]
1500 × 900	200	175	150	470	870	470	300[e]	400[e]	360[e]	400[e]	400[e]
1500 × 1200	200	175	150	400	930	510	300[e]	400[e]	360[e]	440	400[e]
1500 × 1500	200	175	150	340	970	550	300[e]	400[e]	360[e]	470	400[e]
1800 × 900	200	175	175	640	890	440	360[e]	400[e]	360[e]	400[e]	400[e]
1800 × 1200	200	175	175	550	970	510	360[e]	400[e]	360[e]	420	400[e]
1800 × 1500	200	175	175	490	1020	550	360[e]	400[e]	360[e]	440	400[e]
1800 × 1800	200	175	175	420	1080	610	360[e]	400[e]	360[e]	470	400[e]
2100 × 1200	200	200	200	680	950	510	400[e]	400[e]	400[e]	400[e]	400[e]
2100 × 1500	200	200	200	610	1020	570	400[e]	420	400[e]	400[e]	400[e]
2100 × 1800	200	200	200	570	1080	610	400[e]	420	400[e]	420	400[e]
2100 × 2100	200	200	200	530	1120	680	400[e]	490	400[e]	440	400[e]
2400 × 1200	200	200	200	780	1080	570	400[e]	400[e]	400[e]	400[e]	400[e]
2400 × 1500	200	200	200	720	1120	640	400[e]	400[e]	400[e]	440	400[e]
2400 × 1800	200	200	200	680	1190	700	400[e]	530	400[e]	440	400[e]
2400 × 2100	200	200	200	640	1230	740	400[e]	570	470	470	400[e]
2400 × 2400	200	200	200	590	1270	800	490	610	550	470	400[e]
2700 × 1500	225	225	225	720	1060	610	470[e]	470[e]	470[e]	470[e]	470[e]
2700 × 1800	225	225	225	680	1120	680	470[e]	470[e]	470[e]	470[e]	470[e]
2700 × 2100	225	225	225	640	1160	740	470[e]	530	470[e]	470[e]	470[e]
2700 × 2400	225	225	225	590	1210	800	470[e]	570	510	470[e]	470[e]
2700 × 2700	225	225	225	570	1230	870	530	640	590	470[e]	470[e]
3000 × 1500	250	250	250	720	1020	610	510[e]	510[e]	510[e]	510[e]	510[e]
3000 × 1800	250	250	250	680	1060	680	510[e]	510[e]	510[e]	510[e]	510[e]
3000 × 2100	250	250	250	660	1100	740	510[e]	510[e]	510[e]	510[e]	510[e]
3000 × 2400	250	250	250	610	1140	800	510[e]	550	510[e]	510[e]	510[e]
3000 × 2700	250	250	250	570	1160	850	510[e]	590	550	510[e]	510[e]
3000 × 3000	250	250	250	570	1210	910	570	680	660	510[e]	510[e]
3300 × 1200	275	275	275	800	930	550[e]	550[e]	550[e]	550[e]	550[e]	550[e]
3300 × 1800	275	275	275	700	1020	680	550[e]	550[e]	550[e]	550[e]	550[e]
3300 × 2400	275	275	275	610	1080	800	550[e]	550[e]	550[e]	550[e]	550[e]
3300 × 3000	275	275	275	590	1140	910	550[e]	610	610	550[e]	550[e]
3300 × 3300	275	275	275	590	1190	970	640	720	720	550[e]	550[e]
3600 × 1200	300	300	300	850	890	610[e]	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 1800	300	300	300	740	970	680	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 2400	300	300	300	660	1040	800	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 3000	300	300	300	610[e]	1120	910	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 3600	300	300	300	610[e]	1210	1060	700	760	780	610[e]	610[e]

[a] Design requirements are based on maximum effects resulting from cover conditions ranging from 0 to 0.6 m and the material and soil properties and loading data shown in Appendix X1. For modified or special designs, see Section 7.2.

[b] The box section designation, for example 900 by 600, indicates interior horizontal span, in millimeters, by interior vertical rise, in millimeters.

[c] Design reinforcement areas in square millimeters per linear meter of box section length at those locations as shown in Figure 1.

[d] Design reinforcement areas in square millimeters per linear meter of box section width at those locations as shown in Figure 1.

[e] Minimum reinforcement area is specified.

Notes:
1. Reinforcement areas are based on the mass of column of earth over the width of the box section plus live loads as defined in Appendix X1.
2. Concrete design strength, 35 MPa.

Table 2—Design Requirements for Precast Reinforced Concrete Box Sections with Less Than 0.6 m of Cover Subjected to Interstate Loading[a]

	Thickness, mm			Circumferential Reinforcement Areas[c]						Distribution Reinforcement Areas[d]	
Box Section $S \times R$, mm[b]	Top Slab	Bottom Slab	Wall	A_{s1}	A_{s2}	A_{s3}	A_{s4}	A_{s7}	A_{s8}	A_{s5}	A_{s6}
900 × 600	175	150	100	360	720	420	280[e]	360[e]	300[e]	360[e]	360[e]
900 × 900	175	150	100	280[e]	760	470	280[e]	360[e]	300[e]	380	360[e]
1200 × 600	190	150	125	440	800	420	280[e]	380[e]	300[e]	380[e]	380[e]
1200 × 900	190	150	125	400	870	490	280[e]	380[e]	300[e]	420	380[e]
1200 × 1200	190	150	125	380	910	530	280[e]	380[e]	300[e]	440	380[e]
1500 × 900	200	175	150	550	870	590	300[e]	400[e]	360[e]	400[e]	400[e]
1500 × 1200	200	175	150	490	930	660	300[e]	400[e]	360[e]	440	400[e]
1500 × 1500	200	175	150	440	970	720	300[e]	400[e]	360[e]	470	400[e]
1800 × 900	200	175	175	700	890	590	360[e]	400[e]	360[e]	400[e]	400[e]
1800 × 1200	200	175	175	610	970	680	360[e]	400[e]	360[e]	420	400[e]
1800 × 1500	200	175	175	570	1020	720	360[e]	400[e]	360[e]	440	400[e]
1800 × 1800	200	175	175	530	1080	780	360[e]	400[e]	360[e]	470	400[e]
2100 × 1200	200	200	200	700	950	660	400[e]	400[e]	400[e]	400[e]	400[e]
2100 × 1500	200	200	200	640	1020	720	400[e]	420	400[e]	400[e]	400[e]
2100 × 1800	200	200	200	590	1080	780	400[e]	420	400[e]	420	400[e]
2100 × 2100	200	200	200	550	1120	830	400[e]	490	400[e]	440	400[e]
2400 × 1200	200	200	200	910	1080	720	400[e]	400[e]	400[e]	400[e]	400[e]
2400 × 1500	200	200	200	830	1120	800	400[e]	400[e]	400[e]	440	400[e]
2400 × 1800	200	200	200	760	1190	870	400[e]	530	400[e]	440	400[e]
2400 × 2100	200	200	200	720	1230	950	400[e]	570	470	470	400[e]
2400 × 2400	200	200	200	660	1270	1020	490	610	550	470	400[e]
2700 × 1500	225	225	225	890	1060	780	470[e]	470[e]	470[e]	470[e]	470[e]
2700 × 1800	225	225	225	830	1120	850	470[e]	470[e]	470[e]	470[e]	470[e]
2700 × 2100	225	225	225	780	1160	930	470[e]	530	470[e]	470[e]	470[e]
2700 × 2400	225	225	225	720	1210	990	470[e]	570	510	470[e]	470[e]
2700 × 2700	225	225	225	680	1230	1060	530	640	590	470[e]	470[e]
3000 × 1500	250	250	250	930	1020	760	510[e]	510[e]	510[e]	510[e]	510[e]
3000 × 1800	250	250	250	870	1060	850	510[e]	510[e]	510[e]	510[e]	510[e]
3000 × 2100	250	250	250	830	1100	910	510[e]	510[e]	510[e]	510[e]	510[e]
3000 × 2400	250	250	250	760	1140	970	510[e]	550	510[e]	510[e]	510[e]
3000 × 2700	250	250	250	720	1160	1060	510[e]	590	550	510[e]	510[e]
3000 × 3000	250	250	250	700	1210	1120	570	680	660	510[e]	510[e]
3300 × 1200	275	275	275	1040	930	680	550[e]	550[e]	550[e]	550[e]	550[e]
3300 × 1800	275	275	275	910	1020	850	550[e]	550[e]	550[e]	550[e]	550[e]
3300 × 2400	275	275	275	800	1080	970	550[e]	550[e]	550[e]	550[e]	550[e]
3300 × 3000	275	275	275	740	1140	1120	550[e]	610	610	550[e]	550[e]
3300 × 3300	275	275	275	720	1210	1190	640[e]	720[e]	720[e]	550[e]	550[e]
3600 × 1200	300	300	300	1060	890	680	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 1800	300	300	300	930	970	830	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 2400	300	300	300	850	1060	970	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 3000	300	300	300	760	1190	1120	610[e]	610[e]	610[e]	610[e]	610[e]
3600 × 3600	300	300	300	740	1290	1270	700	760	780	610[e]	610[e]

[a] Design requirements are based on maximum effects resulting from cover conditions ranging from 0 to 0.6 m and the material and soil properties and loading data shown in Appendix X1. For modified or special designs, see Section 7.2.

[b] The box section designation, for example 900 by 600, indicates interior horizontal span, in millimeters, by interior vertical rise, in millimeters.

[c] Design reinforcement areas in square millimeters per linear meter of box section length at those locations as shown in Figure 1.

[d] Design reinforcement areas in square millimeters per linear meter of box section width at those locations as shown in Figure 1.

[e] Minimum reinforcement area is specified.

Notes:
1. Reinforcement areas are based on the mass of column of earth over the width of the box section plus live loads as defined in Appendix X1.
2. Concrete design strength, 35 MPa.

5. BASIS OF ACCEPTANCE

5.1. Acceptability of the box sections produced in accordance with Section 7 shall be determined by the results of the concrete compressive strength tests described in Section 10, by the material requirements described in Section 6, and by inspection of the finished box sections.

5.2. Box sections shall be considered ready for acceptance when they conform to the requirements of this specification.

6. MATERIALS

6.1. *Reinforced Concrete*—The reinforced concrete shall consist of cementitious materials, mineral aggregates, and water, in which steel has been embedded in such a manner that the steel and concrete act together.

6.2. *Cementitious Materials*:

6.2.1. *Cement*—Cement shall conform to the requirements for portland cement of M 85 or shall be portland blast-furnace slag cement or portland-pozzolan cement conforming to the requirements of M 240, except that the pozzolan constituent in the Type IP portland-pozzolan cement shall be fly ash and shall not exceed 25 percent by mass.

6.2.2. *Fly Ash*—Fly ash shall conform to the requirements of M 295, Class F or Class C.

6.2.3. *Allowable Combinations of Cementitious Materials*—The combination of cementitious materials used in concrete shall be one of the following:

6.2.3.1. Portland cement only,

6.2.3.2. Portland blast-furnace slag cement only,

6.2.3.3. Portland-pozzolan cement only, and

6.2.3.4. A combination of portland cement and fly ash wherein the proportion of fly ash is between 5 and 25 percent by mass of total cementitious material (portland cement plus fly ash).

6.3. *Aggregates*—Aggregates shall conform to M 6 and M 80, except that the requirements for gradation shall not apply.

6.4. *Admixtures and Blends*—Admixtures and blends may be used with the approval of the owner.

6.5. *Steel Reinforcement*—Reinforcement shall consist of welded wire fabric conforming to M 55M/M 55 or M 221M/M 221. Longitudinal distribution reinforcement may consist of welded wire fabric or deformed billet-steel bars conforming to M 31M/M 31, Grade 400.

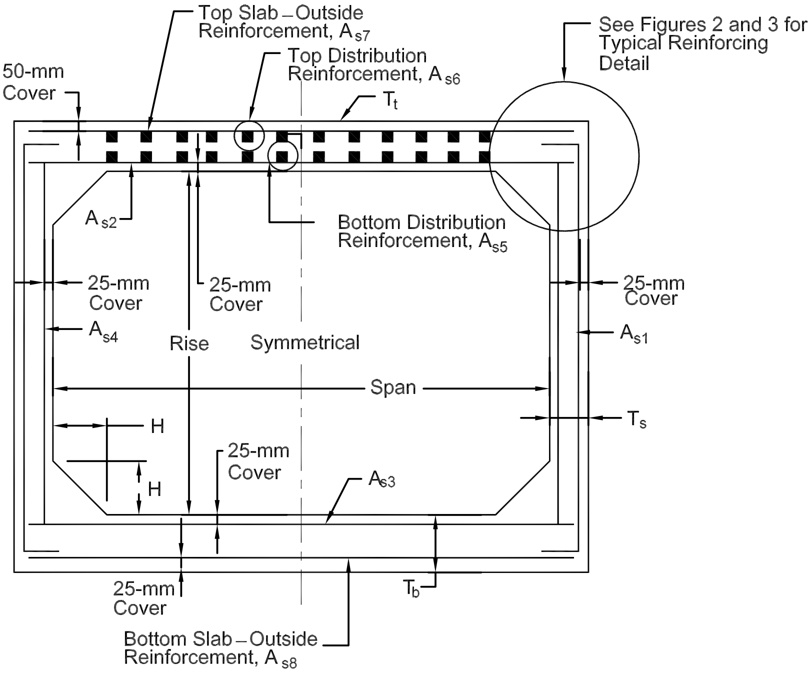
6.6. *Synthetic Fibers*—Polypropylene fibers may be used, at the owner's option, in concrete pipe as a nonstructural manufacturing material. Only Type III synthetic fibers designed and manufactured specifically for use in concrete and conforming to the requirements of ASTM C 1116 shall be accepted.

7. DESIGN

7.1. *Design Tables*—The box section dimensions, compressive strength of the concrete, and reinforcement details shall be as prescribed in Tables 1 or 2 and Figures 1 and 2, subject to the provisions of Section 11. Table 1 sections are designed for a cover range from 0 to 0.6 m plus AASHTO HS20 live load conditions. Table 2 sections are designed for a cover range from 0 to 0.6 m plus Interstate live load conditions. Criteria used to develop Tables 1 and 2 are given in the Appendix X1.

7.2. *Modified and Special Designs*—The manufacturer may request approval by the owner of modified designs that differ from the designs in Section 7.1; or special designs for sizes and loads other than those shown in Tables 1 and 2.

7.3. *Placement of Reinforcement*—The cover of concrete over the circumferential reinforcement shall be 25 mm except in the outside top of the top slab where it shall be 50 mm, subject to the provisions of Section 11. The inside circumferential and longitudinal reinforcement shall extend into the male portion of the joint and the outside circumferential and longitudinal reinforcement shall extend into the female portion of the joint. The clear distance of the end circumferential wires shall not be less than 13 mm or more than 50 mm from the ends of the box section. Reinforcement shall be assembled utilizing any combination of single or multiple layers of welded-wire fabric. Common reinforcement units may be utilized for both A_{s2} (or A_{s3}) and A_{s4}, and also for both A_{s7} (or A_{s8}) and A_{s1}, with the largest area requirement of each combination governing, bending the reinforcement 90 degrees at the corners, and waiving the extension requirements of Figure 2. See Figure 3. The welded-wire fabric shall be composed of circumferential and longitudinal wires meeting the spacing requirements of Section 7.4 and shall contain sufficient longitudinal wires extending through the box section to maintain the shape and position of reinforcement. Longitudinal distribution reinforcement may be welded-wire fabric or deformed billet-steel bars and shall meet the spacing requirements of Section 7.4. The ends of the longitudinal distribution reinforcement shall be not more than 50 mm from the ends of the box section. The exposure of the ends of longitudinals, stirrups, and spacers used to position the reinforcement shall not be a cause for rejection.



Note: The haunch dimension *H* is equal to the thickness T_s.

Figure 1—Typical Box Section

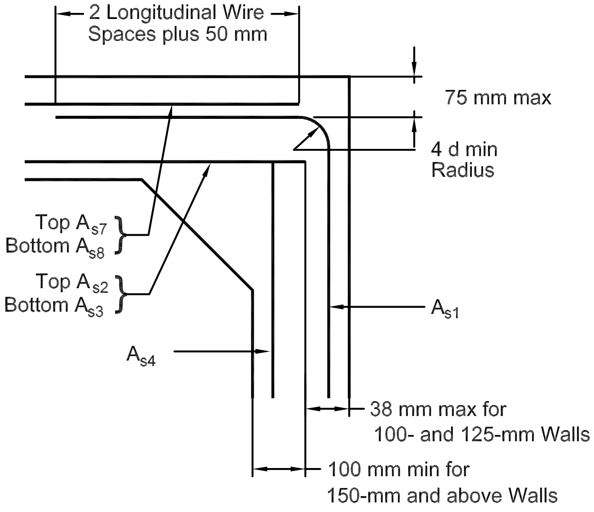


Figure 2—Detail Reinforcement Arrangement

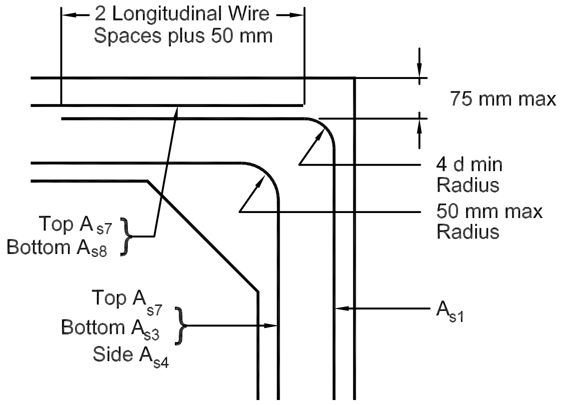


Figure 3—Detail Option

7.4. *Laps, Welds, and Spacing*—Splices in the circumferential reinforcement shall be made by lapping. The overlap measured between the outermost longitudinal wires of each fabric sheet shall not be less than the spacing of the longitudinal wires plus 50 mm. A_{s1} shall be lapped with A_{s7} and A_{s8} as shown in Figure 2 or Figure 3 and may be connected by welding. A_{s4} may be lapped and welded at any location or connected by welding at the corners to A_{s2} and A_{s3}. The spacing center to center of the circumferential wires shall not be less than 50 mm nor more than 100 mm. The spacing center-to-center of the longitudinal wires shall not be more than 200 mm. The spacing center-to-center of the longitudinal distribution wires or bars for either line of reinforcing in the top slab shall not be more than 200 mm.

8. JOINTS

8.1. The precast reinforced concrete box sections shall be produced with male and female ends. The ends shall be of such design and the ends of the box sections so formed that the sections can be laid together to make a continuous line of box sections compatible with the permissible variations given in Section 11.

9. MANUFACTURE

9.1. *Mixture*—The aggregates shall be sized, graded, proportioned, and mixed in a batch mixer with such proportions of cementitious materials and water as will produce a homogeneous concrete mixture of such quality that the pipe will conform to the test and design requirements of this specification. All concrete shall have a water-cementitious materials ratio not exceeding 0.53 by mass. Cementitious materials shall be as specified in Section 6.2 and shall be added to the mix in a proportion not less than 280 kg/m^3 unless mix designs with a lower cementitious materials content demonstrate that the quality and performance of the pipe meet the requirements of this standard.

9.2. *Curing*—The box sections shall be cured for a sufficient length of time so that the concrete will develop the specified compressive strength in 28 days or less. Any one of the following methods of curing or combinations thereof may be used:

9.2.1. *Steam Curing*—The box sections may be low pressure, steam cured by a system that will maintain a moist atmosphere.

9.2.2. *Water Curing*—The box sections may be water cured by any method that will keep the section moist.

9.2.3. *Membrane Curing*—A sealing membrane conforming to the requirements of M 148 may be applied and shall be left intact until the required concrete compressive strength is attained. The concrete temperature at the time of the application shall be within ±6ºC of the atmospheric temperature. All surfaces shall be kept moist prior to the application of the compounds and shall be damp when the compound is applied.

9.3. *Forms*—The forms used in manufacture shall be sufficiently rigid and accurate to maintain the box section dimensions within the permissible variations given in Section 11. All casting surfaces shall be of smooth, nonporous material.

9.4. *Handling*—Handling devices or holes shall be permitted in each box section for the purpose of handling and laying.

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10. PHYSICAL REQUIREMENTS

10.1. *Type of Specimen*—Compression tests for determining concrete compressive strength may be made on either concrete cylinders or on cores drilled from the boxed section. (See T 22.)

10.2. *Compression Testing of Cylinders*:

10.2.1. *Cylinder Production*—Cylinders shall be prepared in accordance with the Cylinder Strength Test Method of T 280.

10.2.2. *Number of Cylinders*—Prepare not fewer than five test cylinders from a group (1 day’s production of each concrete strength) of box sections.

10.2.3. *Acceptability on the Basis of Cylinder Test Results*:

10.2.3.1. When the compressive strengths of all cylinders tested for a group are equal to or greater than the design concrete strength, the compressive strength in the group of box sections shall be accepted.

10.2.3.2. When the average compressive strength of all cylinders tested is equal to or greater than the design concrete strength, not more than 10 percent of the cylinders tested have a compressive strength less than the design concrete strength, and no cylinder tested has a compressive strength less than 80 percent of the design concrete strength, then the compressive strength of the concrete in the group of box sections shall be accepted.

10.2.3.3. When the compressive strength of the cylinders tested does not conform to the acceptance criteria stated in Section 10.2.3.1 or Section 10.2.3.2, the acceptability of the group shall be determined in accordance with the provisions of Section 10.2.

10.3. *Compression Testing of Cores*:

10.3.1. *Obtaining Cores*—Cores shall be obtained and prepared in accordance with the Core Strength Test Method of T 280.

10.3.2. *Number of Cores*—One core shall be taken from a box section selected at random from each group of 15 box sections of a single size or fraction of such a group from each continuous production run.

10.4. *Acceptability on the Basis of Core Test Results*:

10.4.1. When the compressive strengths of cores tested for a group of box sections is equal to or greater than the design concrete strength, the compressive strength of the concrete for the group is acceptable.

10.4.2. If the compressive strength of the core tested is less than the design concrete strength, the box section from which that core was taken may be re-cored. If the compressive strength of the re-core is equal to or greater than the design concrete compressive strength, the compressive strength of the concrete for the group is acceptable.

10.4.3. If the compressive strength of the re-core is less than the design concrete strength, the box section from which the core was taken shall be rejected. Two box sections from the remainder of the group shall be selected at random and one core shall be taken from each box section. If the compressive strength of both cores is equal to or greater than the design concrete compressive strength, the concrete compressive strength of the remainder of the group shall be acceptable. If the compressive strength of either of the two cores tested is less than the design concrete compressive strength, then the remainder of the group shall be either rejected or, at the option of the manufacturer, each box section of the remainder of the group shall be cored and accepted individually, and any of the box sections that have a core with less than the design concrete compressive strength shall be rejected.

10.5. *Plugging Core Holes*—The core holes shall be plugged and sealed by the manufacturer in a manner such that the box section will meet all of the test requirements of this specification. Box sections so sealed shall be considered satisfactory for use.

10.6. *Test Equipment*—Every manufacturer furnishing box sections under this specification shall furnish all facilities and personnel necessary to carry out the test required.

11. PERMISSIBLE VARIATIONS

11.1. *Internal Dimensions*—The box culvert manufacturer shall establish the rise and span of the existing equipment to the nearest millimeter and verify that it is within the limits given in Table 3. The internal dimensions shall not vary more than 1 percent from the manufacturer's established metric size. The haunch dimensions shall vary not more than 6 mm from the design dimensions.

Table 3—Permissible Variation in Internal Size (Span or Rise)

Designated Size, mm	Permissible Variation, Internal Size, mm	
	Min	Max
600	600	620
900	900	920
1200	1200	1230
1500	1500	1540
1800	1810	1850
2100	2110	2160
2400	2410	2460
2700	2710	2770
3000	3020	3080
3330	3320	3390
3600	3620	3690

11.2. *Slab and Wall Thickness*—The slab and wall thickness shall not be less than that shown in the design by more than 5 percent or 5 mm, whichever is greater. A thickness more than that required in the design shall not be cause for rejection.

11.3. *Length of Opposite Surfaces*—Variations in laying lengths of two opposite surfaces of the box section shall not be more than 10 mm/m of internal span, with a maximum of 16 mm for all sizes through 2100-mm internal span, and a maximum of 19 mm for internal spans greater than 2100 mm, except where beveled ends for laying on curves are specified by the owner.

11.4. *Length of Section*—The underrun in length of a section shall not be more than 10 mm/m of length with a maximum of 13 mm in any box section.

11.5. *Position of Reinforcement*—The maximum variation in the position of the reinforcement for 130 mm or less wall thicknesses shall be ±10 mm, and for greater than 130-mm slab and wall thicknesses shall be ±13 mm. In no case, however, shall the cover over the reinforcement be less than 16 mm, as measured to the internal surface or the external surface of the box section except the cover over the reinforcement for the external surface of the top slab shall not be less than 42 mm. The preceding minimum cover limitation does not apply at the mating surfaces of the joint.

11.6. *Area of Reinforcement*—The areas of steel reinforcement shall be the design steel areas as shown in Tables 1 and 2. Steel areas greater than those required shall not be cause for rejection. The permissible variation in diameter of any reinforcement shall conform to the tolerances prescribed in the AASHTO specification for that type of reinforcement.

12. REPAIRS

12.1. Box sections may be repaired, if necessary, because of imperfections in manufacture or handling damage and will be acceptable if, in the opinion of the owner, the repaired box section conforms to the requirements of this specification.

13. INSPECTION

13.1. The quality of materials, the process of manufacture, and the finished box sections shall be subject to inspection by the owner.

14. REJECTION

14.1. Box sections shall be subject to rejection if it fails to conform to any of the specification requirements. Individual box sections may be rejected because of any of the following:

14.1.1. Fractures or cracks passing through the wall, except for a single-end crack that does not exceed the depth of the joint;

14.1.2. Defects that indicate mixing and molding, not in compliance with Section 9.1, or honeycombed or open texture, that would adversely affect the function of the box;

14.1.3. The ends of the box sections are not normal to the walls and centerline of the box section, within the limits of variations given in Section 11, except where beveled ends are specified; and

14.1.4. Damaged ends, where such damage would prevent making a satisfactory joint.

15. PRODUCT MARKING

15.1. The following information shall be legibly marked on each box section by indentation, waterproof paint, or other approved means:

15.1.1. Box section span, rise, table number, and specification designation,

15.1.2. Date of manufacture,

15.1.3. Name or trademark of the manufacturer,

15.1.4. Identification of the plant, and

15.1.5. Each section shall be clearly marked by indentation on either the inner or outer surface during the process of manufacture so that the location of the top will be evident immediately after the forms are stripped. In addition, the word "top" shall be lettered with waterproof paint on the inside top surface.

16. KEYWORDS

16.1. Concrete box—precast; culvert; sewer pipe; storm drain.

APPENDIX

(Nonmandatory Information)

X1. DESIGN CRITERIA USED TO DEVELOP TABLES 1 AND 2

X1.1. *Bedding and Backfill Assumptions*:

X1.1.1. The bedding is assumed to provide a slightly yielding, uniformly distributed support over the bottom width of the box section.

X1.1.2. The cover over the top of the box section may vary from 0 to 0.6 m.

X1.2. *Criteria for Loads*:

X1.2.1. Design loads are based on the AASHTO *Standard Specifications for Highway Bridges*.

X1.2.2. Live loads for designs given in Table 1 are HS20 loadings as defined in the AASHTO specifications. Live loads for designs given in Table 2 are interstate loadings as defined in U.S. Department of Commerce, Bureau of Public Roads Circular Memorandum 22-40, 22 April 1957. Impact allowances are in accordance with AASHTO specifications. Wheel loads are distributed over a width of [1200 + 0.06 × (span minus one haunch)], in millimeters, perpendicular to the span by use of longitudinal distribution reinforcement in top and bottom of top slab. Loads are spread parallel to span over a length equal to (200 + 1.75 *H* cover) in millimeters. Cover loads for designs given in Tables 1 and 2 are the mass of a column of earth of a width equal to the outside width dimension of the box section and a height equal to the depth of cover over the top of the section.

X1.2.3. Lateral earth pressure from mass of earth above and adjacent to a box section is taken as a minimum of 0.25 times vertical pressure, and an additional 0.25 times vertical pressure is added in determining reinforcement areas only when areas are increased by such increased lateral pressure. Additional lateral pressure in kilopascals from approaching wheel loads is taken as 33.5 divided by depth to surface in meters, or 38.3 where depth to surface is less than 0.6 m, and is added when determining reinforcement areas only at sections where areas are increased by increased lateral pressure.

X1.3. *Method of Analysis*:

X1.3.1. The structural effects of the loads described in Section X1.2 are evaluated based on the elastic method of structural analysis. Design moments, shears, and thrusts are determined by computer analysis using the stiffness matrix method, and design is based on maximum stress resultants at critical sections caused by the most severe combination of design loads.

X1.4. *Method of Design*:

X1.4.1. Box section design is based on load factor design provisions given in AASHTO's *Standard Specifications for Highway Bridges*. The load factor for dead load is increased from 1.3 to 1.5 for consistency with AASHTO M 259M. Reinforcement areas are governed by either service live load fatigue stress limitation of 145 MPa, or service total load stress limitation of 248 MPa, or ultimate total load yield stress limitation of 414 MPa. Crack width is controlled by limiting maximum spacing of circumferential reinforcement (welded wire fabric) to 100 mm and longitudinal distribution reinforcement (welded wire fabric or deformed grade 60 bars) to 200 mm. Longitudinal distribution reinforcement called for in Tables 1 and 2 for top slab inside face is in accordance with distribution reinforcement formulas given in AASHTO specification for bridge decks. Longitudinal distribution reinforcement is also required in the top of the top slab, when wheel loads are adjacent to joints that provide only shear connections between box section units. These requirements were determined by evaluating analyses with loads in various positions on and near the edge of slabs having various length-to-width ratios and various conditions of edge restraint.

X1.4.2. Some box section designs shown in Tables 1 and 2 have reinforcement area requirements designated by "E" as minimum reinforcement area. For such cases, the reinforcement areas calculated for support of design loads are less than the minimum area that is specified in AASHTO bridge specifications, 0.002 Ag or 265 mm^2/m whichever is greater.

X1.4.3. For specific criteria used to develop Tables 1 and 2, refer to Table X1.1.

X1.4.4. The top and bottom slab and sidewall thicknesses given in Tables 1 and 2 either conform to the dimensions used in M 259M or provide the minimum thickness required because of shear requirements given in the AASHTO bridge specification. The effective width of top or bottom slab for distribution of shear stress resulting from wheel loads is the same width used for determining maximum bending moments per unit of box section length.

X1.4.5. Haunch dimensions are the values used in M 259M and are the same as the sidewall thickness shown in Tables 1 and 2.

Table X1.1—Specific Criteria Used to Develop Tables 1 and 2

Material Properties:	
Welded wire fabric, (circumferential or longitudinal distribution reinforcement), specified yield stress	414 MPa
Deformed bars (longitudinal distribution reinforcement) specified yield stress	414 MPa
Length of box section resisting truck wheel load	1200 + 0.06 (span minus haunches), mm
Length of wheel bearing area parallel to slab span	(200 + 1.75H) mm
Concrete, minimum specified compressive strength	35 MPa
Soil Data:	
Unit weight	1920 kg/mm^3
Ratio of lateral to vertical pressure from weight of earth	0.25 min to 0.50 max
External water table	below box section invert
Effective weight coefficient for soil load	1.0
Capacity Reduction Factors:	
Shear	0.85
Axial compression combined with bending	0.70 to 0.90
Loading Data:	
Load factor—dead load	1.5
Load factor—live load	2.2
Truck axle load: HS20 (Table 1)	14 500 (See Figure 4.)
Interstate (Table 2)	2 @ 10 900 kg each (See Figure 4.)
Lateral earth pressure from approaching wheel	38.3 kPa to 0.6 m earth cover; 33.5/H kPa where H is depth of earth cover, m, when depth exceeds 0.6 m
Impact (variable with depth) see AASHTO Bridge Specifications, 1977	30 percent to 20 percent
Uniform internal pressure	0.0
Depth of water in box section	Equal to inside height
External ground water pressure	0.0
Structural Arrangements:	
Concrete cover over steel:	
Top of top slab	50 mm
All other surfaces	25 mm
Slab thickness	See Tables 1 and 2.
Side wall thickness	See Tables 1 and 2.
Haunch dimensions	Vertical and horizontal dimensions both equal to side wall thickness
Minimum reinforcement	0.002 Ag or 265 mm^2/m, whichever is greater
The structural arrangement and details are shown in Figures 1 and 2.	

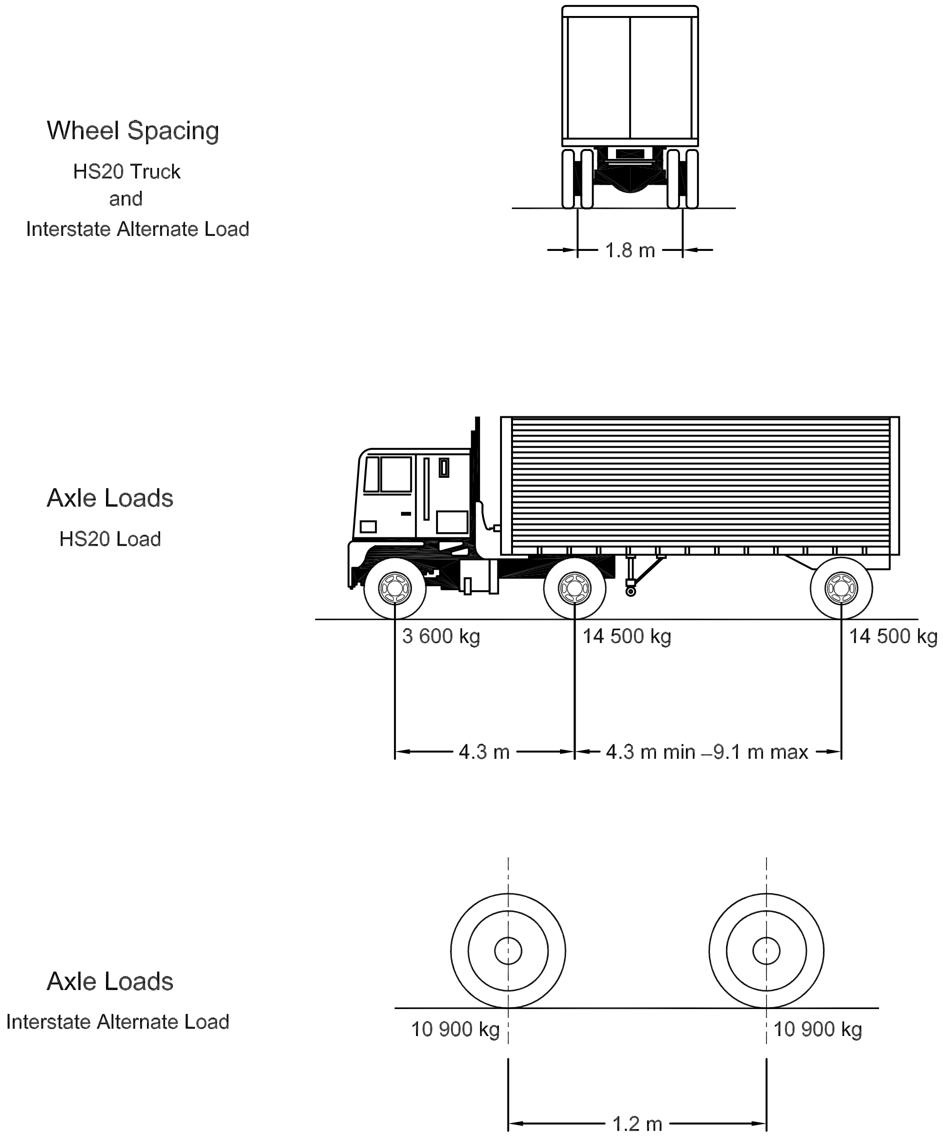

Figure X1.1—Axle Loads for Box Section Standard Designs

X1.5. *Multiple-Cell Installations*:

X1.5.1. The designs given herein are for single cell precast reinforced concrete box sections. The units may be used in parallel for multicell installations if means of positive lateral bearing by continuous contact between the sides of adjacent boxes are provided. Compacted earth fill, granular backfill, or grouting between the units are considered means of providing such positive bearing.

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[1] Standard Designs and Criteria used to develop the designs that are included in this specification are under the jurisdiction of the AASHTO Subcommittee on Bridges and Structures. Agrees with ASTM C 850M-98 except that the use of synthetic fibers will be at the owner’s option.

Standard Specification for

Steel Sheet, Aluminum-Coated (Type 2), for Corrugated Steel Pipe

AASHTO Designation: M 274-87 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Sheet, Aluminum-Coated (Type 2), for Corrugated Steel Pipe

AASHTO Designation: M 274-87 (2008)

1. SCOPE

1.1. This specification covers steel sheet used in the fabrication of corrugated steel pipe (CSP) used for drainage pipe and underdrains. The steel sheet is coated with commercially pure aluminum (referred to as Type 2) on continuous lines by the hot-dip process, and is produced in one coating mass only. The material is furnished flat in coils and cut lengths, and corrugated in cut lengths.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 213M/T 213, Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles

2.2. *ASTM Standards*:

- A 463M, Standard Specification for Steel Sheet, Aluminum-Coated, by the Hot-Dip Process
- A 754, Standard Test Method for Coating Weight (Mass) of Metallic Coatings on Steel by X-Ray Fluorescence
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods

3. TERMINOLOGY

3.1. In this specification, *manufacturer* refers to the producer of the sheet, *fabricator* refers to the producer of the pipe, and *purchaser* refers to the purchaser of the finished pipe.

4. ORDERING INFORMATION

4.1. All sheet covered by this specification shall be ordered only to the specified thicknesses listed in Table 5.

4.2. Unless otherwise specified in the purchase order, all material furnished to this specification will be chemically treated, dry or oiled.

4.3. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product:

4.3.1. Name of material (aluminum-coated steel sheet for CSP);

4.3.2. AASHTO designation number and date of issue;

4.3.3. Corrugation size, if corrugated (Section 8.3);

4.3.4. Dimensions (thickness; width, either flat or overall corrugated; and length, if cut length);

4.3.5. Coil size requirements (specify maximum outside diameter (OD), acceptable inside diameter (ID), and maximum mass);

4.3.6. Certification, if required (Section 11.1); and

4.3.7. Special Requirements.

Note 1—Typical ordering descriptions are as follow:

- Aluminum-coated steel sheet for CSP conforming to M 274-___, 68 by 13 mm corrugations, 1.63 by 648 by 1500 m.
- Aluminum-coated steel sheet for CSP conforming to M 274-___, 2.01 by 699 mm by coil, 1200 mm OD, 600 mm ID, 9000 kg max. certified with test report.

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5. GENERAL REQUIREMENTS

5.1. Steel sheet material supplied under this specification shall meet the applicable requirements of ASTM A 463M unless otherwise specified herein. ASTM A 463M applies to aluminum-coated sheet; however, tolerances, sampling, sample preparation, and methods of testing (except for mass of coating) all are applicable to aluminum-coated sheet.

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6. CHEMICAL COMPOSITION

6.1. The base metal composition shall conform to the requirements of Table 1.

Table 1—Base Metal Chemical Composition by Cast Analysis

	Composition, percent	Tolerance Over the Max Limit by Product Analysis, percent
Sulfur, max	0.05	+0.01
Sum of carbon, manganese, phosphorus, silicon, and sulfur, max	0.70	+0.04

6.2. *Aluminum Bath Analysis*—The bath shall be produced from commercially pure aluminum and the bath analysis shall conform to the limits given in Table 2.

Table 2—Aluminum Bath Analysis

	Composition, percent
Iron, max	3.0
Silicon, max	0.35
Magnesium, max	0.50
Other—each max	0.05
Other—total max	0.20

7. PHYSICAL PROPERTIES

7.1. The aluminum-coated steel sheet shall conform to the mechanical properties shown in Table 3, when tested prior to corrugating or other fabrication.

Table 3—Mechanical Requirements (Properties of Flat Material Prior to Fabrication)

Tensile strength, min, MPa	310
Yield point, min, MPa	230
Elongation in 50 mm, min, percent	20

Note 2—Steel sheet tested after corrugating and other fabricating should conform to the tensile and yield strength requirements in Table 3, but due to cold working, conformance to the elongation requirement may not be obtained.

7.2. The mass of aluminum coating shall conform to the requirements prescribed in Table 4. The mass of coating is the total amount on both surfaces of the sheet expressed in g/m^2 of sheet.

Table 4—Mass of Coating

Min Check Limit Triple Spot Test, g/m^2	Min Check Limit Single-Spot Test, g/m^2
300	270

7.3. Adherence of coating shall be such that no peeling occurs while the material is being corrugated and formed into pipe.

8. DIMENSIONS AND TOLERANCES

8.1. Sheet thickness shall conform to dimensions prescribed in Table 5. The thickness of the sheet includes both the base steel and the aluminum coating.

Table 5—Sheet Thickness[a]

Specified Thickness, mm	Min Thickness, mm
1.32	1.17
1.63	1.45
2.01	1.83
2.77	2.57
3.51	3.28

[a] Thickness is measured at any point on the sheet not less than 10 mm from an edge, and if corrugated, on the tangents of corrugation.

8.2. Permissible variations in width, length, and camber of flat material shall be in accordance with ASTM A 463M. Flatness tolerances of uncorrugated sheet shall conform to the dimensions prescribed in Table 6.

Table 6—Flatness Tolerances (Cut Lengths Only)

Specified Thickness, mm	Specified Width, mm	Flatness Tolerance (Max Deviation from a Horizontal Flat Surface), mm
1.32	To 900 incl	12.7
	More than 900 to 1500 incl	19
1.63 and thicker	To 1500 incl	12.7

Note: This table also applies to sheets cut to length from coils by the user when adequate flattening measures are performed.

8.3. Corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 7 (Note 3).

Table 7—Corrugated Requirements

Nominal Size, mm	Max Pitch,[a] mm	Min Depth,[b] mm	Inside Radius	
			Nominal, mm	Min, mm
38 × 6.5	48	6	7	6.5
68 × 13	73	12	17	12
75 × 25	83	24	14	12
125 × 25	135	24	40	36

[a] Pitch is measured from crest to crest of corrugation, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests to the bottom of the intervening valley.

Note 3—Some sizes of corrugations shown in Table 7 may not be available in cut-length sheets. The 38- by 6.5-mm size, especially, is generally used only for helically corrugated pipe.

8.4. Covering width of corrugated sheet shall be in accordance with Table 8. Covering width is the distance between the crests of the extreme corrugations. There is no established tolerance for overall width since the covering width and lip dimensions are the governing factors for the formed product. The lip dimension of corrugated sheets shall be in accordance with Table 9. This dimension is measured along the radial curvature from the crest of the corrugation to the edge of the sheet.

Table 8—Covering Width Tolerance for Corrugated Sheet

Covering Width, mm	Tolerance Over and Under, mm
To 600 inclusive	6.4
Over 600 to 900 inclusive	9.5
Over 900 to 1200 inclusive	12.7

Table 9—Corrugated Sheet Lip Dimensions

Nominal Corrugation Size, mm	For Riveted Pipe Construction,[a] mm	For Spot Welded Pipe Construction, Min, mm
68 × 13	19	11
75 × 25	22	13
125 × 25	22	13

[a] Tolerances, +4.8 mm, – 0.

9. SAMPLING AND TESTING

9.1. Except as specified below, the manufacturer shall make adequate tests and measurements to ensure that the material produced complies with this specification.

9.1.1. Test results, including chemical composition, mechanical properties, and mass of coating for each heat and coating lot, shall be maintained by the sheet manufacturer for 7 years and shall be made available to the fabricator and purchaser upon request.

9.2. The purchaser of the sheet (fabricator), or purchaser of the pipe made from the sheet, may make such tests as are deemed necessary to determine the acceptability of the material or to verify the correctness of a certification.

9.3. Mechanical properties shall be determined on sheet prior to corrugating or other fabricating, except tests may be made after fabrication by the purchaser for tensile strength and yield point.

9.3.1. Two tension tests shall be made on random samples of finished material from each cast or heat. When the finished material from said cast or heat is less than 45 Mg, one test is sufficient. When material rolled from one cast or heat differs 1.27 mm or more in thickness, one tension test shall be made from both the thickest and thinnest material rolled regardless of the mass represented. The samples shall be prepared and tested in accordance with the method specified in ASTM A 463M.

9.4. *Mass of Coating*—Sampling for mass of coating shall be as prescribed in ASTM A 463M. The mass of coating shall be determined according to T 213M/T 213.

9.4.1. The mass may be converted from the sum of readings of both surfaces of the sheet by a magnetic thickness gauge suitably checked and demonstrated for accuracy (Note 4) (1 μm = 3.2 g/m^2 each surface). When a magnetic thickness gauge is used and a dispute arises, the mass shall be determined by the stripping test in T 213M/T 213.

Note 4—Several magnetic and electromagnetic types of coating thickness gauges are commercially available and are a satisfactory basis for acceptance when properly calibrated just prior to inspection use. (See ASTM E 376.)

9.4.2. The mass of coating may be determined from the coating thickness measured by the x-ray fluorescence method, according to ASTM A 754. When this method is used and a dispute arises, the mass shall be determined by the stripping test in T 213M/T 213.

10. REJECTION

10.1. Material tested by the purchaser and found not conforming to this specification may be rejected.

11. CERTIFICATION

11.1. When specified in the purchase order or contract, a manufacturer’s certification shall be furnished to the purchaser of the sheet (fabricator) or to the purchaser of the finished pipe stating that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements for the material described in the purchase order or contract. When specified in the purchase order or contract, a report of the test results shall be furnished.

12. MARKING

12.1. Each 0.6 to 1.5 m of sheet in coils or cut lengths shall be identified by showing the following:

12.1.1. Name of sheet manufacturer,

12.1.2. Brand name,

12.1.3. Specified thickness,

12.1.4. Specified mass of coating,

12.1.5. Identification symbols relating to a specific heat number and lot number, and

12.1.6. AASHTO designation number.

12.2. The brand shall be removed, obliterated, or rebranded “Non-Specification Material” on each 0.6 to 1.5 m of material in a lot or heat for which control tests do not show conformance to this specification.

Standard Specification for

Class PS46 Poly(Vinyl Chloride) (PVC) Pipe

AASHTO Designation: M 278-02 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Class PS46 Poly(Vinyl Chloride) (PVC) Pipe

AASHTO Designation: M 278-02 (2007)

1. SCOPE

1.1. This specification covers the requirements and methods of test for smooth-wall perforated and unperforated poly(vinyl chloride) (PVC) plastic pipe, couplings, and fittings for use in subsurface drainage and surface drainage (culverts) of transportation facilities, where soil support is given to its flexible walls in all applications.

1.1.1. Nominal sizes of 100 to 375 mm in a stiffness class designated as PS46 are included.

1.1.2. Materials, dimensions, flattening, impact resistance, pipe stiffness, extrusion quality, joining systems, perforations, and form of marking are specified.

1.2. The following precautionary caveat pertains only to the test method portion, Section 6.8, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests

2.2. *ASTM Standards*:

- D 618, Standard Practice for Conditioning Plastics for Testing
- D 883, Standard Terminology Relating to Plastics
- D 1598, Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
- D 1784, Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
- D 2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D 2152, Standard Test Method for Adequacy of Fusion of Extruded Poly(Vinyl Chloride) (PVC) by Pipe and Molded Fittings by Acetone Immersion
- D 2321, Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications
- D 2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading

- D 2444, Standard Test Method for Determination of Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D 2564, Standard Specification for Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Pipe and Fittings
- D 2837, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
- D 2855, Standard Practice for Making Solvent-Cemented Joints with Poly(Vinyl Chloride) (PVC) Pipe and Fittings
- D 3034, Standard Specification for Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings
- D 3212, Standard Specification for Joints for Drain and Sewer Plastic Pipe Using Flexible Elastomeric Seals
- F 402, Standard Practice for Safe Handling of Solvent Cements, Primers, and Cleaners Used for Joining Thermoplastic Pipe and Fittings
- F 412, Standard Terminology Relating to Plastic Piping Systems
- F 477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe

3. NOMENCLATURE

3.1. *General*—The nomenclature used in this specification is in accordance with the definitions given in Definitions ASTM D 883 and Definitions ASTM F 412, unless otherwise specified. The abbreviation for polyvinyl chloride is PVC.

4. MATERIALS

4.1. *Basic Materials*—Pipe and fittings shall be made of virgin PVC plastic having a cell classification of 12454-B as defined in ASTM D 1784. Compounds shall be tested in accordance with ASTM D 1598 and provide a minimum hydrostatic design basis (HDB) of 30 MPa in water. Minimum HDB shall be evaluated in accordance with ASTM D 2837.

4.2. *Rework Materials*—Rework material from the manufacturer's own pipe or fittings production may be used by the same manufacturer, provided that the pipe or fabricated fittings produced meet all the requirements of this specification.

4.3. *Solvent Cement*—The PVC solvent cement used in joining the pipe and fittings for solvent cement joints shall comply with the requirements of ASTM D 2564.

4.4. *Gaskets*—Elastomeric seals (gaskets) shall comply with the requirements of ASTM F 477. The lubricant used for assembly shall have no detrimental effect on the gasket or on the pipe or fittings.

5. JOINING SYSTEMS

5.1. *Gasketed Joints*—The joint shall be designed so that, when assembled, the gasket inside the bell will be compressed radially on the pipe spigot to form a watertight seal.

5.1.1. The joint shall be designed to avoid displacement of the gasket when installed in accordance with the manufacturer's recommendations.

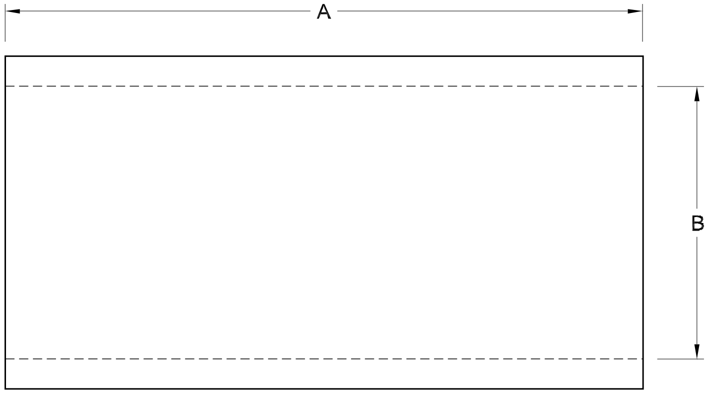
5.1.2. The assembly of joints shall be in accordance with the pipe manufacturer's recommendations.

5.2. *Solvent Cement Joints*—In the solvent cement joint, the pipe spigot wedges into the tapered socket and the surfaces fuse together. The tapered socket may be a portion of a molded fitting or it may be a belled end of a pipe section.

5.2.1. The assembly of joints shall be in accordance with ASTM D 2855 and taking cognizance of ASTM F 402.

Note 1—Difficulty may be encountered in obtaining watertight joints when solvent cementing joints in pipe diameters greater than 150 mm.

5.3. *Unsealed Joints*—Perforated pipe may be connected with stop-type couplings (as described in ASTM D 3034, Figure 9) or belled-ends of pipe conforming to Section 6.2.5 without the use of solvent cement. If sleeve couplings as described in Figure 1 are used, the coupling shall be solvent cemented to one length of pipe, lapping 40 to 50 percent of the coupling length.



Nominal Size, mm	Length (A)		Inside Diameter (B)	
	Average, mm	Tolerance, mm	Average, mm	Tolerance, mm
100	88.9	+6.35, –0	107.44	±0.13
150	152.4	+6.35, –0	159.77	±0.13
200	203.2	+6.35, –0	213.74	±0.15
250	254.0	+6.34, –0	267.21	±0.18
300	304.8	+6.35, –0	318.13	±0.20
375	381.0	+6.35, –0	389.51	±0.23

Figure 1—Sleeve Coupling Dimensions

6. REQUIREMENTS

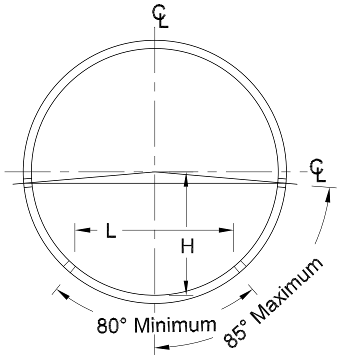
6.1. *Workmanship*—The pipe and fittings shall be homogeneous throughout, and free from visible cracks, flaws, foreign inclusions, or other injurious defects. The pipe shall be as uniform as commercially practical in color, opacity, and other physical properties.

6.2. *Pipe Dimensions*:

6.2.1. *Diameter*—The average outside diameter of the pipe shall be as specified in Figure 2 when measured in accordance with ASTM D 2122.

6.2.2. *Wall Thickness*—The minimum wall thickness shall be as specified in Figure 2 when measured in accordance with ASTM D 2122.

6.2.3. *Length*—Laying length shall be 6 m for diameters up to 200 mm and no less than 3 m for larger sizes; or as mutually agreed upon between purchaser and manufacturer. A tolerance of ±25 mm shall be permitted.



Pipe Dimensions

Nominal Size, mm	Outside Diameter		Out-of-Roundness		Minimum Wall Thickness, mm
	Average, mm	Tolerance, mm	Min, mm	Max, mm	
100	107.06	±0.22	105.80	108.34	3.08
150	159.38	±0.28	158.12	160.66	4.58
200	213.36	±0.30	212.08	214.62	6.10
250	266.70	±0.38	263.66	269.75	7.65
300	317.50	±0.46	313.87	321.14	9.09
375	388.62	±0.58	384.16	393.09	11.13

Figure 2—Requirements for Perforations

6.2.4. *Perforations*—Perforations, when required, shall be circular holes, 4.8 to 9.5 mm in diameter, arranged in rows parallel to the axis of the pipe. Perforations shall be approximately 75 mm center-to-center, along the rows. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment, corresponding to the flowline of the pipe. The spacing of the rows shall be uniform. The distance between the centerlines of rows shall be not less than 25 mm. The minimum number of longitudinal rows of perforations, the maximum heights of the centerlines of the uppermost rows above the bottom of the inverts, and the inside chord lengths of the unperforated segments shall be as specified in Table 1.

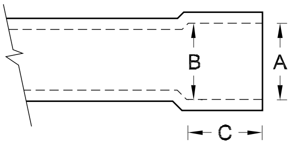
Table 1—Rows of Perforations, Height *H* of the Centerline of the Uppermost Rows above the Invert, and Chord Length *L* of the Unperforated Segment

Internal Diameter of Pipe, mm	Rows of Perforations	*H*, Max, mm	*L*, Min, mm
100	2	46	65
150	4	70	98
200	4	94	130
250	4	116	164
300	6	140	195
375	6	175	244

6.2.5. *Integral Bell Dimensions*—The thickness of the wall shall be considered satisfactory if the bell was formed from pipe meeting the requirements of this specification.

6.2.5.1. *Elastomeric Joints*—Integral bells for elastomeric seal joint shall meet dimensions recommended by the manufacturer.

6.2.5.2. *Solvent Cement Joints*—Socket-type bell dimensions for solvent cement joints shall comply with Figure 3.

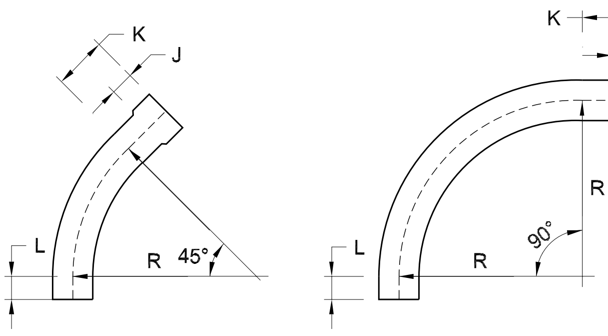


Nominal Size, mm	Entrance (A)		Socket Bottom (B)		Min Bell Depth (C)
	Diameter, mm	Tolerance, mm	Diameter, mm	Tolerance, mm	
100	107.57	±0.22	106.93	±0.22	44.44
150	160.15	±0.28	159.26	±0.28	76.20
200	213.97	±0.30	213.06	±0.30	101.60
250	267.47	±0.38	286.32	±0.38	127.00
300	318.41	±0.46	317.04	±0.46	152.40
375	369.79	±0.58	388.04	±0.58	190.50

Figure 3—Pipe Integral Bell for Solvent Cement Joints

6.3. *Fitting Dimensions*:

6.3.1. *Fitting Wall Thickness*—The minimum wall thickness of sleeve-type couplings and molded fittings shall be no less than the respective minimum thicknesses listed for the equivalent pipe in Figure 2. The wall thickness of bends manufactured from pipe (Figure 4) shall be considered satisfactory, providing the bend was formed from pipe meeting the requirements of this specification. For reducing fittings or those with smaller inlets, the minimum wall thickness of each inlet shall not be less than the minimum wall thickness for that size pipe.



Nominal Size, mm	Dimensions (Min)			
	Radius (R), mm	(J), mm	(K), mm	(L), mm
100	406.4, 609.6, or 914.4	44.44	88.90	50.80
150	609.6 or 914.4	76.20	152.40	88.90
200	609.6 or 914.4	101.60	203.20	127.00

Figure 4—Laying Lengths of Bends Manufactured from Pipe

6.3.2. *Laying Length*—The laying length of fittings shall meet the requirements of Figures 1 and 4 of this specification or Tables 3 to 11 of ASTM D 3034.

6.4. *Minimum Pipe Stiffness*—The minimum pipe stiffness (PS) values shall be 320 kPa when tested in accordance with Section 8.3. Three specimens shall be tested; all shall meet the requirements.

6.5. *Pipe Flattening*—There shall be no evidence of splitting, cracking, or breaking when pipe and couplings tested in accordance with Section 8.4 are examined without the use of magnification equipment.

6.6. *Impact Strength*—The minimum drop weight impact strength for pipe and couplings shall meet the requirements of Table 2, when tested in accordance with Section 8.1.

Table 2—Impact Strength at 0°C

Nominal Size, mm	J
100	90
150	115
200	130
250	130
300	130
375	130

6.7. *Joint Tightness:*

6.7.1. *Elastomeric Seal (Gasketed) Joints*—Joints made with pipe and fittings having elastomeric seals shall show no sign of leakage when tested in accordance with ASTM D 3212. All surfaces of the joint upon which the gasket bears shall be smooth and free of imperfections, ridges, fractures, or cracks that could adversely affect the seal.

6.7.2. *Solvent Cement Joints*—Joints made with solvent cement joining shall show no sign of leakage when tested in accordance with Section 8.2.

Note 2—These requirements are qualifying requirements for joint design and fabrication and are not necessarily indicative of performance in field assembly.

6.8. *Extrusion Quality*—The pipe and fittings shall not flake or disintegrate when tested in accordance with ASTM D 2152. For recommended practices on using specific chemicals to test plastic pipe, refer to R 16.

7. CONDITIONING

7.1. *Referee Test*—When conditioning is required for tests, the specimens shall be conditioned in accordance with Procedure A in ASTM D 618 at 20 to 21ºC and 50 ± 5 percent relative humidity for not less than 40 hours prior to test. Tests shall be conducted under the same conditions of temperature and humidity, unless otherwise specified.

7.2. *Quality Control*—For quality control tests, except impact, specimens shall be conditioned for a minimum of 3 hours in air or 1 hour in liquid at 20 to 25ºC. They shall be tested at 20 to 25ºC without regard to relative humidity.

7.3. *Impact Tests*—For the impact test described in Section 8.1, the specimen and the surrounding conditioning medium are to be in thermal equilibrium with one another at a temperature of 0 to 2ºC.

8. TEST METHODS

8.1. *Impact Resistance*—Five specimens, each 150 ± 2 mm long, shall be tested in accordance with ASTM D 2444, using a 10-kg Tup A, and the Flat plate (holder B). When testing is performed at temperatures above 0ºC, no more than 15 seconds shall elapse from the time of removal of the specimen from the conditioning medium until completion of that test. Perforated specimens must be positioned with the print marking, as described in Section 10, uppermost; other specimens may be positioned with a random surface uppermost. All specimens must be located so that the contact point is centered. All five specimens shall pass. If one specimen fails, another five specimens shall be tested; nine out of ten specimens passing shall be acceptable.

8.2. *Joint Tightness of Solvent Cemented Joints*—A section of unperforated pipe shall be cemented to a bell or coupling, using the manufacturer's recommendations, or, in their absence, the methods described in ASTM D 2855. Unless otherwise specified, the assembly shall be allowed to stand for at least 24 hours. It shall then be subjected to an internal pressure of 0.17 MPa, using water as the test medium. The pressure shall be maintained for at least 1 hour. Examine the joint for leakage.

8.3. *Pipe Stiffness*—Determine the PS at 5 percent deflection of the initial inside diameter, as described in ASTM D 2412. Test three specimens, each 150 ± 2 mm long. Unperforated pipe samples shall be placed so that the minimum wall thickness is uppermost (adjacent to the top bearing plate). Perforated pipe samples shall be placed with the marking, as described in Section 10, uppermost.

8.4. *Pipe Flattening*—Flatten three specimens of pipe, each 150 ± 2 mm long, between parallel plates in a suitable press until the distance between the plates is twice the wall thickness plus 5 percent of the nominal diameter of the pipe. The rate of loading shall be uniform and such that the compression is completed within 2 to 5 minutes. Remove the load and examine the specimens.

8.5. *Dimensions*—Measurements shall be made in accordance with applicable sections of ASTM D 2122.

9. INSPECTION AND RETEST

9.1. *Inspection*—The material shall be inspected as agreed upon by the purchaser and the seller as part of the purchase contract.

9.2. *Retest and Rejection*—If the material fails to meet the requirement of Section 6 when tested in accordance with Section 8, the material may be retested to establish conformity in accordance with agreement between the purchaser and seller.

10. MARKING

10.1. All pipe shall be clearly marked at intervals of no more than 3.0 m, with 9.5 mm or larger letters, and fittings shall be clearly marked, as follows:

10.1.1. Manufacturer's name or trademark,

10.1.2. Nominal size,

10.1.3. The specification designation M 278, and

10.1.4. The plant designation code.

10.2. Pipe shall be tagged with the date of manufacture.

10.3. In addition to the above, all bends made from the pipe shall be marked to show the angle and radius of curvature.

10.4. The marking on perforated pipe shall be 180 degrees from a point equidistant between the bottom row of holes as shown in Table 1.

10.5. When exposed, a "home" mark, located at spigot ends, indicates the proper position of the bell end, when the spigot end is fully inserted.

11. QUALITY ASSURANCE

11.1. A manufacturer's certification that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results and the date each test was completed, shall be furnished upon request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

Standard Specification for

Aluminum-Zinc Alloy Coated Sheet Steel for Corrugated Steel Pipe

AASHTO Designation: M 289-91 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Aluminum-Zinc Alloy Coated Sheet Steel for Corrugated Steel Pipe

AASHTO Designation: M 289-91 (2008)

1. SCOPE

1.1. This specification covers sheet steel for corrugated steel pipe, which is coated with a 55 percent aluminum-zinc alloy on continuous lines by the hot-dip process. The material is furnished in coils, flat cut lengths, and corrugated cut lengths. The standard corrugations available in cut lengths (pitch by depth) are 68 by 13 mm, 75 by 25 mm, and 125 by 25 mm. Aluminum-zinc alloy coated steel sheet for corrugated pipe is produced in one coating mass only, designated as 210 g/m^2.

1.2. Steel sheets or coils furnished under this specification shall meet the applicable requirements of ASTM A 792M unless otherwise specified herein.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *ASTM Standards*:

- A 792M, Specification for Steel Sheet, 55% Aluminum-Zinc Alloy-Coated by the Hot Dip Process, General Requirements (Metric) (Withdrawn 1994)
- A 754/A754M, Standard Test Method for Coating Weight (Mass) of Metallic Coatings on Steel by X-Ray Fluorescence
- E 8/E 8M, Standard Test Methods for Tension Testing of Metallic Materials
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods

3. DESCRIPTION OF TERMS

3.1. In this specification, *manufacturer* refers to the producer of the sheet, *fabricator* refers to the producer of the pipe, and *purchaser* refers to the purchaser of the finished product.

4. ORDERING INFORMATION

4.1. All sheet, both flat and formed, covered by this specification is ordered only to the specified thicknesses listed in Table 4. The thickness of the sheet includes both the base steel and the coating.

4.2. Unless otherwise specified in the purchase order, all material furnished to this specification will be chemically treated.

4.3. Orders for material to this specification shall include the following information, as necessary, to adequately describe the desired product:

4.3.1. Name of material (aluminum-zinc alloy coated sheet for corrugated steel pipe, or corrugated aluminum-zinc alloy coated sheet for corrugated steel pipe);

4.3.2. Description of corrugations, if corrugated (Section 10);

4.3.3. Mass of aluminum-zinc alloy coating (210 g/m^2) (Note 1);

4.3.4. AASHTO designation number and date of issue;

4.3.5. Dimensions: thickness, flat width (if flat) or overall corrugated width (if corrugated), and length (if cut length) (Section 10);

4.3.6. Coil size requirements (specify maximum outside diameter (OD), acceptable inside diameter (ID), and maximum mass); and

4.3.7. Special requirements.

4.4. If a certification by the manufacturer is required, it shall be specified in the purchase order (Section 12).

Note 1—The coating mass should be shown in the order to eliminate possible confusion with coating masses permitted by other specifications.

Note 2—Typical ordering descriptions are as follow:

- Aluminum-zinc alloy coated steel sheet for corrugated steel pipe 68 by 13 mm corrugated, 210-g/m^2 coating, 1.63 by 648 by 1524 mm, in accordance with M 289-___.
- Aluminum-zinc alloy coated steel sheet for corrugated steel pipe, 210-g/m^2 coating, 2.01 by 686 mm by coil, 1200 mm max OD, 600 mm ID, 5445 kg max coils, in accordance with M 289-___.

5. CHEMICAL REQUIREMENTS

5.1. *Cast or Heat (formerly Ladle) Analysis*—The base metal cast or heat (formerly ladle) analysis shall conform to the chemical requirements of Table 1.

Table 1—Chemical Composition by Cast Analysis

	Composition, percent	Tolerance Over the Max Limit by Product Analysis, percent
Carbon, max	—	—
Manganese, max	—	—
Phosphorus, max	—	—
Sulfur, max	0.05	+0.01
Silicon, max	—	—
Sum of first five elements, max	0.07	+0.04

Note: Copper bearing steel availability subject to inquiry.

6. MECHANICAL REQUIREMENTS

6.1. The aluminum-zinc alloy coated sheet steel shall conform to the mechanical properties of Table 2.

Table 2—Mechanical Requirements
(Properties of Flat Material Prior to Fabrication)

Tensile Strength, min, MPa	310
Yield Point, min, MPa	230
Elongation in 50 mm, min percent	20

6.2. Two tension tests shall be made on random samples of finished material from each cast or heat. When the finished material from said cast or heat is less than 45 Mg, one test is sufficient. When material rolled from one cast or heat differs 1.27 mm or more in thickness, one tension test shall be made from both the thickest and thinnest material rolled regardless of the mass represented. The samples shall be prepared and tested in accordance with the method specified in ASTM A 792M and E 8/E 8M.

7. ALUMINUM-ZINC ALLOY COATING

7.1. The coating shall have a nominal composition of 55.0 percent aluminum, 1.6 percent silicon, and the remainder zinc (Note 3). The mass of coating shall conform to the requirements prescribed in Table 3. The mass of coating is the total amount on both surfaces of the sheet expressed in g/m^2 of sheet.

Table 3—Mass of Coating (Total Both Sides)

Min Check Limit Triple-Spot Test, g/m^2 of Sheet	Min Check Limit Single-Spot Test, g/m^2 of Sheet
210	180

Note 3—Chemical Analysis of the coating will typically agree with the nominal composition within ±3 percent for aluminum and zinc, and within ±0.5 percent for silicon.

7.2. Sampling and methods of testing shall be as prescribed in T 65M/T 65 and ASTM A 792M, using the dilute hydrochloric acid method (Note 4).

Note 4—T 65M/T 65 is a method for determining mass of zinc coating on steel, but the dilute hydrochloric acid method is satisfactory for determining the mass of aluminum-zinc alloy coating.

7.2.1. The mass of coating may be determined from the coating thickness measured by the x-ray fluorescence method, according to ASTM A 754. When this method is used and a dispute arises, the mass shall be determined by the stripping test in T 65M/T 65.

7.3. Adherence of coating shall be such that no peeling occurs while the material is being corrugated and formed into pipe.

8. TESTS BY MANUFACTURER

8.1. The manufacturer shall make such tests and measurements as are deemed necessary to ensure that the material produced complies with this specification.

9. SAMPLING BY PURCHASER

9.1. *Product, Check, or Verification Analysis*—Base metal analysis may be made by the purchaser in accordance with ASTM A 792M.

9.2. *Mechanical Testing*—Test for mechanical properties may be made by the purchaser. Testing of flat material shall be made prior to corrugating or other fabrication and shall be in accordance with ASTM A 792M and E 8/E 8M.

9.3. *Mass of Coating*—The purchaser may make random checks of coating masses to assure compliance of minimum values specified in Table 3. The mass may be converted from the sum of the readings on both surfaces of the sheet by a magnetic coating thickness gauge suitably checked and demonstrated for accuracy (Notes 5 and 6). In case of dispute, additional samples shall be taken and tested in accordance with the procedure outlined in T 65M/T 65 and ASTM A 792M, using the dilute hydrochloric acid method (Note 4).

Note 5—Several magnetic types of coating thickness gauges are commercially available and are a satisfactory basis for acceptance when properly calibrated just prior to inspection use. (See ASTM E 376.)

Note 6—An aluminum-zinc alloy coating mass of 210 g/m^2 total both sides is equivalent to an average thickness of 28 μm each side.

9.4. *Rejection and Rehearing*—Material tested by the purchaser and found not conforming to this specification may be rejected, subject to the rejection and rehearing provisions of ASTM A 792M.

10. DIMENSIONS AND TOLERANCES

10.1. Sheet thickness shall conform to dimensions prescribed in Table 4. If corrugated, thickness shall be measured on the tangents of the corrugations.

Table 4—Sheet Thickness for Corrugated Steel Pipe

Specified Thickness, mm	Min Thickness, mm
1.02	0.91
1.32	1.17
1.63	1.45
2.01	1.83
2.77	2.57
3.51	3.28
4.27	4.04

Note: Thickness is measured on the tangents of corrugations on the sheet not less than 10 mm from an edge.

10.2. Permissible variations in width, length, and camber of flat material shall be in accordance with ASTM A 792M.

10.3. Corrugations shall form smooth continuous curves and tangents. The dimensions of the corrugations shall be in accordance with Table 5 (Note 7).

Note 7—Some sizes of corrugations shown in Table 5 may not be available in cut-length sheets. The 38 by 6.5 mm size, especially, is generally used only for helically corrugated pipe.

Table 5—Corrugation Requirements

Nominal Size, mm	Max Pitch,[a] mm	Min Depth,[b] mm	Inside Radius	
			Nominal, mm	Min, mm
38 × 6.5	48	6.0	7	6.5
68 × 13	73	12	17	12
75 × 25	83	24	14	12
125 × 25	135	24	40	36

[a] Pitch is measured from crest to crest of corrugation, at 90 degrees to the direction of the corrugations.

[b] Depth is measured as the vertical distance from a straightedge resting on the corrugation crests to the bottom of the intervening valley.

10.4. Covering width of corrugated sheet shall be in accordance with Table 6. Covering width is the distance between the crests of the extreme corrugations. There is no established tolerance for overall width since the covering width and lip dimensions are the governing factors for the formed product. The lip dimension of corrugated sheet shall be in accordance with Table 7. This dimension is measured along the radial curvature from the crest of the corrugation to the edge of the sheet.

Table 6—Covering Width Tolerances for Corrugated Sheet

Covering Width, mm	Tolerance Over and Under, mm
To 600 incl	6
Over 600 to 900 incl	10
Over 900 to 1200 incl	13

Table 7—Corrugated Sheet Lip Dimensions

Nominal Corrugation Size, mm	For Riveted Pipe Construction,[a] mm	For Spot Welded Pipe Construction, Min, mm
68 by 13	19	11
75 by 25	22	13
125 by 25	22	13

[a] Tolerances, +5 mm, –0.

11. RECORDS

11.1. Test results, including chemical compositions, tensile strength, and mass of coating for each heat and coating lot, shall be maintained by the sheet manufacturer for 7 years and shall be made available to the fabricator and purchaser upon request.

12. CERTIFICATION

12.1. When specified in the purchase order, a manufacturer's certification shall be furnished to the purchaser. The certification shall show results of tests conducted on samples from each lot from which sheet is furnished. A statement shall be included that the test results conform to the requirements of M 289. The certification shall provide information necessary to identify the sheet represented, such as manufacturer's name or brand, heat number, lot number, sheet thickness, coating mass, corrugation size (if corrugated), and sheet size (if cut lengths). Furnishing a certification shall not restrict the right of the purchaser of the sheet (fabricator) or ultimate purchaser of the pipe made from the sheet to sample and test the material furnished.

13. MARKING

13.1. Each 0.5 to 1.5 m of sheet in coils or cut lengths shall be identified by showing the following:

13.1.1. Name of sheet manufacturer,

13.1.2. Brand name,

13.1.3. Specified thickness,

13.1.4. Specified mass of coating,

13.1.5. Identification symbols relating to a specific heat number and coating lot number, and

13.1.6. AASHTO designation number.

13.2. The brand shall be removed, obliterated, or the sheet rebranded "Non Specification" on each 0.5 to 1.5 m of material in a coating lot or heat where control tests, as prescribed herein, show nonconformance to this specification.

Standard Specification for

Corrugated Polyethylene Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

AASHTO Designation: M 294-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Corrugated Polyethylene Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

AASHTO Designation: M 294-10

1. SCOPE

1.1 This specification covers the requirements and methods of tests for corrugated polyethylene (PE) pipe, couplings, and fittings for use in surface and subsurface drainage applications.

1.1.1 Nominal sizes of 300 to 1500 mm (12 to 60 in.) are included.

1.1.2 Materials, workmanship, dimensions, pipe stiffness, slow crack growth resistance, joining systems, brittleness, and form of markings are specified.

1.2 Corrugated PE pipe is intended for surface and subsurface drainage applications where soil provides support to its flexible walls. Its major use is to collect or convey drainage water by open gravity flow, as culverts, storm drains, etc.

Note 1—When PE pipe is to be used in locations where the ends may be exposed, consideration should be given to protection of the exposed portions due to combustibility of the PE and the deteriorating effects of prolonged exposure to ultraviolet radiation.

1.3 *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. customary units are shown in parentheses, and may not be exact equivalents.

1.4 This specification does not include requirements for bedding, backfill, or earth cover load. Successful performance of this product depends upon proper type of bedding and backfill, and care in installation. The structural design of corrugated PE pipe and the proper installation procedures are given in *AASHTO LRFD Bridge Design Specifications,* Section 12, and *LFRD Bridge Construction Specifications,* Section 30, respectively. Upon request of the user or engineer, the manufacturer shall provide profile wall section detail required for a full engineering evaluation.

1.5 The following precautionary caveat pertains only to the test method portion, Section 9.4, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 341, Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading

- *AASHTO LRFD Bridge Construction Specifications*
- *AASHTO LRFD Bridge Design Specifications*

2.2 *ASTM Standards*:

- D 618, Standard Practice for Conditioning Plastics for Testing
- D 638, Standard Test Method for Tensile Properties of Plastics
- D 883, Standard Terminology Relating to Plastics
- D 2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D 2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D 2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D 3212, Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- D 3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- D 4218, Standard Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
- D 4703, Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques, or Sheets
- D 5397, Standard Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test
- F 412, Standard Terminology Relating to Plastic Piping Systems
- F 477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- F 2136, Standard Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

3. TERMINOLOGY

3.1 The terminology used in this standard is in accordance with the definitions given in ASTM D 883 and ASTM F 412 unless otherwise specified.

3.2 *crack*—any break or split that extends through the wall.

3.3 *crease*—an irrecoverable indentation, generally associated with wall buckling.

3.4 *buckling*—any reverse curvature or deformation in the pipe wall that reduces the load-carrying capability of the pipe. Any decrease or downward deviation in the pipe stiffness test curve shall be considered a wall-buckling point.

3.5 *polyethylene (PE) plastics*—plastics based on polymers made with ethylene as essentially the sole monomer (ASTM D 883).

3.6 *reworked plastic*—A plastic from a processor’s own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D 883).

3.7 *virgin polyethylene material*—PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

3.8 *slow crack growth*—A phenomenon by which a stress crack may form. A stress crack is an external or internal crack in plastic caused by tensile stresses less than its short-time mechanical strength.

3.9 *delamination*—A separation between the inner liner and outer corrugated wall of Type S pipe as evidenced by a visible gap extending completely through at least one corrugation valley at any point around the circumference of the pipe. For Type D pipe, delamination is a separation of the inner and outer wall as evidenced by a visible gap extending completely between the internal supports and inner or outer wall at any point around the circumference of the pipe.

4. CLASSIFICATION

4.1 The corrugated PE pipe covered by this specification is classified as follows:

4.1.1 *Type C*—This pipe shall have a full circular cross section, with a corrugated surface both inside and outside. Corrugations shall be annular.

4.1.1.1 *Type CP*—This pipe shall be Type C with perforations.

4.1.2 *Type S*—This pipe shall have a full circular cross section, with an outer corrugated pipe wall and a smooth inner liner. Corrugations shall be annular.

4.1.2.1 *Type SP*—This pipe shall be Type S with perforations.

4.1.3 *Type D*—This pipe shall consist of an essentially smooth inner wall/liner braced circumferentially or spirally with projections or ribs joined to an essentially smooth outer wall.

4.1.3.1 *Type DP*—This pipe shall be Type D with perforations.

4.2 Two classes of perforations are as described in Sections 7.3.1 and 7.3.2.

5. ORDERING INFORMATION

5.1 Orders using this specification shall include the following information, as necessary, to adequately describe the desired product:

5.1.1 AASHTO designation and year of issue;

5.1.2 Type of pipe (Section 4.1);

5.1.3 Diameter and length required, either total length or length of each piece and number of pieces;

5.1.4 Number of couplings;

5.1.5 Class of perforations (Class 2 is furnished if not specified) (Section 7.3); and

5.1.6 Certification, if desired (Section 12.1).

6. MATERIALS

6.1 *Basic Materials*:

6.1.1 *Extruded Pipe and Blow Molded Fittings*—Pipe and fittings shall be made of virgin PE resin compounds meeting the requirements of ASTM D 3350 and cell classification 435400C, except that the carbon black content shall not exceed 5 percent, and the density shall not be less than 0.948 gm/cc nor greater than 0.955 gm/cc. The cell classification shall be based on the virgin PE resin compounds without carbon black. Resins that have higher cell classifications in one or more properties, with the exception of density, are acceptable provided product requirements are met. For slow crack growth resistance, acceptance of resins shall be determined by using the notched constant ligament-stress (NCLS) test according to the procedure described in Section 9.4. For slow crack growth resistance, acceptance of pipe shall be determined by tests on the finished pipe using the NCLS test according to the procedure described in Section 9.4. The average failure time of the pipe liner shall not be less than 18 hours. If profile geometries do not have a flat portion of sufficient length to produce an NCLS tensile specimen of 25 mm (1 in.) length, the pipe sample shall be ground and a test plaque made in accordance with ASTM D 4703 Procedure C at a cooling rate of 15ºC/min (27°F/min) and tested per ASTM F 2136. The average failure time of test specimens from plaques shall not be less than 24 hours.

6.1.2 *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE resins meeting the requirements of ASTM D 3350 and cell classification 213320C, except that the carbon black content shall not exceed 5 percent. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.3 *Injection Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE resins meeting the requirements of ASTM D 3350 and cell classification 314420C, except that the carbon black content shall not exceed 5 percent. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.2 *Reworked Plastic*—In lieu of virgin PE, clean reworked plastic may be used by the manufacturer, provided that it meets the cell class requirements as described in Section 6.1.

6.3 *Resin Blending*—When blended resins are used, the components of the blend must be virgin PE and the final blend must meet all of the requirements of Section 6.1.1 for extruded pipe and blow molded fittings, Section 6.1.2 for rotational molded fittings and couplings, and Section 6.1.3 for injection molded fittings and couplings.

7. REQUIREMENTS

7.1 *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. The ends of the pipe shall be cut squarely and cleanly so as not to adversely affect joining or connecting.

7.1.1 *Visible Defects*—Cracks, creases, delaminations, and unpigmented or nonuniformly pigmented pipe are not permissible in the pipe or fittings as furnished. There shall be no evidence of delamination when tested in accordance with Section 9.7.

7.2 *Pipe Dimensions*:

7.2.1 *Nominal Size*—The nominal size for the pipe and fittings is based on the nominal inside diameter of the pipe. Nominal diameters shall be 300, 375, 450, 525, 600, 675, 750, 900, 1050, 1200, 1350, and 1500 mm (12, 15, 18, 21, 24, 27, 30, 36, 42, 48, 54, and 60 in.).

7.2.2 *Wall Thickness*—The inner wall of Type S pipe, and both inner and outer walls of Type D, pipe shall have the following minimum thicknesses, when measured in accordance with Section 9.6.4.

Diameter, mm (in.)	Wall Thickness, mm (in.)
300 (12)	0.9 (0.035)
375 (15)	1.0 (0.04)
450 (18)	1.3 (0.05)
525 (21)	1.5 (0.06)
600 (24)	1.5 (0.06)
675 (27)	1.5 (0.06)
750 (30)	1.5 (0.06)
900 (36)	1.7 (0.07)
1050 (42)	1.8 (0.07)
1200 (48)	1.8 (0.07)
1350 (54)	2.0 (0.08)
1500 (60)	2.0 (0.08)

7.2.3 *Inside Diameter Tolerances*—The tolerance on the specified inside diameter shall be 4.5 percent oversize and 1.5 percent undersize, but not more than 37 mm (1.5 in.) oversize when measured in accordance with Section 9.6.1.

7.2.4 *Length*—Corrugated PE pipe may be sold in any length agreeable to the user. Lengths shall not be less than 99 percent of the stated quantity when measured in accordance with Section 9.6.2.

7.3 *Perforations*—When perforated pipe is specified, the perforations shall conform to the requirements of Class 2, unless otherwise specified in the order. Class 1 perforations are for pipe intended to be used for subsurface drainage or combination storm and underdrain. Class 2 perforations are for pipe intended to be used for subsurface drainage only. The perforations shall be cleanly cut so as not to restrict the inflow of water. Pipe connected by couplings or bands may be unperforated within 100 mm (4 in.) of each end of each length of pipe. Pipe connected by bell and spigot joints may not be perforated in the area of the bells and spigots.

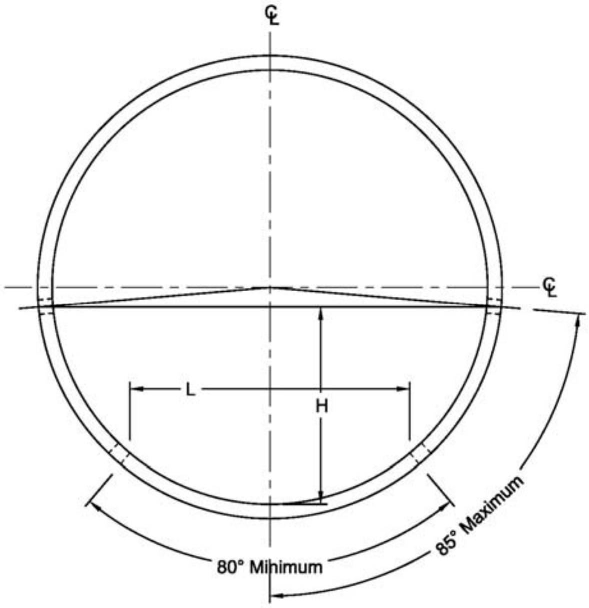


Figure 1—Requirements for Perforations

Table 1—Rows of Perforations, Height *H* of the Centerline of the Uppermost Rows above the Invert, and Chord Length *L* of Unperforated Segment, for Class 1 Perforations

Nominal Diameter, mm (in.)	Rows of Perforations[a]	*H*, Max,[b] mm (in.)	*L*, Min,[b] mm (in.)
300 (12)	6	138 (5.4)	192 (7.5)
375 (15)	6	172 (6.75)	240 (9.5)
450 (18)	6	207 (8.15)	288 (11.3)
525 (21)	6	241 (9.5)	336 (13.2)
600 and larger (24 and larger)	8	[c]	[c]

[a] Minimum number of rows. A greater number of rows for increased inlet area shall be subject to agreement between purchaser and manufacturer. Note that the number of perforations per meter in each row (and inlet area) is dependent on the corrugation pitch.

[b] See Figure 1 for location of dimensions *H* and *L*.

[c] *H*(max) = 0.46*D*; *L*(min) = 0.64D, where *D* = nominal diameter of pipe, mm.

7.3.1 *Class 1 Perforations*—The perforations shall be approximately circular and shall have nominal diameters of not less than 5 mm (0.2 in.) nor greater than 10 mm (0.4 in.) and shall be arranged in rows parallel to the axis of the pipe. For Type CP and SP pipe, the perforations shall be located in the external valleys with perforations in each row for each corrugation. (The perforations shall not cut into the corrugation sidewalls.) For Type DP pipe, perforations shall be located in the center of the cells. The perforations shall not cut into the vertical sections of the cells. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of the lower unperforated segment corresponding to the flow line of the pipe. The spacing of the rows shall be uniform. The distance between the centerlines of the rows shall not be less than 25 mm (1 in.). The minimum number of longitudinal rows of perforations, the maximum height of the centerlines of the uppermost rows of perforations above the bottom of the invert, and the inside chord lengths of the unperforated segments illustrated in Figure 1 shall be as specified in Table 1.

7.3.2 *Class 2 Perforations*—Circular perforations shall be a minimum of 5 mm (0.2 in.) and shall not exceed 10 mm (0.4 in.) in diameter. The width of slots shall not exceed 3 mm (0.1 in.). The length of slots shall not exceed 70 mm (2.75 in.) for 300 mm (12 in.) and 375 mm (15 in.) pipe and 75 mm (3 in.) for 450 mm (18 in.) and larger pipe. Perforations shall be placed in the external valleys for Type CP and SP pipe and in the center of the cells for Type DP pipe. Perforations shall be uniformly spaced along the length and circumference of the pipe. The water inlet area shall be a minimum of 30 cm^2/m (1.5 $in.^2$/ft) for pipe sizes 300 to 450 mm (12 to 18 in.) and 40 cm^2/m (2 $in.^2$/ft) for pipe sizes larger than 450 mm (18 in.). All measurements shall be made in accordance with Section 9.6.3.

7.4 *Pipe Stiffness*—The pipe shall have a minimum pipe stiffness at 5 percent deflection as follows when tested in accordance with Section 9.1.

Diameter, mm (in.)	Pipe Stiffness, kPa (psi)
300 (12)	345 (50)
375 (15)	290 (42)
450 (18)	275 (40)
525 (21)	260 (38)
600 (24)	235 (34)
675 (27)	205 (30)[a]
750 (30)	200 (29)[a]
900 (36)	155 (22.5)[a]
1050 (42)	145 (21)[a]
1200 (48)	135 (20)[a]
1350 (54)	120 (18)[a]
1500 (60)	105 (15)[a]

[a] For diameters 675 mm (27 in.) and larger, the stiffness test is conducted at a higher loading rate than ASTM D 2412 as described in Section 9.7.3.

7.5 *Pipe Flattening*—There shall be no evidence of wall buckling, cracking, splitting, delamination, or decrease or downward deviation in the load-deflection curve when the pipe is tested in accordance with Section 9.2.

7.6 *Brittleness*—Pipe specimens shall not crack or split when tested in accordance with Section 9.3. Five non-failures out of six impacts will be acceptable.

7.7 *Stub Compression Test*—Profile compression capacity in any specimen in the stub compression test shall not be less than 50 percent of the gross cross section area times the minimum specified yield strength when tested in accordance with Section 9.8. The stub compression test, AASHTO T 341, shall be a material and wall design qualification test conducted once a year or whenever there are changes in wall design or material distribution. Computing the minimum capacity requires determining the cross-sectional area of the pipe wall. This can be accomplished conveniently by optically scanning the profile and determining the section properties using a computer drafting program.

7.8 *Fitting Requirements*:

7.8.1 The fittings shall not reduce or impair the overall integrity or function of the pipe line.

7.8.2 Common corrugated fittings include in-line joint fittings, such as couplings and reducers, and branch or complimentary assembly fittings such as tees, wyes, and end caps. These fittings are installed by various methods.

7.8.3 All fittings shall be within an overall length dimensional tolerance ±12 mm (0.5 in.) of the manufacturer's specified dimensions when measured in accordance with Section 9.6.2.

7.8.4 Fittings shall not reduce the inside diameter of the pipe being joined by more than 12 mm (0.5 in.). Reducer fittings shall not reduce the cross-sectional area of the small size.

7.8.5 Couplings shall be corrugated to match the pipe corrugations and shall provide sufficient longitudinal strength to preserve pipe alignment and prevent separation at the joints. Couplings shall be bell and spigot or split collar. Split couplings shall engage at least two full corrugations on each pipe section.

7.8.6 The design of the fittings shall be such that when connected with the pipe, the axis of the assembly will be level and true when tested in accordance with Section 9.5.2.

7.8.7 Other types of coupling bands or fastening devices that are equally effective as those described, and that comply with the joint performance criteria of *AASHTO LRFD Bridge Construction Specifications*, Section 30, may be used when approved by the purchaser.

7.9 Only fittings supplied or recommended by the pipe manufacturer should be used. Fabricated fittings should be supplied with joints compatible with the overall system. All joints shall meet the requirements of a soiltight joint unless otherwise specified by the owner/designer.

7.9.1 *Soiltight joints* are specified as a function of opening size, channel length and backfill particle size. If the size of the opening exceeds 3 mm (0.12 in.), the length of the channel must be at least four times the size of the opening. A backfill material containing a high percentage of fine-graded soils requires investigation for the specific type of joint to be used to guard against soil infiltration. Information regarding joint soiltightness criteria can be found in *AASHTO LRFD Bridge Construction Specifications*, Section 30, “Thermoplastic Pipe.”

7.9.2 *Silt-tight joints* should be used where the backfill material has a high percentage of fines. Silt-tight bell and spigot joints will utilize an elastomeric rubber seal meeting ASTM F 477. Silt-tight joints must be designated to pass a laboratory pressure test of at least 14 kPa (2 psi).

7.9.3 *Watertight joints* must meet a 74 kPa (10.8 psi) laboratory test per ASTM D 3212 and utilize a bell and spigot design with a gasket meeting ASTM F 477.

8. CONDITIONING

8.1 *Conditioning*—Condition the specimen prior to test at 21 to 25ºC (70 to 77°F) for not fewer than 24 hours in accordance with Procedure A in ASTM D 618 for those tests for which conditioning is required, and unless otherwise specified.

8.2 *Conditions*—Conduct all tests at a laboratory temperature of 21 to 25ºC (70 to 77°F) unless otherwise specified herein.

9. TEST METHODS

9.1 *Pipe Stiffness*—Select a minimum of two (2) pipe specimens and test for pipe stiffness (PS), as described in ASTM D 2412 except for the following: (1) the test specimens shall be a minimum of one diameter length for 300-mm (12-in.) to 600-mm (24-in.) diameter pipe, and one half diameter length for pipe diameters greater than 600 mm (24 in.); (2) locate the first specimen in the loading machine with an imaginary line connecting the two seams formed by the corrugation mold (end view) parallel to the loading plates, when applicable. The specimen must lie flat on the plate within 3 mm (0.12 in.) and may be straightened by hand bending at room temperature to accomplish this. Use the first location as a reference point for rotation and testing of the other specimen. Rotate the second specimen 90 degrees from the orientation of the first specimen and test. Test each specimen in one position only; (3) the deflection indicator shall be readable and accurate to ±0.02 mm (0.001 in.); (4) the residual curvature found in tubing frequently results in an erratic initial load-deflection curve. When this occurs, the beginning point for deflection measurement shall be at a load of 20 ± 5 newtons (4.5 lbf ± 1.1 lbf). The point shall be considered as the origin of the load-deflection curve; (5) the crosshead speed shall be the faster of 12.7 mm per minute (0.5 in. per minute) or 2 percent of the nominal inside diameter per minute.

Note 2—The parallel plates must exceed the length of the test specimen as specified above.

Note 3—Additional pipe specimens may be tested at other orientations for pipe stiffness and flattening if desired.

9.2 *Pipe Flattening*—Flatten the two-pipe specimens from Section 9.1 until the vertical inside diameter is reduced by 20 percent. The rate of loading shall be the same as in Section 9.1. Examine the specimen with the unaided eye for cracking, splitting, or delamination. The specimen shall fail if wall buckling, cracking, splitting, or delamination is observed with the unaided eye or if there is a decrease or downward deviation in load-deflection curve at 20 percent or less deflection. The load-deflection curve shall be carried beyond 20 percent deflection so that the shape of the curve at 20 percent deflection can be determined.

9.3 *Brittleness*—Test pipe specimens in accordance with ASTM D 2444 except six specimens shall be tested, or six impacts shall be made on one specimen. In the latter case, successive impacts shall be separated by 120 ± 10 degrees for impacts made on one circle, or at least 300 mm (12 in.) longitudinally for impacts made on one element. Impact points shall be at least 150 mm (6 in.) from the end of the specimen. Tup B shall be used, with a mass of 4.5 kg (10 lb). The height of drop shall be 3.0 m (10 ft). Use a flat plate specimen holder. Condition the specimens for 24 hours at a temperature of –4 ± 2ºC (25 ± 3.6°F), and conduct all tests within 60 seconds of removal from this atmosphere. The center of the falling tup shall strike on a corrugation crown for all impacts.

9.4 *Slow Crack Growth Resistance of Polyethylene Pipe* —Test specimens from the pipe liner for stress crack resistance in accordance with ASTM F 2136, the NCLS test, except for the following modifications:

9.4.1 The applied stress for the NCLS test shall be 4100 kPa (600 psi).

Note 4—The notched depth of 20 percent of the nominal thickness of the specimen is critical to this procedure.

9.4.2 When the pipe liner cannot be sampled, then a specimen may be taken from the profile wall of the pipe. Where the pipe wall profile does not have flat longitudinal sections of sufficient size to obtain a tensile specimen, a sample of the pipe wall shall be ground, made into plaques per ASTM D 4703 Procedure C , samples cut from those plaques and tested as noted in 6.1.1.

9.5 *Joints and Fittings*:

9.5.1 *Joint Integrity*—Pipes that have a welded bell shall be tested to verify the strength of the weld as follows: Assemble the joint in accordance with the manufacturer’s recommendations. Use pipe samples at least 300 mm (12 in.) in length. Assemble a specimen at least 600 mm (24 in.) in length with the connection at the center. Load the connected pipe and joint between parallel plates at the rate of 12.5 mm per minute (0.5 in/min) until the vertical inside diameter is reduced by at least 20 percent of the nominal diameter of the pipe. Inspect for damage while at the specified deflection and after load removal.

9.5.2 *Alignment*—Assure that the assembly or joint is correct and complete. If the pipe is bent, it should be straightened prior to performing this test. Lay the assembly or joint on a flat surface and verify that it will accommodate straight-line flow.

9.6 *Dimensions*:

9.6.1 *Inside Diameter*—Measure the inside diameter of the pipe with a tapered plug in accordance with ASTM D 2122. As an alternative, measure the inside diameter with a suitable device accurate to ±3.0 mm (0.12 in.) by taking two inside diameter measurements, the first at the seam and the second 90 degrees from the seam, and averaging the two measurements. The average inside diameter shall meet the requirements of Section 7.2.3.

9.6.2 *Length*—Measure pipe with any suitable device accurate to ±6.0 mm in 3 m (0.25 in. in 10 ft). Make all measurements on the pipe while it is stress-free and at rest on a flat surface in a straight line. These measurements may be taken at ambient temperature.

9.6.3 *Perforations*—Measure dimensions of perforations on a straight specimen with no external forces applied. Make linear measurements with instruments accurate to 0.2 mm (0.008 in.).

9.6.4 *Wall Thickness*—Measure the wall thickness in accordance with ASTM D 2122.

9.7 *Delamination*—Examine Type S pipe for evidence of delamination as defined and described in Section 3.9 by cutting the pipe at the corrugation crest as shown in Figure 3 and attempting to insert a feeler gauge between the inner and outer corrugated wall at the corrugation valley as shown in Figure 4. The feeler gauge should not pass through the corrugation valley into a void at any location along the circumference of the pipe.

Examine Type D pipe for evidence of delamination as defined and described in Section 3.9 by cutting a section through the pipe as shown in Figure 3 and attempting to insert a feeler gauge between the internal supports and the inner and outer walls as shown in Figure 4. The feeler gauge should not pass between the internal support and the inner or outer wall at any point along the circumference of the pipe.

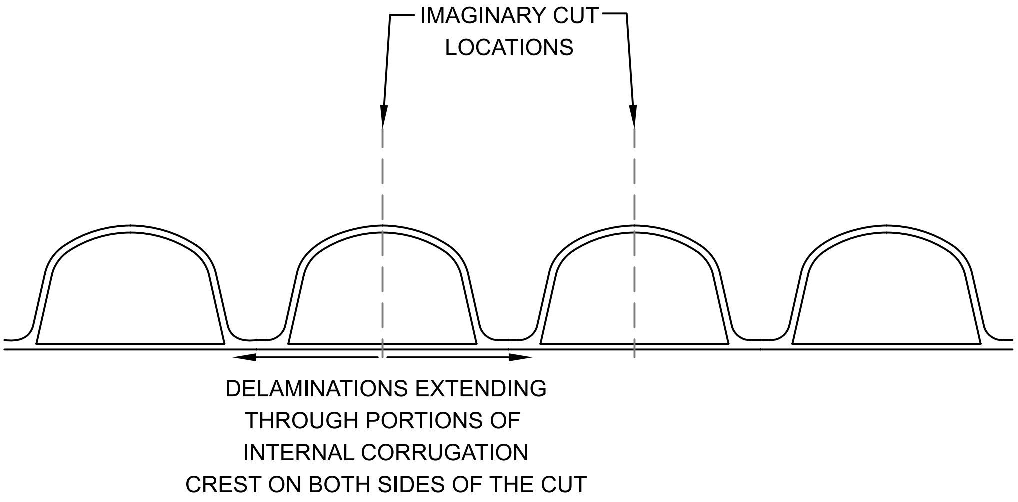


Figure 3—Location of Pipe Cut

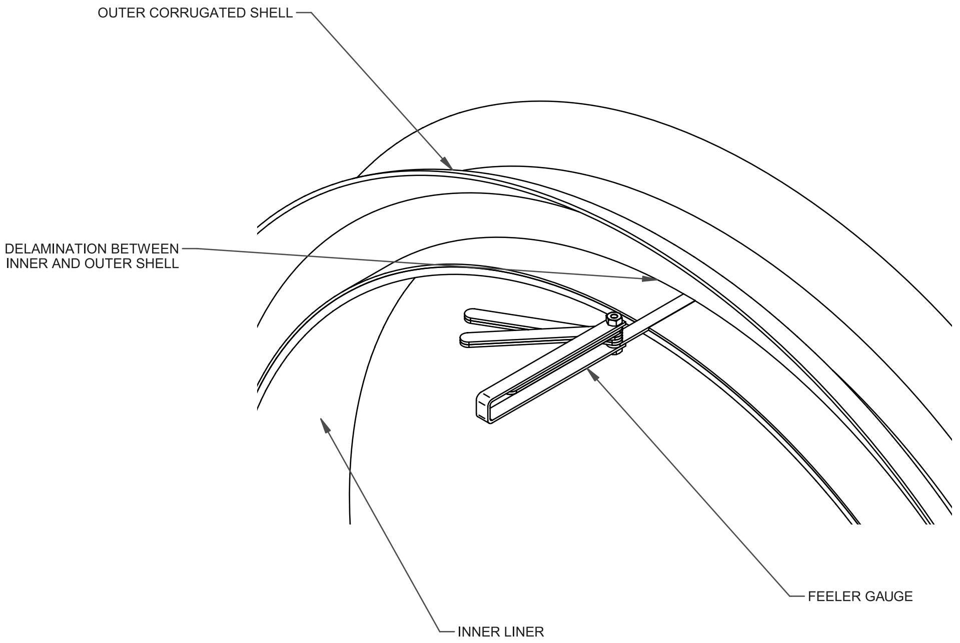


Figure 4—Feeler Gauge Insertion

9.8 *Stub Compression Capacity*—Determine the stub compression capacity of the pipe section in accordance with AASHTO Test Standard T 341. Conduct four tests on specimens cut from the same ring of pipe at 90-degree intervals around the circumference.

10. INSPECTION AND RETEST

10.1 *Inspection*—Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

10.2 *Retest and Rejection*—If any failure to conform to these specifications occurs, the pipe or fittings may be retested to establish conformity in accordance with agreement between the purchaser and seller. Individual results, not averages, constitute failure.

11. MARKING

11.1 All pipe shall be clearly marked at intervals of no more than 3 m (10 ft) as follows:

11.1.1 Manufacturer’s name or trademark;

11.1.2 Nominal size;

11.1.3 This specification designation, M 294;

11.1.4 The plant designation code; and

11.1.5 The date of manufacture or an appropriate code. If a date code is used, a durable manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

Note 5—A durable sticker is one that is substantial enough to remain in place and be legible through installation of the pipe.

11.2 Fittings shall be marked with the designation number of this specification, M 294, and with the manufacturer's identification symbol.

12. QUALITY ASSURANCE

12.1 A manufacturer's certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results, and the date each test was completed, shall be furnished upon request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

12.2 Manufacturer records—Manufacturers shall keep records of the following: (1) resin manufacturer's data sheets and certification that the base resin meets minimum cell class requirements of the product specification; (2) manufacturer's data sheets and quantities for all additives blended with the resin by the pipe manufacturer; (3) test results to demonstrate that, if resins of two different cell classifications are blended, the resulting mixture meets the requirements of the specified cell classification; (4) correlation of resin shipment source with pipe markings.

ANNEX

(Mandatory Information)

A1. GUIDELINES FOR PIPE MADE FROM BLENDED RESINS

A1.1. If pipe is made from a blend of component resins or from off-prime resin or blends, the manufacturer of each component resin should supply a certificate of analysis for each lot that includes the lot-specific melt index and density. The pipe manufacturer should have a resin testing program in place that includes the testing of each resin blend lot for density and melt index and have the means of conducting (in-house or contract lab) the remaining cell class and NCLS testing as specified in this standard. The manufacturer shall test each resin or resin blend lot for full cell class and NCLS, unless a regular quality assurance program is in place to correlate cell class results to density and melt index. In any case, full cell class and NCLS testing should be performed on all approved/certified resin blends at least quarterly. Additionally, the pipe manufacturer shall have the resin blend independently tested and pre-qualified based on a "recipe" with component percentage tolerances of no more than ±1.5 percent substantiated by independent testing.

A1.2. When blends of virgin resins are used for pipe manufacture, the final blended resin must meet the requirements of the standard. It is not necessary for the individual components of the blend to meet the cell class or NCLS requirements of this standard, provided that the final blend meets all the requirements.

A1.2.1. Sampling and testing of the final blended resin shall be performed as follows:

A1.2.1.1. The sample shall be prepared either by direct sampling from the feed hopper of the extruder (after the material has already been weigh-blended by the blenders or other means), or by manually weigh-blending the individual components to the specified finished blend ratios. The manufacturer shall have current calibration records for the automated or manual weigh blending equipment.

A1.2.1.2. The blended sample shall not contain carbon black concentrate. If carbon black concentrate is present in the sampled material, the carbon black concentrate shall be removed prior to further sample preparation.

A1.2.1.3. The dry-blended sample shall be fully homogenized by melt blending via a twin screw lab extruder prior to testing for physical properties.

A1.2.1.4. The melt-blended sample shall be tested for melt index, density, and NCLS in accordance with the number of hours per the requirements of the standard.

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL/QUALITY ASSURANCE PROGRAM

X1.1. *Scope*:

X1.1.1. As required in Sections 10 and 12, the acceptance of these products relies on the adequate inspection and certification agreed to between the buyer and the seller/producer. This appendix should serve as a guide for both the manufacturer and the user. It places the responsibility on the producer to control the quality of the material they produce and to provide the quality control information needed for acceptance by the buyer/user. The producer is required to perform quality control sampling, testing and record keeping on materials they ship. It also sets forth quality assurance sampling, testing and record keeping that should be performed by the buyer/user to confirm the performance of the producer's control plan.

X1.2. *Program Requirements*:

X1.2.1. The producing company must have a quality control plan approved by the specifying agency.

X1.2.2. The producing plant must have an approved quality control plan.

X1.2.3. The plant must have an approved laboratory, either within the company or an independent laboratory.

X1.2.4. The producing plant(s) must have a designated quality control technician.

X1.3. *Quality Control Plan*:

X1.3.1. The producer must supply to the specifying agency a written quality control plan that shows how the producer will control the equipment, materials, and production methods to ensure that the specified products are supplied. The following information must be included in the plan:

X1.3.1.1. Titles of the personnel responsible for production quality at the plant(s);

X1.3.1.2. The physical location of the plant(s);

X1.3.1.3. The methods of identification for each lot of material during manufacture, testing, storage, and shipment. The method of identification shall allow the specifying agency to trace the finished product to the material provider;

X1.3.1.4. The method of sampling and testing of raw materials and finished product, including lot sizes and types of tests performed; and

X1.3.1.5. A plan for dealing with nonconforming product, including how the producer plans to initiate immediate investigation and how corrective action will be implemented to remedy the cause of the problem.

X1.4. *Approved Laboratory*:

X1.4.1. All tests must be conducted at laboratories approved by the specifier. Each manufacturer may establish and maintain its own laboratory for performance of quality control testing or may utilize an approved independent laboratory. Records of instrument calibration and maintenance and sample collection and analysis must be maintained at the laboratory.

X1.5. *Quality Control Technician*:

X1.5.1. All samples must be taken and tested by the quality control technician designated by the producer. The designated quality control technicians will be responsible for overall quality control at the producing plant.

X1.6. *Annual Update*:

X1.6.1. An annual update may be required. The annual update may be submitted by the manufacturer to the specifying agency by December 31st of each calendar year.

X1.7. *Plant Approval*:

X1.7.1. The plant approval process requires the manufacturer to submit an annual update to the specifying agency. The update must identify the specific product manufactured at the plant.

X1.7.2. The specifying agency will review the manufacturer's written quality control plan and a plant inspection may be scheduled. This inspection will verify that the quality control plan has been implemented and is being followed and that at least one designated quality control technician is on-site and will be present when material is being produced under this program. The laboratory will be inspected and approved if it meets the requirements.

X1.8. *Sampling and Testing*:

X1.8.1. The quality assurance plan approved for each manufacturer, and/or manufacturer's location, shall detail the methods and frequency of sampling and testing for all raw materials and products purchased or manufactured at that location. All testing shall be in accordance with current specifications and procedures referenced in M 294.

X1.8.2. Samples of materials and pipe may be taken by the specifying agency.

X1.8.3. The specifying agency may require an annual third-party independent assurance test.

X1.9. *Sample Identification and Record Keeping*:

X1.9.1. Manufacturer's Quality Control samples are to be uniquely identified by the producing plant.

X1.9.2. Quality control and quality assurance data are to be retained by the manufacturer for 2 years and made available to the specifying agency upon request.

X1.9.3. Quality control test reports shall include the lot identification.

X1.9.4. Unless requested at the time of ordering, test reports do not have to be filed for specific projects.

X1.9.5. Reports shall indicate the action taken to resolve nonconforming product.

Standard Specification for

Poly(Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter

AASHTO Designation: M 304-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Poly(Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter

AASHTO Designation: M 304-10

1. SCOPE

1.1. This specification covers poly(vinyl chloride) (PVC) profile wall perforated and non-perforated pipe and fittings, 100 to 1200 mm (4 to 48 in.) nominal inside diameter, for use in non-pressure storm drains, culverts, underdrains, and other subsurface drainage systems providing either soiltight or watertight joints.

1.2. Industrial waste disposal lines should be installed only with the specific approval of the governing code authority since chemicals not commonly found in drains and temperatures in excess of 60ºC (140ºF) may be encountered.

1.3. Pipe and fittings produced to this specification should be installed in accordance with ASTM D 2321 and the manufacturer’s recommendation.

1.4. *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. customary units are shown in parentheses for informational purposes, and may not be exact equivalents.

1.5. The following precautionary caveat pertains only to the test method portion, Section 8, of this specification. *This standard does not purport to address the safety concerns associated with its use. It is the responsibility of whoever uses this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 341, Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading
- *AASHTO LRFD Bridge Construction Specifications*

2.2. *ASTM Standards*:

- D 618, Standard Practice for Conditioning Plastics for Testing
- D 883, Standard Terminology Relating to Plastics
- D 1600, Standard Terminology for Abbreviated Terms Relating to Plastic
- D 1784, Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds

- D 2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D 2152, Standard Test Method for Adequacy of Fusion of Extruded Poly(Vinyl Chloride) (PVC) Pipe and Molded Fittings by Acetone Immersion
- D 2321, Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications
- D 2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D 2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D 3212, Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- F 412, Standard Terminology Relating to Plastic Piping Systems
- F 477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- F 1057, Standard Practice for Estimating the Quality of Extruded Poly (Vinyl Chloride) (PVC) Pipe by the Heat Reversion Technique

3. TERMINOLOGY

3.1. *General*—Definitions used in this specification are in accordance with definitions given in ASTM D 883 and ASTM F 412 unless otherwise indicated.

3.2. *profile wall pipe*—a pipe product consisting of an essentially smooth wall waterway braced with annular or helical projections or ribs on the outside of the pipe, or with annular or helical bracing between essentially smooth outer and inner walls. (See Figure 1.)

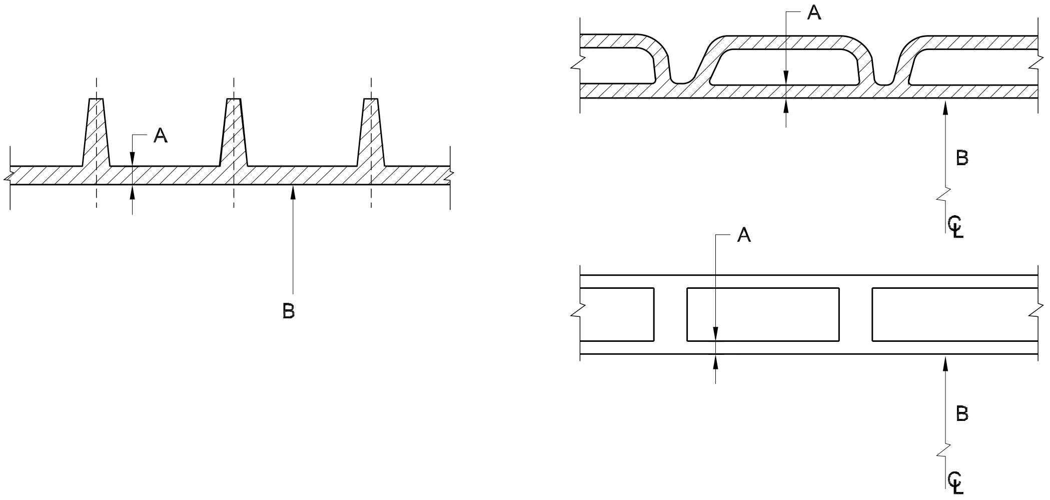


Figure 1—Typical Profiles (Cross Section): A–Waterway Minimum Wall, B–Average Inside Diameter (Other Configurations of Ribs and Spacing Are Permissible)

3.3. *soiltight joints*—joints that do not allow soil migration through the joint into the pipe are deemed soiltight. Both the size of any opening or flow channel into the joint and the soil particle size determine soil tightness.

4. ORDERING INFORMATION

4.1. *Orders*—Orders for materials to this specification shall include the following information as necessary to adequately describe the desired product:

4.1.1. Name of material (PVC ribbed drain pipe);

4.1.2. AASHTO designation, including year;

4.1.3. Perforations, when perforations are required;

4.1.4. Diameter of pipe;

4.1.5. Length, either total length or length of each piece and number of pieces; and

4.1.6. Special requirements.

5. MATERIALS

5.1. *Basic Materials*—The pipe, internal sleeves, and fittings shall be made of PVC plastic having a minimum cell classification of 12454C or 12364C as defined in ASTM D 1784. Homopolymer PVC compounds must meet or exceed the requirements of the above listed minimum cell classification number.

5.2. *Reworked Material*—Clean reworked material generated from the manufacturer's own production, when used by the manufacturer, shall meet the requirements for minimum cell classification as described in Section 5.1.

5.3. *Gaskets*—Elastomeric gaskets shall comply with low head-application requirements described in ASTM F 477.

5.4. *Lubricant*—The lubricant used for assembly shall have no detrimental effect on the gasket or on the pipe. Only lubricant recommended by the manufacturer shall be used.

6. JOINT SYSTEMS

6.1. *Joint Types*—Joints may consist of bells, external sleeves, internal sleeves, or band couplers.

6.2. *Joint Classifications*—Joints shall be classified as soiltight or watertight. Soiltight joints must meet the requirements of Section 7.6. Watertight joints must meet the requirements of Section 7.7.

Note 1—The outside diameters of products of different manufacturers are not specified and therefore compatibility should be reviewed.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be homogeneous throughout and free from visible cracks, holes, foreign inclusions, or other injurious defects. The pipe shall be as uniform as commercially practical in color, opacity, density, and other physical properties.

7.2. *Pipe Dimensions*:

7.2.1. *Diameter*—The inside diameter of the pipe shall meet the requirements given in Table 1 when measured in accordance with Section 8.3.1.

7.2.2. *Wall Thickness*—The minimum wall thickness of the waterway of ribbed pipe and fitting shall meet the requirement given in Table 1 when measured in accordance with Section 8.3.2.

Table 1—Pipe Requirements

Nominal Pipe Size, mm (in.)	Min Average Inside Diameter,[a] mm (in.)	Min Waterway Wall, mm (in.)	Min Pipe Impact Strength, J(ft-lbf)	Min Pipe Stiffness, kPa (psi)
100 (4)	100.0 (3.9)	0.56 (0.022)	108 (80)	318 (46)
150 (6)	149.7 (5.9)	0.64 (0.025)	108 (80)	318 (46)
200 (8)	199.7 (7.9)	0.89 (0.035)	136 (100)	318 (46)
250 (10)	249.6 (9.8)	1.14 (0.044)	136 (100)	318 (46)
300 (12)	296.8 (11.7)	1.52 (0.06)	136 (100)	318 (46)
375 (15)	363.3 (14.3)	1.90 (0.07)	136 (100)	262 (38)
450 (18)	444.8 (17.5)	2.16 (0.08)	136 (100)	221 (32)
525 (21)	524.7 (20.7)	2.54 (0.10)	136 (100)	193 (28)
600 (24)	594.7 (23.4)	2.92 (0.11)	136 (100)	165 (24)
675 (27)	669.8 (26.4)	3.18 (0.12)	136 (100)	152 (22)
750 (30)	746.4 (29.4)	3.43 (0.14)	163 (120)	131 (19)
900 (36)	898.4 (35.4)	3.94 (0.15)	163 (120)	110 (16)
1050 (42)	1050.9 (41.4)	4.32 (0.17)	163 (120)	97 (14)
1200 (48)	1202.9 (47.4)	4.83 (0.19)	163 (120)	83 (12)

[a] Tolerance on inside diameter shall be +2 percent of nominal pipe size, but not to exceed 13 mm (0.5 in.).

7.2.3. *Bell Wall Thickness*—In the case of belled pipe and fittings fabricated from pipe sections, the thickness of the wall in the bell shall be considered satisfactory if it was formed from pipe meeting the requirements in Table 1. For reducing fittings or those with smaller inlets, the minimum wall thickness for each inlet shall be no less than the minimum wall thickness for that size pipe.

Note 2—Due to the present state of technology in the industry, some fittings are fabricated fittings. Fabricated fittings made from pipe meeting the requirements of the pipe specification should be acceptable providing that the joints are adequately lapped or reinforced. Unreinforced mitered joints should not be used. Laying lengths of fittings should be in accordance with manufacturer's requirements.

7.3. *Pipe Flattening*—There shall be no evidence of splitting, cracking, breaking, or separation of ribs or seams, when pipe is tested in accordance with Section 8.4, and the load on the pipe shall not decrease until the pipe inside diameter is reduced by 20 percent of its original dimension.

7.4. *Pipe Impact Strength*—The impact strength shall not be less than values shown in Table 1 when tested in accordance with Section 8.5.

Note 3—This requirement is intended only for use as a quality control test, not as a simulated service test.

7.5. *Pipe Stiffness*—The pipe shall have a minimum pipe stiffness at 5 percent deflection as listed in Table 1 when tested in accordance with Section 8.6.

Note 4—Pipe meeting the test requirements for stiffness of this specification will provide a flexibility factor not exceeding 0.54 mm/N (0.095 in/lbf) for all pipe diameters above 300 mm

(12 in.). For nominal pipe sizes 300 mm (12 in.) and smaller, the minimum pipe stiffness is 320 kPa (46 psi).

7.6. *Soiltight Joints*—Joints classified as soiltight shall meet the requirements of *AASHTO LRFD Bridge Construction Specifications*, Section 26 when measured in accordance with Section 8.8. The ratio of the D_{85} soil size to the size of the opening must be greater than 0.3 for medium to fine sand and greater than 0.2 for uniform sand.

7.7. *Watertight Joints*—Gasketed joints classified as watertight shall show no sign of leakage when tested in accordance with Section 8.9.

7.8. *Gaskets*—When a gasketed joint is used, gaskets shall meet the low head application requirements of ASTM F 477 and be molded into a circular form or extruded to the proper section and then spliced into circular form.

7.9. *Extrusion Quality*:

7.9.1. *Acetone Immersion*—The pipe shall meet the requirements as defined in ASTM D 2152 when tested in accordance with Section 8.7.1.

Note 5—This is intended only for use as a quality control test and not for use as a simulated service test.

7.9.2. *Heat reversion*—The pipe shall not exhibit any of the effects listed in the suggested interpretation of results of the ASTM Practice F1057 when tested in accordance with Section 8.7.2.

7.10. *Internal Sleeve Dimensions*—The dimensions of the internal sleeve shall be such that they provide a minimum interference to internal flow and provide a soiltight joint with the pipe. The internal sleeve shall lap a minimum of 50 mm (2 in.) on each pipe, and shall contain a device so that the sleeve is centered on the joint. (See Figure 2.)

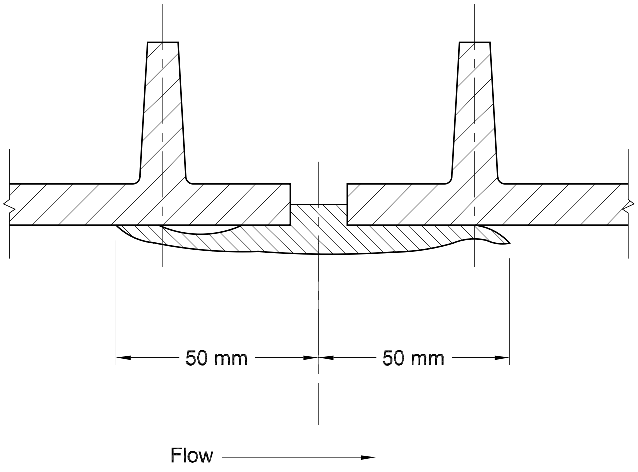


Figure 2—Typical Internal Sleeve Profile (Cross Section). (Other Configurations of Internal Sleeve Are Permissible.)

7.11. *Perforations*—Perforations, when required, shall be circular holes 5 to 10 mm (0.2 to 0.4 in.) in diameter, or slots not to exceed 3 mm (0.12 in.) in width and limited in length to 10 percent of pipe circumference or 75 mm (3 in.), whichever is less, to provide an inlet area as follows:

Pipe Size, mm (in.)	Inlet Area, Min, cm^2/m (in.^2/ft)
100 (4)	11 (0.5)
150 to 250 (6 to 10)	21 (1.0)
300 to 525 (12 to 21)	32 (1.5)
600 (24) and over	42 (2.0)

Perforations shall be arranged in rows parallel to the axis of the pipe. Perforations shall not occur within the rib structure itself but between. The rows of perforations shall be arranged in two equal groups placed symmetrically on either side of a lower unperforated segment, corresponding to the flowline of the pipe. The spacing of the rows shall be uniform. The distance between the centerlines of rows shall be not less than 25 mm (1 in.). The maximum heights (*H*) of the centerlines of the uppermost rows (or upper end of slots) above the bottom of the invert shall be 0.46*D*, and the minimum chord lengths (*L*) of the unperforated invert segment shall be 0.64*D*, where *D* equals the nominal pipe diameter. (See Figure 3.)

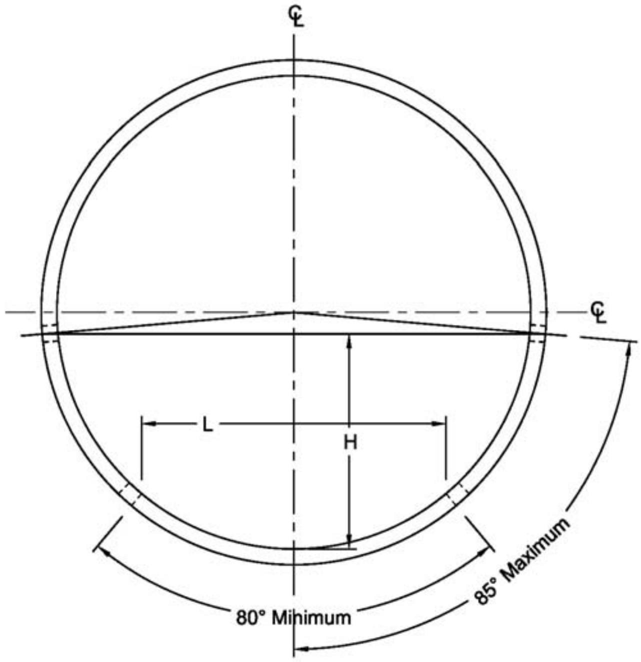


Figure 3—Requirements for Perforations

7.12. *Stub Compression Test*—Profile compression capacity in any specimen in the stub compression test T 341 shall not be less than 75 percent of the gross section area times the minimum specified yield strength when tested in accordance with Section 8.10. The stub compression test, AASHTO T 341, shall be a material and wall design qualification test conducted once a year or whenever there are changes in wall design or material distribution. Computing the minimum capacity requires determining the cross-sectional area of the pipe wall. This can be conveniently accomplished by optically scanning the profile and determining the section properties using computer drafting program.

7.13. *Manufacturer Records*—Manufacturers shall keep records of the following: (1) resin manufacturer's data sheets and certification that the base resin meets cell class requirements of the product specifications; (2) manufacturer's data sheets and quantities for all additives: (3) test results to demonstrate that if resins of two different cell classifications are blended, the resulting mixture meets the requirements of the specified cell class; (4) correlation of the resin shipment source with pipe markings.

8. TEST METHODS

8.1. *Conditioning*:

8.1.1. *Referee Testing*—When conditioning is required for referee tests, condition the specimens in accordance with Procedure A of ASTM D 618 at 23 ± 2ºC (73.5 ± 3.5°F) and 50 percent ±5 percent relative humidity for not less than 40 hours prior to test. Conduct tests under the same conditions of temperature and humidity, unless otherwise specified.

8.1.2. *Quality Control Testing*—Condition specimens for a minimum of 4 hours in air or 1 hour in water at 23 ± 2ºC (73.5 ± 3.5°F). Test the specimens at 23 ± 2ºC (73.5 ± 3.5°F) without regard to relative humidity.

8.2. *Sampling*—The selection of the samples of pipe shall be as agreed upon between the purchaser and seller. In case of no prior agreement, any sample selected by the testing laboratory shall be deemed adequate.

8.3. *Dimensions*:

8.3.1. *Inside Diameter*—Determine the average inside diameter using an internal micrometer telescoping gauge or metal rule accurate to 1 mm ($^1/_{32}$ in.). Take sufficient readings, a minimum of four, in at least two locations and determine the average diameter.

8.3.2. *Wall Thickness*—Measure the wall thickness of the waterway in the gaps between ribs in accordance with ASTM D 2122. Make sufficient readings, a minimum of eight, to ensure that the minimum thickness has been determined.

8.4. *Flattening*—Flatten three specimens of pipe, each with a length equal to one pipe diameter (but not less than 300 mm (12 in.) nor greater than 900 mm (36 in.)) between parallel plates in a suitable press until the pipe inside diameter is reduced by 60 percent of its original dimension for pipes with a measured pipe stiffness less than 318 kPa (46 psi). Pipes with a pipe stiffness of 318 kPa (46 psi) or greater shall be flattened until the pipe inside diameter is reduced by an amount determined by [3.43(OD)/(OD-ID)], expressed as a percent, where OD and ID are the measured outside and inside diameters of the pipe. Record the deflection at which the peak load occurs. The rate of loading shall be uniform and such that the compression is completed within 120 to 300 seconds. The specimen shall pass if no splitting, cracking, breaking, or separation of ribs or seams, or both, is observed under normal light with the unaided eye. Small tears initiated at the cut end of the rib shall not constitute failure.

Note 6—Small tears, observable after test, may be up to approximately 10 percent of nominal diameter in length.

8.5. *Impact Resistance*—Determine the impact resistance of the pipe in accordance with conditions and apparatus in ASTM D 2444 using Tup B and flat plate holder B. Test temperature shall be 23 ± 2ºC (73.5 ± 3.5°F). Test six specimens; all six specimens shall pass. If one specimen fails, test another six specimens. Eleven passes out of 12 tested shall be acceptable. If a rib is chipped by an indirect hit, the specimen may be replaced in the test.

8.5.1. In sizes 100 mm (4 in.) through 375 mm (15 in.), each specimen shall be 150 mm (6 in.) long. In sizes 450 mm (18 in.) and greater, each specimen shall be 300 mm (12 in.) long.

8.5.2. For 100- and 150-mm (4- and 6-in.) pipe, use a 10-kg Tup B. For larger sizes, use either a 10-kg (22-lb) or 15-kg (33-lb) Tup B.

8.5.3. Orient the specimens so the tup will strike the area between the ribs if the physical spacing is such that a clean hit can be made. Where this is not possible, orient the specimens so that one of the ribs receives the strike essentially centered on the tup face. Failure of the test specimen shall be any crack, split, shattering, or separation on ribs, body, or seam.

8.6. *Pipe Stiffness*—Determine the pipe stiffness at 5 percent deflection in accordance with ASTM D 2412, except that the crosshead speed shall be the faster of 12.7 mm per minute (0.5 in. per minute) or 2 percent of the nominal inside diameter per minute. Test three specimens, each with a length equal to one pipe diameter (but not less than 300 mm (12 in.) nor greater than 900 mm (36 in.)) and determine the average pipe stiffness.

Note 7—The 5 percent deflection criterion, which was arbitrarily selected for testing convenience, should not be considered as a limitation with respect to in-use deflection. The Engineer is responsible for establishing the acceptable deflection limit.

8.7. *Extrusion Quality*:

8.7.1. *Acetone Immersion*—Conduct this test in accordance with ASTM D 2152. This procedure is used to determine the degree of fusion of extruded PVC plastic pipe as indicated by reaction to immersion in anhydrous acetone. It is applicable only for distinguishing between unfused and properly fused PVC.

8.7.2. *Heat Reversion*—Conduct this test in accordance with ASTM Practice F 1057. This procedure is used for estimating the quality of extruded PVC plastic pipes by observing the reaction of pipe specimens after exposure to heat.

8.8. *Soiltightness*—Assemble the joint in accordance with the manufacturer’s recommendations. Using a measuring device accurate to 0.4 mm (0.016 in.), locate the maximum size opening between the pipe and jointing device by measuring the opening radially from the pipe wall. No opening may exceed 25 mm (1 in.). For openings exceeding 3 mm (0.12 in.), the length of the channel must exceed four times the size of the opening.

8.9. *Watertightness*—Conduct the internal pressure test in accordance with ASTM D 3212 using 74 kPa (10.8 psi) water pressure.

8.10. *Stub Compression Test for Finished Pipe*—Determine the stub compression capacity of the pipe section in accordance with AASHTO Test Standard T 341. Conduct four tests on specimens cut from the same ring of pipe at 90 degree intervals around the circumference.

9. RETEST AND REJECTION

9.1. *Material Failure*—Material failing to conform to the requirements of this specification may be rejected. Material may be retested to establish conformity in accordance with agreement between the purchaser and seller.

10. PRODUCT MARKING

10.1. *Pipe Marking*—Each standard and random length of pipe compliant with this specification shall be clearly marked by the producer per the following example at intervals of 1.5 m (4.9 ft) or less:

10.1.1. Manufacturer's name, trade name or trademark, and code;

10.1.2. Nominal pipe size in millimeters;

10.1.3. The PVC minimum cell classification as listed in Table 1, ASTM D 1784; for example, 12364C;

10.1.4. The legend "DRAIN PIPE"; and

10.1.5. This specification designation, AASHTO M 304.

10.2. *Fittings Marking*—The fittings in compliance with this specification shall be clearly marked per the following example:

10.2.1. Manufacturer's name or trademark and code;

10.2.2. Nominal size in millimeters;

10.2.3. The material designation "PVC" and ASTM Cell Class; and

10.2.4. This specification designation, AASHTO M 304, and manufacturer's code to include day, month, year, shift, and plant of manufacturer.

10.3. *Markings*—The markings shall be applied to the pipe in such a manner that they remain legible after installation and inspection have been completed.

10.4. *Quality Assurance*—When the product is marked with M 304, it affirms that the product was manufactured, inspected, sampled, and tested in accordance with this specification and has been found to meet the requirements of this specification.

10.4.1. *Notification*—If inspection is specified by the purchaser, the manufacturer shall notify the purchaser in advance of the date, time, and place of testing of the pipe in order that the purchaser may be represented.

10.4.2. *Access*—The inspector shall have free access to those parts of the manufacturer's plant that are involved in work performed under this specification. The manufacturer shall afford the inspector all reasonable facilities for determining whether the pipe meets the requirements of this specification.

10.5. *Certification*—When agreed upon in writing by the purchaser and the seller, a certification shall be made on the basis of acceptance of material. This shall consist of a copy of the manufacturer's test report or a statement by the seller that the material has been sampled, tested, and inspected in accordance with the provisions of this specification. Each certification, so furnished, shall be signed by an authorized agent of the seller or manufacturer.

11. DELIVERY

11.1. *Packaging*—All pipe and couplings and fittings shall, unless otherwise specified, be packaged for standard commercial shipment.

Standard Specification for

Drainage, Sewer, Utility, and Related Castings

AASHTO Designation: M 306-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Drainage, Sewer, Utility, and Related Castings

AASHTO Designation: M 306-10

1. SCOPE

1.1. This specification is applicable to frames, grates, rings, and covers for inlets, manholes, and other structures for civil engineering use where items may be placed in traffic service and load bearing is a consideration.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 105, Gray Iron Castings
- *LRFD Bridge Design Specifications*, Fifth Edition

2.2. *ASTM Standards*:

- A 48/A 48M, Standard Specification for Gray Iron Castings
- A 536, Standard Specification for Ductile Iron Castings

2.3. *Federal Specification*:

- CID A-A-60005, Frames, Covers, Gratings, Steps, Sump and Catch Basin Manhole

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *manufacturer*—a producing foundry/facility where iron is melted and poured into molds.

3.1.2. *supplier*—an agent, representative, or organization that provides castings that it did not manufacture.

3.1.3. *purchaser*—the end user of the casting.

3.2. The preceding terms and definitions are specific to this specification. ASTM A 644 contains other terms and definitions relating to gray iron castings.

4. MATERIALS

4.1. Gray Iron Castings shall conform to the requirements of M 105 Class 35B or ASTM A 48 Class 35B.

4.2. Ductile Iron Castings shall conform to the requirements of ASTM A 536 Grade 80-55-06, unless otherwise specified by the customer.

5. MANUFACTURE

5.1. Castings shall be manufactured true to pattern and component parts shall fit together in a satisfactory manner. They shall be smooth and well cleaned by shotblasting. Circular manhole frames, covers, and grates shall be furnished with machined horizontal bearing surfaces unless otherwise specified. All square and rectangular units shall be furnished with an as-cast bearing surface unless otherwise specified.

5.2. *Permissible Variations*:

5.2.1. As-cast dimensions may vary one-half the maximum shrinkage possessed by the metal or ±5.21 mm/m [$\pm^{1}/_{16}$ in./ft].

5.2.2. Mass [weight] ±5 percent drawing/specification mass [weight].

5.3. *Performance and other Requirements*:

5.3.1. The cover or grate shall not rock when rotated to any position in the frame.

5.3.2. The cover or grate shall sit down into the frame so that the top surface of the cover or grate will be flush with the top surface of the frame.

The difference in the level between the cover or grate shall not exceed 3.2 mm [$^{1}/_{8}$ in.] at any point when placed in the frame. The cover or grate shall not sit higher than 1.6 mm [$^{1}/_{16}$ in.] over more than $^{1}/_{4}$ of the circumference when placed in the frame.

5.3.3. *Welding, Plugging*—Not allowed.

5.3.4. *No Painting*—Unless specified by the customer.

5.4. *Quality and Appearance:*

5.4.1. The finished casting shall show careful finished workmanship in all particulars. Castings which have been damaged either during manufacture or shipping may be rejected. Among others, the following defects may be considered as constituting poor workmanship.

5.4.1.1. *Defects, Major (Items that may affect casting load bearing ability)*—Casting could be rejected or require proof that the defect is not injurious. Examples of such defects include: shrinkage, cracks, cold shuts, large cavities, major porosity episodes, or major sand inclusions.

5.4.1.2. *Defects, Minor (Items that may affect top surface appearance)*—Casting could be reworked and resubmitted. Examples of such defects include: dirt, scab, slag, minor surface porosity, or minor sand inclusions.

6. PROOF-LOAD TESTING

6.1. For first article inspection or when specified for quality conformance inspection, the frames and covers or gratings shall show no detrimental permanent deformation when a proof load of 178 kN [40,000 lb] is concentrated on a 229 mm by 229 mm [9 in. by 9 in.] area placed at the center of the cover or grate. To distribute the load evenly in testing, an intermediate layer of material (i.e., fiberboard, felt, rubber, etc.) can be placed between the test block and the casting to be tested. This layer shall not be larger than the area of the test block. The load shall be applied at a constant rate between 45 kg/sec and 454 kg/sec [between 100 lb/sec and 1000 lb/sec]. The castings shall be tested in a frame. If the product is not installed with a frame, or if proof-load testing in a frame is unfeasible, the cover or grate shall be supported in such a fashion as to simulate how an item would be supported following installation. The specified load shall be applied and held for a period of 1 minute by a suitable testing machine. Upon removal of the load, the cover or grating and frame shall be examined for cracks or detrimental permanent deformation. Permanent deformation shall not exceed 3.2 mm [$^1/_8$ in.]. Any cracks shall be cause for rejection. Any permanent deformation that exceeds 3.2 mm [$^1/_8$ in.] shall be cause for rejection. All testing shall occur in the United States on a testing machine calibrated in accordance with and traceable to National Institute of Standards and Technology (NIST) standards. All castings that are subjected to the proof-load test shall be destroyed.

For items that are smaller than a 229 mm by 229 mm [9 in. by 9 in.] footprint, or where a 229 mm by 229 mm [9 in. by 9 in.] footprint would transfer load directly to the frame, an alternate proof load test shall be used. For H-20 or HS-20 loading, the applied load shall be the product of 3.39 MPa [494 psi] multiplied by the area of the cover/grate, but not to exceed 178 kN [40,000 lb]. For H-25 or HS-25 loading, the applied load shall be the product of 4.23 MPa [617 psi] multiplied by the area of the cover/grate, but not to exceed 222 kN [50,000 lb]. The footprint size shall not exceed 229 mm [9 in.] in any direction and shall be smaller than the corresponding frame clear opening.

Example 1:

Given loading is H-20. Therefore, use 3.39 MPa [494 psi].

Given cover diameter is 203 mm [8 in.], which equates to a cover area of 0.0324 m^2 [50.3 in.^{2}].

Given frame has a clear opening of 152 mm [6 in.].

Therefore, the required loading is 0.0324 m^2 [50.3 in.^{2}] multiplied by 3.39 MPa [494 psi], or 110 kN [24,850 lb]. This value does not exceed the 178 kN [40,000 lb] specified in the standard; therefore, it shall be the applied load. The footprint size must be smaller than 152 mm [6 in.] in diameter for the given frame clear opening.

Example 2:

Given loading is HS-25. Therefore, use 4.23 MPa [617 psi].

Given grate size is 203 mm [8 in.] wide and 610 mm [24 in.] long, which equates to a grate area of 0.124 m^2 [192 in.^{2}].

Given frame has a clear opening of 152 mm [6 in.].

Therefore, the required loading is 0.124 m^2 [192 in.^{2}] multiplied by 4.23 MPa [617 psi], or 525 kN [118,465 lb]. This value exceeds the maximum allowed load of 222 kN [50,000 lb]. As a result, 222 kN [50,000 lb] shall be the applied load. The footprint size shall be smaller than 152 mm [6 in.] by 229 mm [9 in.]. Note that the footprint size cannot exceed 229 mm [9 in.] in any direction; consequently, even though the length is 610 mm [24 in.], the maximum value of 229 mm [9 in.] is used.

6.2. The 178-kN [40,000-lb] proof-load requirement listed in Sections 6.1 and 6.2 represents a safety factor of 2.5 for H-20 or HS-20 loading. A 222-kN [50,000-lb] proof load should be used in Sections 6.1 and 6.2, which represents a safety factor of 2.5 for H-25 or HS-25 loading.

6.3. *Precision and Bias*—No statement is made about the precision or the bias for the proof-load test method described in Sections 6.1 and 6.2 for measuring the ultimate strength of the casting. The result merely states whether there is conformance to the criteria for success specified in the procedure outlined in Sections 6.1 and 6.2.

7. MATERIAL TESTING

7.1. Test bar testing shall be conducted in accordance with the applicable inspection requirements of Section 8. Test bar preparation and tensile testing shall be in accordance with the applicable material specification listed in Section 4. Failure to meet the material specifications shall be cause for rejection.

8. INSPECTION

8.1. Unless otherwise specified in the contract or purchase order, the supplier/manufacturer shall be responsible for carrying out all the tests and inspections required by this specification, using purchaser approved reliable facilities, and he shall maintain complete records of all such tests and inspections. Such records shall be available for review by the purchaser. Three separate and alternative bases of acceptance are permitted: If the producing foundry is located within the United States of America, and operates in accordance with an acceptable Quality System approved by the purchaser, all castings must adhere to the inspection criteria listed in Sections 8.1.1 and 8.1.2. If the producing foundry is not located within the United States of America, or if the producing foundry is located within the United States of America and it is not operating in accordance with an acceptable Quality System approved by the purchaser, all castings must adhere to the inspection criteria listed in Sections 8.1.1 and 8.1.3.

8.1.1. *Acceptance on the Basis of Proof-Load Tests*—Acceptability of the castings produced in accordance with this specification shall be determined by the results of the proof-load test as listed in Sections 6.1, 6.2, and 6.3. The producing foundry shall provide information about the ultimate strength of the castings to the purchaser upon request.

8.1.2. *Acceptance on the Basis of Separately Cast Test Bar*—Before supplying any castings to a purchaser, the manufacturer must first submit to the purchaser for acceptance, documentation that a Quality System is in place to ensure material compliance. Thereafter, acceptability of the castings produced in accordance with this specification shall be by certification of the results of material tests conducted on separately cast test bars, and by inspection of the finished castings for freedom from defects. The manufacturer shall provide certification that the test bars furnished for testing represent the castings furnished for the order. If there are more than three test bar failures in one calendar year, the producing facility shall immediately report the three failing test results to the purchaser and shall discontinue supplying product. In order for the producing foundry to resume supplying product, documentation that a new Quality System is in place to ensure material compliance must be submitted to and accepted by the purchaser. The purchaser shall also have the option of allowing production under Section 8.1.3.

8.1.3. *Acceptance on the Basis of Cast-On Test Bars*—A test bar for determining the class of iron shall be cast on each member at a place where it can be easily broken off with a breakage pattern remaining on the member. Test bars are to be removed only after receipt of permission from the purchaser. Test bars shall be of sufficient size to produce a machined test specimen complying with the dimensional requirements for a Type B test bar as shown in Table 2 of M 105. For lots of

15 or fewer, 30 percent of the test bars selected at random from castings shall be tested by the supplier/manufacturer. For lots of 16 to 100, 10 percent or a minimum of 5 test bars, whichever is greater, selected at random from castings shall be tested by the supplier/manufacturer. For lots greater than 100, a minimum of 10 percent of all test bars selected at random from castings shall be tested by the supplier/manufacturer. All test bars shall conform to the strength requirements specified. If any of those test bars fail to conform to the strength requirements herein specified because of surface or internal defects, additional testing shall be performed at the direction of the purchaser. For lots of 15 or fewer, all remaining test bars must be tested. For larger lots, an additional 10 or 10 percent, whichever is greater, of the remaining test bars selected at random from the entire lot must be tested. All test results from this additional testing must conform to the strength requirements of this specification for the lot of castings to be acceptable. Each casting that has a test bar removed from it and evaluated must be inspected for mass [weight] and dimensions by the supplier/manufacturer. If the casting does not conform to the mass [weight] and dimensional requirements, the casting will be rejected. If a casting fails to conform to the mass [weight] or dimensional requirements, all remaining castings shall be inspected and all must conform to the requirements for the lot of castings to be acceptable. If the purchaser elects to select a casting for verification of test results, the member shall be furnished by the supplier/manufacturer at no cost to the purchaser. All test specimen preparation and testing shall be paid for by the supplier/manufacturer.

9. CERTIFICATION

9.1. All shipments to the purchaser shall include appropriate certification from the producing foundry. The certification shall state that the castings have been produced in facilities operating in accordance with the applicable laws and regulations of the United States and the appropriate state, province, or local unit of government. This certification shall also state that all samples representing each lot have been tested, inspected, and have been found to meet the requirements of this specification and the applicable AASHTO or ASTM material specifications listed in Section 4. Certifications shall also state country of origin of the castings. If specified in the order, a report of the test results shall be furnished.

10. MARKING

10.1. Each individual casting shall be identified by the foundry, showing the following:

10.1.1. Name of producing foundry and country of manufacture preceded by the words “Made in,” such as “Made in USA”;

10.1.2. AASHTO designation or ASTM designation number;

10.1.3. Class by a number followed by a letter indicating the minimum tensile strength and size of test bar;

10.1.4. Heat identification and cast date (MM/DD/YY);

10.1.5. Casting lettering as required by the purchaser; and

10.1.6. Markings as required to meet Federal requirements.

11. RECORDS

11.1. All test results as required by this specification shall be maintained by the producing foundry for 7 years and shall be made available to the purchaser upon request.

11.2. Records of casting certifications issued by a producing foundry shall be maintained by the producing foundry for 7 years and shall be made available upon request.

Standard Specification for

Joints for Concrete Pipe and Manholes, Using Rubber Gaskets

AASHTO Designation: M 315-07
ASTM Designation: C 443-05a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Joints for Concrete Pipe and Manholes, Using Rubber Gaskets

AASHTO Designation: M 315-07
ASTM Designation: C 443-05a

AASHTO M 315-07 is identical to ASTM C 443-05a.

Standard Specification for

Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets [Metric]

AASHTO Designation: M 315M-09
ASTM Designation: C 443M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets [Metric]

AASHTO Designation: M 315M-09
ASTM Designation: C 443M-07

AASHTO M 315M-09 is identical to ASTM C 443M-07.

Standard Specification for

Polyethylene (PE) Liner Pipe, 300- to 1600-mm Diameter, Based on Controlled Outside Diameter

AASHTO Designation: M 326-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Specification for

Polyethylene (PE) Liner Pipe, 300- to 1600-mm Diameter, Based on Controlled Outside Diameter

AASHTO Designation: M 326-08

1. SCOPE

1.1. This specification covers the requirements and methods of tests for outside diameter dimension controlled polyethylene liner pipe (PE liner pipe), jointing, and fittings for use in pipe relining and culvert rehabilitation for industrial wastes, sanitary sewer, and surface and subsurface drainage applications.

1.1.1. Nominal sizes of 300 to 1600 mm are included.

1.1.2. Materials, workmanship, dimensions, pipe stiffness, joining systems, and form of markings are specified.

1.2. This specification is intended for rehabilitation of industrial waste, sanitary sewer, and surface and subsurface drainage applications by the insertion of PE liner pipe through existing pipe. PE liner pipe is designed to minimize traffic disruption and subsurface damage, and rehabilitate existing sewers and culverts with little or no interruption in service or traffic.

Note 1—When polyethylene pipe is to be used in locations where the ends may be exposed, consideration should be given to protection of the exposed portions due to combustibility of the polyethylene and the effects of prolonged exposure to ultraviolet radiation.

1.3. For the PE liner pipe to perform properly, the annular space between existing and PE liner pipe must be filled. This specification does not include methods to fill the annular space between the existing pipe and the PE liner pipe, insertion techniques, and termination techniques. Construction and installation procedures are described in ASTM F 585, *Standard Practice for Insertion of Flexible Polyethylene Pipe into Existing Sewers.*

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- D 618, Standard Practice for Conditioning Plastics for Testing
- D 883, Standard Terminology Relating to Plastics
- D 2122, Standard Test Methods for Determining Dimensions of Thermoplastic Pipe and Fittings

- D 2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D 3212, Standard Specification for Joints for Drains and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- D 3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- F 412, Standard Terminology Relating to Plastic Piping Systems
- F 477, Standard Specification for Elastomeric Seals (Gaskets) for Jointing Plastic Pipe
- F 585, Standard Practice for Insertion of Flexible Polyethylene Pipe into Existing Sewers
- F 714, Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
- F 1473, Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins
- F 2620, Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings

3. TERMINOLOGY

3.1. The terminology used in this standard is in accordance with the definitions given in ASTM D 883 and ASTM F 412 unless otherwise specified.

3.2. *Crack*—Any break or split that extends through the wall.

3.3. *Crease*—An irrecoverable indentation, generally associated with wall buckling.

3.4. *Buckling*—Any reverse curvature or deformation in the pipe wall that reduces the load-carrying capability of the pipe. Any decrease or downward deviation in the pipe stiffness test curve shall be considered a wall buckling point.

3.5. *Polyethylene (PE) Plastics*—Plastics based on polymers made with ethylene as essentially the sole monomer (ASTM D 883).

3.6. *Reworked Plastic*—A plastic from a processor’s own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D 883).

3.7. *Virgin Polyethylene Material*—PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

4. CLASSIFICATION

4.1. The PE liner pipe covered by this specification is classified by the Standard Dimension Ratio (SDR) system. The relationship between SDR, outside diameter and minimum wall thickness is as follows:

$$SDR = \frac{D_o}{t} \qquad (1)$$

where:

SDR = Standard Dimension Ratio;

D_o = Average Outside Diameter, mm; and

t = minimum wall thickness, mm.

4.2. Standard Dimension Ratios covered by this specification are SDR 41, SDR 32.5, and SDR 26.

4.3. Where existing conditions or special requirements make other SDR classifications necessary, other sizes or dimension ratios or both shall be acceptable for engineering applications when mutually agreed upon by the customer and the manufacturer. This is provided that the pipe is manufactured from plastic compounds meeting the material requirement of this specification.

5. ORDERING INFORMATION

5.1. Orders using this specification shall include the following information as necessary to adequately describe the desired product:

5.2. AASHTO designation and year of issue;

5.2.1. Type of pipe (Section 4.2);

5.2.2. Diameter and length required, either total length or length of each piece and number of pieces;

5.2.3. Certification, if desired (Section 12.1).

6. MATERIALS

6.1. *Basic Materials*:

6.1.1. *Extruded Pipe and Fittings*—Pipe and fittings shall be made of virgin PE conforming with the requirements of cell class 345464C as defined and described in ASTM D 3350. Resins that have higher cell classifications in one or more properties are acceptable provided that product requirements are met.

6.1.2. *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE resins which conform with the requirements of cell class 213320C as defined and described in ASTM D 3350, except that the carbon black content shall not exceed 3 percent. Resins that have higher cell classifications in one or more properties are acceptable provided that product requirements are met.

6.2. *Reworked Plastic*—In lieu of virgin PE, clean reworked plastic may be used by the manufacturer, provided that it meets the cell class requirements as described in Section 6.1.

6.3. The manufacturer shall not blend resins to meet the cell classification specified in Section 6.1.1 or 6.1.2. Blending of reworked plastic and virgin plastic is allowed provided that both the reworked resin and the virgin resin meet the requirements of Section 6.1.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. The ends of the pipe shall be cut squarely and cleanly so as not to adversely affect joining or connecting. Field cuts shall be de-burred and free of defects.

7.2. *Visible Defects*—Cracks, creases, unpigmented or nonuniformly pigmented pipe are not permissible in the pipe or fittings as furnished.

7.3. *Pipe Dimensions*:

7.3.1. *Nominal Size*—The nominal size for the pipe and fittings is based on the nominal outside diameter of the pipe. Nominal diameters, outside diameters, and tolerance shall be in accordance with Table 1, when measured in accordance with Section 9.5.1.

Table 1—Outside Diameter and Tolerance

Nominal Pipe Size, mm (in.)	Outside Diameter, mm (in.)	Tolerance, ± mm (± in.)
300 (12)	323.8 (12.750)	1.5 (0.057)
325 (13)	339.7 (13.375)	1.5 (0.060)
350 (14)	355.6 (14.000)	1.6 (0.063)
400 (16)	406.4 (16.000)	1.8 (0.072)
450 (18)	457.2 (18.000)	2.1 (0.081)
500 (20)	508.0 (20.000)	2.3 (0.090)
538 (21.5)	546.1 (21.500)	2.5 (0.097)
550 (22)	558.8 (22.000)	2.5 (0.099)
600 (24)	609.6 (24.000)	2.7 (0.108)
650 (26)	660.4 (26.000)	3.0 (0.117)
700 (28)	711.2 (28.000)	3.2 (0.126)
750 (30)	762.0 (30.000)	3.4 (0.135)
800 (32)	812.5 (32.000)	3.7 (0.144)
850 (34)	863.6 (34.000)	3.9 (0.153)
900 (36)	914.4 (36.000)	4.1 (0.162)
1,050 (42)	1,066.8 (42.000)	4.8 (0.189)
1,200 (48)	1,219.2 (48.000)	5.5 (0.216)
1,350 (54)	1,371.6 (54.000)	6.2 (0.243)
1,600 (63)	1,600.2 (63.000)	7.20 (0.284)

7.3.2. *Wall Thickness*—The wall thickness shall have the minimum thicknesses in Table 2 for each standard dimension ratio, when measured in accordance with Section 9.5.3.

Table 2—Minimum Wall Thickness

Nominal Pipe Size, mm (in.)	Outside Diameter, mm (in.)	SDR 41 Wall Thickness, mm (in.)	SDR 32.5 Wall Thickness, mm (in.)	SDR 26 Wall Thickness, mm (in.)
300 (12)	323.8 (12.750)	7.9 (0.310)	10 (0.392)	12.4 (0.490)
325 (13)	339.7 (13.375)	8.2 (0.326)	10.4 (0.412)	13.1 (0.514)
350 (14)	355.6 (14.000)	8.0 (0.314)	10.9 (0.431)	13.6 (0.538)
400 (16)	406.4 (16.000)	9.9 (0.390)	12.5 (0.492)	15.6 (0.615)
450 (18)	457.2 (18.000)	11.2 (0.439)	14.1 (0.554)	17.6 (0.692)
500 (20)	508.0 (20.000)	12.4 (0.488)	15.6 (0.615)	19.5 (0.769)
538 (21.5)	546.1 (21.500)	13.3 (0.524)	16.8 (0.662)	21.0 (0.827)
550 (22)	558.8 (22.000)	13.6 (0.537)	17.2 (0.677)	23.4 (0.846)
600 (24)	609.6 (24.000)	14.9 (0.585)	18.7 (0.738)	23.4 (0.923)
650 (26)	660.4 (26.000)	16.1 (0.634)	20.3 (0.800)	25.4 (1.000)
700 (28)	711.2 (28.000)	17.4 (0.683)	21.9 (0.862)	27.4 (1.077)
750 (30)	762.0 (30.000)	18.6 (0.732)	23.4 (0.923)	29.3 (1.154)
800 (32)	812.5 (32.000)	19.8 (0.780)	25.0 (0.985)	31.3 (1.231)
850 (34)	863.6 (34.000)	21.1 (0.829)	26.6 (1.046)	33.2 (1.308)
900 (36)	914.4 (36.000)	22.3 (0.878)	28.1 (1.108)	35.2 (1.385)
1,050 (42)	1,066.8 (42.000)	26.0 (1.024)	32.8 (1.292)	41.0 (1.615)
1,200 (48)	1,219.2 (48.000)	29.7 (1.171)	37.5 (1.477)	46.9 (1.846)
1,350 (54)	1,371.6 (54.000)	33.4 (1.317)	42.2 (1.662)	52.8 (2.077)
1,600 (63)	1,600.2 (63.000)	Not Available	49.2 (1.938)	61.5 (2.423)

7.3.3. *Average Inside Diameter*—The average inside diameter (*ID*) shall be calculated as follows:

$$AvgID = \frac{OD_{\min} + OD_{\max}}{2} - 2\left(t_{\min} \times 1.06\right) \qquad (2)$$

where:

$AvgID$ = Average inside diameter, mm (in.);

OD_{min} = Minimum outside diameter from Table 1, mm (in.);

OD_{max} = Maximum outside diameter from Table 1, mm (in.); and

t_{min} = Minimum wall thickness from Table 2, mm (in.).

7.3.4. *Length*—PE liner pipe may be sold in any length agreeable to the user. The furnished length shall not be less than the shorter of 99 percent of the agreed length or 12 mm ($^{1}/_{2}$ in.), whichever is less.

7.4. *Pipe Stiffness*—The pipe shall have a minimum pipe stiffness at 5 percent deflection as follows when tested in accordance with Section 9.1. The minimum pipe stiffness shall be as follows:

41 SDR – 55.2 kPa (8 psi)

32.5 SDR – 110.3 kPa (16 psi)

26 SDR – 213.7 kPa (31 psi)

7.4.1. Pipe stiffness test for 600 mm (24 in.) and smaller diameters may be extrapolated to larger sizes of the same SDR classification, provided the manufacturer can document the following equation accurately predicts the pipe stiffness for all sizes and SDR:

$$PS = \frac{C \times E}{\left(SDR - 1\right)^3} \qquad (3)$$

where:

C = Design constant;

= 0.649 in SI units;

= 4.472 in U.S. customary units;

E = Flexural Modulus, kPa (psi); and

SDR = Standard Dimension Ratio (as defined in Section 4).

7.5. *Pipe Flattening*—There shall be no evidence of wall buckling, cracking, or splitting, when the pipe is tested in accordance with Section 9.2.

7.6. *Fitting Requirements*:

7.6.1. The fittings shall not reduce or impair the overall integrity or function of the PE liner pipe.

7.6.2. Common fittings include in-line joint fittings, reducers, and branch or complimentary assembly fittings such as tees and wyes. These fittings shall be installed or coupled to the pipe by various methods in accordance with Section 7.7.

7.6.3. All fittings shall be within an overall length dimensional tolerance ±12 mm ($^{1}/_{2}$ in.) of the manufacturer's specified dimensions when measured in accordance with Section 9.5.2.

7.6.4. Fittings shall not reduce the inside diameter of the pipe being joined by more than 12 mm ($^{1}/_{2}$ in.). Reducer fittings shall not reduce the cross-sectional area of the small size.

7.6.5. Fabricated fittings should be supplied with joints compatible with the overall system.

7.7. *Jointing Requirements*:

7.7.1. Joints shall provide sufficient longitudinal (or axial) strength to preserve pipe alignment, prevent separation at the joints, and maintain integrity while pushing or pulling pipe lengths into existing pipes or culverts. Joints shall be mechanical or male and female joint connections. Mechanical or male and female joints connections shall be an integral part of the PE liner pipe. Alternatively, the mechanical joint, male and female joints, or pipe ends may be heat fused provided that the fusion process meets the requirements of ASTM F 2620 and that the fused connection meets the requirements of Section 7 of this standard.

7.7.2. Joints shall have sufficient longitudinal or axial compression strength to withstand a maximum compressive force of 17.5 newtons per mm (100 lbs force per in.) of outside diameter circumference in compression while maintaining joint integrity when tested in accordance with Section 9.4.1.

7.7.3. Joints shall have sufficient pull apart strength to withstand a maximum tensile force of 17.5 newtons per mm (100 lbs force per in.) of outside diameter circumference in tension without joint disassembly when tested in accordance with Section 9.4.2.

7.7.4. Joints shall not reduce the inside diameter or enlarge the outside diameter of the pipe being joined by more than 6 mm ($^1/_4$ in.). When the pipe is coupled, the axis of the assembly will be level and true when tested in accordance with Section 9.4.3.

7.7.5. Other types of mechanical jointing, which are equally effective as those described and which comply with the joint performance criteria of Section 7.7, may be used when approved by the purchaser.

7.7.6. All joints shall meet the watertight joint requirements of Section 7.8 unless otherwise specified by the owner/designer.

7.8. *Watertight joints* must meet a 74 kPa (10.8 psi) laboratory test per ASTM D 3212. Mechanical coupler or male and female joint design shall use a gasket meeting ASTM F 477.

8. CONDITIONING

8.1. *Conditioning*—Unless otherwise specified, for those tests for which conditioning is required, condition the specimen for not fewer than 24 hours prior to test at 21 to 25ºC (70 to 77 ºF) in accordance with Procedure A in ASTM D 618.

8.2. *Conditions*—Conduct all tests at a laboratory temperature of 21 to 25ºC (70 to 77 ºF) unless otherwise specified herein.

9. TEST METHODS

9.1. *Pipe Stiffness*—Select a minimum of two pipe specimens and test for pipe stiffness, as described in ASTM D 2412 except the test specimens shall be a minimum of 300 mm (12 in.) in length for pipe diameters 300 to 600 mm (12 to 24 in.), and one-half diameter length for diameters greater than 600 mm (24 in.). Use the first location as a reference point for rotation and testing of the other specimen. Rotate subsequent specimen 90 degrees from the original orientation. Test each specimen in one position only. The deflection indicator shall be readable and accurate to ±0.02 mm (0.0008 in.).

Note 2—The parallel plates must exceed the length of the test specimen as specified above.

9.2. *Pipe Flattening*—Flatten the two pipe specimens from Section 9.1 until the vertical inside diameter is reduced by 20 percent. The rate of loading shall be the same as in Section 9.1. Examine the specimen with the unaided eye for cracking or splitting.

9.3. *Slow Crack Growth Resistance of Resin Compounds*—Test PE liner pipe basic resin compounds for stress crack resistance in accordance with ASTM F 1473 PENT test with a minimum time to failure of 100 hours.

9.4. *Jointing Fittings*:

9.4.1. *Joint Integrity Longitudinal Compression*—Assemble each male and female joint to the appropriate pipe in accordance with the manufacturer's recommendations. Use pipe samples at least 300 mm (12 in.) in length. Assemble a specimen at least 600 mm (24 in.) in length with the connection at the center. Load the coupled pipe lengths in axial compression at a rate not to exceed 25.4 mm (1 in.) per second until the total compressive load equals the circumference of the PE liner pipe outside diameter, measured in millimeters (inches), times 17.5 newtons (4 lb). The applied load shall be aligned with the longitudinal axis of the pipe. After 2 minutes, unload the pipe coupler assembly and inspect for damage such as splitting, cracking, tearing, or a reduction to the inside diameter of 6 mm ($^1/_4$ in.) or greater. Any damage and/or reduction to the inside diameter by 6 mm ($^1/_4$ in.) or greater is considered a failure.

9.4.2. *Joint Integrity Pull Apart*—Assemble each male and female jointing to the appropriate pipe in accordance with the manufacturer's recommendations. Use pipe samples at least 300 mm (12 in.) in length. Assemble a specimen at least 600 mm (24 in.) in length with the connection at the center. Pull heads may be heat fused to the pipe lengths. Load the coupled pipe in axial tension at a rate not to exceed 25.4 mm (1 in.) per second until the total tensile load equals the circumference of the PE liner pipe outside diameter, measured in millimeters (inches), times 17.5 newtons (4 lb). After 2 minutes, unload the pipe lengths and inspect for damage. The applied load shall be aligned with the longitudinal axis of the pipe. Damage to the pipe such as splitting, cracking, tearing, or joint separation is considered a failure.

9.4.3. *Alignment*—Assure that the assembly or joint is correct and complete. If the pipe is bent, it should be straightened prior to performing this test. Lay the assembly or joint on a flat surface and verify that it will accommodate straight-line flow.

9.5. *Dimensions*:

9.5.1. *Outside Diameter*—Measure the outside diameter of the pipe with a tapered sleeve gauge or a circumferential wrap tape in accordance with ASTM D 2122. As an alternative, measure the outside diameter with a suitable device accurate to ±3.0 mm ($^1/_8$ in.) on two sections. Take eight measurements equally spaced around the circumference of each section and average these 16 measurements. The average outside diameter shall meet the requirements of Section 7.3.1.

9.5.2. *Length*—Measure pipe with any suitable device accurate to ±6.0 mm ($^1/_4$ in.) in 3 m (10 ft). Make all measurements on the pipe while it is stress-free and at rest on a flat surface in a straight line.

9.5.3. *Wall Thickness*—Measure the wall thickness in accordance with ASTM D 2122.

10. INSPECTION AND RETEST

10.1. *Inspection*—Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

10.2. *Retest and Rejection*—If any failure to conform to these specifications occurs, the pipe or fittings may be retested to establish conformity in accordance with agreement between the purchaser and seller. Individual results, not averages, constitute failure.

10.3. *Pipe Marking*—Pipe marking may include ASTM F 714 marking. However, to ensure conformance with this specification, the PE liner pipe shall include markings described in Section 11 of this specification.

11. MARKING

11.1. All pipe shall be clearly marked at intervals of no more than 3.5 m (12 ft) as follows:

11.1.1. Manufacturer's name or trademark,

11.1.2. Nominal outside size,

11.1.3. Dimensional ratio,

11.1.4. The specification designation, AASHTO M 326,

11.1.5. The plant designation code, and

11.1.6. The date of manufacturer or an appropriate code.

11.1.6.1. If the date code is used, a temporary manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

11.2. Fittings shall be marked with a designation number of this specification, AASHTO M 326 and with the manufacturer's identification symbol.

12. QUALITY ASSURANCE

12.1. A manufacturer's certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results, and the date each test was completed, shall be furnished upon request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL/QUALITY ASSURANCE PROGRAM

X1.1. *Scope*:

X1.1.1. As required in Sections 10 and 12, the acceptance of these products relies on the adequate inspection and certification agreed to between the buyer and the seller/producer. This appendix should serve as a guide for both the manufacturer and the user. It places the responsibility on producers to control the quality of the material they produce and to provide the quality control information needed for acceptance by the buyer/user. Producers are required to perform quality control sampling, testing, and record keeping on materials they ship. It also sets forth quality assurance sampling, testing, and record keeping that should be performed by the buyer/user to confirm the performance of the producer's control plan.

X1.2. *Program Requirements*:

X1.2.1. The producing company must have a quality control plan approved by the specifying agency.

X1.2.2. The producing plant must have an approved quality control plan.

X1.2.3. The plant must have an approved laboratory, either within the company or an independent laboratory.

X1.2.4. The producing plant(s) must have a designated quality control technician.

X1.3. *Quality Control Plan*:

X1.3.1. The producer must supply to the specifying agency a written quality control plan that shows how the producer will control the equipment, materials, and production methods to ensure that the specified products are supplied. The following information must be included in the plan:

X1.3.1.1. Titles of the personnel responsible for production quality at the plant(s);

X1.3.1.2. The physical location of the plant(s);

X1.3.1.3. The methods of identification of each lot of material during manufacture, testing, storage, and shipment. The method of identification shall allow the specifying agency to trace the finished product to the material provider;

X1.3.1.4. The method of sampling and testing of raw materials and of finished product, including lot sizes and types of tests performed; and

X1.3.1.5. A plan for dealing with nonconforming product, including how the producer plans to initiate immediate investigation and how corrective action will be implemented to remedy the cause of the problem.

X1.4. *Approved Laboratory*:

X1.4.1. All tests must be conducted at laboratories approved by the specifier. Each manufacturer may establish and maintain its own laboratory for performance of quality control testing or may utilize an approved independent laboratory. Records of instrument calibration and maintenance and sample collection and analysis must be maintained at the laboratory.

X1.5. *Quality Control Technician*:

X1.5.1. All samples must be taken and tested by quality control technicians designated by the producer. The designated quality control technicians will be responsible for overall quality control at the producing plant.

X1.6. *Annual Update*:

X1.6.1. An annual update may be required. The annual update may be submitted by the manufacturer to the specifying agency by December 31st of each calendar year.

X1.7. *Plant Approval*:

X1.7.1. The plant approval process requires the manufacturer to submit an annual update to the specifying agency. The update must identify the specific product manufactured at the plant.

X1.7.2. The specifying agency will review the manufacturer's written quality control plan and a plant inspection may be scheduled. This inspection will verify that the quality control plan has been implemented and is being followed and that at least one designated quality control technician is on-site and will be present when material is being produced under this program. The laboratory will be inspected and approved if it meets the requirements.

X1.8. *Sampling and Testing*:

X1.8.1. The quality assurance plan approved for each manufacturer, and/or manufacturer's location, shall detail the methods and frequency of sampling and testing for all raw materials and products purchased or manufactured at that location. All testing shall be in accordance with current specifications and procedures referenced in M 326.

X1.8.2. Samples of materials and pipe may be taken by the specifying agency.

X1.8.3. The specifying agency may require an annual third-party independent assurance test.

X1.9. *Sample Identification and Record Keeping*:

X1.9.1. Manufacturer's quality control samples are to be uniquely identified by the producing plant.

X1.9.2. Quality control and quality assurance data are to be retained by the manufacturer for 2 years and made available to the specifying agency upon request.

X1.9.3. Quality control test reports shall include the lot identification.

X1.9.4. Unless requested at the time of ordering, test reports do not have to be filed for specific projects.

X1.9.5. Reports shall indicate the action taken to resolve nonconforming product.

Standard Specification for

Sewer and Manhole Brick (Made from Clay or Shale)

AASHTO Designation: M 91-10
ASTM Designation: C 32-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Sewer and Manhole Brick (Made from Clay or Shale)

AASHTO Designation: M 91-10
ASTM Designation: C 32-09

AASHTO M 91-10 is identical to ASTM C 32-09 except that all references to ASTM C 67 contained in ASTM C 32-09 shall be replaced with T 32.

Standard Specification for

Building Brick (Solid Masonry Units Made from Clay or Shale)

AASHTO Designation: M 114-10
ASTM Designation: C 62-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Building Brick (Solid Masonry Units Made from Clay or Shale)

AASHTO Designation: M 114-10
ASTM Designation: C 62-08

AASHTO M 114-10 is identical to ASTM C 62-08.

Standard Specification for

Liquid Membrane-Forming Compounds for Curing Concrete

AASHTO Designation: M 148-05
ASTM Designation: C 309-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Liquid Membrane-Forming Compounds for Curing Concrete

AASHTO Designation: M 148-05
ASTM Designation: C 309-03

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM C 309-03 for the information formerly contained in this standard.

Standard Specification for

Air-Entraining Admixtures for Concrete

AASHTO Designation: M 154-06
ASTM Designation: C 260-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Air-Entraining Admixtures for Concrete

AASHTO Designation: M 154-06
ASTM Designation: C 260-01

AASHTO M 154-06 is identical to ASTM C 260-01 except for the following provision:

1. All references to the ASTM Standards contained in ASTM C 260-01 listed in the following table shall be replaced with the corresponding AASHTO Standard.

Referenced Standards

ASTM	AASHTO
C 183	T 127
C 185	T 137
C 233	T 157

2. Section 8.1 of ASTM C 260-01 shall be replaced with the following:

   8.1 Determine the properties enumerated in Section 6 in accordance with Test Method C 233. It is recommended that, whenever practicable, tests be made in accordance with the section on Materials for Tests for Specific Uses in Test Method C 233, using the cementitious materials proposed for the specific work.

3. Table 1 Physical Requirements of ASTM C 260-01 shall be revised to include compressive strength and flexural strength at 56 days with the same requirements as listed for 28 days. The 56-days requirements shall be applicable only when specified by the purchaser.

Standard Specification for

Ready-Mixed Concrete

AASHTO Designation: M 157-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Ready-Mixed Concrete

AASHTO Designation: M 157-06

1. SCOPE

1.1. This specification covers ready-mixed concrete manufactured and delivered to a purchaser in a freshly mixed and unhardened state as hereinafter specified. Requirements for quality of concrete shall be either as hereinafter specified or as specified by the purchaser. In any case where the requirements of the purchaser differ from those in this specification, the purchaser's specification shall govern. This specification does not cover the placement, consolidation, curing, or protection of the concrete after delivery to the purchaser.

1.2. The values stated in SI units are the preferred standard. The values given in parentheses are for information only.

1.3. As used throughout this specification the manufacturer shall be the contractor, subcontractor, supplier, or producer who furnishes the ready-mixed concrete. The purchaser shall be the specifying agency and designated representatives thereof. The engineer shall be interpreted to mean the designated representative of the specifying agency.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 154, Air-Entraining Admixtures for Concrete
- M 194M/M 194, Chemical Admixtures for Concrete
- M 195, Lightweight Aggregates for Structural Concrete
- M 240, Blended Hydraulic Cement
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- M 307, Silica Fume Used in Cementitious Mixtures
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 26, Quality of Water to Be Used in Concrete
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

2.2. *ASTM Standards*:

- C 567, Standard Test Method for Determining Density of Structural Lightweight Concrete
- C 1157, Standard Performance Specification for Hydraulic Cement

2.3. *American Concrete Institute Standards*:

- 211.1, Standard Practice for Selecting Proportions for Normal and Heavyweight and Mass Concrete
- 211.2, Standard Practice for Selecting Proportions for Structural Lightweight Concrete
- 305R, Hot Weather Concreting
- 306R, Cold Weather Concreting

3. DEFINITIONS

3.1. For the purpose of this specification, ready-mixed concrete is hydraulic cement concrete manufactured for delivery to a purchaser in a plastic state and delivered as hereinafter specified.

3.2. The volume of freshly mixed and unhardened concrete in a given batch shall be determined from the total mass of the batch divided by the actual mass per cubic foot of the concrete. The total mass of the batch shall be calculated either as the sum of the masses of all materials, including water, entering the batch or as the net mass of the concrete in the batch as delivered. The mass per cubic foot shall be determined in accordance with T 121M/T 121 from the average of at least three measurements, each on a different sample using a 14 L ($^1/_2$-ft^3) container. Each sample shall be taken from the midpoint of each of three different truck loads by the procedure outlined in T 142.

Note 1—It should be understood that the volume of hardened concrete may be, or appear to be, less than expected due to waste and spillage, overexcavation, spreading forms, some loss of entrained air, or settlement of wet mixtures.

4. MATERIALS

4.1. Storage and facilities satisfactory to the engineer shall be provided at the batching plant to permit proper sampling, testing, and control of materials prior to and during use. The following specifications shall apply:

4.1.1. *Cement*—Cement shall conform to M 85 for hydraulic cement, M 240 for blended hydraulic cement, or ASTM C 1157 for blended hydraulic cement. The engineer shall specify the type or types required. If no type is specified, the requirements of Type 1 as specified in M 85 shall apply. These different cements will produce concrete of different properties and should not be used interchangeably. Cement from different sources shall not be used interchangeably without approval of the engineer.

4.1.2. *Other Cementitious Materials*—Cementitious materials other than cement shall meet the requirement of the following specification unless specified otherwise by the purchaser:

- Fly Ash—M 295
- Ground Granulated Blast Furnace Slag—M 302
- Silica Fume—M 307

4.1.3. *Aggregates*—Coarse aggregates shall conform to M 80. Fine aggregates shall conform to M 6. Lightweight aggregates shall conform to M 195.

4.1.4. *Water*—Water shall be clear and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substance. It shall not be salty or brackish. It shall be tested in accordance with T 26. Water of questionable quality shall be subject to the acceptance criteria of Tables 1 and 2 or as designated by the purchaser.

Table 1—Acceptance Criteria for Questionable Water Supplies

	Limits	Test Method
Compressive strength, min percent control at 7 days	90	T 106[a]
Time of set, deviation from control	From 1:00 earlier to 1:30 later	T 131[a]

[a] Comparison shall be based on fixed proportions and the same volume of test water compared to control mix using water or distilled water.

Table 2—Chemical Limitations for Wash Water

	Limits	Test Method
Chemical requirements, maximum concentration		
Chloride as $C1^{[-1]}$ expressed as a percent by weight of cement when added to the $C1^{[-1]}$ in the other components of the concrete mixture shall not exceed the following levels:		
1. Prestressed concrete	0.06 percent	T 260
2. Conventionally reinforced concrete in a moist environment and exposed to chloride	0.10 percent	
3. Conventionally reinforced concrete in a moist environment but not exposed to chloride	0.15 percent	
4. Above ground building construction where the concrete will stay dry	No limit for corrosion	
Sulfate as SO_4 ppm[a]	3000	ASTM D 516
Alkalis as (Na_2O + 0.658 K_2O), ppm	600	ASTM D 4191, D 4192
Totals, solids, ppm	50000	T 26

[a] Wash water reused as mixing water in concrete may exceed listed concentrations of sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregate and other sources, does not exceed the stated limits.

4.1.4.1. Wash water from mixer washout may be used only with the purchaser's approval. When wash water is permitted, the producer will provide satisfactory proof or data of nondetrimental effects if potentially reactive aggregates are to be used. Use of wash water will be discontinued if undesirable reaction with admixtures or aggregates occurs.

4.1.5. *Admixtures*—When air entrained concrete is specified and an admixture is used to secure the desired air content, the admixture shall meet the requirements of M 154. Where it is desired to use admixtures for purposes other than entrainment of air, the admixture shall conform to the requirements of M 194.

5. QUALITY OF CONCRETE

5.1. The mix design may be specified by the engineer or submitted to the engineer by the contractor for approval, or a performance based specification can be used. When specified by the engineer, it shall include the following:

5.1.1. Each cementitious materials content in kg/m^3 (lb/yd^3) of concrete, or equivalent units;

5.1.2. Designated size, or sizes, and amount by mass of aggregates;

5.1.3. Maximum water to cementitious materials ratio where water includes surface moisture and water in the admixture, but excludes the absorption water of the aggregates;

5.1.4. Consistency desired at the point of delivery (Section 6.1.1 for acceptable tolerances);

5.1.5. The range of air content of the concrete when air-entraining cement or an air-entraining admixture is specified. The air content shall be determined on samples taken at the point of placement; and

5.1.6. The type and amounts of admixture other than air-entraining agents when such admixtures are specified.

5.2. When submitted by the contractor for approval by the engineer, the mix design shall be within the limitation specified for:

5.2.1. Minimum cement content,

5.2.2. Maximum amount of water,

5.2.3. Range for air content,

5.2.4. Range for consistency, and

5.2.5. Maximum aggregate size.

5.3. When a performance-based specification is used, the engineer shall specify the desired fresh and hardened concrete properties and permit the contractor to design the mixture. The specifying agency may specify the design method to be used by the contractor. The contractor will demonstrate through trial mixtures that the mix designs will provide the specified fresh and hardened properties. Selection of slump for placement shall be the responsibility of the contractor. The contractor shall make trial placements to demonstrate that concrete can be placed without any segregation, and without any difficulty in consolidating and finishing.

6. TOLERANCES IN SLUMP

6.1. Unless other tolerances are included in the project specifications, the following shall apply:

6.1.1. When the project specifications for slump are written as a “maximum” or “not to exceed” requirement, see Table 3. This option is to be used only if one addition of water is permitted on the job provided such addition does not increase the water-cement ratio above the maximum permitted by the specifications.

Table 3—Specified Slump

	If 76 mm (3 in.) or Less	If More Than 76 mm (3 in.)
Plus tolerance	0	0
Minus tolerance	38 mm ($1^1/_2$ in.)	63 mm ($2^1/_2$ in.)

6.1.2. When the project specifications for slump are not written as a “maximum” or “not to exceed” requirement, see Table 4.

Table 4—Tolerances for Nominal Slumps

For Specified Slump of—	Tolerance
51 mm (2 in.) and less	13 mm (± $^1/_2$ in.)
More than 51 to 102 mm (2 through 4 in.)	25 mm (± 1 in.)
More than 102 mm (4 in.)	38 mm (± $1^1/_2$ in.)

7. AIR-ENTRAINED CONCRETE

7.1. The purchaser shall specify or approve the design total air content of the concrete.

7.2. The air content of air-entrained concrete when sampled from the transportation unit at the point of placement shall be within the purchaser specified tolerances. Where it is not practical to test at this point, comparison of values measured at the point of placement and the nearest practical location shall be established.

8. MEASURING MATERIALS

8.1. Except as otherwise specifically permitted, cement shall be measured by mass. When fly ash or other cementitious materials are specified in the mix design, they may be weighed cumulatively with cement. Cement and other cementitious material shall be weighed on a scale and in a weigh hopper, which is separate and distinct from those used for other materials. Cement shall be weighed before other cementitious material. When the quantity of cement exceeds 30 percent of the full capacity of the scale, the quantity of cement, and the cumulative quantity of cement plus other cementitious material, shall be within ±1 percent of the required mass For small batches to a minimum of 1 m^3 (1 yd^3), the quantity of cement, and the quantity of cement plus other cementitious material, used shall not be less than the required amount nor more than 4 percent in excess. Under special circumstances, approved by the purchaser, cement may be measured in bags of standard mass (Note 2). No fraction of a bag of cement shall be used unless weighed.

Note 2—In the United States the standard mass of a bag of portland cement is 42.6 kg (94 lb) ±3 percent.

8.2. Aggregate shall be measured by mass. Batch mass shall be based on dry materials and shall be required mass of dry materials plus the total mass of moisture (both absorbed and surface) contained in the aggregate. The quantity of aggregate used in any batch of concrete as indicated by the scale shall be within ±2 percent of the required mass when weighed in individual weigh batchers. In a cumulative aggregate weigh batcher, the cumulative mass after each successive weighing shall be within ±1 percent of the required cumulative amount when the scale is used in excess of 30 percent of its capacity. For cumulative mass for less than 30 percent of scale capacity, the tolerance shall be ±0.3 percent of scale capacity or ±3 percent of the required cumulative mass, whichever is less.

8.3. Mixing water shall consist of water added to the batch, ice added to the batch, water occurring as surface moisture on the aggregates, and water introduced in the form of admixtures. The added water shall be measured by mass or volume to an accuracy of 1 percent of the required total mixing water. Added ice shall be measured by weight. In the case of truck mixers, any wash water retained in the drum for use in the next batch of concrete shall be accurately measured; if this proves impractical or impossible, the wash water shall be discharged prior to loading the next batch of concrete. Total water (including any wash water) shall be measured or weighed to an accuracy of ±3 percent of the specified total amount.

8.4. Powdered admixtures shall be measured by weight, and paste or liquid admixtures by weight or volume. Accuracy of weighing admixtures shall be within ±3 percent of the required weight. Volumetric measurement shall be within an accuracy of ±3 percent of the total amount required or plus and minus the volume of dose required for one sack of cement, whichever is greater.

Note 3—Admixture dispensers of the mechanical type capable of adjustment for variation of dosage, and of simple calibration, are recommended.

9. BATCHING PLANT

9.1. Bins with adequate separate compartments shall be provided in the batching plant for fine and for each required size of coarse aggregate. Each bin compartment shall be designed and operated so as to discharge efficiently and freely, with minimum segregation, into the weighing hopper. Means of control shall be provided so that, as the quantity desired in the weighing hopper is approached, the material may be shut off with precision. Weighing hoppers shall be constructed so as to eliminate accumulations of tare materials and to discharge fully.

9.2. Indicating devices shall be in full view and near enough to be read accurately by the operator while charging the hopper. The operators shall have convenient access to all controls.

9.3. Scales in use shall be accurate when static load tested to ±0.4 percent of the total capacity of the scale.

9.4. Scales for batching concrete ingredients may be either beam or springless dial scales and shall conform to the applicable sections of the current edition of the *National Bureau of Standards Handbook 44, Specifications, Tolerances, and other Technical Requirements for Commercial Weighing and Measuring Devices*,[1] except as may be otherwise specified. Methods for weighing (electric, hydraulic, load cells, etc.) other than beam or springless dial scales that meet the above weighing tolerances are also acceptable.

9.5. Adequate standard test masses shall be available for checking accuracy. All exposed fulcrums, clevises, and similar working parts of scales shall be kept clean. Beam scales shall be equipped with a balance indicator sensitive enough to show movement when a mass equal to 0.1 percent of the nominal capacity of the scale is placed in the batch hopper. Pointer travel shall be a minimum of 5 percent of the net-rated capacity of the largest weigh beam for underweight and 4 percent for overweight.

9.6. The device for the measurement of the added water shall be capable of delivering to the batch the quantity required within the accuracy required in Section 8.3. The device shall be so arranged that the measurements will not be affected by variable pressure in the water supply line. Measuring tanks shall be equipped with outside taps and valves to provide for checking their calibration unless other means are provided for readily and accurately determining the amount of water in the tank.

Note 4—The scale accuracy limitations of the National Ready Mixed Concrete Association Plant Certification meet the requirements of M 157.

10. MIXERS AND AGITATORS

10.1. Mixers may be stationary mixers or truck mixers. Agitators may be truck mixers or truck agitators.

10.1.1. Stationary mixers shall be equipped with a metal plate or plates on which are plainly marked the mixing speed of the drum or paddles and the maximum capacity in terms of the volume of mixed concrete. When used for the complete mixing of concrete, stationary mixers shall be equipped with an acceptable timing device that will not permit that batch to be discharged until the specified mixing time has elapsed.

10.1.2. Each truck mixer or agitator shall have attached thereto in a prominent place a metal plate or plates on which are plainly marked the gross volume of the drum, the capacity of the drum or container in terms of the volume of mixed concrete, and the minimum and maximum mixing speeds of rotation of the drum, blades, or paddles. When the concrete is truck-mixed as described in Section 11.1.3, or shrink mixed as described in Section 11.1.2, the volume of mixed concrete shall not exceed 63 percent of the total volume of the drum or container. When the concrete is central mixed as described in Section 11.1.1, the volume of concrete in the truck mixer or agitator shall not exceed 80 percent of the total volume of the drum or container. Truck mixers and agitators shall be equipped with means by which the number of revolutions of the drum, blades, or paddles may be readily verified.

10.2. All stationary and truck mixers shall be capable of combining the ingredients of the concrete within the specified time or number of revolutions specified in Section 10.5, into a thoroughly mixed and uniform mass and of discharging the concrete so that no less than five of the six requirements shown in Table 5 shall have been met.

Table 5—Requirements for Uniformity of Concrete

Test Requirement Expressed as Maximum Permissible Difference in Results of Tests of Samples Taken from Two Locations in the Concrete Batch	
Mass per cubic meter (mass per cubic foot) calculated to an air-free basis, kg/m^3 (lb/ft^3)	16 (1.0)
Air content, volume percent of concrete	1.0
Slump:	
If average slump is 102 mm (4 in.) or less, mm (in.)	25 (1.0)
If average slump is 102 to 152 mm (4 to 6 in.), mm (in.)	38 (1.5)
Coarse aggregate content, portion by mass of each sample retained on No. 4 (4.75-mm) sieve, percent	6.0
Unit weight of air-free mortar[a] based on average for all comparative samples tested, percent	1.6
Average compressive strength at 7 days for each sample,[b] based on average strength of all comparative test specimens, percent	7.5[c]

[a] "Test for Variability of Constituents in Concrete." Designation 26, *Bureau of Reclamation Concrete Manual*, 7th Edition. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[b] No fewer than three cylinders will be molded and tested from each of the samples.

[c] Tentative approval of the mixer may be granted pending results of the 7-day compressive strength tests.

Note 5—The sequence or method of charging the mixer will have an important effect on the uniformity of the concrete.

10.3. The agitator shall be capable of maintaining the mixed concrete in a thoroughly mixed and uniform mass and of discharging the concrete with a satisfactory degree of uniformity as defined by Annex A.

10.4. Slump tests of individual samples taken after discharge of approximately 15 percent and 85 percent of the load may be made for a quick check of the probable degree of uniformity (Note 6). These two samples shall be obtained within an elapsed time of not more than 15 minutes. If these slumps differ more than that specified in Annex A, the mixer or agitator shall not be used unless the condition is corrected, except as provided in Section 10.5.

Note 6—No samples should be taken before 10 percent or after 90 percent of the batch has been discharged. Due to the difficulty of determining the actual quantity of concrete discharged, the intent is to provide samples that are representative of widely separated portions, but not the beginning and end of the load.

10.5. Use of the equipment may be permitted when operation with a longer mixing time, a smaller load, or a more efficient charging sequence will permit the requirements of Annex A to be met.

10.6. Mixers and agitators shall be examined or weighed routinely as frequently as necessary to detect changes in condition due to accumulations of hardened concrete or mortar and examined to detect wear of blades. When such changes are extensive enough to affect the mixer performance, the proof-tests described in Annex A shall be performed to show whether the correction of deficiencies is required.

11. MIXING AND DELIVERY

11.1. Ready-mixed concrete shall be mixed and delivered to the point designated by the purchaser by means of one of the following combinations of operations:

11.1.1. Central-mixed concrete,

11.1.2. Shrink-mixed concrete, and

11.1.3. Truck-mixed concrete.

11.2. Mixers and agitators shall be operated within the limits of capacity and speed of rotation designated by the manufacturer of the equipment.

11.3. *Central-Mixed Concrete*—Concrete that is mixed completely in a stationary mixer and transported to the point of delivery either in a truck agitator, or a truck mixer operating at agitating speed, or in nonagitating equipment approved by the purchaser and meeting the requirements of Section 12, shall conform to the following: the mixing time shall be counted from the time all the solid materials are in the drum. The batch shall be so charged into the mixer that some water will enter in advance of the cement and aggregate, and all water shall be in the drum by the end of the first one-fourth of the specified mixing time.

11.3.1. Where no mixer performance tests are made, the acceptable mixing time for mixers having capacities of 0.76 m^3 (1 yd^3) or less shall be not less than 1 minute. For mixers of greater capacity, this minimum shall be increased 15 seconds for each cubic yard or fraction thereof of additional capacity.

Note 7—HPC mixtures—especially those with stiff consistency having high cementitious material content, low water-cementitious material ratio, and several admixtures—may need longer mixing times and a higher number of revolutions for thorough mixing.

11.3.2. Where mixer performance tests have been made on given concrete mixtures in accordance with the testing program set forth in the following paragraphs, and the mixers have been charged to their rated capacity, the acceptable mixing time may be reduced from those particular circumstances to a point at which satisfactory mixing defined in Section 11.3.3 shall have been accomplished. When the mixing time is so reduced, the maximum time of mixing shall not exceed this reduced time by more than 60 seconds for air-entrained concrete.

11.3.3. *Sampling for Uniformity Tests of Stationary Mixers*—Samples of concrete for comparative purposes shall be obtained immediately after arbitrarily designated mixing times, in accordance with one of the following procedures:

11.3.3.1. *Alternative Procedure 1*—The mixer shall be stopped, and the required samples removed by any suitable means from the concrete at approximately equal distances from the front and back of the drum, or

11.3.3.2. *Alternative Procedure 2*—As the mixer is being emptied, individual samples shall be taken after discharge of approximately 15 percent and 85 percent of the load. Any appropriate method of sampling may be used, provided the samples are representative of widely separated portions, but not the very ends of the batch (Note 6).

11.3.3.3. The samples of concrete shall be tested in accordance with Section 17, and differences in test results for the two samples shall not exceed those given in Annex A. Mixer performance tests shall be repeated whenever the appearance of the concrete or the coarse aggregate content of samples selected as outlined in this section indicates that adequate mixing has not been accomplished.

11.4. *Shrink-Mixed Concrete*—Concrete that is partially mixed in a stationary mixer, and then mixed completely in a truck mixer, shall conform to the following: the time of partial mixing shall be the minimum required to intermingle the ingredients. After transfer to a truck mixer the amount of mixing at the designated mixing speed will be that necessary to meet the requirements for uniformity of concrete as indicated in Annex A. Tests to confirm such performance may be made in accordance with Sections 11.3.3 and 11.3.3.3. Additional turning of the mixer, if any, shall be at a designated agitating speed.

11.5. *Truck-Mixed Concrete*—Concrete that is completely mixed in a truck mixer, 70 to 100 revolutions at the mixing speed designated by the manufacturer to produce the uniformity of concrete indicated in Annex A. Concrete uniformity tests may be made in accordance with Section 11.5.1 and if requirements for uniformity of concrete indicated in Annex A are not met with 100 revolutions of mixing, after all ingredients, including water, are in the drum, that mixer shall not be used until the condition is corrected, except as provided in Section 10.5. When satisfactory performance is found in one truck mixer, the performance of mixers of substantially the same design and condition of blades may be regarded as satisfactory. Additional revolutions of the mixer beyond the number found to produce the required uniformity of concrete shall be at a designated agitating speed. (Also see Note 7.)

11.5.1. *Sampling for Uniformity of Concrete Produced in Truck Mixers*—The samples shall be secured from the concrete discharged at the normal operating rate for the mixer being tested, with care being exercised not to obstruct or retard the discharge. Approximately 0.1 m^3 (2 ft^3 approximately) shall be taken after discharge of approximately 15 percent and 85 percent of the load (Note 6). These samples shall be obtained within an elapsed time of not more than 15 minutes. The samples shall be secured and shall be kept separate to represent specific points in the batch rather than combined to form a composite sample. Between samples, where necessary to maintain slump, the mixer may be turned in mixing direction at agitating speed. During sampling, the receptacle shall receive the full discharge of the chute. Sufficient personnel must be available to perform the required tests promptly. Segregation during sampling and handling must be avoided. Each sample shall be remixed the minimum amount to ensure uniformity before specimens are molded for a particular test.

11.6. When a truck mixer or truck agitator is used for transporting concrete that has been completely mixed in a stationary mixer, the truck mixer or agitator shall be agitated continuously during transport at the speed designated by the manufacturer of the equipment as agitating speed.

11.7. When a truck mixer or agitator is approved for mixing or delivery of concrete, no water from the truck water system or elsewhere shall be added after the initial introduction of mixing water for the batch except when, on arrival at the job site, the slump of the concrete is less than that specified. Such additional water to bring the slump within required limits shall be injected into the mixer under such pressure and direction of flow that the requirements for uniformity specified in Annex A are met. The drum or blades shall be turned an additional 30 revolutions or more if necessary, at mixing speed, until the uniformity of the concrete is within these limits. Water shall not be added to the batch at any later time. Discharge of the concrete shall be completed within $1^{1}/_{2}$ hours or before the drum has revolved 300 revolutions, whichever comes first, after the introduction of the mixing water to the cement and aggregates or the introduction of the cement to the aggregates. These limitations may be waived by the purchaser if the concrete is of such slump after the $1^{1}/_{2}$-hours time or the 300-revolutions limit has been reached that it can be placed without the addition of water to the batch. In hot weather, or under conditions contributing to quick stiffening of the concrete, a time less than $1^{1}/_{2}$ hours may be specified by the purchaser.

11.8. Concrete delivered in cold weather shall have the applicable minimum temperature indicated in Table 6.

Table 6—Minimum Concrete Temperature

	As Delivered Concrete Temperature	
Air Temperature, °C	Thin Sections and Unformed Slabs, °C	Heavy Sections and Mass Concrete, °C
–1 to 7	16	10
–18 to –1	18	13
Below –18	21	16
°F	°F	°F
30 to 45	60	50
0 to 30	65	55
Below 0	70	60

The maximum temperature of concrete produced with heated aggregates, heated water, or both, shall at no time during its production or transportation exceed 32ºC (90ºF).

Note 8—When hot water is used, rapid stiffening may occur if hot water is brought in direct contact with the cement. Additional information on cold weather concreting is contained in ACI 306R.

11.9. Every effort should be made to maintain the temperature of the concrete produced during hot weather as low as practicable. In some situations, difficulty may be encountered when concrete temperatures approach 32ºC (90ºF).

Note 9—Additional information is contained in ACI 305R.

12. USE OF NON-AGITATING EQUIPMENT

12.1. Central-mixed concrete may be transported in suitable nonagitating equipment approved by the purchaser. The proportions of the concrete shall be approved by the purchaser and the following limitations shall apply:

12.1.1. Bodies of nonagitating equipment shall be smooth, watertight, metal containers equipped with gates that will permit control of the discharge of the concrete. Covers shall be provided for protection against the weather when required by the purchaser.

12.1.2. The concrete shall be delivered to the site of the work in a thoroughly mixed and uniform mass and discharged with a satisfactory degree of uniformity as prescribed in Annex A.

12.1.3. Slump tests of individual samples taken after discharge of approximately 15 percent and 85 percent of the load may be made for a quick check of the probable degree of uniformity (Note 6). These two samples shall be obtained within an elapsed time of not more than 15 minutes. If these slumps differ more than that specified in Table 5, the nonagitating equipment shall not be used unless the conditions are corrected as provided in Section 12.5.

12.1.4. If the requirements of Annex A are not met when the nonagitating equipment is operated for the maximum time of haul, and with the concrete mixed the minimum time, the equipment may still be used when operated using shorter hauls, or longer mixing times, or combinations thereof that will result in the requirements of Annex A being met.

13. INSPECTION

13.1. Proper facilities shall be provided for the engineer to inspect ingredients and process used in the manufacture and delivery of the concrete. The manufacturer shall, without charge, afford the inspector representing the engineer all reasonable facilities for securing samples to determine whether the concrete is being furnished in accordance with this inspection.

14. INSPECTION OF FRESH CONCRETE AND SAMPLING

14.1. The contractor shall afford the engineer all reasonable access, without charge, for the procurement of samples of fresh concrete at time of placement to determine conformance of it to this specification.

14.2. Samples of concrete shall be obtained in accordance with T 142, except when taken to determine uniformity of slump within any one batch or load of concrete (Sections 10.4, 11.3.3, 11.5.1, and 12.4).

15. SLUMP, AIR CONTENT, AND DENSITY

15.1. Slump, air-content, and density tests shall be made at the time of placement at the option of the engineer as often as is necessary for control checks and acceptance purposes, and always when strength specimens are made.

15.2. If the measured slump, air content, or density falls outside the specified limits, a check test shall be made immediately on another portion of the same sample. In the event of a second failure, the concrete shall be considered to have failed the requirements of the specification. Density shall be required for lightweight concretes and is recommended for normal weight concretes.

16. BATCH TICKET INFORMATION

16.1. The manufacturer of the concrete shall furnish to the purchaser with each batch of concrete before unloading at the site a delivery ticket on which is printed, stamped, or written information concerning said concrete as follows:

16.1.1. Name of ready-mix batch plant,

16.1.2. Serial number of ticket,

16.1.3. Date,

16.1.4. Truck number,

16.1.5. Name of purchaser,

16.1.6. Specific designation of job (name and location),

16.1.7. Specific class or designation of the concrete in conformance with that employed in job specifications,

16.1.8. Amount of concrete in cubic yards (or cubic meters),

16.1.9. Time loaded or of first mixing of cement and aggregates, and

16.1.10. Water added by receiver of concrete and his initials.

16.2. Additional information for certification purposes as designated by the purchaser and required by the job specifications shall be furnished when requested; such information may include the following:

16.2.1. Reading of revolution counter at the first addition of water;

16.2.2. Type and brand, and amount of cement;

16.2.3. Type and brand, and amount of admixtures;

16.2.4. Information necessary to calculate the total mixing water added by the producer. Total mixing water includes free water on the aggregates, water, and ice batched at the plant, and water added by the truck operator from the mixer tank;

16.2.5. Maximum size of aggregate;

16.2.6. Mass of fine and coarse aggregate;

16.2.7. Ingredients certified as being previously approved; and

16.2.8. Signature or initials of ready-mix representative.

17. METHODS OF SAMPLING AND TESTING

17.1. Test ready-mixed concrete in accordance with the following methods:

17.1.1. *Compression Test Specimens*—T 23, using standard moist curing in accordance with Sections 9.1 and 9.2 of T 23.

17.1.2. *Compression Test*—T 22.

17.1.3. *Yield, Mass per Cubic Foot*—T 121M/T 121 or ASTM C 567.

17.1.4. *Air Content*—T 121M/T 121, T 196, or T 152.

17.1.5. *Slump*—T 119M/T 119.

17.1.6. *Sampling Fresh Concrete*—T 142.

17.2. Tests made for determination of mixer performance or for acceptance of concrete shall be conducted by the specifying agency or, with specifying agency approval, by a testing laboratory meeting the requirements of ASTM E 329.

ANNEX

(Mandatory Information)

A1. CONCRETE UNIFORMITY REQUIREMENTS

A1.1. The variation within a batch as provided in Table 5 shall be determined for each property listed as the difference between the highest value and the lowest value obtained from the different portions of the same batch. For this specification the comparison will be between two samples, representing the first and the last portions of the batch being tested. Test results conforming to the limits of five of the six tests listed in Table 5 shall indicate uniform concrete within the limits of this specification.

A1.2. Coarse Aggregate Content, using the washout test, shall be computed from the following relations:

$$P = (c/b) \times 100 \qquad (1)$$

where:

P = mass percent of coarse aggregate in concrete;

c = saturated surface-dry mass in kg (lb) of aggregate retained on the No. 4 (4.75-mm) sieve, resulting from washing all material finer than this sieve from the fresh concrete; and

b = mass of sample of fresh concrete in unit weight container, kg (lb).

A1.3. Unit Weight of Air Free Mortar shall be calculated as follows:

A1.3.1. *Inch-pound units*:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{G \times 62.4} \right)} \qquad (2)$$

A1.3.2. *Metric units*:

$$M = \frac{b - c}{V - \left(\frac{V \times A}{100} + \frac{c}{1000\,G} \right)} \qquad (3)$$

where:

M = unit weight of air-free mortar, kg/m^3 (lb/ft^3);

b = mass of concrete sample in unit weight container, kg (lb);

c = saturated surface-dry mass of aggregate retained on No. 4 (4.75-mm) sieve, kg (lb);

V = volume of unit weight container, m^3 (ft^3);

A = air content of concrete, percent, measured in accordance with Section 18.1.4 on the sample being tested; and

G = specific gravity of coarse aggregate (SSD).

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[1] Available at Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Standard Specification for

Sheet Materials for Curing Concrete

AASHTO Designation: M 171-05
ASTM Designation: C 171-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Sheet Materials for Curing Concrete

AASHTO Designation: M 171-05
ASTM Designation: C 171-03

The AASHTO equivalent of this test method has been discontinued. Please refer to ASTM C 171-03 for the information formerly contained in this standard.

Standard Specification for

Burlap Cloth Made from Jute or Kenaf and Cotton Mats

AASHTO Designation: M 182-05 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Burlap Cloth Made from Jute or Kenaf and Cotton Mats

AASHTO Designation: M 182-05 (2009)

1. SCOPE, CLASSIFICATION, AND DEFINITION

1.1. *Scope*—This specification covers requirements for burlap made from jute or kenaf and cotton mats for use in curing concrete.

1.2. *Classifications*—The burlap shall be of one type and four classes [mass based on a 1016 mm (40 in.) width, as specified:

Class 1—233 g/m (7.5 oz/yd)
Class 2—248 g/m (8 oz/yd)
Class 3—310 g/m (10 oz/yd)
Class 4—372 g/m (12 oz/yd)

1.3. *Jute and Kenaf*—Jute is defined as the bast fiber obtained from various species of Corchorus. Kenaf is defined as the bast fiber obtained from Hibiscus Cannabinus.

1.4. *Cotton*—Cotton is a vegetable fiber harvested from the cotton plant. The cotton plant belongs to the genus Gossypium of the family Malvaceae.

1.5. The values stated in SI units are to be regarded as the preferred standard.

2. MATERIAL

2.1. The burlap cloth shall be made of jute or kenaf at the option of the manufacturer. It shall have a plain weave and conform to the physical requirements given in Tables 1 or 2.

Table 1—Physical Requirements (SI)

Class	Mass per Linear Meter (1016 mm Basis), g	Yarns per Meter of Warp	Yarns per Meter of Filling	Mass per Square Meter,[a] g
1	233	315 to 433 inclusive	315 to 433 inclusive	229
2	248	354 to 472 inclusive	354 to 433 inclusive	244
3	310	433 to 512 inclusive	394 to 472 inclusive	305
4	372	433 to 512 inclusive	433 to 512 inclusive	366

[a] A plus or minus tolerance of five percent will be permitted.

Table 2—Physical Requirements (inch-pound)

Class	Weight per Linear Yard (40-Inch Basis), Ounces	Yarns per Inch of Warp	Yarns per Inch of Filling	Weight per Square Yard[a]
1	$7^1/_2$	8 to 11, inclusive	8 to 11, inclusive	6.7
2	8	9 to 12, inclusive	9 to 11, inclusive	7.2
3	10	11 to 13, inclusive	10 to 12, inclusive	9.0
4	12	11 to 13, inclusive	11 to 13, inclusive	10.8

[a] A plus or minus tolerance of five percent will be permitted.

2.2. Unless otherwise specified, the burlap shall have minimum width of 1016 mm (40 in.) inclusive of selvage, and shall be in one continuous piece of not less than 23 m (25 yd).

2.3. The selvages shall be firm and straight, and may contain cotton yarn.

2.4. Cotton mats shall consist of a filling material of cotton "bat" or "bats" of at least 400 g/m^2 (12 oz per yd^2); covered with unsized cloth at a minimum of 200 g/m^2 (6 oz per yd^2); tufted or stitched to maintain stability.

3. FREEDOM FROM DEFECTS

3.1. The burlap and cotton mats shall be clean, evenly woven, and shall conform to the quality and product requirements established by this specification. The occurrence of defects shall not exceed the applicable acceptable quality levels.

3.2. Examine the burlap and cotton mats for visual defects that would impair their suitability for use. Cuts, tears, broken or missing yarns, thin, open, or weak places, uneven weaving, and grease spots or stains shall be noted.

4. SAMPLING AND TESTING

4.1. *Lot*—Unless otherwise specified, cloths and cotton mats of the same class presented at one time shall be considered a lot for purposes of inspection and tests.

4.2. *Sampling for Test*—Unless otherwise specified, take random samples of cloth and cotton mats from each inspection lot in accordance with Table 3.

4.3. *Inspection*—Each of the samples selected in accordance with Table 3, or as specified, shall be visually and dimensionally inspected in accordance with the requirements of Sections 3.1 and 3.2.

Table 3—Sampling for Inspection and Tests

Number of Rolls in Lot	Number of Rolls in Sample[a]	Acceptance Number (Defective)	Rejection Number (Defective)
8 and under	2	0	1
9 to 15	3	0	1
16 to 40	4	0	1
41 and over	5	0	1

[a] One unit of product at least 1 m (1 yd) long and the full width of the cloth shall be taken from each sample roll.

4.4. *Tests*—Samples selected for tests in accordance with Table 3, or as otherwise specified, shall be tested to determine compliance with the requirements given in Tables 1 or 2.

5. BASIS FOR REJECTION

5.1. Any unit of product in the sample failing to conform to the requirements shall be considered defective. If the number of defective units of products in the sample for test exceeds the acceptance number for that sample specified in Table 3, the entire lot of cloth from which the sample was taken shall be considered as having failed to meet the requirements of this specification and may be rejected.

6. PACKING

6.1. Pack the burlap cloth and cotton mats in a manner acceptable to common carriers for safe transportation to point of destination specified in shipping instructions at the lowest transportation rate for such supplies.

6.2. Each roll or cotton mat shall have a ticket attached to the selvage at the inner end of the cloth or cotton mat giving the length and width, and name and address of the manufacturer.

Standard Specification for

Chemical Admixtures for Concrete

AASHTO Designation: M 194M/M 194-06
ASTM Designation: C 494/C 494M-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Chemical Admixtures for Concrete

AASHTO Designation: M 194M/M 194-06
ASTM Designation: C 494/C 494M-05

AASHTO M 194M/M 194-06 agrees with ASTM C 494/C 494M-05 except for the following provisions:

1. All references to ASTM Standards contained in ASTM C 494/C 494M-05 listed in the following table shall be replaced with the corresponding AASHTO Standard.

Referenced Standards

ASTM	AASHTO
C 33	M 43
C 39	T 22
C 78	T 97
C 136	T 27
C 138	T 121M/T 121
C 143	T 119M/T 119
C 150	M 85
C 157	T 160
C 183	T 127
C 192	R 39
C 231	T 152
C 260	M 154
C 403	T 197M/T 197
C 666	T 161

2. Table 1 Physical Requirements of ASTM C 494/C 494M-05 shall be revised to include compressive strength and flexural strength at 56 days with the same requirements as listed for 28 days. The 56-day requirements shall be applicable only when specified by the purchaser.
3. The first word in the last sentence of Paragraph 15.1 of ASTM C 494/C 494M-05 has been modified to “As” in lieu of “If.”

Standard Specification for

Molds for Forming Concrete Test Cylinders Vertically

AASHTO Designation: M 205M/M 205-08
ASTM Designation: C 470/C 470M-02a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Molds for Forming Concrete Test Cylinders Vertically

AASHTO Designation: M 205M/M 205-08
ASTM Designation: C 470/C 470M-02a

AASHTO M 205M/M 205-08 is identical to ASTM C 470/C 470M-02a except for the following provisions:

1. All references to the ASTM Standards contained in ASTM C 470/C 470M-02a listed in the following table shall be replaced with the corresponding AASHTO Standard.

Referenced Standards

ASTM	AASHTO
C 31	T 23
C 33	M 43
C 192	R 39

2. Section 5.1 of ASTM C 470/C 470M-02a shall be replaced with the following:

   5.1 Single use molds may be made of sheet metal, plastic, or other materials and must conform to the requirements of this specification. Paper molds shall not be used.

3. Add new sections to ASTM C 470/C 470M-02a containing the following:

   5.3.4 *Top Cap*. Molds shall be provided with tightly fitting plastic caps to maintain the circular shape at the top of the cylinder and to provide a clearance above the finished concrete surface.

   5.5.5 *Top Cap*. Molds shall be provided with tightly fitting metal caps to maintain the circular shape at the top of the cylinder and to provide a clearance above the finished concrete surface.

4. All references to paper molds in sections 5.4, 5.4.1, 5.4.2, and 5.4.3 shall be considered null.

Standard Specification for

Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

AASHTO Designation: M 210-10[1]
ASTM Designation: C 490-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete

AASHTO Designation: M 210-10[1]
ASTM Designation: C 490-08

1. SCOPE

1.1. This practice covers the requirements for the apparatus and equipment used to prepare specimens for the determination of length change in hardened cement paste, mortar, and concrete; the apparatus and equipment used for the determination of these length changes; and the procedures for its use.

1.2. Methods for the preparation and curing of test specimens, conditions of testing and curing, and detailed procedures for calculating and reporting test results are contained in applicable test methods.

1.3. The values stated in either SI units or inch-pound units are to be regarded separately as the standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4. Values in SI units shall be obtained by measurement in SI units or by appropriate conversion, using the Rules for Conversion and Rounding given in IEEE/ASTM SI 10, of measurements made in other units.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

2.2. *ASTM Standard*:

- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *length change*—an increase or decrease in the linear dimension of a test specimen, measured along the longitudinal axis, due to causes other than applied load.

4. SIGNIFICANCE AND USE

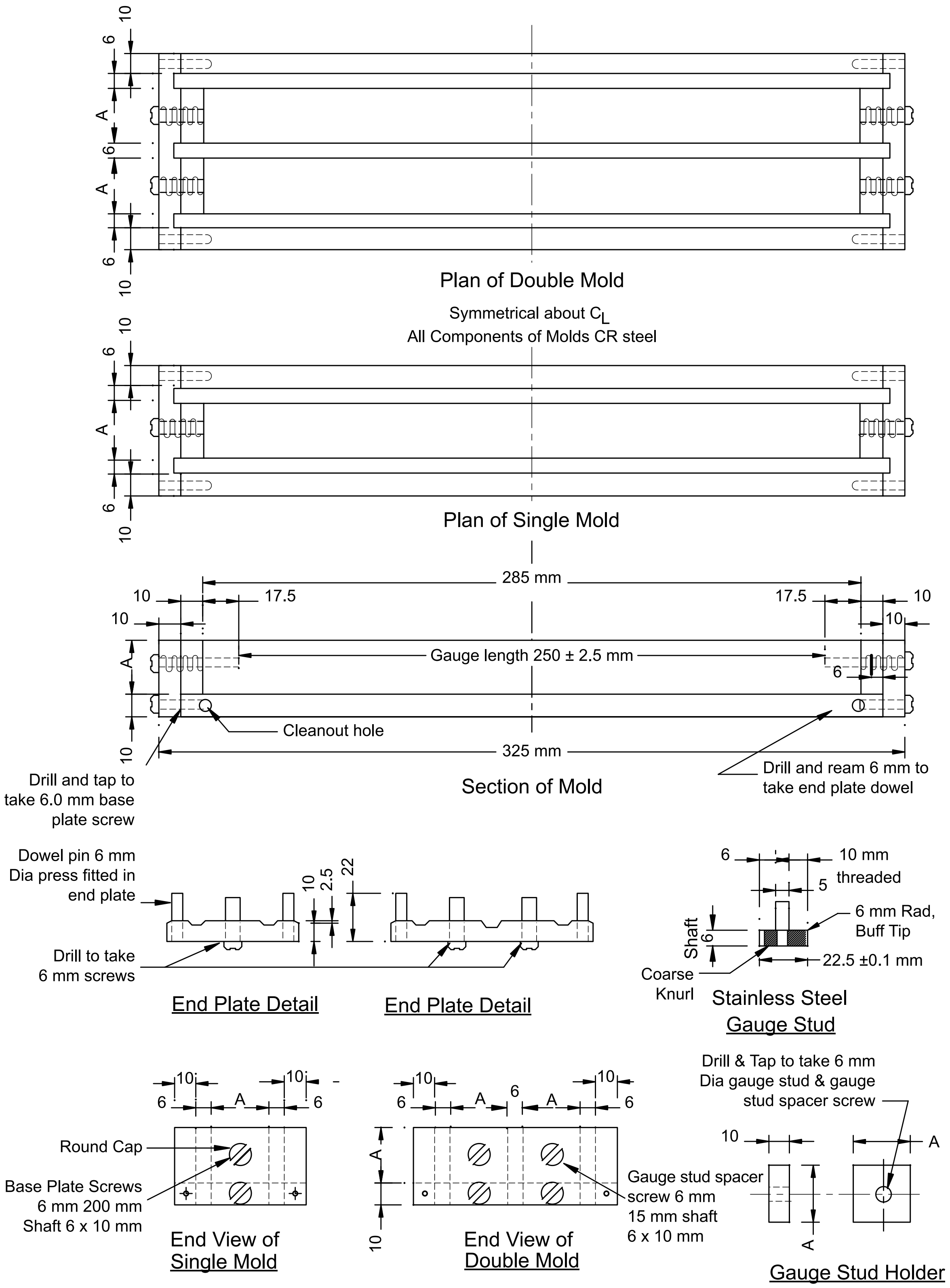
4.1. This practice is intended to provide standard requirements for apparatus common to many test methods used in connection with cement and concrete and standardized procedures for its use. The detailed requirements as to materials, mixtures, specimens, conditioning of specimens, number of specimens, ages at which measurements are to be made, interpretation of results, and precision and bias are left to be dealt with in specific test methods.

5. APPARATUS

5.1. *Reference Masses and Devices for Determining Mass and Volume* shall conform to the requirements of ASTM C 1005.

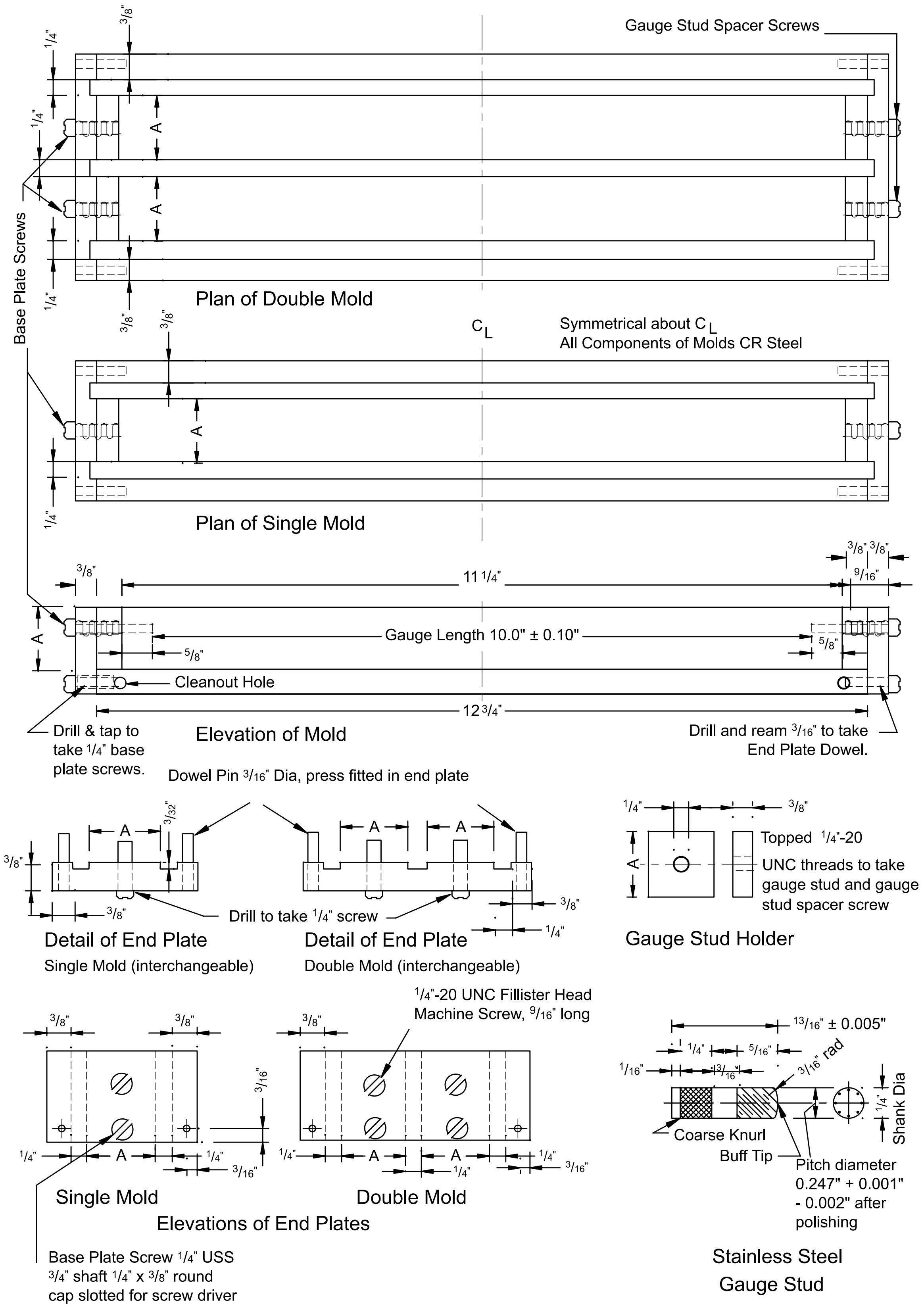
5.2. *Molds* shall have either one or two compartments and shall be constructed as shown in Figures 1 or 2. Molds for test specimens used in determining the length change of cement pastes and mortars shall provide for 25 by 25 by 285-mm prisms having a 250-mm gauge length, or for 1 by 1 by $11^1/_4$-in. prisms having a 10-in. gauge length. Molds for test specimens used in the length change of concretes shall provide for prisms of the desired cross section having a 250-mm or 10-in. gauge length. In some routine tests, 25 by 25 by 160-mm specimens with a gauge length of 125 mm or 1 by 1 by $6^1/_4$-in. specimens with a gauge length of 5 in. are permitted, but in case of dispute, results obtained with specimens of 250-mm (10-in.) gauge length shall govern.

5.2.1. The gauge length shall be considered as the nominal length between the innermost ends of the gauge studs. The parts of the molds shall be tight fitting and firmly held together when assembled, and their surfaces shall be smooth and free of pits. The molds shall be made of steel or other hard metal not readily attacked by the cement paste, mortar, or concrete. The sides of the molds shall be sufficiently rigid to prevent spreading or warping. For the molds shown in Figure 1, the tolerance on dimension A is ±0.7 mm. For the molds shown in Figure 2, the tolerance on dimension A is ±0.03 in.



Note:
1. All dimensions shown in millimeters unless otherwise noted.
2. Dimension "A" to be specified by purchaser.

Figure 1—Molds (SI Units)



Note: Dimension "A" to be specified by purchaser.

Figure 2—Molds (Inch-Pound Units)

5.2.2. Each end plate of the mold shall be equipped to hold properly in place, during the setting period, one of the gauge studs shown in Figures 1 or 2. The gauge studs shall be of American Iron and Steel Institute (AISI)[2] Type 316 stainless steel or other corrosion-resistant metal of similar hardness. Gauge studs of Invar or similar metal shall be used when specimens are tested at widely different temperatures. To prevent restraint of the gauge studs before demolding of the specimen, the device for holding the gauge studs in position shall be so arranged that, if necessary, it can be partially or completely released after the compaction of the paste or mortar into place in the mold. The gauge studs shall be set so that their principal axes coincide with the principal axis of the test specimen. For the molds shown in Figure 1, gauge studs shall extend into the specimen 17.5 ± 0.5 mm and the distance between the inner ends of the gauge studs shall be 250.0 ± 2.5 mm and 250 mm shall be considered the gauge length for calculating length change. For the molds shown in Figure 2, gauge studs shall extend into the specimen 0.625 ± 0.025 in. and the distance between the inner ends of the gauge studs shall be 10.00 ± 0.10 in. and 10 in. shall be considered the gauge length for calculating length change.

5.3. *Length Comparator*, for determining length change of specimens, shall be designed to accommodate the size of specimen employed and to provide or permit a positive means of contact with the gauge studs and the convenient and rapid obtaining of comparator readings (Note 1).

5.3.1. The comparator for determining length changes of specimens produced in the molds shown in Figure 1 shall provide a dial micrometer or other measuring device graduated to read in 0.002-mm units or less, accurate within 0.002 mm in any 0.020-mm range, and within 0.004 mm in any 0.200-mm range, and sufficient range (at least 8.0 mm) in the measuring device to allow for small variations in the actual length of various specimens. The terminals of the comparator shall be plane, polished, and heat-treated. They shall be fitted with collars held in place with set screws. The collars shall extend 1.5 ± 0.1 mm beyond the plane face of the terminal. The collars shall allow free rotation of the gauge stud tips that fit inside the collars and have an inside diameter no more than 0.5 mm larger than the average diameter of that portion of the gauge stud tips that fit into the collars.

5.3.2. The comparator for determining length changes of specimens produced in the molds shown in Figure 2 shall provide a dial micrometer or other measuring device graduated to read in 0.0001-in. units, accurate within 0.0001 in. in any 0.0010-in. range, and within 0.0002 in. in any 0.0100-in. range, and sufficient range (at least 0.3 in.) in the measuring device to allow for small variations in the actual length of various specimens. The terminals of the comparator shall be plane, polished and heat-treated. They shall be fitted with collars held in place with set screws. The collars shall extend 0.062 ± 0.003 in. beyond the plane face of the terminal. The collars shall allow free rotation of the gauge stud tips that fit inside the collars and have an inside diameter no more than 0.02 in. greater than the average diameter of that portion of the gauge stud tips that fit into the collars.

5.3.3. The design shall provide a means for checking the measuring device against a reference bar at regular intervals. The reference bar shall have an overall length of 295.0 ± 3.0 mm or 170.0 ± 3.0 mm ($11^5/_8 \pm {}^1/_8$ in. or $6^5/_8 \pm {}^1/_8$ in.), whichever is appropriate for the specimen in use. The bar shall be of a steel alloy having a coefficient of thermal expansion not greater than two millionths per degree Celsius. Each end of the reference bar shall be fitted with heat-treated, hardened, and polished tips machined to the same shape as the contact end of the gauge studs used in test specimens. Except for the tips, which are attached after heat treatment, no part of the reference bar shall be heat treated. The central 100 mm (4 in.) of the length of the reference bar shall be covered by a rubber tube with a wall at least 3 mm (${}^1/_8$ in.) thick to minimize the effect of temperature change during handling. The reference bar shall be provided near one end with a positioning mark.

Note 1—One type of instrument that has been found satisfactory for use with small prisms is shown in Figure 3. A horizontal comparator should be used with prisms with a cross section greater than 58 cm^2 (9 $in.^2$).

Note 2—Alloys such as Invar lose their low coefficient of thermal expansion properties when heat treated.

5.4. Check and document the bar mold dimension, gauge stud projection into the mold interior, length comparator, and length measuring device for conformance to the design and dimensional requirements of this specification at least every 2 $^1/_2$ years.

Figure 3—Type of Suitable Apparatus for Measurement of Length Changes

6. PROCEDURE

6.1. *Preparation of Molds*—Prior to the molding of specimens, the outside joints of the mold and the contact lines of the molds and base plate shall be sealed to prevent loss of mixing water from a freshly molded specimen. Thinly cover the interior surfaces of the mold with mineral oil. After this operation, set the gauge studs, taking care to keep them clean and free of oil, grease, and foreign matter.

6.2. *Use of Reference Bar*—Place the reference bar in the instrument in the same position each time a comparator reading is taken. Check the dial gauge setting of the measuring device by use of the reference bar at least at the beginning and end of the readings made within a half day when the apparatus is kept in a room maintained at constant temperature. Check it more often when kept in a room where the temperature is not constant.

Note 3—The equation given in the section on calculation of length change contemplates that a comparator reading for the reference bar will be recorded each time the reference bar is used and a difference calculated for each test specimen reading. Alternatively, the dial gauge setting can be reset, if necessary, to its original setting with the reference bar in place each time the reference bar is read. Doing so simplifies the calculation of length change by canceling the comparator reading of the reference bar from the values of L_x and L_i. If this procedure is used, care should be taken to ensure that the dial set screw is tightened adequately each time the dial is reset.

6.3. *Obtaining Comparator Readings*—Rotate specimens slowly in the measuring instrument while the comparator reading is being taken. Record the minimum reading of the dial if the rotation causes a change in the dial reading. Place specimens in the instrument with the same end up each time a comparator reading is taken.

6.3.1. *Obtaining Comparator Readings of Specimens Stored Moist*—Clean the hole in the base of the comparator into which the gauge stud on the lower end of the bar fits. (This hole tends to collect water and sand and should be cleaned after every reading.) Read and record the comparator indication of the length of the reference bar. Take one bar out of immersion, blot the pins, put the bar in the comparator, read, and record the indication. Return the bar to immersion and clean the hole in the base of the comparator. Take out the second bar and treat it in a like manner. Return the second bar to immersion, record the reading, and clean the hole in the base of the comparator. Continue the procedure until all bars have been read, returned to immersion, and the readings recorded, cleaning the hole in the bottom of the comparator each time. After reading the last bar, clean the hole in the comparator base and read and record the reference-bar indication. Blot only around the pins (Note 4).

Note 4—The purpose of the minimal blotting of the pins and no blotting of the bars is to avoid drying and shrinkage of the bars. It has been observed that if the pins are blotted, and the bar placed in the comparator and the dial read, and the bar is then wiped gently with a dry cloth, the bar will shrink measurably. Therefore, drying should be minimized.

7. CALCULATION OF LENGTH CHANGE

7.1. Calculate the length change at any age as follows:

$$L = \frac{(L_x - L_i)}{G} \times 100 \qquad (1)$$

where:

L = change in length at x age, percent,

L_x = comparator reading of specimen at x age minus comparator reading of reference bar at x age, in inches when using Figure 2 apparatus, in millimeters when using Figure 1 apparatus,

L_i = initial comparator reading of specimen minus comparator reading of reference bar at that same time, in inches when using Figure 2 apparatus, in millimeters when using Figure 1 apparatus, and

G = nominal gauge length, 10 in. when using Figure 2 apparatus, 250 mm when using Figure 1 apparatus.

7.2. Calculate length change values for each specimen to the nearest 0.001 percent and report averages to the nearest 0.01 percent.

8. TEMPERATURE, HUMIDITY, AND TIME

8.1. *Molding Room*—The temperature of the molding room and dry materials shall be maintained between 23.0 ± 4°C. The relative humidity shall be not less than 50 percent. The temperature of the mixing water shall not vary from 23.0 ± 2.0°C.

8.2. *Moist Storage Facility*—The temperature and humidity of the air in the moist storage facility shall conform to the requirements of M 201.

8.3. *Time*—Comparator readings shall be taken at specified time intervals or ages. All intervals and ages shall be met within ±2 percent.

9. KEYWORDS

9.1. Cement paste; comparator; concrete; length change apparatus; molds; mortar.

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[1] Except for the use of SI units, this method agrees with ASTM C 490-08.

[2] Details on this material are available from the American Iron and Steel Institute, 1133 15th St. N.W., Washington, DC 20005.

Standard Specification for

Use of Protective Sealers for Portland Cement Concrete

AASHTO Designation: M 224-91 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Use of Protective Sealers for Portland Cement Concrete

AASHTO Designation: M 224-91 (2009)

1. SCOPE

1.1. This guide includes the selection factors for and use of protective sealers for highway purposes to be applied to hardened concrete for the purpose of protecting new concrete or prolonging the life of sound, in-service concrete. Information in this guide is not applicable to the repair of badly deteriorated concrete.

1.2. Sealers may be divided into two basic types: coatings, which remain on the surface; and penetrants, which penetrate into the concrete to some measurable depth.

1.3. There are strong differences of opinion about the effectiveness and durability of some types of sealers under actual service and conditions as opposed to laboratory tests which may show the sealers to be effective. It must also be understood that there can be considerable differences in performance of material from different manufacturers for the same type of sealer.

1.4. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 200, Epoxy Protective Coatings
- M 233, Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete

2.2. *ASTM Standard*:

- D 490, Standard Specification for Road Tar

2.3. *Other Reports*:

- Pfeifer, D. W. and M. J. Scali, 1981, *Concrete Sealers for Protection of Bridge Structures*, National Cooperative Highway Research Program Report 244, 138 pp.
- Munshi, Snehal and Leonid Millstein, 1984, *Low Cost Bridge Deck Surface Treatment*, Federal Highway Administration Report No. FHWA/RD-84/001, 70 pp.

3. SELECTION OF THE SEALER

3.1. A number of factors must be carefully considered when choosing a sealer. These factors include the following:

3.1.1. *Purpose*—Will the sealer be used to waterproof the concrete or prevent the ingress of chlorides? A given sealer may be better suited to one or the other of these purposes.

3.1.2. *Effectiveness*—Coatings should form an impervious membrane tightly bonded to the concrete surface, while penetrants should seal the surface pores and fill the capillaries of the concrete. Sealers should maintain their protective properties through wide temperature fluctuations and when subject to all chemical and physical conditions at the site of use.

3.1.3. *Economy*—It is desirable that the chosen sealer be low in initial cost; however, this should not take precedence over life-cycle costs, that is, cost should include consideration of frequency of reapplication necessary to maintain effectiveness.

3.1.4. *Traffic*—Sealers on traveled surfaces must not reduce the frictional properties of the concrete; some types may, with the use of a cover aggregate, increase the frictional properties. Coatings must be resistant to traffic wear; penetrants should be evaluated according to depth of penetration, since they will wear away with the concrete. If an overlay will be placed after sealer application, wear will not be a factor.

3.1.5. *Application and Curing*—Ease and simplicity of application without the use of special skills or equipment is desirable, but not critical. It is usually advantageous for a material to cure or dry in a few hours so that neither damage by rain nor lengthy closure of the facility is necessary.

3.1.6. *Color*—If color of the treated concrete is important, test blocks should be treated with candidate materials for evaluation prior to use.

3.1.7. *Safety*—Safety should be carefully considered. Several of the materials involve toxic or hazardous components. Others may have to be heated. Refer to Section 7 for details.

3.1.8. *Adverse Conditions*—Rarely, it may be necessary to apply the sealer under adverse conditions such as low ambient temperatures or dampness. In these cases, a coating must be chosen that would offer some chance for reasonable success. Experience and the manufacturer’s recommendations should be used in determining whether or not conditions are suitable for application.

4. SEALER TYPES

4.1. Sealers commonly used for concrete are two general types: (1) coatings—those that remain on the surface and tend to build up a layer or membrane of some thickness, and (2) penetrants—those that penetrate the concrete, forming an interior or subsurface barrier. As an aid in the choice of a material suitable for a specific application, the more commonly used sealers are discussed in Sections 4.2 through 4.9.

4.1.1. *References*—additional sources of information regarding sealers are:

4.1.1.1. *AASHTO Standards*—M 200 and M 233.

4.1.1.2. *ASTM Standard*—D 490.

4.1.1.3. *Other Reports*—National Cooperative Highway Research Program Report 244 and Federal Highway Administration Report No. FHWA/RD-84/001.

4.2. *Epoxy Resin*—Epoxy may be considered a coating or penetrant depending on the percent of solids in the formulation. The two component epoxy resin system forms a sealer which is tough, hard, and resistant to chemicals that normally attack roadway surfaces and weathering. Before curing, epoxy has a tendency to "pin-hole," permitting later entrance of water and salt solution into the underlying concrete. Experience indicates the use of suitable primer may alleviate this. Also, application of the material during that part of the day when the concrete is cooling helps prevent "pin-holing." If formulated as a coating, flaking or peeling of the epoxy can occur due to a difference in thermal expansion of the coating and the concrete or to improper surface preparation. The protective film formed by these materials reduces frictional properties. The use of a suitable aggregate spread over the freshly applied coating greatly improves frictional properties. Epoxy systems require skill in handling and application. It is essential that the recommendations of the manufacturer be followed precisely for both application procedures and equipment. Special materials will be required for cleaning of equipment. Most persons are allergic to contact with epoxies. Therefore, recommended safety practices must be followed carefully.

4.3. *Coal Tar Epoxy*—Coal tar resins form surface coatings that are hard and durable. They are relatively resistant to many corrosive and abrasive environments and are durable under exposure to weather. They appear to function best on roadway surfaces when filled with sand and other suitable aggregate. These materials contain curing agents and strong solvents which may cause allergic reactions. They must be handled with caution; recommended safety precautions must be followed. These materials are naturally dark to black in color and may not be desirable in some locations.

4.4. *Linseed Oil*—Linseed oil applied to concrete surfaces penetrates and forms a partial barrier to water. It is, therefore, not subject to traffic abrasion and it does not materially change the original frictional properties of the concrete if applied at the proper rate. Linseed oil may be applied as solution. Experience indicates the solutions are more effective and longer lasting than are emulsions, probably due to redispersion of the linseed oil applied as an emulsion, when subjected to salt solutions. These materials are easily applied with simple, readily available equipment and require no specialized knowledge or skills. Safety hazards are minimal; only routine precautions for handling and using flammable liquids are necessary with the solvent types. For best results on new concrete surfaces, the concrete should be allowed to dry for about 30 days prior to the application of the compound. To remain effective, concrete surfaces should be recoated annually for 2 years followed by a bi-annual or tri-annual schedule of treatment.

4.5. *Tar Primer and Seal*—Tars applied to concrete surfaces form a coating that is an effective surface barrier to water. Usually a primer must be used because of wetting difficulties on concrete. These materials may be applied in solution or softened by heat. Due to relatively poor resistance to sunlight, weather, and abrasion, these materials should be covered by a suitable bituminous mix.

4.6. *Silanes and Siloxanes*—These materials are classified as penetrants. Unlike other sealers, these materials do not truly "seal" the concrete, but react chemically with the concrete, both at the surface and in pores and capillaries, to form a hydrophobic layer which is repellant to water. They can be applied in one coat.

4.7. *Methacrylates*—These materials may be described as a coating or penetrant depending on the formulation. Two coats are usually required to get proper sealing. The surface to be treated must be dry and free of oil, grease, and loose material. Time needed between coats will vary according to ambient temperature conditions.

4.8. *Sodium Silicate*—This material is a penetrant in the form of an aqueous solution. Concrete surfaces must be clean and dry at the time of application. The material should not be applied at temperatures below 4ºC (40ºF) or during rain.

4.9. *Urethane*—This material is classified as a penetrant or a coating depending on formulation. Two coats may be required. The concrete surface should be free of loose material, clean, and dry. Some formulations should not be applied under high humidity conditions. (See manufacturer's recommendation.)

5. SURFACE PREPARATION

5.1. Surfaces to which the sealers are applied may be new concrete or concrete which has been in service for some time.

5.2. Preparation of the surfaces will vary according to the type of sealer being used. In all cases, the surfaces should be clean and free of all dirt, dust, and loose material. Old surfaces should have any oil or paint removed. The required degree of dryness of the concrete will vary accordingly to the material being used, and the manufacturer's literature should be consulted for this and other specific surface requirements.

6. SEALER PREPARATION AND APPLICATION

6.1. For best results, manufacturer's recommendations should be followed in preparing and applying sealers for concrete. Common practices for the different materials follow:

6.1.1. *Epoxy Resins and Coal Tar Epoxy*—All materials should be within applicable temperature ranges before mixing. Thorough mixing of the components in the specified proportions is essential. No more should be mixed than will be used within the pot life of the materials. Small-batch mixing can best be done in clean, dry pails or disposable containers using a mechanical stirrer, although with care, hand mixing is acceptable. For large jobs, specialized continuous mixing equipment is available and should be used.

6.1.1.1. Application on small areas can readily be made by brush, roller, squeegee, hand sprayer, or other means. Power spray equipment is most satisfactory for covering large areas.

6.1.1.2. For most materials, the temperature of the concrete surface should be not less than 15ºC (60ºF). A satisfactory temperature range for the compound at application is 21 to 32ºC (70 to 90ºF).

6.1.1.3. Equipment used in application must be cleaned using solvent wash before setting of the epoxy. The solvent recommended by the manufacturer of the epoxy is best but the others may be satisfactory, such as toluene, trichloroethylene, etc. Use appropriate safety precautions when using these solvents.

6.1.2. *Linseed Oil*—Application of linseed oil may be readily accomplished by brush, squeegee, roller, hand sprayer, or power sprayer. The concrete surface should be dry and at a temperature of not less than 10ºC (50ºF) at the time of application. The rate of application should be specified. Two approximately equal applications are best with a 24-hour minimum drying time between applications. Cleaning of tools and equipment is easily accomplished by use of kerosene or other petroleum solvents.

6.1.3. *Tars*—These materials may be applied by power or hand spray, by brush, or by squeegee. The concrete surface to be treated should be dry and clean. The prime coat should be permitted to dry thoroughly before applying succeeding coats. Depending on the grade of tar selected, temperature of application will vary to provide the proper viscosity for application.

6.1.4. *Silanes and Siloxanes*—These materials should not be applied at temperatures below 0ºC (32ºF) or when the temperature is expected to fall below 0ºC (32ºF) within 12 hours of application. These materials appear to penetrate best on a thoroughly dry surface. Application rate should range between 2.45 and 9.82 m^2/L (100 and 400 ft^2/gallon) depending on surface texture and absorption. The recommended method of application may vary depending on the material. The manufacturer's recommendations should always be followed. The most common method of application is low pressure airless spray and most sealers require enough material to sufficiently saturate the surface of the concrete.

6.1.5. *Methacrylates*—Depending on the formulation, these materials should not be applied when the temperature is below 10ºC (50ºF). A primer is required for some formulations. The concrete surface must be dry. Application rates range from 2.45 to 9.82 m^2/L (100 to 400 ft^2/gallon). Sealers should be applied as the manufacturer recommends. Common methods of application include spray, roller, brush, and squeegee.

6.1.6. *Sodium Silicate*—This material should not be applied at temperatures below 4ºC (40ºF). It may be applied by brush, squeegee, or spraying. After three to six hours, the surface should be flushed with water, the flushing to be repeated at 24-hour intervals for 72 hours. The coverage rate is 4.91 to 7.36 m^2/L (200 to 300 ft^2/gal).

6.1.7. *Urethane*—This material can be applied in the temperature range of 4 to 38ºC (40 to 100ºF) with some formulations having an allowable application temperature as low as –8ºC (18ºF). The surface should be free of moisture. Coverage is in the range of 4.91 to 9.82 m^2/L (200 to 400 ft^2/gal). Sealers are best applied with either air atomized or conventional airless spray—although brush, roller, or squeegee may be used. Manufacturer's recommendations should be followed.

7. SAFETY

7.1. The usual precautions exercised in the working environment should be followed. All waste solvents shall be disposed of in accordance with all applicable federal, state, and local environmental regulations.

7.2. General hazards and cautions for each sealer type are given in Sections 7.2.1 through 7.2.7. See manufacturer's literature for information on specific formulations.

7.2.1. *Epoxy Resins and Coal Tar Epoxy*—These materials almost always cause skin irritation or allergic reactions if allowed to contact the skin. Allergic reactions may not occur immediately. Workers should never think themselves immune to these reactions. Mixing and application should always be in well-ventilated areas. Disposable equipment and clothing should be used whenever possible. Clothing of any kind should not be re-used if soiled by epoxy resin. Safety glasses or goggles are recommended while mixing or applying these materials. The workmen should always wash up thoroughly immediately after completing work. Equipment must be kept clean at all times.

7.2.1.1. In case of direct contact to the body, wash immediately with soap and water until all epoxy compound is removed. If contact is to the eyes, flush with large quantities of water and secure immediate medical attention. Use only soap and water or water-soluble cleaners on the body. The use of solvents for epoxy is to be avoided.

7.2.2. *Linseed Oil*—These oils are not considered toxic or irritating; therefore, the only safety hazard with their use is from burning. Normal precautions indicated for any flammable liquid should be followed.

7.2.3. *Tars*—Caution should be exercised around the hot material and heating equipment.

7.2.4. *Silanes and Siloxanes*—These materials may be flammable, therefore, do not store or use them near heat or open flame. They react chemically with glass, and therefore, should not be stored in glass containers.

7.2.5. *Methacrylates*—These materials are flammable and toxic, and caution should be taken to avoid contact with the skin or breathing concentrated vapors. Safety glasses or goggles should be worn.

7.2.6. *Sodium Silicate*—This material is nontoxic, noncaustic, and nonflammable. It should not be stored in glass containers since it reacts chemically with glass.

7.2.7. *Urethane*—This material is flammable, and some formulations produce vapors. Special protective clothing, including goggles, gloves, and respirators, must be worn when working with urethanes.

Standard Specification for

Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete

AASHTO Designation: M 233-86 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete

AASHTO Designation: M 233-86 (2009)

1. SCOPE

1.1. This specification covers boiled linseed oil-petroleum spirits mixture to be applied to hardened portland cement concrete as a protection against damage by deicing chemicals.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- D 56, Standard Test Method for Flash Point by Tag Closed Cup Tester
- D 235, Standard Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
- D 260, Standard Specification for Boiled Linseed Oil
- D 1544, Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)
- D 1639, Standard Test Method for Acid Value of Organic Coating Materials (Withdrawn 2005)
- D 1640, Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature
- D 1644, Standard Test Methods for Nonvolatile Content of Varnishes
- D 1959, Standard Test Method for Iodine Value of Drying Oils and Fatty Acids (Withdrawn 2006)
- D 1962, Standard Test Method for Saponification Value of Drying Oils, Fatty Acids, and Polymerized Fatty Acids (Withdrawn 2004)
- D 1963, Standard Test Method for Specific Gravity of Drying Oils, Varnishes, Resins, and Related Materials at 25/25°C (Withdrawn 2004)

3. PROPERTIES

3.1. The compound shall consist of a homogeneous mixture of 50 percent boiled linseed oil and 50 percent petroleum spirits by volume.

3.2. The boiled linseed oil shall conform to the requirements of ASTM D 260, for Boiled Linseed Oil Type 1 or Type 11.

3.3. The petroleum spirits shall conform to the requirements of ASTM D 235, for Petroleum Spirits (Mineral Spirits).

3.4. When requested by the purchaser, the manufacturer shall certify that the boiled linseed oil and petroleum spirits used in the mixture fully conform to the requirements specified in Sections 3.2 and 3.3, respectively.

3.5. The mixture shall have the following properties:

	Minimum	Maximum
Specific gravity 25/25°C	0.84	0.88
Acid value		5
Nonvolatile by mass, percent	55	57
Drying time, h		16
Color, Gardner		13
Iodine value	90	
Saponification	100	
Flash point (T.C.C.) °C (°F)	37.8 (100)	

4. METHODS OF TESTING

4.1. The properties enumerated in this specification shall be determined in accordance with the following methods of test:

4.1.1. *Specific Gravity*—ASTM D 1963.

4.1.2. *Acid Value*—ASTM D 1639.

4.1.3. *Nonvolatile Content*—ASTM D 1644, Method A.

4.1.4. *Drying Time*—ASTM D 1640.

4.1.5. *Color*—ASTM D 1544.

4.1.6. *Iodine Value*—ASTM D 1959.

4.1.7. *Saponification Value*—ASTM D 1962.

4.1.8. *Flash Point*—ASTM D 56.

Standard Specification for

Concrete Made by Volumetric Batching and Continuous Mixing

AASHTO Designation: M 241M/M 241-09
ASTM Designation: C 685/C 685M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Concrete Made by Volumetric Batching and Continuous Mixing

AASHTO Designation: M 241M/M 241-09
ASTM Designation: C 685/C 685M-07

AASHTO M 241M/M 241-09 is identical to ASTM C 685/C 685M-07 except for the following provisions:

1. All references to the ASTM Standards contained in ASTM C 685/C 685M-07 listed in the following table shall be replaced with the corresponding AASHTO Standard.

Referenced Standards

ASTM	AASHTO
C 31	T 23
C 33	M 6 and M 80
C 39	T 22
C 109	T 106
C 138	T 121M/T 121
C 143	T 119M/T 119
C 150	M 85
C 172	T 141
C 173	T 196M/T 196
C 191	T 131
C 231	T 152
C 260	M 154
C 330	M 195
C 494	M 194
C 595	M 240
C 618	M 295

2. Section 6 (Ordering Information), Section 11 (Strength), and Section 12 (Failure to Meet Strength Requirements) are excluded.
3. The following Table 2 shall be used in lieu of Table 2 of ASTM C 685/C 685M-07.

Table 2—Chemical Limitations for Wash Water

	Limits	Test Method
Chemical requirements, max concentration		
Chloride as $Cl^{(-1)}$ expressed as a percent by mass of cement when added to the $Cl^{(-1)}$ in the other components of the concrete mixture shall not exceed the following levels:		
1. Prestressed concrete	0.06 percent	AASHTO T 260
2. Conventionally reinforced concrete in a moist environment and exposed to chloride	0.10 percent	
3. Conventionally reinforced concrete in a moist environment but not exposed to chloride	0.15 percent	
4. Above ground building construction where the concrete will stay dry	No limit for corrosion	
Sulfate as SO_4, ppm[a]	3,000	ASTM D 516
Alkalies as (Na_4O + 0.658 K_2O), ppm	600	ASTM D 516
Total solids, ppm	50,000	AASHTO T 26

[a] Wash water reused as mixing water in concrete may exceed listed concentrations of sulfate if it can be shown that the concentration calculated in the total mixing water, including mixing water on the aggregate and other sources, does not exceed the stated limits.

4. The following referenced document is added to Section 2.3 of ASTM C 685/C 685M-07:
    - M 307, Silica Fume Used in Cementitious Mixtures.
5. Add a new section to ASTM C 685/C 685M-07 as follows:

    5.1.7 Coal fly ash and raw calcined natural pozzolan shall conform to Specification M 295.

    5.1.8 *Silica Fume*—Silica fume shall conform to Specification M 307.

Standard Specification for

Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

AASHTO Designation: M 295-07
ASTM Designation: C 618-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

AASHTO Designation: M 295-07
ASTM Designation: C 618-05

1. SCOPE

1.1. This specification covers coal fly ash and raw or calcined natural pozzolan for use in concrete where cementitious or pozzolanic action, or both, is desired, or where other properties normally attributed to finely divided coal fly ash and raw or calcined natural pozzolans may be desired or where both objectives are to be achieved.

Note 1—Finely divided materials may tend to reduce the entrained air content of concrete. Hence, if a fly ash or natural pozzolan is added to any concrete for which entrainment of air is specified, provision should be made to ensure that the specified air content is maintained by air content tests and by use of additional air-entraining admixture or use of an air-entraining admixture in combination with air-entraining hydraulic cement.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 311, Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. The terms used in this specification are defined in ASTM C 125.

3.1.2. *fly ash*—finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses.

Note 2—This definition of fly ash does not include, among other things, the residue resulting from: (1) the burning of municipal garbage or any other refuse with coal; (2) the injection of lime directly into the boiler for sulfur removal; or (3) the burning of industrial or municipal garbage in incinerators commonly known as "incinerator ash."

4. CLASSIFICATION

4.1. *Class N*—Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given herein, such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales.

4.2. *Class F*—Fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class as given herein. This class fly ash has pozzolanic properties.

4.3. *Class C*—Fly ash normally produced from lignite or subbituminous coal that meets the applicable requirements for this class as given herein. This class of fly ash, in addition to having pozzolanic properties, also has some cementitious properties. Some Class C fly ashes may contain lime contents higher than 10 percent.

5. ORDERING INFORMATION

5.1. The purchaser shall specify any supplementary optional chemical and physical requirements.

5.2. The purchaser shall indicate which procedure, A or B, shall be used when specifying requirements for effectiveness in contribution to sulfate resistance under Table 4.

6. CHEMICAL COMPOSITION

6.1. Fly ash and natural pozzolans shall conform to the requirements as to chemical composition prescribed in Table 1.

Table 1—Chemical Requirements

	Coal Fly Ash and Raw or Calcined Natural Pozzolan Class		
	N	F	C
Silicon dioxide (SiO_2) plus aluminum oxide ($A1_2O_3$) plus iron oxide (Fe_2O_3), min percent	70.0	70.0	50.0
Sulfur trioxide (SO_3), max percent	4.0	5.0	5.0
Moisture content, max percent	3.0	3.0	3.0
Loss on ignition, max percent	5.0	5.0	5.0

Table 2—Supplementary Optional Chemical Requirement

	Coal Fly Ash and Raw or Calcined Natural Pozzolan Class		
	N	F	C
Available alkalies, as equivalent, as Na_2O, max percent[a]	1.5	1.5	1.5

[a] Applicable only when specifically required by the purchaser for mineral admixture to be used in concrete containing reactive aggregate and cement to meet a limitation on content of alkalies.

Note 3—The chemical component determinations and the limits placed on each do not predict the performance of the fly ash or natural pozzolan with hydraulic cement in concrete, but collectively help describe composition and uniformity of the material.

7. PHYSICAL PROPERTIES

7.1. Fly ash and natural pozzolans shall conform to the physical requirements prescribed in Table 3. Supplementary optional physical requirements are shown in Table 4.

Table 3—Physical Requirements

	Coal Fly Ash and Raw or Calcined Natural Pozzolan Class		
	N	F	C
Fineness:			
Amount retained when wet-sieved on 45-μm (No. 325) sieve, max percent[a]	34	34	34
Strength activity index:[b]			
With portland cement, at 7 days, min percent of control	75[e]	75[e]	75[e]
With portland cement, at 28 or 56[c] days, min percent of control	75[e]	75[e]	75[e]
Water requirement, max percent of control	115	105	105
Soundness:[d]			
Autoclave expansion or contraction, max percent	0.8	0.8	0.8
Uniformity requirements:			
The density and fineness of individual samples shall not vary from the average established by the 10 preceding tests, or by all preceding tests if the number is less than 10, by more than:			
Density, max variation from average, percent	5	5	5
Percent retained on 45-μm (No. 325) sieve, max variation, percentage points from average	5	5	5

[a] Care should be taken to avoid the retaining of agglomerations of extremely fine material.

[b] The strength activity index with portland cement is not to be considered a measure of the compressive strength of concrete containing the coal fly ash and raw or calcined natural pozzolan. The strength activity index with portland cement is determined by an accelerated test, and is intended to evaluate the contribution to be expected from the coal fly ash and raw or calcined natural pozzolan to the longer strength development of concrete. The mass of coal fly ash and raw or calcined natural pozzolan specified for the test to determine the strength activity index with portland cement is not considered to be the proportion recommended for the concrete to be used in the work. The optimum amount of coal fly ash and raw or calcined natural pozzolan for any specific project is determined by the required properties of the concrete and other constituents of the concrete and should be established by testing. Strength activity index with portland cement is a measure of reactivity with a given cement and is subject to variation depending on the source of both the coal fly ash and raw or calcined natural pozzolan and the cement.

[c] Only applicable when testing at 56 days is specified.

[d] If the coal fly ash and raw or calcined natural pozzolan will constitute more than 20 percent by mass of the cementitious material in the project mix design, the test specimens for autoclave expansion shall contain that anticipated percentage. Excessive autoclave expansion is highly significant in cases where water to coal fly ash and raw or calcined natural pozzolan and cement ratios are low, for example, in block or shotcrete mixes.

[e] Meeting the 7-day, 28-day, or 56-day (if specified) strength activity index will indicate specification compliance.

Table 4—Supplementary Optional Physical Requirements

	Coal Fly Ash and Raw or Calcined Natural Pozzolan Class		
	N	F	C
Multiple factor, calculated as the product of loss on ignition and fineness, amount retained when wet-sieved on 45-µm (No. 325) sieve, max percent[a]	—	255	—
Increase of drying shrinkage of mortar bars at 28 days, max difference in percent over control[b]	0.03	0.03	0.03
Uniformity requirements:			
In addition, when air-entrained concrete is specified, the quantity of air-entraining agent required to produce an air content of 18.0 vol percent of mortar shall not vary from the average established by the 10 preceding tests or by all preceding tests if less than 10, by more than, percent	20	20	20
Effectiveness in controlling alkali-silica reaction: [c]			
Expansion of test mixture as percentage of low-alkali cement control, at 14 days, max percent	100	100	100
Effectiveness in contributing to sulfate resistance: [d]			
Procedure A:			
Expansion of test mixture:			
For moderate sulfate exposure after 6 months of exposure, max percent	0.10	0.10	0.10
For high sulfate exposure after 6 months of exposure, max percent	0.05	0.05	0.05
Procedure B:			
Expansion of test mixture as a percentage of sulfate resistance cement control after at least 6 months of exposure, max percent	100	100	100

[a] Applicable only for Class F coal fly ash and raw or calcined natural pozzolan since the loss on ignition limitations predominate for Class C.

[b] Determination of compliance or noncompliance with the requirement relating to increase in drying shrinkage will be made only at the request of the owner.

[c] Coal fly ash and raw or calcined natural pozzolans meeting this requirement are considered as effective in controlling alkali aggregate reactions as the use of the low-alkali control cement used in the evaluation. However, the coal fly ash and raw or calcined natural pozzolan shall be considered effective only when the coal fly ash and raw or calcined natural pozzolan are used at percentages by mass of the total cementitious material equal to or exceeding that used in the tests and when the alkali content of the cement to be used with the coal fly ash and raw or calcined natural pozzolan does not exceed that used in the tests by more than 0.05 percent. See Appendix X1, ASTM C 311.

[d] Fly ash or natural pozzolan shall be considered effective only when the fly ash or natural pozzolan is used at percentages, by mass, of the total cementitious material within 2 percent of those that are successful in the test mixtures or between 2 percentages that are successful, and when the C_3A content of the project cement is less than or equal to that which was used in the test mixtures. See Appendix X2 of ASTM C 311.

Note: These optional requirements apply only when specifically requested.

8. METHODS OF SAMPLING AND TESTING

8.1. Sample and test the coal fly ash and raw or calcined natural pozzolan in accordance with the requirements of ASTM C 311.

8.2. Use cement of the type proposed for use in the work and, if available, from the mill proposed as the source of the cement, in all tests requiring the use of hydraulic cement.

9. STORAGE AND INSPECTION

9.1. The coal fly ash and raw or calcined natural pozzolan shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.

9.2. Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchaser contract.

10. REJECTION

10.1. Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing.

10.2. Packages varying more than five percent from the stated mass may be rejected. If the average mass of the packages in any shipment, as shown by determining the mass of 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

10.3. Any coal fly ash and raw or calcined natural pozzolan in storage prior to shipment for a period longer than 180 days after testing may be retested and may be rejected if it fails to meet the fineness requirements.

11. PACKAGING AND PACKAGE MARKING

11.1. When the fly ash or natural pozzolan is delivered in packages, the class, name, and brand of the producer and the mass of the material contained therein shall be plainly marked on each package. Similar information shall be provided in the shipping invoices accompanying the shipment of packaged or bulk material.

12. KEYWORDS

12.1. Coal fly ash; raw or calcined natural pozzolan; pozzolans.

Standard Specification for

Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

AASHTO Designation: M 302-06
ASTM Designation: C 989-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

AASHTO Designation: M 302-06
ASTM Designation: C 989-05

1. SCOPE

1.1. This specification covers three strength grades of finely ground granulated blast-furnace slag for use as a cementitious material in concrete and mortar.

1.2. The values stated in SI units are to be regarded as standard. The values given in parentheses are given for information only.

1.3. *The following safety hazards caveat pertains only to the test methods described in this specification. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4. The text of this standard references notes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of this standard.

Note 1—The material described in this specification may be used for blending with portland cement to produce a cement meeting the requirements of M 240 or as a separate ingredient in concrete or mortar mixtures. The material may also be useful in a variety of special grouts and mortars and, when used with an appropriate activator, as the principal cementitious material in some applications.

Note 2—Information on technical aspects of the use of the material described in this specification is contained in Appendix A. More detailed information on that subject is contained in ACI 233R-03, formerly ACI 226.1R.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 240, Blended Hydraulic Cement
- T 105, Chemical Analysis of Hydraulic Cement
- T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 133, Density of Hydraulic Cement
- T 137, Air Content of Hydraulic Cement Mortar

- T 153, Fineness of Hydraulic Cement by Air Permeability Apparatus
- T 192, Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 441, Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
- C 452, Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
- C 465, Standard Specification for Processing Additions for Use in the Manufacture of Hydraulic Cements
- C 1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
- D 3665, Standard Practice for Random Sampling of Construction Materials

2.3. *American Concrete Institute Reports*:

- 226.1R, Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete[1]
- 233R-03, Slag Cement in Concrete and Mortar

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *blast-furnace slag*—the nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. (See ASTM C 125.)

3.2. *Descriptions of Terms Specific to This Standard*:

3.2.1. *granulated blast-furnace slag*—the glassy granular material formed when molten blast-furnace slag is rapidly chilled as by immersion in water. (See ASTM C 125.) Compositional adjustments may be made while the blast-furnace slag is molten.

3.2.2. *slag*—granulated blast-furnace slag, as defined and described in Sections 3.1.1 and 3.2.1 and ground to cement fineness with or without additions meeting the requirements of the section on additions.

4. CLASSIFICATION

4.1. Slag is classified by performance in the slag activity test in three grades: Grade 80, Grade 100, and Grade 120. (See Table 1.)

5. ORDERING INFORMATION

5.1. The purchaser shall specify the grade slag desired and the optional chemical or physical data to be reported.

6. ADDITIONS

6.1. The slag covered by this specification shall contain no additions except as follows:

6.1.1. Calcium sulfate may be added in amounts such that the limits in Table 2 for sulfur trioxide are not exceeded.

6.1.2. Processing additions may be used in the manufacture of the slag, provided such materials, in the amounts used, have been shown to meet the requirements of ASTM C 465 when tested using a 50/50 blend by mass with portland cement.

7. PHYSICAL PROPERTIES

7.1. Slag shall conform to the physical requirements of Table 1.

Table 1—Physical Requirements

Item	
Fineness:	
Amount retained when wet-screened on a 45-µm (No. 325) sieve, max percent	20
Specific surface by air permeability, Method T 153 shall be determined and reported although no limits are required	—
Air content of slag mortar, max percent	12

Slag Activity Index, Min, percent	Average of Last 5 Consecutive Samples	Any Individual Sample
7-Day index:		
Grade 80	—	—
Grade 100	75	70
Grade 120	95	90
28- or 56[a]-Day index:		
Grade 80	75	70
Grade 100	95	90
Grade 120	115	110

[a] Only applicable when testing at 56 days is specified.

8. CHEMICAL COMPOSITION

8.1. Slag shall conform to the chemical requirements prescribed in Table 2.

Table 2—Chemical Requirements

Sulfide sulfur (S), max percent	2.5
Sulfate ion reported as SO_3, max percent	4.0

Note 3—Sulfur in granulated blast-furnace slag is present predominantly as sulfide sulfur. In most cases, instrumental analyses, such as x-ray fluorescence, cannot differentiate sulfide sulfur from sulfate. Determine and report the sulfide sulfur content separately and do not include it in the SO_3 calculations.

9. SAMPLING

9.1. The following sampling and testing procedures shall be used by the purchaser to verify compliance with this specification.

9.2. Take random grab samples either from a delivery unit or at some point in the loading or unloading process so that no sample represents more than 115 Mg (125 tons) (Note 4). If samples are taken from rail cars or trucks, take at least two separate 2-kg (5-lb) portions and thoroughly mix them to obtain a test sample (Note 5). Sample by removing approximately a 300-mm (12-in.) layer of slag. Make a hole before obtaining a sample to avoid dust collector material that may be discharged into the delivery unit after the slag flow ceases. Sample at a rate of 10 samples per month or one sample for each 2300 Mg (2500 tons) of shipments, whichever is more frequent.

Note 4—Standard statistical procedures are recommended for ensuring that samples are selected by a random procedure; see ASTM D 3665. These procedures can be used to select the days within a month or within a week that samples will be taken. The delivery unit or time of day then should be chosen randomly.

Note 5—The quantity of sample specified is more than adequate for the testing required. A 2-kg (5-lb) portion should be retained in a sealed container for retesting if that is considered necessary to verify compliance.

10. TEST METHODS

10.1. *Slag-Activity Tests with Portland Cement*:

10.1.1. Slag activity shall be evaluated by determining the compressive strength of both portland-cement mortars and corresponding mortars made with the same mass of 50/50 mass combinations of slag and portland cement. Appendix X1 discusses the effects of cement, temperature, and amount of slag used on performance with portland cement.

10.1.2. *Reference Cement*—The portland cement used in the slag activity tests shall comply with the standard chemical and physical requirements of M 85 and with the additional requirements of total alkali content and compressive strength limits as shown in Table 3. Sufficient cement shall be reserved to avoid changing reference cement more often than every 2 months. Following the compressive strength requirement of Table 3, the referenced cement shall be re-qualified at intervals no greater than 6 months.

Table 3—Alkali and Strength Limits of Reference Cement for Slag Activity Tests

Total alkalies (Na_2O + 0.658 K_2O),	min percent max percent	0.60 0.90
Compressive strength, MPa, min 28 days[a]		35 (5000 psi)

[a] The minimum strength limit is based solely on the strength of the T 106M/T 106 mortar cubes, as required in specification M 85, regardless of the strength of the flow controlled Specification M 302 mortar cubes.

10.1.3. *Preparation of Specimens*—Prepare mortars in accordance with T 106M/T 106, except that sufficient water shall be used in each batch to produce a flow of 110 ± 5 percent. The proportions shall be as follows:

- Reference Cement Mortar:
  500 g portland cement
  1375 g graded standard sand
- Slag-Reference Cement Mortar:
  250 g portland cement
  250 g slag
  1375 g graded standard sand

10.1.3.1. Mix a reference cement batch each day that a slag-reference cement batch is mixed until at least five batches have been mixed with the reference cement. Thereafter, reference cement batches need not be mixed more often than once a week whenever slag is being produced or shipped.

10.1.4. *Test Ages*—Determine the compressive strength of mortar specimens at 7 and 28 days age in accordance with T 106M/T 106.

10.1.5. *Calculation*—Calculate the slag activity index to the nearest percent for both 7 days and 28 days as follows:

$$\text{Slag Activity Index, percent} = (SP/P) \times 100$$

where:

SP = average compressive strength of slag-reference cement mortar cubes at designated ages, MPa (psi); and

P = average compressive strength of reference cement mortar cubes at designated age, MPa (psi).

The reference cement-mortar strength used to calculate the slag activity index shall, when a reference cement mortar is mixed on the same day as a slag-reference cement mortar, be the result for that batch. Otherwise, the average of tests of the five most recent reference cement-mortar batches shall be used.

10.1.6. *Report*—The report should include the following:

10.1.6.1. Slag activity index, percent;

10.1.6.2. Compressive strength at 7 and 28 days of slag-reference cement mortar;

10.1.6.3. Compressive strength at 7 and 28 days of portland cement mortar;

10.1.6.4. Total alkalies of the reference cement ($Na_2O + 0.658\ K_2O$);

10.1.6.5. Fineness of reference cement; and

10.1.6.6. Potential compound composition of the reference portland cement.

10.1.7. *Precision*—The following precision statements are applicable when the slag activity index with portland cement is based on results of tests of two cubes from single batches of reference cement and 50/50 slag-reference cement mortars mixed on the same day. They are applicable to the slag activity index determined at 7 or 28 days.

10.1.7.1. The single-laboratory coefficient of variation has been found to be 4.1 percent. Therefore, the slag activity index based on single batches of mortar mixed on the same day should not differ by more than 11.6 percent of their average.

10.1.7.2. The multilaboratory coefficient of variation has been found to be 5.7 percent. Therefore, the slag activity index based on tests of single batches made by different laboratories should not differ by more than 16.1 percent.

10.2. *Slag Density*—Determine in accordance with T 133.

10.3. *Amount of Slag Retained on a 45-μm (No. 325) Sieve*—Determine in accordance with T 192.

10.4. *Slag Fineness by Air Permeability*—Determine in accordance with T 153.

10.5. *Sulfate Ion in Slag Reported as* SO_3—Determine as sulfur trioxide in accordance with T 105, except the sample need not be completely decomposed by acid.

10.6. *Sulfide Sulfur in the Slag*—Determine in accordance with T 105.

10.7. *Chloride Content of Slag*—Determine in accordance with T 105.

10.8. *Air Content of Slag Mortar*—Determine in accordance with T 137, except use 350 g of slag instead of cement in the standard mortar batch. Calculate using the appropriate density of the slag.

11. REJECTION AND REHEARING

11.1. The purchaser has the right to reject material that fails to conform to the requirements of this specification. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the tests, the producer or supplier is not prohibited from making a claim for retesting.

12. CERTIFICATION

12.1. Upon request of the purchaser in the contract or order, a manufacturer’s report shall be furnished at the time of shipment stating the results of tests made on samples of the material taken during production or transfer and certifying that applicable requirements of this specification have been met. When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each lot have been tested as directed in this specification and the specified requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished.

12.2. When specified in the purchase order or contract, test data shall be furnished on the chloride ion content of the slag.

13. MANUFACTURER’S STATEMENT

13.1. At the request of the purchaser, the manufacturer shall state in writing the nature, amount, and identity of any processing or other additions made to the slag.

14. PACKAGE MARKING AND SHIPPING INFORMATION

14.1. When the ground slag is delivered in packages, the classification of slag, the name and brand of the manufacturer, and the mass of the slag contained therein shall be plainly marked on each package. Similar information shall be provided in the shipping invoices accompanying the shipment of packaged or bulk slag. All packages shall be in good condition at the time of inspection.

15. STORAGE

15.1. The slag shall be stored to permit easy access for proper inspection and identification of each shipment and in a suitable weather-tight building that will protect the slag from dampness and minimize quality deterioration.

APPENDIXES

(Nonmandatory Information)

X1. CONTRIBUTION OF SLAG TO CONCRETE STRENGTH

X1.1. When slag is used in concrete with portland cement, the levels and rate of strength development will depend importantly on the properties of the slag, the properties of the portland cement, the relative and total amounts of slag and cement, and the concrete curing temperatures.

X1.2. The reference cement used to test slag activity in this specification must have a minimum 28-day strength of 35 MPa (5000 psi) and an alkali content between 0.6 and 0.9 percent. Performance of the slag with other portland cements may be significantly different. The slag-activity test also can be used to evaluate relative hydraulicity of different slags with a specific cement or of different shipments of the same slag. Such comparisons will be improved if all tests are made with a single sample of cement. To properly classify a slag, the reference portland cement must conform to the limits on strength and alkali content. Even within these limits, performance will depend to some extent on the particular cement used. The percentages developed in the slag activity test do not provide quantitative predictions of strength performance in concrete. Performance in concrete will depend on a large number of factors including the properties and proportions of the slag, the portland cement, and other concrete ingredients, concrete temperatures and curing conditions, and other conditions.

X1.3. Concrete strengths at 1, 3, and even 7 days may tend to be lower using slag-cement combinations, particularly at low temperatures or at high slag percentages. Concrete proportions will need to be established considering the importance of early strengths, the curing temperatures involved and the properties of the slag, the portland cement, and other concrete materials. Generally a higher numerical grade of slag can be used in larger amounts and will provide improved early strength performance; however, tests must be made using job materials under job conditions.

X2. SULFATE RESISTANCE

X2.1. *General*—Slag cements are generally considered to have greater resistance to attack by sulfates than do portland cements, based largely upon comparisons of high slag-content portland blast-furnace slag cements with ordinary (Type I) portlands. These cements (containing 60 percent or more slag) are widely used for sulfate- and seawater-resistant concretes throughout the world.

X2.2. *Sulfate Resistance of Portland Cements*—The sulfate resistance of concrete is dependent upon a number of factors, including mortar permeability and the type and concentration of the sulfate solutions involved. Other factors, directly related to the cement characteristics, include calcium hydroxide concentration and the tricalcium aluminate (C_3A) content. Specification M 85 provides limits on the C_3A for sulfate-resistant cements. Specification M 85 Type V requirements provide for a limit on the tetracalcium aluminoferrite (C_4AF) plus twice the C_3A. The M 85 table of Optional Physical Requirements includes a maximum limit on expansion of Type V cement in mortar bars when tested by ASTM C 452. When this option is selected, the standard limits on tricalcium aluminate and on tetracalcium aluminoferrite plus twice the tricalcium aluminate do not apply. ASTM C 1012 can be used to measure the effects of exposure to external sulfate environments on mortar or concrete.

X2.3. *Effect of Slag on Sulfate Resistance*[2,3]—The use of slag will decrease the C_3A content of the cementing materials and decrease the permeability and calcium hydroxide content of the mortar or concrete. Tests have shown that the alumina content of the slag also influences sulfate resistance, and that high alumina content can have a detrimental influence at low slag-replacement percentages. The data from these studies of laboratory exposure of mortars to sodium and magnesium sulfate solutions provide the following general conclusions.

X2.3.1. The combination of slag and portland cement, in which the slag content was greater than 60 to 65 percent, had high sulfate resistance, always better than the portland cement alone, irrespective of the Al_2O_3 content of the slag. The improvement in sulfate resistance was greatest for the cements with the higher C_3A contents.

X2.3.2. The low-alumina (11 percent) slag tested increased the sulfate resistance independently of the C_3A content of the cement. To obtain adequate sulfate resistance, higher slag percentages were necessary with the higher C_3A cements.

X2.3.3. The high-alumina (18 percent) slag tested adversely affected the sulfate resistance of portland cements when blended in low percentages (50 percent or less). Some tests indicated rapid decreases in resistance for cements in the 8 and 11 percent C_3A ranges with slag percentages as low as 20 percent or less in the blends.

X2.3.4. Tests on slag (7 to 8 percent alumina) in Ontario have shown that a 50:50 combination by mass with Type I portland cement having up to about 12 percent C_3A is equivalent in sulfate resistance to the Type V cement used in that study.[4]

X2.4. *Tests for Sulfate Resistance*—When the relative sulfate resistance of a specific cement-slag combination is desired, tests should be conducted in accordance with ASTM C 1012.[5] Studies by ASTM Subcommittee C 01.29 on sulfate resistance using ASTM C 1012, as reported by Patzias,[6] recommended the following limits for expansion of portland cement and ground slag combinations at 6 months of exposure:

- Moderate sulfate resistance—0.10 percent max.
- High sulfate resistance—0.05 percent.

X3. EFFECTIVENESS OF SLAG IN PREVENTING EXCESSIVE EXPANSION OF CONCRETE DUE TO ALKALI-AGGREGATE REACTION

X3.1. Tests for effectiveness of slag in preventing excessive expansion due to alkali-aggregate reaction are not considered necessary unless the slag is to be used: (a) with a high-alkali portland cement ($Na_2O + 0.658\ K_2O \geq 0.6$ percent) or the concrete contains added water-soluble alkalies (added as an activator to improve early strength); and (b) with an aggregate that is regarded as deleteriously reactive with alkalies.

X3.2. It should be expected that the effectiveness of the slag will depend upon the amount used and the reactivity of the slag itself. Data suggest that slags used as 40 percent or more of the cementitious material will generally prevent excessive expansion with cements having alkali contents up to 1.0 percent; however, definitive data are not available, and tests must be made in accordance with ASTM C 441. Further information on preventing excessive expansion due to alkali-silica reaction is given in M 6 and M 80.

X3.3. When the job cement and proportions of cement to slag are known, test mortars should be proportioned in accordance with the job mixture requirements of ASTM C 441, and the average expansion of mortar bars at 14 days should not exceed 0.020 percent.

X3.4. When the job cement and proportions of slag to cement are not known, tests can be made for the reduction in mortar expansion in accordance with ASTM C 441. To be considered effective the slag must reduce 14-day expansions of mixtures made with the required high-alkali cement by 75 percent. The slag should be considered effective only when the ratio of slag to cement equals or exceeds that found effective in the tests.

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[1] Available from American Concrete Institute, P.O. Box 19150, Detroit, MI 48219.

[2] Locher, F. W. The Problems of the Sulfate Resistance of Slag Cements. Zement-Kalk-Gips, No. 9, September, 1966.

[3] Van Aardt, J. H. P. and S. Visser. The Behavior of Mixtures of Milled Granulated Blast Furnace Slag and Portland Cement in Sulfate Solutions. Bulletin 47, National Building Research Institute, South Africa, 1967.

[4] Chojnacki, B. Sulfate Resistance of Blended (Slag) Cement. Report EM-52. Ministry of Transport and Communications, Ontario, Canada, 1981.

[5] Hooton, R. D. and J. J. Emery. Sulfate Resistance of a Canadian Slag Cement. *ACI Materials Journal*, Vol. 87, No. 6, November–December 1990.

[6] Patzias, T. The Development of ASTM Method C 1012 with Recommended Acceptance Limits for Sulfate Resistance of Hydraulic Cements. *Cement, Concrete, and Aggregates*, Vol. 13, No. 1, ASTM, 1991.

Standard Practice for

Making and Curing Concrete Test Specimens in the Laboratory

AASHTO Designation: R 39-07
ASTM Designation: C 192/C 192M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Practice for

Making and Curing Concrete Test Specimens in the Laboratory

AASHTO Designation: R 39-07
ASTM Designation: C 192/C 192M-06

1. SCOPE

1.1 This standard practice covers procedures for making and curing test specimens of concrete in the laboratory under accurate control of materials and test conditions using concrete that can be consolidated by rodding or vibration as described herein. This standard practice does not address and does not apply to self-consolidating concrete.

1.2 The values stated in the inch-pound units are to be regarded as standard. The values given in parentheses are for information purposes only.

1.3 *This standard practice does not purport to address the safety concerns associated with its use. It is the responsibility of the user of this standard practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 43, Sizes of Aggregate for Road and Bridge Construction
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 194M/M 194, Chemical Admixture for Concrete
- M 195, Lightweight Aggregates for Structural Concrete
- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 205, Molds for Forming Concrete Test Cylinders Vertically
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
- T 197M/T 197, Time of Setting of Concrete Mixtures by Penetration Resistance
- T 231, Capping Cylindrical Concrete Specimens

- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 309, Temperature of Freshly Mixed Hydraulic Cement Concrete

2.2 *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 330, Standard Specification for Lightweight Aggregates for Structural Concrete
- C 1064, Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
- C 1077, Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation

2.3 *American Concrete Institute Publications*:

- 211.3 Practice for Selecting Proportions for No Slump Concrete[1]
- 309 Guide for Concrete Consolidation[1]

3. SIGNIFICANCE AND USE

3.1 This standard practice provides standardized requirements for preparation of materials, mixing concrete, and making and curing concrete test specimens under laboratory conditions.

3.2 If specimen preparation is controlled as stipulated herein, the specimens may be used to develop information for the following purposes:

3.2.1 Mixture proportioning for project concrete,

3.2.2 Evaluation of different mixtures and materials,

3.2.3 Correlation with nondestructive tests, and

3.2.4 Providing specimens for research purposes.

Note 1—The concrete test results for concrete specimens made and cured using this standard practice are widely used. They may be the basis for acceptance testing for project concrete, research evaluation, and other studies. Careful and knowledgeable handling of materials, mixing concrete, molding test specimens, and curing test specimens is necessary. Many laboratories performing this important work are independently inspected or accredited. ASTM C 1077 identifies and defines duties, responsibilities, including minimum responsibilities of the laboratory personnel, and minimum technical requirements for laboratory equipment used. Many laboratories ensure qualified technicians by participating in national certification programs such as the American Concrete Institute Laboratory program or equivalent program.

4. APPARATUS

4.1 *Molds, General*—Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall conform to the dimensions and tolerances specified in the method for which the specimens are required. Molds shall hold their dimensions and shape under conditions of severe use. Watertightness of molds during use shall be judged by their ability to hold water poured into them. Test procedures for watertightness are given in the section on Test Methods for Elongation, Absorption, and Watertightness in ASTM C 470.

A suitable sealant—such as heavy grease, modeling clay, or microscrystalline wax—shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

4.2 *Cylinder Molds*:

4.2.1 Molds for casting specimens vertically shall conform to the requirements of Section 4.1 and M 205.

4.2.2 Horizontal molds for creep test cylinders shall conform to the requirements of Section 4.1 and to the requirements for symmetry and dimensional tolerance in Section 3.1.2 of M 205. The use of horizontal molds is intended only for creep specimens that contain axially embedded strain gauges. Molds for creep cylinders to be filled while supported in a horizontal position shall have a filling slot parallel to the axis of the mold that extends the full length to receive the concrete. The width of the slot shall be one-half the diameter of the specimen. If necessary, the edges of the slot shall be reinforced to maintain dimensional stability. Unless specimens are to be capped or ground to produce plane ends, the molds shall be provided with two machined metal end plates at least 1 in. (25 mm) thick, and the working surfaces shall comply with the requirements for planeness and surface roughness of Section 3.1 of T 231. Provision shall be made for fixing both end plates firmly to the mold. The inside surface of each end plate shall be provided with at least three lugs or studs approximately 1 in. (25 mm) long, firmly fastened to the plate for embedment in the concrete. One base plate shall be drilled from the inside at an angle to permit the lead wire from the strain gauge to exit the specimen through the edge of the plate. Provision shall be made for accurately positioning the strain gauge. All necessary holes shall be as small as possible to minimize disturbance to subsequent strain measurements and shall be sealed to prevent leakage.

4.3 *Beam and Prism Molds*—Beam and prism molds shall be rectangular in shape (unless otherwise specified) and of the dimensions required to produce the desired specimen size. The inside surfaces of the molds shall be smooth and free from indentations. The sides, bottom, and ends shall be at right angles to each other and shall be straight and true and free of warpage. Maximum variation from the nominal cross section shall not exceed $^1/_8$ in. (3 mm) for molds with depth or breadth of 6 in. (150 mm) or more, or $^1/_{16}$ in. (1.6 mm) for molds of smaller depth or breadth. Except for flexure specimens, molds shall not vary from the nominal length by more than $^1/_{16}$ in. (1.6 mm). Flexure molds shall not be shorter than $^1/_{16}$ in. (1.6 mm) of the required length, but may exceed it by more than that amount.

4.4 *Tamping Rods*—Two sizes are specified in AASHTO methods. Each shall be a round, straight steel rod with at least the tamping end rounded to a hemispherical tip of the same diameter as the rod. Both ends may be rounded, if preferred.

4.4.1 *Larger Rod*—$^5/_8$ in. (16 mm) in diameter and approximately 24 in. (600 mm) long.

4.4.2 *Small Rod*—$^3/_8$ in. (10 mm) in diameter and approximately 12 in. (300 mm) long.

4.5 *Mallets*—A mallet with a rubber or rawhide head weighing 1.25 ± 0.50 lb (0.6 ± 0.20 kg) shall be used.

4.6 *Vibrators*:

4.6.1 *Internal Vibrators*—The vibrator frequency shall be at least 7000 vibrations per minute (115 Hz) while the vibrator is operating in the concrete. The diameter of a round vibrator shall be no more than one-fourth the diameter of the cylinder mold or one-fourth the width of the beam or prism mold. Other shaped vibrators shall have a perimeter equivalent to the circumference of an appropriate round vibrator. The combined length of the vibratory shaft and vibrating element shall exceed the depth of the section being vibrated by at least 3 in. (75 mm).

4.6.2 *External Vibrators*—The two types of external vibrators permitted are either table or plank. The external vibrator frequency shall be 3600 vibrations per minute (60 Hz) or higher.

4.6.2.1 Provisions shall be made for clamping the mold securely to the apparatus.

Note 2—For more information on size and frequency of various vibrators and method to periodically check vibrator frequency, see ACI 309.

Note 3—Vibratory impulses are frequently imparted to a table or plank vibrator through electromagnetic means, or by use of an eccentric weight on the shaft of an electric motor or on a separate shaft driven by a motor.

4.7 *Small Tools*—Tools and items such as shovels, pails, trowels, wood float, blunted trowels, straightedge, feeler gauge, scoops, rulers, rubber gloves, and metal mixing bowls shall be provided.

4.8 *Slump Apparatus*—The apparatus for measurement of slump shall conform to the requirements of T 119M/T 119.

4.9 *Sampling and Mixing Pan*—The pan shall be flat-bottomed and of heavy-gauge metal, watertight, of convenient depth, and of sufficient capacity to allow easy mixing by shovel or trowel of the entire batch; or if mixing is by machine, to receive the entire batch on discharge of the mixer and allow remixing in the pan by trowel or shovel.

4.10 *Wet-Sieving Equipment*—If wet-sieving is required, the equipment shall conform to the requirements of T 141.

4.11 *Air Content Apparatus*—The apparatus for measuring air content shall conform to the requirements of T 196M/T 196, or of T 152.

4.12 *Scales*—Scales for determining the mass of batches of materials and concrete shall be accurate within 0.3 percent of the test load at any point within the range of use.

Note 4—In general the mass of small quantities should not be determined on large capacity scales. In many applications the smallest quantity weighed on a scale should be greater than about 10 percent of the maximum capacity of the scale; however, this will vary with the performance characteristics of the scale and the required accuracy of the determination. Acceptable scales used for weighing concrete materials preferably should weigh accurately to about 0.1 percent of total capacity and the foregoing precaution is applicable. However, certain analytical and precision balances are exceptions to this rule and may weigh accurately to 0.001 percent. Particular care must be exercised in measuring small quantities of material by determining the difference between two much larger weights.

4.13 *Temperature Measuring Device*—The temperature measuring device shall conform to the requirements of T 309M/T 309.

4.14 *Concrete Mixer*—A power-driven concrete mixer shall be a revolving drum, tilting mixer, or suitable revolving pan or revolving-paddle mixer capable of thoroughly mixing batches of the prescribed sizes at the required slump.

Note 5—A pan mixer may be found more suitable for mixing concrete with less than 1-in. (25-mm) slump than a revolving drum mixer. The rate of rotation, degree of tilt, and rated capacity of tilting mixers may not always be suitable for laboratory mixed concrete. It may be found desirable to reduce the rate of rotation, decrease the angle of tilt from the horizontal, and use the mixer at somewhat less than the manufacturer's rated capacity.

5. SPECIMENS

5.1 *Cylindrical Specimens*—Cylinder dimensions shall be as stipulated in the specification, test method or practice for the laboratory studies being performed and shall meet the requirements of Section 5.4. If dimensions are not stipulated in a specification, test method, or practice, the specimen selected shall have a length that is twice the diameter and meet the requirements of Section 5.4.

Note 6—When molds in SI units are required and not available, equivalent inch-pound unit size mold should be permitted.

Note 7—The same cylinder size should be used for the reference (control) concrete mixture and test concrete mixtures when conducting comparative studies such as those required in M 194M/M 194. For mixture proportioning of project concrete, it is preferable for the cylinder size in the laboratory to be the same as that specified for acceptance testing.

5.1.1 Cylindrical specimens for tests other than creep shall be molded and allowed to harden with the axis of the cylinder vertical.

5.1.2 Cylindrical creep specimens may be cast with the cylindrical axis either vertically or horizontally and allowed to harden in the position in which cast.

5.2 *Prismatic Specimens*—Beams for flexural strength, prisms for freezing and thawing, bond, length change, volume change, etc., shall be formed with their long axes horizontally, unless otherwise required by the method of test in question, and shall conform in dimension to the requirements of the specific test method.

5.3 *Other Specimens*—Other shapes and sizes of specimens for particular tests may be molded as desired following the general procedures set forth in this standard practice.

5.4 *Specimen Size versus Aggregate Size*—The diameter of a cylindrical specimen or minimum cross-sectional dimension of a rectangular section shall be at least three times the nominal maximum size of the coarse aggregate in the concrete (as defined in ASTM C 125). Occasional oversized aggregate particles (of a size not normally found in the average aggregate grading) shall be removed by handpicking during the molding of the specimens. When the concrete contains aggregate larger than that appropriate for the size of the molds or equipment to be used, wet-sieve the sample as described in T 141.

5.5 *Number of Specimens*—The number of specimens and the number of test batches are dependent on established practice and the nature of the test program. Guidance is usually given in the test method or specification for which the specimens are made. Usually three or more are molded for each test age and test condition unless otherwise specified (Note 7). Specimens involving a given variable should be made from three separate batches mixed on different days. An equal number of specimens for each variable should be made on any given day. When it is impossible to make at least one specimen for each variable on a given day, the mixing of the entire series of specimens should be completed in as few days as possible, and one of the mixtures should be repeated each day as a standard of comparison.

Note 8—Test ages often used are 7 and 28 days for compressive strength tests, or 14 and 28 days for flexural strength tests. Specimens containing Type III cement are often tested at 1, 3, 7, and 28 days. For later test ages, 3 months, 6 months, and 1 year are often used for both compressive and flexural strength tests. Other test ages may be required for other types of specimens.

6. PREPARATION OF MATERIALS

6.1 *Temperature*—Before mixing the concrete, bring the concrete materials to room temperature in the range of 68 to 86ºF (20 to 30ºC) except when the temperature of the concrete is stipulated. When a concrete temperature is stipulated, the method proposed to obtain the concrete temperature needs approval of the stipulator.

6.2 *Cement*—Store the cement in a dry place, in moisture-proof containers, preferably made of metal. The cement shall be thoroughly mixed to provide a uniform supply throughout the tests. It shall be passed through a No. 20 (850 μm) or finer sieve to remove all lumps, remixed on a plastic sheet, and returned to sample containers.

6.3 *Aggregates*—In order to preclude segregation of a coarse aggregate, separate into individual-sized fractions and for each batch recombine in the proper proportions to produce the desired grading.

Note 9—Only rarely can a coarse aggregate be batched as a single-sized fraction. The number of sized fractions will generally be between two and five for aggregate smaller than $2^1/_2$ in. (63 mm). When a sized fraction to be batched is present in amounts in excess of 10 percent, the ratio of the opening of the larger to the smaller sieve should not exceed 2.0. More closely sized groups are sometimes advisable.

6.3.1 Unless fine aggregate is separated into individual-sized fractions, maintain it in a damp condition or restore to a damp condition until use, to prevent segregation, unless material uniformly graded is subdivided into batch-sized lots using a sample splitter with proper-sized openings. If unusual gradings are being studied, the fine aggregate may have to be dried and separated into individual sizes. In this instance, if the total quantity of fine aggregate required is larger than can be efficiently blended in a single unit, then the individual-sized fractions should be determined in mass required for each individual batch. When the total quantity of fine aggregate needed for the complete investigation is such that it can be thoroughly mixed, blended, and maintained in a damp condition, then it should be handled in that manner. Determine the specific gravity and absorption of aggregates in accordance with either T 85 or T 84.

6.3.2 Before incorporating in concrete, prepare the aggregate to ensure a definite and uniform condition of moisture. Determine the weight of aggregate to be used in the batch by one of the following procedures:

6.3.2.1 Determine the weight of low-absorption aggregates (absorption less than 1.0 percent) in the room-dry condition with allowance made for the amount of water that will be absorbed from the unset concrete (Note 10). This procedure is particularly useful for coarse aggregate that must be batched as individual sizes because of the danger of segregation. This procedure can be used for fine aggregate only when the fine aggregate is separated into individual-sized fractions.

Note 10—When using aggregates with low absorption in room-dry condition, the amount of water that will be absorbed by the aggregates before the concrete sets may be assumed to be 80 percent of the difference between the 24-hour absorption of the aggregates determined by T 85 or T 84, and the amount of water in the pores of the aggregates in their room-dry state, as determined by T 255.

6.3.2.2 Individual-sized fractions of aggregate may be weighed separately, recombined into a tared container in the amounts required for the batch, and immersed for 24 hours prior to use. After immersion, the excess water is decanted and the combined weight of aggregate and mixing water determined. Allowance shall be made for the amount of water absorbed by the aggregate. The moisture content of the aggregates may be determined in accordance with T 255.

6.3.2.3 The aggregate may be brought to and maintained in a saturated condition, with surface moisture contained in sufficiently small amounts to preclude loss by draining, at least 24 hours prior to use. When this method is used, the moisture content of the aggregate must be determined to permit calculation of proper quantities of the damp aggregate. The quantity of surface moisture present must be counted as a part of the required amount of mixing water. Surface moisture in fine aggregate may be determined in accordance with T 255, making due allowance for the amount of water absorbed. The method outlined here (moisture content slightly exceeding absorption) is particularly useful for fine aggregate. It is used less frequently for coarse aggregate because of the difficulty of accurately determining the moisture content, but if used, each sized fraction must be handled separately to ensure that the proper grading is obtained.

6.3.2.4 Aggregates, fine or coarse, may be brought to and maintained in a saturated surface-dry condition until batched for use. This method is used primarily to prepare material for batches not to exceed $^1/_4$ ft^3 (0.007 m^3) in volume. Care must be taken to prevent drying during weighing and use.

6.4 *Lightweight Aggregates*—The procedures for specific gravity, absorption, and preparation of aggregates mentioned in this standard practice pertain to materials with normal absorption values. Lightweight aggregates, air-cooled slag, and certain highly porous or vesicular natural aggregate may be so absorptive as to be difficult to treat as described. The moisture content of lightweight aggregate at the time of mixing may have important effects on properties of freshly mixed and hardened concretes such as slump loss, compressive strength, and resistance to freezing and thawing.

6.5 *Admixtures*—Powdered admixtures that are entirely or largely insoluble, that do not contain hygroscopic salts and are to be added in small quantities, should be mixed with a portion of the cement before introduction of the batch to the mixer so as to assure thorough distribution throughout the concrete. Essentially, insoluble materials that are used in amounts exceeding 10 percent by weight of cement, such as pozzolans, should be handled and added to the batch in the same manner as cement. Powdered admixtures that are largely insoluble but contain hygroscopic salts may cause balling of cement and should be mixed with the sand. Water-soluble and liquid admixtures should be added to the mixer in solution in the mixing water. The quantity of such solution used must be included in the calculation of the water content of the concrete. Admixtures, incompatible in concentrated form, such as solutions of calcium chloride and certain air-entraining and set-retarding admixtures, should not be intermixed prior to their addition to concrete. The time, sequence, and method of adding some admixtures to a batch of concrete can have important effects on concrete properties such as time of set and air content. The method selected must be uniform from batch to batch.

Note 11—The mixing apparatus and accessories shall be thoroughly cleaned to ensure that chemical additions or admixtures used in dissimilar batches of concrete do not affect subsequent batches.

7. PROCEDURE

7.1 *Mixing Concrete*:

7.1.1 *General*—Mix concrete in a suitable mixer or by hand in batches of such size as to leave about 10 percent excess after molding the test specimens. Hand-mixing procedures are not applicable to air-entrained concrete or concrete with no measurable slump. Hand mixing should be limited to batches of $^1/_4$ ft^3 (0.007 m^3) volume or less. Mixing procedures are given in Sections 7.1.2 and 7.1.3. However, other procedures may be used when it is desired to simulate special conditions or practices, or when the procedures specified are impracticable. A machine-mixing procedure suitable for drum type mixers is described. It is important not to vary the mixing sequence and procedure from batch to batch unless the effect of such variation is under study.

7.1.2 *Machine Mixing*—Prior to starting rotation of the mixer, add the coarse aggregate, some of the mixing water, and the solution of admixture, when required, in accordance with Section 6.5. When feasible, the admixture shall be dispersed in the mixing water before addition. Start the mixer and then add the fine aggregate, cement, and water with the mixer running. If it is impractical for a particular mixer or for a particular test to add the fine aggregate, cement, and water while the mixer is running, these components may be added to the stopped mixer after permitting it to turn a few revolutions following charging with coarse aggregate and some of the water (Note 12). Mix the concrete, after all ingredients are in the mixer, for 3 minutes followed by 3 minutes of rest, followed by 2 minutes of final mixing. Cover the open end or top of the mixer to prevent evaporation during the rest period. Take precautions to compensate for mortar retained by the mixer so that the discharged batch, as used, will be correctly proportioned (Note 13). To eliminate segregation, deposit machine-mixed concrete in the clean, damp mixing pan and remix by shovel or trowel until it appears to be uniform.

Note 12—An experienced operator may add water incrementally during mixing to adjust to the desired slump.

Note 13—It is difficult to recover all of the mortar from mixers. To compensate for this difficulty, one of the following procedures may be used to ensure the correct final proportions in the batch:

1. *"Buttering" Mixer*—Just prior to mixing the test batch, the mixer is "buttered" by mixing a batch proportioned to simulate closely the test batch. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch.
2. *"Over-Mortaring" The Mix*—The test mix is proportioned by the use of an excess mortar, the amount established in advance, to compensate for that which, on the average, adheres to the mixer. In this case the mixer is cleaned before mixing the test batch.

7.1.3 *Hand Mixing*—Mix the batch in a watertight, clean (Note 11), damp, metal pan or bowl with a bricklayer's blunted trowel, using the following procedure when aggregates have been prepared in accordance with Sections 6.3.2.1, 6.3.2.3, and 6.3.2.4.

7.1.3.1 Mix the cement, powdered insoluble admixture, if used, and fine aggregate without addition of water until they are thoroughly blended.

7.1.3.2 Add the coarse aggregate and mix the entire batch without addition of water until the coarse aggregate is uniformly distributed throughout the batch.

7.1.3.3 Add water, and the admixture solution if used, and mix the mass until the concrete is homogeneous in appearance and has the desired consistency. If prolonged mixing is necessary because of the addition of water in increments while adjusting the consistency, discard the batch and make a new batch in which the mixing is not interrupted to make trial consistency tests.

7.1.4 *Mixed Concrete*—Select the portions of the batch of mixed concrete to be used in tests and for molding specimens so as to be representative of the actual proportions and condition of the concrete. When the concrete is not being remixed or sampled, cover it to prevent evaporation.

7.2 *Slump, Air Content, Yield, and Temperature*:

7.2.1 *Slump*—Measure the slump of each batch of concrete immediately after mixing in accordance with T 119M/T 119.

Note 14—The slump test is unsuitable for concrete so dry that it slumps less than $^{1}/_{4}$ in. (6 mm). No-slump concrete may be tested by one of several means described in ACI 211.3.

7.2.2 *Air Content*—Determine the air content, when required, in accordance with either T 196 or T 152. T 152 should not be used with concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. Discard the concrete used for the determination of air content.

7.2.3 *Yield*—Determine the yield of each batch of concrete, if required, in accordance with T 121M/T 121. Concrete used for slump and yield tests may be returned to the mixing pan and remixed into the batch.

7.2.4 *Temperature*—Determine the temperature of each batch of concrete in accordance with ASTM C 1064.

7.3 *Making Specimens*:

7.3.1 *Place of Molding*—Mold specimens as near as practicable to the place where they are to be stored during the first 24 hours. If it is not practicable to mold the specimens where they will be stored, move them to the place of storage immediately after being struck off. Place molds on a rigid surface free from vibration and other disturbances. Avoid jarring, striking, tilting, or scarring of the surface of the specimens when moving the specimens to the storage place.

7.3.2 *Placing*—Place the concrete in the molds using a scoop, blunted trowel, or shovel. Select each scoopful, trowelful, or shovelful of concrete from the mixing pan to ensure that it is representative of the batch. It may be necessary to remix the concrete in the mixing pan with a shovel or trowel to prevent segregation during the molding of specimens. Move the scoop or trowel around the top edge of the mold as the concrete is discharged in order to ensure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate within the mold. Further distribute the concrete by use of a tamping rod prior to the start of consolidation. In placing the final layer, the operator shall attempt to add an amount of concrete that will exactly fill the mold after compaction. Do not add nonrepresentative samples of concrete to an underfilled mold.

7.3.2.1 *Number of Layers*—Make specimens in layers as indicated in Table 1.

Table 1—Number of Layers Required for Specimens

Specimen Type and Size	Mode of Compaction	Number of Layers of Approximate Equal Depth
Cylinders, diameter in. (mm):		
3 or 4 (75 to 100)	Rodding	2
6 (150)	Rodding	3
9 (225)	Rodding	4
Up to 9 (225)	Vibration	2
Prisms and horizontal creep cylinders, depth in. (mm):		
Up to 8 (200)	Rodding	2
Over 8 (200)	Rodding	3 or more
Up to 8 (200)	Vibration	1
Over 8 (200)	Vibration	2 or more

7.4 *Consolidation*:

7.4.1 *Methods of Consolidation*—Preparation of satisfactory specimens requires different methods of consolidation. The methods of consolidation are rodding, and internal or external vibration. Base the selection of the method of consolidation on the slump, unless the method is stated in the specifications under which the work is being performed. Rod or vibrate concretes with slump greater than 1 in. (25 mm). Vibrate concretes with slump less than 1 in. (25 mm) (Note 14). Do not use internal vibration for cylinders with a diameter less than 4 in. (100 mm), and for beams or prisms with breadth or depth less than 4 in. (100 mm).

Note 15—Concrete of such low water content that it cannot be properly consolidated by the methods described herein is not covered by this method. Provisions for specimens and methods of testing will be found in the standards concerned. There are concretes that can be consolidated by external vibrations, but additional forces on the surface are required to embed the coarse aggregate thoroughly and consolidate the mixture. For such mixtures the following procedures may be followed: using external vibration fill 6- by 12-in. (or 150- by 300-mm) cylinder molds in 3-in. (75-mm) lifts using a 10-lb (4.5-kg) cylindrical surcharge, or 3- by 6-in. (75- by 150-mm) cylinder molds in 2-in. (50-mm) lifts using a 2.5-lb (1.1-kg) cylindrical surcharge. The surcharge should have a diameter $^1/_4$ in. (6 mm) less than the inside of the mold. Simultaneously each lift should be compacted by external vibration with the surcharge on the top surface of the concrete until the mortar begins to ooze around the bottom of the surcharge.

7.4.2 *Rodding*—Place the concrete in the mold, in the required number of layers of approximately equal volume. Rod each layer with the rounded end of the rod using the number of strokes and size of rod specified in Table 2. Rod the bottom layer throughout its depth. Distribute the strokes uniformly over the cross section of the mold, and for each upper layer allow the rod to penetrate through the layer being rodded and into the layer below approximately 1 in. (25 mm). After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. Use an open hand to tap light-gauge single-use molds that are susceptible to damage if tapped with the mallet. After tapping, spade the concrete along the sides and ends of beam and prism molds with a trowel or other suitable tool.

Table 2—Diameter of Rod and Number of Roddings to be Used in Molding Test Specimens

Cylinders		
Diameter of Cylinder, in. (mm)	Diameter of Rod, in. (mm)	Number of Strokes/Layer
2 (50) to <6 (150)	$^3/_8$ (10)	25
6 (150)	$^5/_8$ (16)	25
8 (200)	$^5/_8$ (16)	50
10 (250)	$^5/_8$ (16)	75
Beams and Prisms		
Top Surface Area of Specimen, in.^{2} (cm^2)	Diameter of Rod, in. (mm)	Number of Roddings/Layer
25 (160) or less	$^3/_8$ (10)	25
26 to 49 (165 to 310)	$^3/_8$ (10)	one for each 1 in.^{2} (7 cm^2) of surface
50 (320) or more	$^5/_8$ (16)	one for each 2 in.^{2} (14 cm^2) of surface
Horizontal Creep Cylinders		
Diameter of Cylinder, in. (mm)	Diameter of Rod, in. (mm)	Number of Roddings/Layer
6 (150)	$^5/_8$ (16)	50 total, 25 along both sides of axis

7.4.3 *Vibration*—Maintain a uniform duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and large air bubbles cease to break through the top surface. Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 16). Overvibration may cause segregation. Fill the molds and vibrate in the required number of approximately equal layers (Table 2). Place all the concrete for each layer in the mold before starting vibration of that layer. When placing the final layer, avoid overfilling by more than $^1/_4$ in. (6 mm). When the finish is applied after vibration, add only enough concrete with a trowel to overfill the mold about $^1/_8$ in. (3 mm), work it into the surface and then strike it off.

Note 16—Generally, no more than 5 s of vibration should be required for each insertion to adequately consolidate the concrete with a slump greater than 3 in. (75 mm). Longer times may be required for lower slump concrete, but the vibration times should rarely exceed 10 s per insertion.

7.4.3.1 *Internal Vibration*—In compacting the specimen, insert the vibrator slowly and do not allow the vibrator to rest on or touch the bottom or sides of the mold or strike embedded items such as strain meters. Slowly withdraw the vibrator so that no large air pockets are left in the specimen.

7.4.3.2 *Cylinders*—The number of insertions of the vibrator is given in Table 3. When more than one insertion per layer is required, distribute the insertions uniformly within each layer. Allow the vibrator to penetrate into the layer below, approximately 1 in. (25 mm). After each layer is vibrated, tap the outsides of the mold at least 10 times with the mallet to close the holes that remain and to release entrapped air voids. Use an open hand to tap cardboard or single-use metal molds that are susceptible to damage if tapped with a mallet.

7.4.3.3 *Beams, Prisms, and Horizontal Creep Cylinders*—Insert the vibrator at intervals not exceeding 6 in. (150 mm) along the center line of the long dimension of the specimen, or along both sides but not in contact with the strain gauge in the case of creep cylinders. For specimens wider than 6 in. (150 mm), use alternating insertions along two lines. Allow the shaft of the vibrator to penetrate into the bottom layer approximately 1 in. (25 mm). After each layer is vibrated, tap the outsides of the mold sharply at least 10 times with the mallet to close holes left by vibrating and to release any entrapped air voids.

7.4.4 *External Vibration*—When external vibration is used, take care to ensure that the mold is rigidly attached to or securely held against the vibrating element or vibrating surface (Note 15).

Table 3—Number of Vibrator Insertions per Layer

Specimen Type and Size, Cylinder: Diameter, in. (mm)	Number of Insertions per Layer
4 in. (100 mm)	1
6 in. (150 mm)	2
9 in. (225 mm)	4

7.5 *Finishing*—After consolidation, by any of the methods, strike-off the surface of the concrete and float or trowel it in accordance with the method concerned. If no finish is specified, finish the surface with a wood or magnesium float. Perform all finishing with the minimum manipulation necessary to produce a flat even surface that is level with the rim or edge of the mold and has no depressions or projections larger than $^1/_8$ in. (3 mm).

7.5.1 *Cylinders*—After consolidation, finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits, or with a wood float or trowel. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste that is permitted to harden and cure with the specimen. See Section 4 of T 231.

7.5.2 *Horizontally Cast Creep Cylinders*—After consolidation, strike off the specimen with a trowel or float, then trowel the minimum amount required to form the concrete in the opening concentrically with the rest of the specimen. Use a screed curved to the radius of the specimen to more precisely shape and finish the concrete in the opening.

8. CURING

8.1 *Initial Curing*—To prevent evaporation of water from the unhardened concrete, cover the specimens immediately after finishing, preferably with a nonabsorptive, nonreactive plate or a sheet of tough, durable, impervious plastic. Specimens shall be stored immediately after finishing until the removal of molds to prevent loss of moisture from the specimen. Select an appropriate procedure or combination of procedures that will prevent moisture loss and is nonabsorptive and nonreactive with the concrete. When burlap is used for covering, the burlap must not be in contact with the fresh concrete surface and care must be exercised to keep the burlap wet until the specimens are removed from the molds. Placing a sheet of plastic over the burlap will facilitate keeping it wet. To prevent damage to the specimen, protect the outside of cardboard molds from all contact with wet burlap or other sources of water until the molds are removed. Record the maximum and minimum ambient temperatures during the initial curing.

8.2 *Removal from Molds*—Remove the specimens from the molds within 24 ± 8 hours after casting. For concrete with prolonged setting time, molds shall not be removed until 20 ± 4 hours after final set. If needed, determine setting times in accordance with T 197M/T 197.

8.3 *Curing Environment*—Unless otherwise specified, all specimens shall be moist cured at 73.5 ± 3.5ºF (23.0 ± 2.0ºC) from the time of molding until the moment of test (Note 17). Storage during the first 48 hours of curing shall be in a vibration-free environment. As applied to the treatment of demolded specimens, moist curing means that the test specimens shall have free water maintained on the entire surface area at all times. This condition is met by using water storage tanks or a moist room in accordance with the requirements of M 201. When water storage tanks are used, specimens shall be immersed in a water saturated with calcium hydroxide to prevent leaching from the specimens. Specimens shall not be exposed to dripping or running water. Cure structural lightweight concrete cylinders in accordance with ASTM C 330.

Note 17—The temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

8.4 *Flexural Strength Test Specimens*—Cure the flexural strength test specimens in accordance with Sections 8.1 and 8.2, except that while in storage for a minimum period of 20 hours immediately prior to testing they shall be immersed in saturated-lime solution at 73.5 ± 3.5ºF (23.0 ± 2.0ºC). At the end of the curing period, between the time the specimen is removed from curing until testing is completed, drying of the surfaces shall be prevented.

Note 18—Relatively small amounts of drying of the surface of flexural strength specimens will induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9. PRECISION AND BIAS

9.1 Data to establish precision statements for various testing required by this standard practice were obtained in the Concrete Reference Sample Program of the Cement and Concrete Reference Laboratory. The single-operator standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 0.7 in. (18 mm), 0.9 lb/ft^3 (14.4 kg/m^3), 0.3 percent, and 203 psi (1400 kPa), respectively; therefore, the results of properly conducted tests on two trial batches made in the same laboratory should not differ by more than 2.0 in. (50 mm), 2.5 lb/ft^3 (40 kg/m^3), 0.8 percent, and 574 psi (3960 kPa), respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have constant water–cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 in. (50 mm) or over 6 in. (150 mm), or concrete made with other than normal weight aggregate or aggregate larger than 1 in. (25 mm) nominal maximum size.

9.2 The multilaboratory standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 1.0 in. (25 mm), 1.4 lb/ft^3 (22.4 kg/m^3), 0.4 percent, and 347 psi (2390 kPa), respectively; therefore, the results of properly conducted tests on single trial batches made in two different laboratories should not differ by more than 2.8 in. (70 mm), 4.0 lb/ft^3 (64.1 kg/m^3), 1.1 percent, and 981 psi (6765 kPa), respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a prescribed water-cement ratio. The values should be used with caution for air–entrained concrete, concrete with slump less than 2 in. (50 mm), or over 6 in. (150 mm), or concrete made with other than normal weight aggregate or aggregate larger than 1 in. (25 mm) nominal maximum size.

9.3 *Bias*—The procedures for the test methods in Section 9.3 have no bias because the values obtained from each of those test methods are defined only in terms of the test method.

10. KEYWORDS

10.1 Concrete; cylinders; laboratory; prisms; strength testing.

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[1] Available from the American Concrete Institute, P.O. Box 9094, Farmington Hills, MI 48333-9094.

Standard Practice for

Chemical, Biological, and Physical Analysis of Water

AASHTO Designation: R 23-99 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Chemical, Biological, and Physical Analysis of Water

AASHTO Designation: R 23-99 (2008)

1. SCOPE

1.1. This standard practice provides a listing of various parameters used in the analysis of natural waters and wastewaters. The analysis of these waters is becoming an increasing area of concern for environmental reasons. The passage of laws governing the usage of our natural waterways and limiting the discharges into these waterways, along with an increased public awareness, have caused a much greater demand for this information. To ensure that these data are accurate and reliable, it is essential that testing be conducted using standard procedures that are known to have reproducible results. The test methods given for the following parameters are from referenced sources that are used by most transportation departments testing water. They are listed in order of most frequently used parameters to those parameters rarely used.

1.2. The values stated in SI units are to be regarded as the standard.

2. METHOD OF DESIGNATION

2.1. Each parameter listed contains one or more test methods for the analysis of that parameter. When more than one procedure is listed, the choice is left to the individual laboratory. These alternate methods generally give comparable results and are intended to provide flexibility to the analyst for parameters for which test methods are used fairly equally.

3. TEST METHOD REFERENCE

3.1. *Standard Methods for the Examination of Water and Wastewater*, current edition, published jointly by American Public Health Association, Washington, DC; American Water Works Association, Denver, CO; and Water Environmental Federation, Alexandria, VA.

3.2. *Manual of Methods for Chemical Analysis of Water and Waste*, current edition, published by U.S. Environmental Protection Agency, Office of Technology Transfer, Washington, DC 20460.

3.3. American Society for Testing and Materials, Volume “Water,” current edition, published by ASTM, West Conshohocken, PA.

4. HYDROGEN ION CONCENTRATION

4.1. pH Value by Electrometric Method, Method 4500 H, Reference 3.1.

5. ELECTRICAL CONDUCTIVITY

5.1. Micro MHOS at 25ºC, Method 2510 B, Reference 3.1.

6. ALKALINITY

6.1. Electrometric Method or Color Change Titration, Method 2320 B, Reference 3.1.

7. HARDNESS

7.1. EDTA Titrimetric, Method 2340 C, Reference 3.1.

7.2. Hardness by Calculation, Method 2340 B, Reference 3.1.

8. TURBIDITY

8.1. Nephlometric Method, Method 2130 B, Reference 3.1.

9. BIOCHEMICAL OXYGEN DEMAND

9.1. Five days at 20ºC, Method 5210 B, Reference 3.1.

10. TOTAL NONFILTRABLE RESIDUE

10.1. Dried at 103ºC–105ºC, Method 2540 D, Reference 3.1.

11. TEMPERATURE

11.1. Method 2550 B, Reference 3.1.

12. DISSOLVED OXYGEN

12.1. Modified Winkler with Full Bottle Titration, Storet No. 00300, Reference 3.2.

12.2. Electrode Method, Method 4500-O G, Reference 3.1.

13. TOTAL RESIDUE IN WATER

13.1. Dried at 103ºC–105ºC, Method 2540 B, Reference 3.1.

14. CALCIUM

14.1. Atomic Absorption, Method 3500-Ca B, Reference 3.1.

15. POTASSIUM

15.1. Flame Photometric Method, Method 3500-K B, Reference 3.1.

16. ZINC

16.1. Atomic Absorption Method, Method 3500-Zn B, Reference 3.1.

17. TOTAL FILTRABLE RESIDUE

17.1. Dried at 103ºC–105ºC, Method 2540 D, Reference 3.1.

18. SULFATE

18.1. Gravimetric Method with Ignition of Residue, Method 4500-SO4 D, Reference 3.1.

18.2. Turbidimetric Method, Method 427C, Reference 3.1.

19. IRON

19.1. Atomic Absorption Method, Method 3500-Fe B, Reference 3.1.

20. SODIUM

20.1. Flame Photometric Method, Method 3500-Na B, Reference 3.1.

21. CHEMICAL OXYGEN DEMAND

21.1. Dichromate Method, Method 5220 B, Reference 3.1.

21.2. Low-Level Dichromate Method, Storet No. 00335, Reference 3.2.

22. COPPER

22.1. Atomic Absorption Method, Method 3500-Cu B, Reference 3.1.

23. LEAD

23.1. Atomic Absorption Method, Method 3500-Pb B, Reference 3.1.

24. MAGNESIUM

24.1. Atomic Absorption Method, Method 3500-Mg B, Reference 3.1.

25. AMMONIA NITROGEN

25.1. Distillation Procedure, Storet No. 00610, Reference 3.2.

26. TOTAL KJELDAHL NITROGEN

26.1. Digestion with Distillation, Storet No. 00625, Reference 3.2.

27. MANGANESE

27.1. Atomic Absorption Method, Method 3500-Mn B, Reference 3.1.

28. CHLORIDE

28.1. Mercuric Nitrate Method, Method 4500-Cl C, Reference 3.1.

28.2. Argentometric Method, Method 4500-Cl B, Reference 3.1.

29. NITRATE NITROGEN

29.1. Brucine Method, Storet No. 00620, Reference 3.2.

30. NITRITE NITROGEN

30.1. Method 4500-NO_2 B, Reference 3.1.

31. CHROMIUM

31.1. Atomic Absorption Method, Method 3500-Cr B, Reference 3.1.

32. FECAL COLIFORM

32.1. Membrane Filtration Method, Method 9221 E, Reference 3.1.

33. PHOSPHOROUS

33.1. Ascorbic Acid with Preliminary Digestion, Method 4500-P E, Reference 3.1.

34. ALUMINUM

34.1. Atomic Absorption Method, Method 3500-Al B, Reference 3.1.

35. BARIUM

35.1. Atomic Absorption Method, Method 3500-Ba B, Reference 3.1.

36. CADMIUM

36.1. Atomic Absorption Method, Method 3500-Cd B, Reference 3.1.

37. NICKEL

37.1. Atomic Absorption Method, Method 3500-Ni B, Reference 3.1.

38. TOTAL COLIFORM

38.1. Membrane Filtration Method, Method 9222 B, Reference 3.1.

39. BENTHIC MACROINVERTEBRATES

39.1. Method 10500 C, Reference 3.1.

40. ACIDITY

40.1. Method 2310 B, Reference 3.1.

41. OIL AND GREASE

41.1. Soxhlet Extract Method, Method 5520 D, Reference 3.1.

42. TOTAL VOLATILE AND FIXED RESIDUE

42.1. Ignited at 550ºC, Method 2540 E, Reference 3.1.

43. SETTLEABLE MATTER

43.1. Method 2540 F, Reference 3.1.

44. FISH POPULATIONS

44.1. Method 10060, Reference 3.1.

45. SALINITY

45.1. Electrical Conductivity Method, Method 2500 B, Reference 3.1.

46. PERIPHYTON

46.1. Method 10300, Reference 3.1.

47. CHLORINE (RESIDUAL)

47.1. DPD Titrimetric Method, Method 4500-Cl F, Reference 3.1.

47.2. DPD Colorimetric Method, Method 4500-Cl G, Reference 3.1.

48. MERCURY

48.1. Flameless Atomic Absorption, Method 3500-Hg B, Reference 3.1.

49. PLANKTON

49.1. Method 10200, Reference 3.1.

50. MACROPHYTON

50.1. Method 10400, Reference 3.1.

51. SILVER

51.1. Atomic Absorption Method, Method 3500-Ag B, Reference 3.1.

52. VANADIUM

52.1. Atomic Absorption Method, Method 3500-V B, Reference 3.1.

53. BIOASSAY

53.1. Section 10400 F, Reference 3.1.

54. PHENOLS

54.1. Aminoantipyrine Method, Method 5530, Reference 3.1.

55. FLUORIDE

55.1. Preliminary Distillation with SPADNS Colorimetric Method, Method 4500-F D, Reference 3.1.

56. ARSENIC

56.1. Silver Diethyldithiocarbamate Method, Method 3500-As C, Reference 3.1.

57. SELENIUM

57.1. Atomic Absorption Method, Method 3500-Se B, Reference 3.1.

58. CYANIDE

58.1. Colorimetric Method 4500-CN E, Reference 3.1.

59. ODOR

59.1. Method 2150 B, Reference 3.1.

60. ALKYL BENZENE SULFONATE

60.1. Methylene Blue Method, Method D-2330, Reference 3.3.

Standard Practice for

Collection and Preservation of Water Samples

AASHTO Designation: R 24-99 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Collection and Preservation of Water Samples

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1. SCOPE

1.1. The objective of sampling is to collect a portion of material small enough in volume to be conveniently transported to and handled in the laboratory while still accurately representing the material being sampled. This implies, first, that the relative portions or concentrations of all pertinent components must be the same in the sample as in the material being sampled, and second, that the sample must be handled in such a way that no significant changes in composition occur before the tests are performed. Complete and unequivocal preservation of samples, whether domestic sewage, industrial waste, or natural waters, is a practical impossibility. Regardless of the nature of the sample, complete stability for every constituent can never be achieved. At best, preservation techniques can only retard the chemical and biological changes that inevitably continue after the sample is removed from the parent source.

1.2. The values stated in SI units are to be regarded as the standard.

2. TYPES OF SAMPLES

2.1. *Grab or Catch Samples*—Strictly speaking, a sample collected at a particular time and place can represent only the composition of the source at that time and place. However, when a source is known to be fairly constant in composition over a considerable period of time or over substantial distances in all directions, then the sample may be said to represent a longer time period or a larger volume or both, than the specific point at which it was collected. In such circumstances, some sources may be quite well represented by single grab samples. Examples are some water supplies, some surface waters, and, rarely, some wastewater streams.

2.1.1. When a source is known to vary with time, grab samples collected at suitable intervals and analyzed separately can be of great value in documenting the extent, frequency, and duration of these variations. Choose sampling intervals on the basis of the frequency with which changes may be expected, which may vary from as little as five minutes to as long as one hour or more.

2.1.2. When the composition of a source varies in space rather than time, a set of samples collected from appropriate locations with less emphasis on timing may provide the most useful information.

2.1.3. Use great care in sampling wastewater sludges, sludge banks, and muds. No definite procedure can be given, but every possible precaution should be taken to obtain a representative sample.

2.2. *Composite Samples*—In most cases, the term *composite sample* refers to a mixture of grab samples collected at the same sampling point at different times. Sometimes the term *time-composite* is used when it is necessary to distinguish this type of sample from others. Time-composite samples are most useful for observing average concentrations that are used, for example, in calculating the loading or the efficiency of a wastewater treatment plant. As an alternative to the separate analysis of a large number of samples, followed by computation of average and total results, composite samples of this type represent substantial savings in laboratory effort and expense. For these purposes, a composite sample representing a 24-hour period is considered standard for most determinations. Under certain circumstances, however, a composite sample representing one shift, or a shorter time period, or a complete cycle of a periodic operation, may be preferable. Evaluation of the effects of special, variable, or irregular discharges and operations may require composite samples representing the period during which such discharges occur.

2.2.1. For determination of components or characteristics subject to significant and unavoidable changes during storage, composite samples cannot be used. Perform such determinations on individual samples as soon as possible after collection and preferably at the sampling point. Analyses for all dissolved gases, residual chlorine, soluble sulfide, temperature, and pH are examples of determinations of this type. Changes in components such as dissolved oxygen or carbon dioxide, pH, or temperature may produce secondary changes in certain inorganic components such as iron, manganese, alkalinity, or hardness. Use time-composite samples only for determining components that can be demonstrated to remain unchanged under the existing conditions of sample collection and preservation.

2.2.2. Take individual portions in a wide-mouth bottle having a diameter of at least 35 mm at the mouth and capacity of at least 120 mL. Collect these portions each hour—in some cases half-hour or even every five minutes—and mix at the end of the sampling period or combine in a single bottle as collected. If preservatives are used, add them to the sample bottle initially so that all portions of the composite are preserved as soon as collected. Analysis of individual samples may sometimes be necessary.

2.2.3. It is desirable, and often absolutely essential, to combine the individual samples in volumes proportional to the volume of flow. A final volume of 2 to 3 liters is sufficient for sewage, effluents, and wastes.

2.2.3.1. Automatic sampling devices are available but should not be used unless the sample is preserved as described below. Clean sampling devices, including bottles, daily to eliminate biological growths and other deposits.

2.3. *Integrated Samples*—For certain purposes, the information needed is provided best by analysis of mixtures of grab samples collected from different points simultaneously, or as nearly so as possible. Such mixtures sometimes are called *integrated samples*. An example of the need for such sampling occurs in a river or stream that varies in composition across its width and depth. For evaluation of average composition or total loading, a mixture of samples representing various points in the cross-section, in proportion to their relative flows, may be useful. The need for integrated samples also may exist if combined treatment is proposed for several separate wastewater streams, the interaction of which may have a significant effect on treatability or even the composition of the mixture. Mathematical prediction of the interactions may be inaccurate or impossible, and testing of a suitable integrated sample may provide more useful information.

2.3.1. Both natural and artificial lakes often show variations of composition with both depth and horizontal location. However, under most conditions, neither total nor average figures are especially significant in these situations. The local variations are of more importance, and the samples are examined separately rather than integrated.

2.3.2. The preparation of integrated samples usually requires special equipment to collect a sample from a known depth, without contamination by the overlying water. Prior knowledge about the volume, movement, and composition of the various parts of the water being sampled usually is required.

Therefore, the collection of the integrated samples becomes a complicated and specialized process that cannot be described in complete detail here.

3. FREQUENCY AND DURATION OF SAMPLING

3.1. A reasonably accurate estimate of the composition of a raw water piped from a large body of water, such as the Great Lakes, far enough from the shoreline to avoid variation from inflowing tributaries and waste discharges, may be made by taking individual samples at infrequent intervals, such as biweekly or monthly, sufficient to cover seasonal changes. If samples are taken from near the shoreline of such a body of water or from a river, take them at shorter intervals, for instance daily, to provide more exact knowledge of the variations in composition where these are of importance in the use to which the water is to be put. If greater variations or cycles of pollution occur, or closer surveillance of plant intake water is required, collect more frequent samples; for example, at hourly intervals.

3.2. Water undergoing continuous or intermittent treatment must be sampled with such frequency that adequate control is assured. The interval between samples is directly related to the rate at which critical characteristics can reach intolerable limits.

4. POINT OF SAMPLING

4.1. Choose the point of sampling with extreme care so that a representative sample of the water to be tested is obtained. Avoid surface scum.

4.2. Because of a wide variety of conditions found in streams, lakes, reservoirs, and other bodies of water, it is not possible to prescribe the exact point of sampling. Where the water in a stream is mixed so as to approach uniformity, a sample taken at any point in the cross-section is satisfactory. For large rivers or for streams not likely to be uniformly mixed, more samples are desirable and are usually taken at a number of points at the surface across the entire width and at a number of depths at each point. Take care, when boats are used, to avoid collecting samples where the turbulence caused by a propeller or by oars has disturbed the characteristics of the water. Ordinarily, samples are taken at these points and then combined to obtain an integrated sample of such a stream of water. Alternatively, test the single grab samples, for example, to determine the point of highest bacterial density.

4.3. Choose the location of the sampling point with respect to the information desired and in conformity with local conditions. Allow sufficient distance downstream, with respect to stream flow at the time of sampling, from a tributary or source of pollution to permit thorough mixing. If this is not possible, it is better to sample the stream above the tributary or source of pollution and, in addition, to sample the tributary or source of pollution. In general, a distance of 1.5 to 5 km (1 to 3 mi) below the tributary is sufficient.

4.4. Collect samples at least 0.8 km (0.5 mi) below dams or waterfalls to allow time for the escape of entrained air. When lakes, reservoirs, or other bodies of water are sampled, it is necessary to avoid nonrepresentative areas such as those created by inlet streams, more stagnant areas, or abrupt changes in shorelines, unless determining the effect of such local conditions is a part of the sampling program.

4.5. It is desirable to take a series of samples from any source of water to determine whether differences in composition are likely to exist before final selection of the sampling point.

5. SAMPLE CONTAINERS

5.1. Sample containers shall be made of materials that will not contaminate the sample and, before use, shall be cleaned thoroughly to remove all extraneous surface dirt. Chemically resistant glass and polyethylene are suitable materials for the containers. Only polyethylene containers shall be used for samples in which small amounts of hardness, silica, sodium, or potassium are to be determined. The collection, storage, and subsequent analytical determination in plastic containers will result in erroneous pH values due to the permeability of plastic to gases such as CO_2.

Note 1—New chemically resistant glass containers shall be conditioned by allowing them to stand full of distilled water for several days. Conditioning may be hastened by a preliminary treatment with dilute hydrochloric acid solution.

5.2. The closures for the sample containers shall be glass stoppers that have been thoroughly washed or plastic caps with suitable liners.

5.3. Refer to Table 1 for the recommended container for individual parameters.

6. GENERAL PRECAUTIONS

6.1. For sampling of unconfined water at any specified depth in ponds, lagoons, reservoirs, etc., during which contact with air or agitation of the water would cause a change in concentration of characteristics of a constituent to be determined, use a sampling apparatus so constructed that the solution at the depth to be sampled flows through a tube to the bottom of the container, and that a volume of sample equal to 4 to 10 times the volume of the receiving container passes through it. When no determinations of dissolved gases are to be made, any less complicated apparatus may be used that will permit the collection of a sample at a desired depth, or of an integrated sample containing water from all points in a vertical section.

6.2. Some test methods require adjustment to other than ambient temperature. Such adjustment should be carried out when indicated.

6.3. Normally, samples are taken without separation of particulate matter. If constituents are present in colloidal or flocculent suspension, take the sample so that they are present in representative portion.

6.4. *Volume of sample*:

6.4.1. Collect a minimum volume of 2 liters; 4 liters is preferable.

6.4.2. The estimates in Table 1 cover the volume of sample required for the usual determinations that are made on a water sample as well as for several tests that are made for special purposes.

6.4.3. The sample volume required for bacteriological analysis varies greatly with the bacterial density of the water. Serial dilutions are necessary for high-density samples.

6.5. When samples are to be shipped, do not fill the bottle entirely in order to allow some room for expansion when subjected to a change in temperature. An air space of 10 to 25 mL usually suffices for this purpose, although this does not protect against bursting of the container due to freezing.

6.6. If contact with air would cause a change in the concentration or characteristics of a constituent to be determined, secure the sample without contact with air and completely fill the container.

6.7. *Microbiological samples*:

6.7.1. When taking a sample from a sample line or tap, allow the water to run for at least five minutes or long enough to flush, with 6 to 10 times its volume, the entire part of the system that has been stagnant for two hours or more.

6.7.2. Turn off the sample outlet and empty it of water without touching the inside. Flame the outlet with a suitable torch or other device that will avoid the deposition of soot, which is undesirable. This flaming procedure may be omitted if the outlet is carefully cleaned by use of a swab of cotton or other suitable material thoroughly saturated with denatured ethyl alcohol (70 percent).

Table 1—Recommendation for Sampling and Preservation of Samples According to Measurement[a]

Measurement	Volume Req, mL	Container	Preservative	Holding Time[b]
Acidity	100	P, G[c]	Cool, 4°C	24 hours
Alkalinity	100	P, G	Cool, 4°C	24 hours
Arsenic	100	P, G	HNO_3 to pH < 2	6 months
BOD	1000	P, G	Cool, 4°C	6 hours[d]
Bromide	100	P, G	Cool, 4°C	24 hours
COD	50	P, G	H_2SO_4 to pH < 2	7 days
Chloride	50	P, G	None required	7 days
Chlorine req	50	P, G	Determine on site	No holding
Color	50	P, G	Cool, 4°C	24 hours
Cyanides	500	P, G	Cool, 4°C NaOH to pH < 2	24 hours
Dissolved oxygen:				
Probe	300	G only	Determine on site	No holding
Winkler	300	G only	Fix on site	4 to 8 hours
Fluoride	300	P, G	Cool, 4°C	7 days
Hardness	100	P, G	Cool, 4°C HNO_3 to pH < 2	7 days
Iodide	100	P, G	Cool, 4°C	24 hours
MBAS	250	P, G	Cool, 4°C	24 hours
Metals:				
Dissolved	200	P, G	Filter on site HNO_3 to pH < 2	6 months
Suspended			Filter on site	6 months
Total	100		HNO_3 to pH < 2	6 months
Mercury:				
Dissolved	100	P, G	Filter HNO_3 to pH < 2	38 days (glass) 13 days (hard plastic)
Total	100	P, G	Filter HNO_3 to pH < 2	38 days (glass) 13 days (hard plastic)
Nitrogen:				
Ammonia	400	P, G	Cool, 4°C H_2SO_4 to pH < 2	24 hours[e]
Kjeldahl Total	500	P, G	Cool, 4°C H_2SO_4 to pH < 2	7 days
Nitrate	100	P, G	Cool, 4°C H_2SO_4 to pH < 2	24 hours[e]
Nitrite	50	P, G	Cool, 4°C	24 hours[e]
NTA	50	P, G	Cool, 4°C	24 hours
Oil and grease	1000	G only	Cool, 4°C H_2SO_4 to pH < 2 or HCI	24 hours
Organic carbon	25	P, G	Cool, 4°C H_2SO_4 to pH < 2	24 hours

Continued on next page.

Table 1—Recommendation for Sampling and Preservation of Samples According to Measurement[a] (Continued)

Measurement	Volume Req, mL	Container	Preservative	Holding Time[b]
pH	25	P, G	Cool, 4˚C Determine on site	6 hours[e]
Phenolics	500	G only	Cool, 4˚C H_3PO_4 to pH < 4 1.0 g $CuSO_4$/I	24 hours
Phosphorous:				
Orthophosphate, dissolved	50	P, G	Filter on site Cool, 4˚C	24 hours[e]
Hydrolyzable	50	P, G	Cool, 4˚C	24 hours[e]
Total	50	P, G	Cool, 4˚C H_2SO_4 to pH < 2	7 days
Total, dissolved	50	P, G	Filter on site Cool, 4˚C	24 hours[e]
Residue:				
Filterable	100	P, G	Cool, 4˚C	7 days
Nonfilterable	100	P, G	Cool, 4˚C	7 days
Total	100	P, G	Cool, 4˚C	7 days
Volatile	100	P, G	Cool, 4˚C	7 days
Settleable matter	1000	P, G	None required	24 hours
Selenium	50	P, G	HNO_3 to pH < 2	6 months
Silica	50	P only	Cool, 4˚C	7 days
Specific conductance	100	P, G	Cool, 4˚C	24 hours[f]
Sulfate	50	P, G	Cool, 4˚C	7 days
Sulfide	500	P, G	2 mL zinc acetate	24 hours
Sulfite	50	P, G	Determine on site	No holding
Temperature	1000	P, G	Determine on site	No holding
Threshold odor	200	G only	Cool, 4˚C	24 hours
Turbidity	100	P, G	Cool, 4˚C	7 days

[a] More specific instructions for preservation and sampling are found with each procedure as detailed in the appropriate reference.

[b] It has been shown that samples properly preserved may be held for extended periods beyond the recommended holding time.

[c] Plastic or glass.

[d] If samples cannot be returned to the laboratory in less than six hours and holding time exceeds this limit, the final reported data should indicate the actual holding time.

[e] Mercuric chloride may be used as an alternate preservative at a concentration of 40 mL/L, especially if a longer holding time is required. However, the use of mercuric chloride is discouraged whenever possible.

[f] If the sample is stabilized by cooling, it should be warmed to 25˚C for reading, or temperature correction made and results reported at 25˚C.

6.7.3. Choose a sterile sample bottle containing $Na_2S_2O_3$ if the water being sampled contains residual chlorine, has been chlorinated, or contains any free or combined available oxidizing agent intended to sterilize it. If such sterilizing agents are not present, the thiosulfate may be omitted. In cases in which thiosulfate interferes with subsequent examination, such as examination for sulfate-reducing bacteria, etc., omit the use of thiosulfate in the sample bottle even if such sterilizing agents are present. In this case, if such sterilizing agents are present, the examination must be performed as soon as possible.

6.7.4. Remove the stopper from the sample bottle. Grasp the stopper by the dust cover to avoid contaminating it by touching it; do not lay it down. Hold the bottle by the bottom to avoid touching the neck. Do not rinse the bottle with the sample. Quickly hold the bottle under the flowing water to be sampled until it is about three-fourths full to permit mixing by shaking prior to testing. Replace the stopper and promptly crimp the metal dust cover in place over the neck of the bottle. Take care that the stopper and bottle neck are not touched during this operation and that no dust blows into the bottle, insofar as possible.

7. PRESERVATION OF SAMPLES

7.1. Add chemical preservatives to samples for chemical, physical, or radiological examination only as specified in Table 1. Quick freezing has been found to be beneficial in preserving some organic constituents. Note any preservatives added on the label.

7.2. Samples for bacteriological examination require refrigeration if they cannot be processed within one hour after collection.

7.3. If the sample is to be examined within one hour of collection, store it in a cool place without icing.

7.4. If the sample is held more than one hour before examination, store it in a refrigerator or ice chest at a temperature of not more than 4ºC. The interval between collection and examination of the sample must, in no case, be more than 12 hours, or 6 hours if the sample is suspected to contain large numbers of organisms. Field examination procedures should be considered for longer periods.

7.5. If the sample is transported, ship it in an insulated, iced container to maintain the temperature between 0 and 4ºC to allow it to be examined within 12 hours of collection.

7.6. If the conditions in Section 7.4 or Section 7.5 cannot be met, note the actual conditions on the examination report.

8. TIME INTERVAL BETWEEN COLLECTION AND ANALYSIS OF SAMPLES

8.1. In general, allow as short a time as possible to elapse between the collection of a sample and its analysis. Under some conditions, analysis in the field is necessary to secure reliable results. The actual time that may be allowed to intervene between the collection and analysis of a sample varies with the type of examination to be conducted, the character of the sample, and the time interval allowable for applying corrective treatment.

8.2. On the statement of an analysis, specify the length of time elapsed between collection and analysis of the sample.

8.3. Make the determination of dissolved gases, such as oxygen, hydrogen sulfide, and carbon dioxide, at the source, except that in some cases such constituents may be fixed and determined later as specified in the specific test methods.

8.4. When sampling for radioactivity determinations, note the exact time of sample collection. If short-lived activity is of interest, analysis should be made as rapidly as practical to minimize loss of activity by radioactive decay. If only long-lived activity is of interest, measurement of the radioactivity sometimes can be simplified by allowing sufficient time before analysis for the decay of the short-lived radionuclides.

9. LABELING AND TRANSPORTATION OF SAMPLES

9.1. Provide space for the following information on an etched area of the bottle, a gummed label, or a cardboard or linen tag securely affixed to the container:

- Sample number,
- Date and time of sampling,
- Source of sample,
- Point of sampling (designated in sufficient detail to enable anyone to collect a second sample from the identical spot from which the first sample was taken),
- Temperature and rate of flow of the fluid in the equipment from which the sample was taken,
- Temperature of sample,
- Type and quantity of preservative added,
- Results of field tests made on the sample, and
- Signature of sampler.

9.2. Fix the stoppers closing the sample containers in place by wire, tape, or cord to prevent leakage in transit. The sample containers shall be of such size that when filled with the desired amount of sample, space roughly equivalent to 1 percent of the volumetric capacity of the containers will be available for expansion of the liquid. Exceptions to this are for those constituents noted in Section 8.3.

9.3. The sample shipping container shall be a case (wood preferred) having a separate compartment for each sample container. Line the compartment around each sample container with corrugated paper, felt, or similar material; or hold the sample containers in place with spring clips, sawdust, excelsior, foamed plastic, or similar material. Use insulated containers for quick-frozen samples, usually shipped with solid carbon dioxide to maintain the sample in frozen condition.

9.4. Print the addresses of consignee and consignor plainly upon two sides of the outer container, or attach firmly thereon by cards or labels. Attach warning and descriptive labels to the outer container such as “Fragile,” “Liquid,” “Glass,” “Handle With Care,” “This Side Up,” etc., when applicable. In cold weather, attach the label “Keep from Freezing” to the outer container, except for those samples that are intentionally frozen.

Standard Specification for

Corrugated Sheet Steel Beams for Highway Guardrail

AASHTO Designation: M 180-00 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Corrugated Sheet Steel Beams for Highway Guardrail

AASHTO Designation: M 180-00 (2008)

1. SCOPE

1.1 This specification covers corrugated sheet steel prepared for use as beams in highway guardrails.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 120, Zinc
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2 *ASTM Standards*:

- A 307, Standard Specification for Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength
- A 653/A 653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods
- F 568M, Standard Specification for Carbon and Alloy Steel Externally Threaded Metric Fasteners

2.3 *ANSI Standards*:

- B1.13M, Metric Screw Threads D M Profile
- B18.2.4.1M, Hex Nuts, Style 1, Metric
- B18.2.4.6M, Hex Nuts, Heavy, Metric

2.4 *Military Standard*:

- DOD-P-21035, Paint, High Zinc Dust Content, Galvanizing Repair (Metric)

3. CLASSIFICATION

3.1 Four types and two classes of guardrail are provided as follows:

3.1.1 *Types*:

Type I—Zinc coated, 550 g/m^2 (1.80 oz/ft^2) minimum single-spot.

Type II—Zinc coated, 1100 g/m^2 (3.60 oz/ft^2) minimum single-spot.

Type III—Beams to be painted.

Type IV—Beams of corrosion resistant steel.

3.1.2 *Classes*:

Class A—Base metal nominal thickness—2.67 mm (0.105 in.).

Class B—Base metal nominal thickness—3.43 mm (0.135 in.).

4. ORDERING INFORMATION

4.1 Orders for guardrail under this specification shall include the following information, as required, to adequately describe the desired material:

4.1.1 Quantity (linear meter or number of pieces),

4.1.2 Class of Guardrail,

4.1.3 Type of Guardrail,

4.1.4 Effective length of beam section 3.8 or 7.6 m (12.5 ft or 25.0 ft),

4.1.5 Shape (W-Beam or Thrie Beam), and

4.1.6 Exceptions to this specification or special requirements, if any.

5. BASIS OF ACCEPTANCE

5.1 All material shall be subject to inspection and sampling at the fabricating plant, warehouse, or after delivery to the site of construction.

5.2 *Acceptance by Sampling*:

5.2.1 The engineer may take one piece of guardrail, a backup plate, and end or buffer section from each 200 pieces in a lot, or from each lot if less than 200 pieces are included therein, for determination of compliance with specification requirements. If one piece fails to meet the requirements, two other pieces shall be tested. If either of these pieces fails to conform to the requirements of this specification, the lot of material represented by these samples shall be rejected. A lot shall be considered that quantity of material offered for inspection at one time which bears the same heat and coating identification.

5.3 *Acceptance by Brand Registration and Guarantee*:

5.3.1 By mutual agreement between the fabricator and engineer, acceptance may be based upon a brand registration and guarantee filed with the engineer by the fabricator. For acceptance of a brand, the fabricator shall furnish a brand registration and guarantee meeting the approval of the engineer and showing the brand name or designation, the manner in which it will appear on the fabricated beams, the typical mechanical properties, chemical composition if specified, the class and type of guardrail, and other specified properties. The fabricator shall also guarantee that as long as material is furnished under that brand and designation, it will conform fully to the requirements of the specification and shall be replaced without cost to the engineer when found not in conformity with any of the specified requirements. The brand registration and guarantee shall be sworn to for the fabricator by a person having legal authority to bind the company. Upon approval of a brand registration and guarantee, that brand will be accepted without further certification. If, in subsequent actual field use, there is evidence of misbranding as determined by random sampling and detection of inadequate tensile strength, yield strength, elongation, improper coating, deficient thickness, or improper fabrication, the material will be rejected and approval for further use withdrawn until subsequently reapproved. Samples for test of any material offered for use may be taken at any time deemed desirable by the engineer.

5.3.2 The manufacturer or fabricator shall make such tests and measurements as necessary to insure that the material produced complies with all specification requirements. These tests and measurements shall be so identified by the identification symbols or code used on the beam that the manufacturer can produce specific reports showing these test results. Copies of reports of these tests shall be kept on file and shall be submitted to the engineer upon request.

5.3.3 The brand shall be removed or obliterated by the manufacturer or fabricator on all material where control tests, as outlined herein, do not show conformance to this specification.

6. MATERIALS

6.1 *Base Metal*—The beam, transition, end, and buffer sections shall consist of sheet made of open hearth, electric furnace, or basic oxygen steel and shall meet the mechanical properties specified in Section 8. The chemical composition of the base metal for Type IV beams shall be as approved by the engineer.

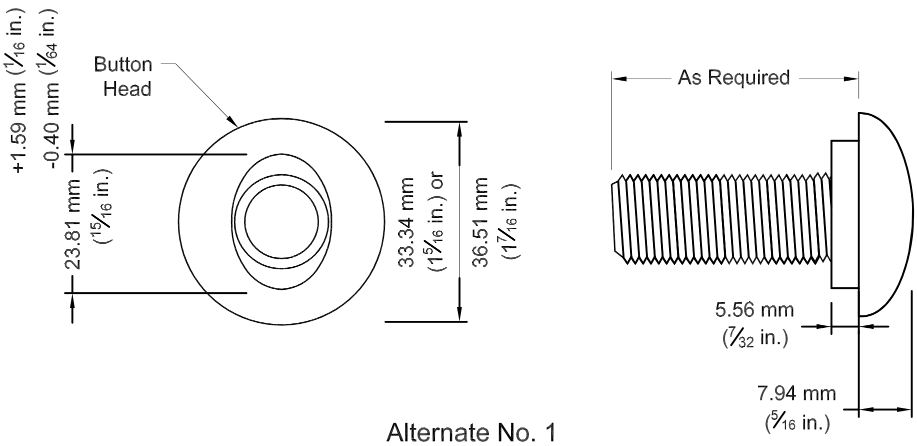
6.2 *Zinc*—The zinc used for the coating of Type I and II sections shall be as prescribed in M 120, and shall be at least equal to the grade designated as “Prime Western.”

6.3 *Bolts and Nuts*:

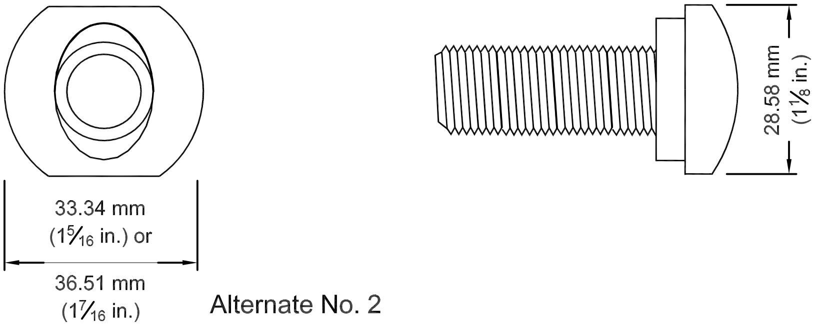
6.3.1 Unless otherwise specified, bolts and nuts for Types I, II, and III beams shall conform to or exceed the requirements of ASTM A 307 and shall be coated in accordance with Section 9.4.

6.3.2 Bolts and nuts for Type IV beams shall be of an approved corrosion resistant material and conform to or exceed the requirements of ASTM A 307.

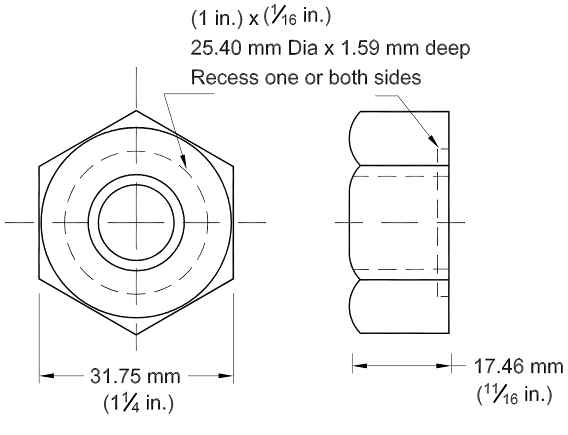
6.3.3 All connections or splices shall be formed with oval shoulder button headed bolts to minimize projections on the roadside of the guardrail. Splice and post bolts and nuts shall conform to one of the configurations shown in Figure 1 or Figure 2. Either of the alternate configurations may be furnished unless otherwise specified by the engineer.



Alternate No. 1

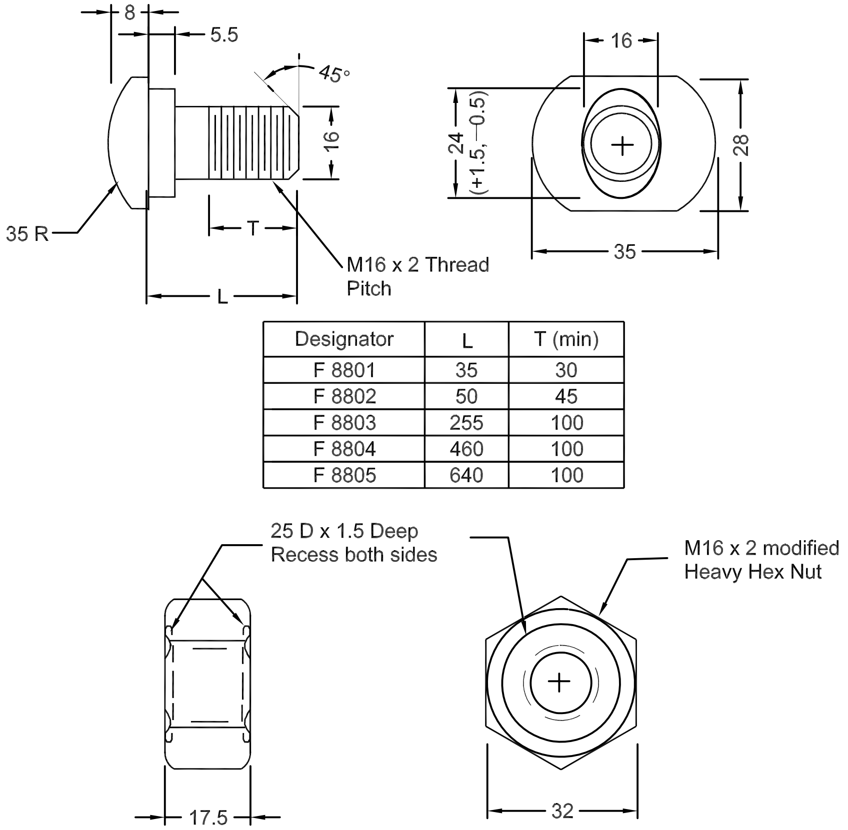


Alternate No. 2



Note: Oval shoulder shall have smooth radii and shall maintain an essentially full vertical height of the apex of the oval.
All dimensions shown on Alternate Bolt No. 1 also apply to Alternate Bolt No. 2. All dimensions are subject to manufacturer's tolerances except where allowable tolerances are shown.

Figure 1—15.88-mm ($^5/_8$-in.) Post or Splice Bolt and Nut



Designator	L	T (min)
F 8801	35	30
F 8802	50	45
F 8803	255	100
F 8804	460	100
F 8805	640	100

Notes:

1. The bolt shall have M16 × 2 threads as defined in ANSI B1.13M for Grade 6 g tolerances. Bolt material shall conform to ASTM F 568M for Class 4.6. Material for corrosion resistant bolts shall conform to ASTM F 568M for Class 8.8.3 bolts.
2. Nuts shall have ANSI B1.13M M16 × 2 Grade 6H threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B 18.2.4.1M Style 1 for zinc-coated hex nuts and ANSI B18.2.4.6M heavy hex corrosion resistant nuts shall conform to the requirements of M 291M for Class 8S3. Zinc-coated nuts shall be tapped over-size as specified in M 291M, except that a diametrical allowance of 510 mm shall be used instead of 420 mm.
3. Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

Figure 2—16-mm Post or Splice Metric Bolt and Nut

6.4 *Washers and Backup Plates*:

6.4.1 Washers shall be rectangular as shown in Figure 3. Washers for Types I, II, and III beams shall be galvanized in accordance with Section 9. Washers for Type IV beams shall be of an approved corrosion resistant steel. Back-up plates if specified for use at non-splice points shall consist of 305-mm (1-ft) sections of beams and shall be of the same Class and Type specified for the full-length beams.

6.5 *End or Buffer Sections*:

6.5.1 End or buffer sections shall be of the same or greater thickness of metal and the same type as the beam to which it is attached, or the engineer may specify the minimum thickness of metal and type.

7. MANUFACTURE

7.1 The beams and end or buffer sections shall be shaped and punched in conformance with the requirements shown in Figures 3 and 4. Transition sections shall be fabricated in accordance with Figure 5 and shall provide a smooth and uniform transition between beams. They shall be ready for assembly when delivered. Only drilling or cutting necessary for special connections and for sampling will be permitted in the field. Warped or deformed beams will be rejected. Beams to be erected on a radius of 46 m (150 ft) or less shall be shop curved to the appropriate curvature of the installation.

8. MECHANICAL PROPERTIES

8.1 The mechanical properties of the base metal shall conform to the following requirements:

8.1.1 *Beams and transition sections*:

- Yield Point, minimum, 345 MPa (50000 psi);
- Tensile Strength, minimum 483 MPa (70000 psi); and
- Elongation, in 50 mm (2 in.), minimum, 12 percent.

8.1.2 *End and buffer sections*:

- Yield Point, minimum, 227 MPa (33000 psi); and
- Tensile Strength, minimum 310 MPa (45000 psi).

8.1.3 Test specimens for mechanical properties shall be prepared and tested as specified in ASTM A 653 except that correction for thickness of zinc-coated specimens shall be 0.08 mm (0.003 in.) for Type I beam and 0.15 mm (0.006 in.) for Type II beam.

9. COATING REQUIREMENTS

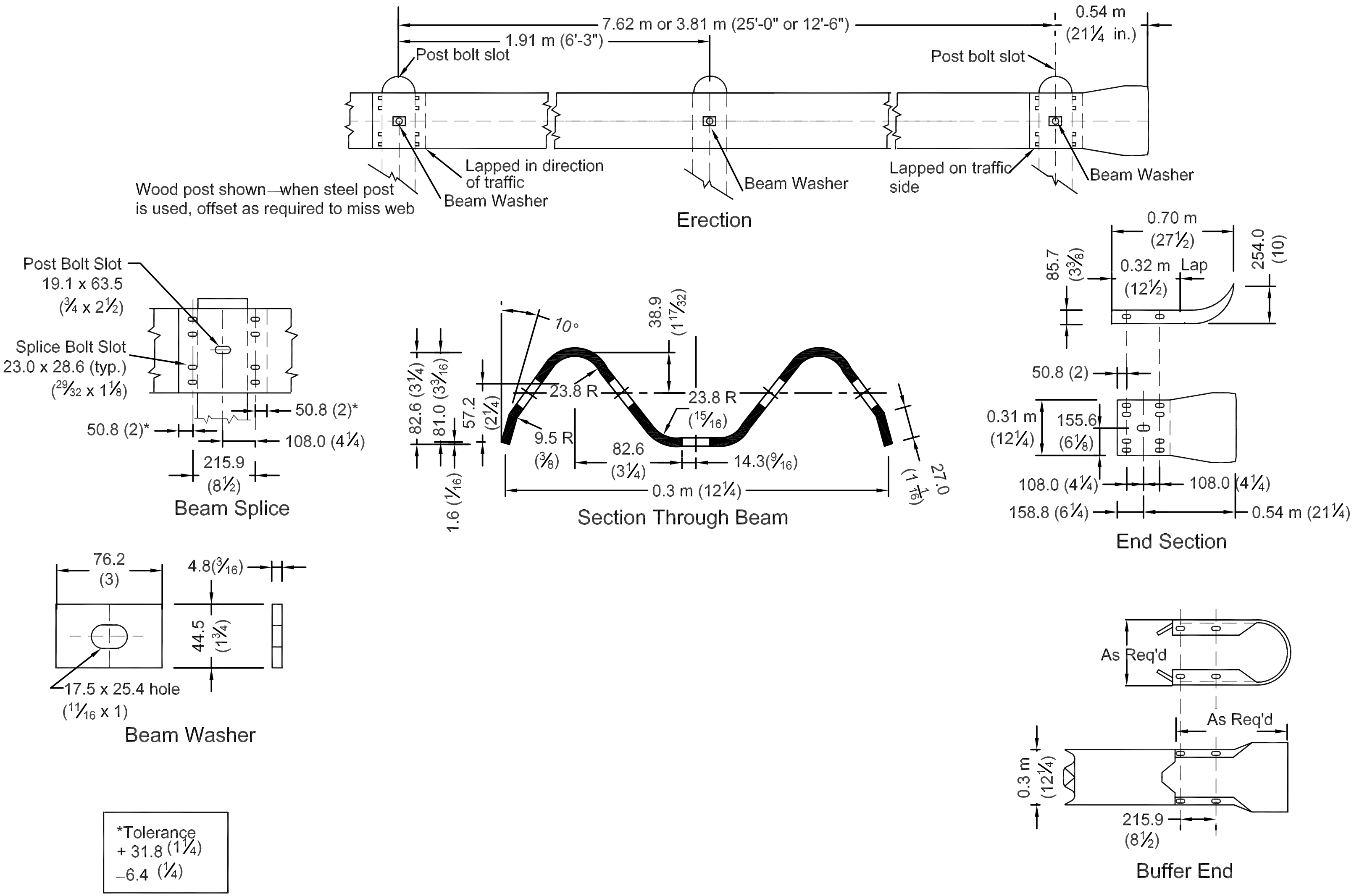
9.1 *Type I and II Beams*:

9.1.1 The beams may be galvanized before or after fabrication.

9.1.2 The mass of coating shall conform to the requirements prescribed in Table 1 for the types specified. The mass of coating is the total amount of galvanizing on both sides of a sheet or beam, expressed as grams per square meter (oz/ft^2) of sheet.

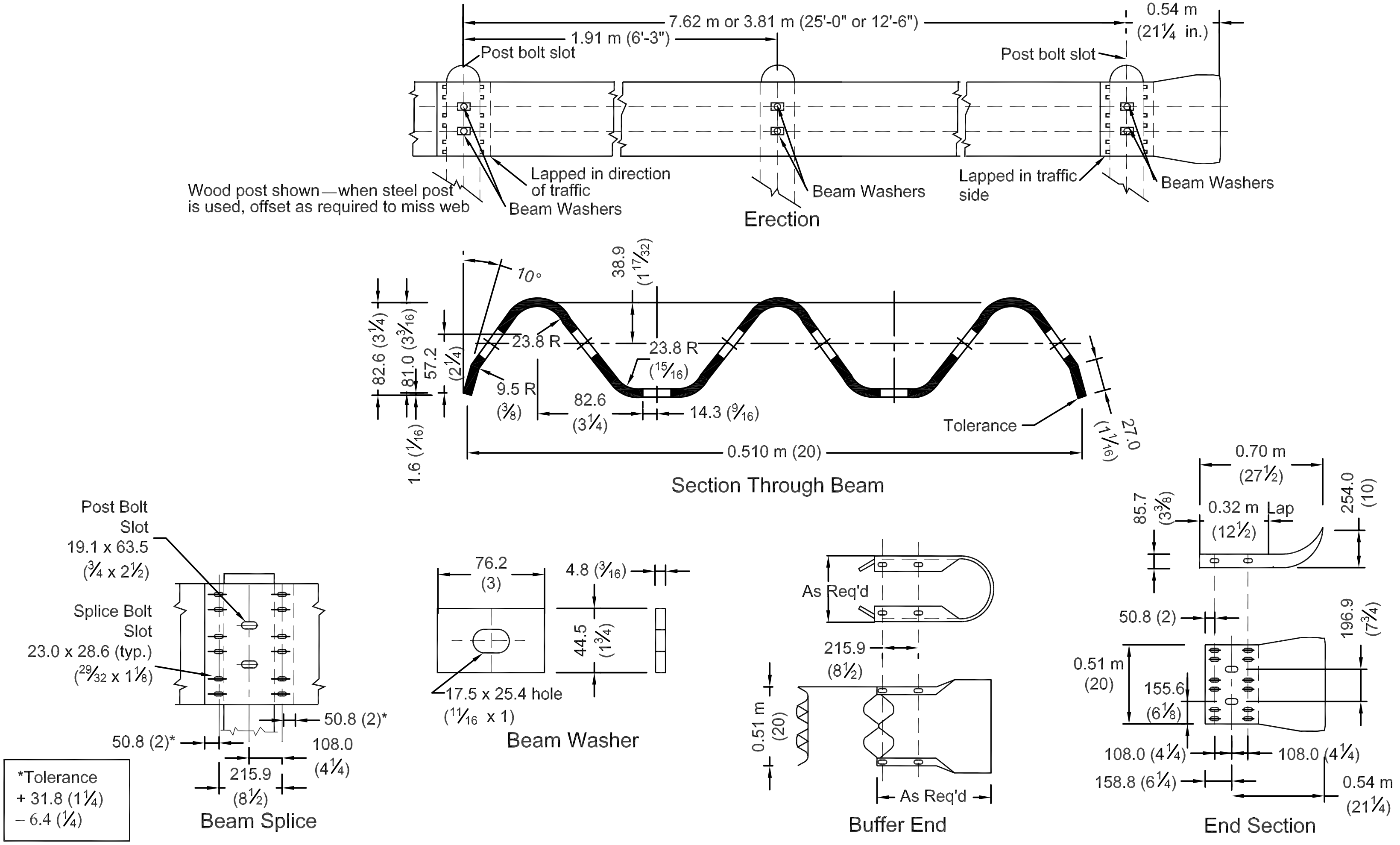
Table 1—Weight of Coating

	Weight of Coating			
	Min Check Limit Single-Spot Test		Min Check Limit Triple-Spot Test	
Type	g/m^2	oz/ft^3	g/m^2	oz/ft^2
I	550	1.80	610	2.00
II	1100	3.60	1220	4.00



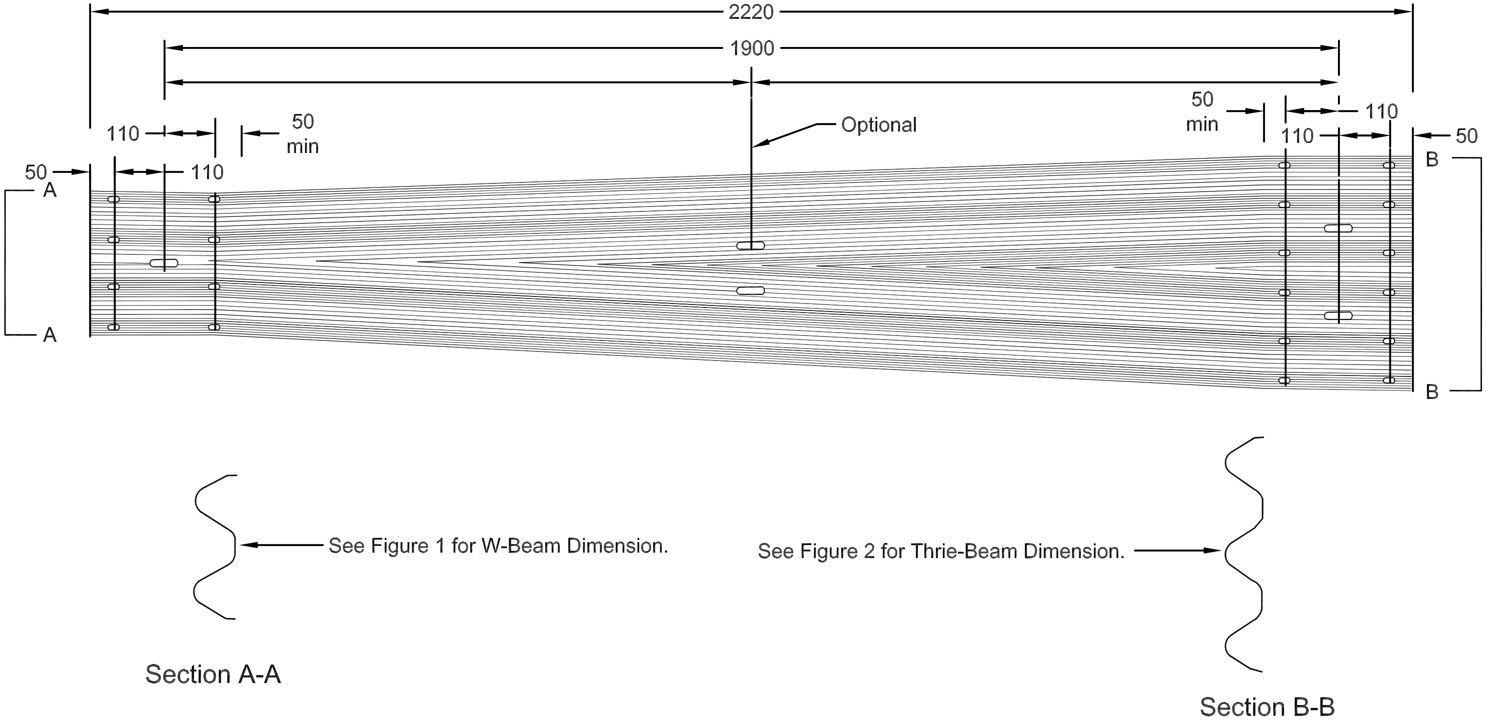
Notes:
1. All dimensions are subject to manufacturer’s tolerances except where allowable tolerances are shown.
2. All dimensions shown in millimeters unless otherwise noted. (All parenthetical values are in inches unless otherwise noted.)
3. Rectangular plate washers are optional only in the transition sections. They are not to be used in the main sections of strong-post guardrail.

Figure 3—W-Beam



Notes:
1. All dimensions are subject to manufacturer's tolerances except where allowable tolerances are shown.
2. All dimensions shown in millimeters unless otherwise noted. (All parenthetical values are in inches unless otherwise noted.)
3. Rectangular plate washers are optional only in the transition sections. They are not to be used in the main sections of strong-post guardrail.

Figure 4—Thrie Beam



Note: All dimensions are in millimeters.

Figure 5—Transition Section

9.1.3 The sheets or beams shall be of prime finish, that is, free from injurious defects such as blisters, flux, and uncoated spots. Uncoated edges resulting from transverse shearing or punching of holes will not be considered objectionable.

9.1.4 The coating shall be smooth, free of beading or sharp projections along the edges, and shall adhere tenaciously to the surface of the metal. The adherence of the zinc coating to the surface of the base metal shall be determined by cutting or prying with a stout knife, applied with considerable pressure in a manner tending to remove a portion of the coating by paring or whittling, and it shall not be possible to peel any portion of the coating so as to expose the base metal.

9.1.5 The test specimen size and method of tests for determining the mass of coating shall be as prescribed in T 65. At the option of the engineer, material may be accepted on the basis of magnetic gauge determinations made in accordance with ASTM E 376.

9.2 *Type III Beams*:

9.2.1 Beams that are to be painted shall be cleaned and shop painted with one coat of rust-inhibitive primer. The primer shall have a tough and durable surface and shall be thoroughly dry before the sheets are handled or packed for shipment.

9.3 *Type IV Beams*:

9.3.1 Beams of corrosion resistant steel shall not be painted or galvanized. They shall be so handled and stored that the traffic face of these beams, used in a continuous run of guardrail, shall not show a distinctive color differential.

9.4 *Bolts and Nuts*:

9.4.1 Bolts and nuts shall be hot-dip zinc coated in accordance with the requirements of M 232M/M 232, Class C or mechanically zinc coated in accordance with M 298, Class 50, Type 1.

9.5 *Washers*:

9.5.1 Washers shall be hot-dip zinc coated in accordance with the requirements of M 232M/M 232.

9.6 *Galvanizing Repair*:

9.6.1 Where the galvanizing on guardrail or fittings has been damaged, the coating shall be repaired by regalvanizing, or the surface repaired by painting with two coats of zinc dust/zinc oxide paint conforming to Federal Specification TT-P-641 or DOD-P-21035.

10. DIMENSIONS

10.1 *Sheet or Beam Thickness*:

10.1.1 The nominal thickness for the finished beam or sheet shall conform to the requirements as prescribed in Table 2.

Table 2—Beam or Sheet Thickness

	Beam or Sheet Thickness							
	Class A				Class B			
	Thickness		Tolerance Under Specified Thickness, No Limit for Over Thickness		Thickness		Tolerance Under Specified Thickness, No Limit for Over Thickness	
Type	mm	in.	mm	in.	mm	in.	mm	in.
I	2.74	0.108	0.23	0.009	3.51	0.138	0.25	0.010
II	2.82	0.111	0.23	0.009	3.58	0.141	0.25	0.010
III	2.67	0.105	0.23	0.009	3.43	0.135	0.25	0.010
IV	2.67	0.105	0.23	0.009	3.43	0.135	0.25	0.010

10.1.2 For fabricated beams, thickness measurements will be made on tangent portions of the cross section.

10.2 *Sheet Width*:

10.2.1 The beam elements shall be formed from sheets having nominal widths of 483 mm (19 in.) for W-beams and 749 mm ($29^1/_2$ in.) for thrie beams. Tolerance from the nominal width of minus 3.2 mm ($^1/_8$ in.) will be permissible.

Note 1—The requirements of Section 10.2.1 are intended to define the minimum width sheet permissible. Calculation of exact width dimensions from Figures 3 and 4 shows that the finished product may slightly exceed these widths. However, the dimensions of Figures 3 and 4 can be met within allowable tolerance by using the nominal widths. Use of sheets slightly greater than the nominal widths is permissible provided the tolerances in Figures 3 and 4 are met.

11. MARKING

11.1 Each beam element shall be identified by the following:

- Name or brand of manufacturer,
- Identification symbols or code for heat,
- Number and coating lot,
- AASHTO specification number, and
- Class and type.

11.2 Markings shall not be placed at such a location that they will be obscured after erection, or in a manner that the brand will be conspicuous to any traffic. Markings placed on the traffic face of the beam shall be placed in the valley of the center corrugation and shall be die imprinted with letters and numerals having a maximum height of 32 mm ($1^1/_4$ in.) and a minimum height of 19 mm ($^3/_4$ in.) and shall be clearly legible after galvanization of the rail elements.

11.3 Marking material shall be such as to resist obliteration during storage, transportation, and erection.

11.4 Markings for end sections and backup plates may be on durable tags securely attached to each section or bundle, except that when specified by the engineer, each individual piece shall be marked.

Standard Specification for

Chain-Link Fence

AASHTO Designation: M 181-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Chain-Link Fence

AASHTO Designation: M 181-10

1. SCOPE

1.1 This specification covers materials used in the construction of fences and gates that comprise (a) chain-link fence fabric and (b) posts, rails, ties, bands, bars, rods and other fittings, and hardware designed to support the fabric in a vertical, taut position.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 111M/M 111, Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
- M 120, Zinc
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 68M/T 68, Tension Testing of Metallic Materials (Discontinued)
- T 213M/T 213, Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles

2.2 *ASTM Standards*:

- B 26, Standard Specification for Aluminum-Alloy Sand Castings
- B 85, Standard Specification for Aluminum-Alloy Die Castings
- B 108, Standard Specification for Aluminum-Alloy Permanent Mold Castings
- B 117, Standard Practice for Operating Salt Spray (Fog) Apparatus
- B 209, Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
- B 211, Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire
- B 221, Standard Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes
- B 429, Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube
- B 750, Standard Specification for GALFAN (Zinc-5 % Aluminum-Mischmetal) Alloy in Ingot Form for Hot-Dip Coatings
- D 1535, Standard Practice for Specifying Color by the Munsell System
- D 1729, Standard Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials
- D 2247, Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods
- F 467, Standard Specification for Nonferrous Nuts for General Use

- F 468, Standard Specification for Nonferrous Bolts, Hex Cap Screws, and Studs for General Use
- F 668, Standard Specification for Polyvinyl Chloride (PVC) and Other Organic Polymer-Coated Steel Chain-Link Fence Fabric
- F 1043, Standard Specification for Strength and Protective Coatings on Steel Industrial Chain Link Fence Framework
- F 1083, Standard Specification for Pipe, Steel, Hot-Dipped Zinc-Coated (Galvanized) Welded, for Fence Structures
- F 1664, Standard Specification for Poly(Vinyl Chloride) (PVC) and Other Conforming Organic Polymer-Coated Steel Tension Wire Used with Chain-Link Fence
- G 152, Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
- G 155, Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

2.3 *ANSI Standard*:

- H35.2, Dimensional Tolerances for Aluminum Mill Products

3. CLASSIFICATION

3.1 Chain-link fabric, posts, rails, ties, bands, bars, rods and other fittings, and hardware covered by this specification shall be composed of the following types of material, as specified:

- *Type I*—Zinc-coated steel,
- *Type II*—Aluminum-coated steel,
- *Type III*—Aluminum alloy, and
- *Type IV*—Polyvinyl Chloride (PVC) and other organic polymer-coated steel.

3.1.1 Zinc-5 Percent Aluminum-Mischmetal alloy meeting the requirements of ASTM B 750 may be substituted for zinc coating (hot-dipped) at the application rate specified herein for hot-dip zinc coating.

3.2 *Metallic-coated steel posts, rails, or gate frames are furnished in two grades as follows*:

3.2.1 *Grade 1*—Steel posts, rails, or gate frames may be round or other shapes and shall have a hot-dip zinc interior and exterior coating meeting the requirements of ASTM F 1083 and shall have a hot-dip zinc interior and exterior coating as prescribed in this specification.

3.2.2 *Grade 2*—Steel posts, rails, or gate frames shall be round pipe or tubing manufactured by electric resistance welding and shall have an exterior coating of hot-dip zinc plus an organic topcoat and a zinc-rich or hot-dip zinc interior coating conforming to the requirements of ASTM F 1043 Group IC.

3.3 *Type IV fabric is furnished in two classes of coating as follows*:

3.3.1 *Class A*—Fabric with polymer-coated wire made by coating the wire with zinc by either the hot-dip or electrolytic process, prior to the wire being coated with either an extruded polymer coating or an extruded and bonded polymer coating.

3.3.2 *Class B*—Fabric with bonded polymer-coated wire shall be made with wire coated with zinc by the hot-dip or electrolytic process, prior to having a polymer coating thermally fused and bonded to a primer that has been thermally cured onto the zinc-coated wire.

3.4 *Type I fabric is furnished in two classes of coating as follows*:

3.4.1 *Class C*—Fabric has a specified coating mass of 366 g/m^2 (1.2 oz/ft^2), and

3.4.2 *Class D*—Fabric has a specified coating mass of 610 g/m^2 (2.0 oz/ft^2).

3.5 Type I tension wire is furnished in three classes as follows:

3.5.1 *Class 1*—Wire has a minimum coating mass of 244 g/m^2 (0.8 oz/ft^2),

3.5.2 *Class 2*—Wire has a minimum coating mass of 366 g/m^2 (1.2 oz/ft^2), and

3.5.3 *Class 3*—Wire has a minimum coating mass of 610 g/m^2 (2.0 oz/ft^2).

3.6 The type of fabric and type of framework need not be the same.

4. DESCRIPTION OF TERMS

4.1 Unless the context clearly indicates another meaning, the terms used herein shall have the meaning as defined in Section 101, Definitions and Terms, *Guide Specifications for Highway Construction*, AASHTO (1998) or as amended.

4.2 *chain-link fence fabric*—a fencing material made from wire helically wound and interwoven in such a manner as to provide a continuous mesh without knots or ties except in the form of knuckling or of twisting to form the selvage of the fabric.

4.3 *knuckling*—the selvage obtained by interlocking adjacent pairs of wire ends and bending the wire back into a loop.

4.4 *twisting*—the type of selvage obtained by twisting adjacent pairs of wire ends together in a close helix of 1.5 machine turns, which is the equivalent to three full twists and cutting the wire end at an angle. The wire ends beyond the twist shall be at least 6.4 mm ($^1/_4$ in.) long.

5. ORDERING INFORMATION

5.1 Orders for chain-link fence fabric purchased to this specification shall include the following information:

5.1.1 Quantity of fabric (Section 17);

5.1.2 Number of gates;

5.1.3 Type (Section 3) and if applicable, grade or class;

5.1.4 Size of mesh;

5.1.5 Size of wire;

5.1.6 Height of fabric;

5.1.7 Diamond count, if specified;

5.1.8 Type of selvage, if nonstandard;

5.1.9 For Type IV fabric, the class of polymer coating, and for Class A fabric whether an extruded coating or an extruded and bonded coating is required;

5.1.10 Color, if applicable;

5.1.11 Type and class of tension wire;

5.1.12 Type, grade, size, shape, and number of or spacing of posts, rails, rods, and other fittings;

5.1.13 Certification, if required;

5.1.14 AASHTO Designation and date of issue; and

5.1.15 Exceptions to this specification, or special requirements, if any.

Note 1—These details may be covered in whole, or in part, by accompanying the order with design drawings and notations thereon.

CHAIN-LINK FENCE FABRIC

6. MATERIALS (FABRIC)

6.1 Base metal for Type I, II, and IV chain-link fence fabric shall be steel of such quality and purity that, when drawn to the size of wire specified and coated as specified, the finished fabric shall be of uniform quality and have the properties and characteristics as prescribed in this specification.

6.2 Wire used for the manufacture of fabric that is zinc-coated, aluminum-coated, or polymer-coated before weaving shall meet the requirements of this specification and shall be capable of being woven into fabric without the coating cracking, flaking, or peeling to such an extent that any of the coating material can be removed by rubbing with the bare fingers.

Note 2—Loosening or detachment during the adhesion test of superficial, small particles of zinc, aluminum, or polymer formed by mechanical polishing of the surface of the coated wire should not be considered cause for rejection.

6.3 Zinc used for hot-dip galvanized or electrolytically zinc-plated coatings shall be of any grade of zinc conforming to the requirements of M 120.

6.4 Ingot or pig aluminum used for coating shall conform to the following impurity limits:

- Copper, max, percent 0.10
- Iron, max, percent 0.50

6.5 Polymer coatings shall be formulated to conform to the requirements of this specification. These coatings shall be either ultraviolet resistant, or shall contain a UV inhibitor.

6.6 Type III chain-link fence fabric shall be made of aluminum alloy wire meeting the requirements of ASTM B 211, alloy 6061-T89 or T94. The finished fabric shall be of uniform quality and have the properties and characteristics as prescribed in this specification.

7. MANUFACTURE (FABRIC)

7.1 Wire used for zinc-coated, chain-link fence may be coated before or after weaving into fabric. Fabric that is zinc-coated after weaving shall be hot-dip galvanized in a continuous process and the coating shall not be applied to the fabric in roll form. Wire that is zinc-coated before weaving into fabric may be either electrolytically zinc-plated or hot-dip galvanized.

7.2 Wire used for aluminum-coated steel, chain-link fabric shall be coated before weaving into fabric.

7.3 Wire used for polymer-coated chain-link fence shall be coated before weaving into fabric.

8. WEAVE (FABRIC)

8.1 The wire shall be woven throughout in the form of approximately uniform square mesh, having parallel sides and horizontal and vertical diagonals of approximately uniform dimensions. The top and bottom of the fabric shall be knuckled or twisted as specified in Section 13.

8.2 A typical diamond count for each standard height is shown in Tables 1 and 2. Other diamond counts are permissible provided they are consistent within a lot. The purchaser has the option to specify the diamond count in the order, Section 5.1.7.

Table 1—Typical Diamond Counts (mm)

Specified Diameter of Types I, II, and III Coated Wire and Type IV's Metallic-Coated Core Wire, mm	Mesh Size, mm	Diamond Count Fabric Height, mm[a]									
		914.4	1066.8	1219.2	1524	1828.8	2133.6	2438.4	2743.2	3048	3657.6
4.88	50.8	266.7	317.5	342.9	444.5	520.7	622.3	698.5	800.1	876.3	1054.1
3.76	50.8	266.7	317.5	342.9	444.5	520.7	622.3	698.5	800.1	876.3	1054.1
3.05	50.8	266.7	317.5	342.9	444.5	520.7	622.3	—	—	—	—
3.05	44.4	—	—	—	—	—	—	800.1	901.7	1003.3	1206.5

[a] Diamond count not available for 25.4-mm mesh size.

Table 2—Typical Diamond Counts (in.)

Specified Diameter of Types I, II, and III Coated Wire and Type IV's Metallic-Coated Core Wire, in.	Mesh Size, in.	Diamond Count Fabric Height, in.[a]									
		36	42	48	60	72	84	96	108	120	144
0.192	2	$10^{1}/_{2}$	$12^{1}/_{2}$	$13^{1}/_{2}$	$17^{1}/_{2}$	$20^{1}/_{2}$	$24^{1}/_{2}$	$27^{1}/_{2}$	$31^{1}/_{2}$	$34^{1}/_{2}$	$41^{1}/_{2}$
0.148	2	$10^{1}/_{2}$	$12^{1}/_{2}$	$13^{1}/_{2}$	$17^{1}/_{2}$	$20^{1}/_{2}$	$24^{1}/_{2}$	$27^{1}/_{2}$	$31^{1}/_{2}$	$34^{1}/_{2}$	$41^{1}/_{2}$
0.120	2	$10^{1}/_{2}$	$12^{1}/_{2}$	$13^{1}/_{2}$	$17^{1}/_{2}$	$20^{1}/_{2}$	$24^{1}/_{2}$	—	—	—	—
0.120	$1^{3}/_{4}$	—	—	—	—	—	—	$31^{1}/_{2}$	$35^{1}/_{2}$	$39^{1}/_{2}$	$47^{1}/_{2}$

[a] Diamond count not available for 1-in. mesh size.

9. SIZE OF MESH (FABRIC)

9.1 The size of mesh shall be as indicated in Tables 3 and 4. The permissible variation from the specified size of mesh shall be ±3.2 mm (±$^1/_8$ in.).

Table 3—Size of Wire and Mesh (mm)

Specified Diameter of Types I, II, and III Coated Wire and Type IV's Metallic-Coated Core Wire		Size of Mesh,	Height of Fabric,
mm	Gauge	mm	mm
4.88	6	50.8	914.4, 1066.8, 1219.2, 1524, 1828.8, 2133.6, 2438.4, 2743.2, 3048, 3657.6
3.76	9	50.8	914.4, 1066.8, 1219.2, 1524, 1828.8, 2133.6, 2438.4, 2743.2, 3048, 3657.6
3.05	11	50.8	914.4, 1066.8, 1219.2, 1524, 1828.8, 2133.6
3.05	11	44.4	2438.4, 2743.2, 3048, 3657.6
3.76	9	25.4	914.4, 1066.8, 1219.2, 1524, 1828.8, 2133.6
3.05	11	25.4	914.4, 1066.8, 1219.2, 1524, 1828.8, 2133.6

Table 4—Size of Wire and Mesh (in.)

Specified Diameter of Types I, II, and III Coated Wire and Type IV's Metallic-Coated Core Wire		Size of Mesh,	Height of Fabric,
in.	Gauge	in.	in.
0.192	6	2	36, 42, 48, 60, 72, 84, 96, 108, 120, 144
0.148	9	2	36, 42, 48, 60, 72, 84, 96, 108, 120, 144
0.120	11	2	36, 42, 48, 60, 72, 84,
0.120	11	1$^3/_4$	96, 108, 120, 144
0.148	9	1	36, 42, 48, 60, 72, 84
0.120	11	1	36, 42, 48, 60, 72, 84

9.2 The size of mesh shall be determined by measuring the minimum clear distance between the wires forming the parallel sides of the mesh.

10. BREAKING STRENGTH (FABRIC)

10.1 Wire constituting the fabric shall meet the minimum breaking strength shown in Tables 5 and 6 when tested in accordance with T 68. Specimens to establish conformance to this requirement shall be individual pickets from a section of the fence fabric, sampled in accordance with Section 18. The specimens shall be of sufficient length so as to be firmly gripped in the testing machine after straightening. The actual gauge length (distance between jaws) of the specimen shall be limited to the undeformed length of wire between the two adjacent straightened bends.

Table 5—Breaking Loads (mm and kN)

Specified Diameter of Types I, II, and III Coated Wire and Type IV's Metallic-Coated Core Wire		Breaking Loads		
mm	Gauge	Type I or II, kN	Type III, kN	Type IV[a] Core Wire, kN
4.88	6	9.650	6.940	9.655
3.76	9	5.740	4.135	5.740
3.05	11	3.780	2.715	3.780

[a] Polymer coating may be mechanically removed prior to testing, if desired.

Table 6—Breaking Loads (in. and lbf)

Specified Diameter of Types I, II, and III Coated Wire and Type IV's Metallic-Coated Core Wire		Breaking Loads		
in.	Gauge	Type I or II, lbf	Type III, lbf	Type IV[a] Core Wire, lbf
0.192	6	2170	1560	2170
0.148	9	1290	930	1290
0.120	11	850	610	850

[a] Polymer coating may be mechanically removed prior to testing, if desired.

11. SIZE OF WIRE (FABRIC)

11.1 Chain-link fabric shall be fabricated from wire diameters as necessary to meet the requirements of Tables 3 and 4. The diameter of the wire shall be determined as the average of two readings taken at right angles to each other on the straight portion of the parallel sides of the mesh and measured to the nearest 0.02 mm (0.001 in.). The permissible variation from the specified diameter of the wire shall be ±0.13 mm (±0.005 in.) (see Note 3).

11.2 For Type I or II fabric, the specified diameter is the coated wire diameter. Measurements shall be made on the coated wire and allowed tolerance applied to the coated diameter.

11.3 For Type IV fabric, the specified diameter is the metallic-coated core wire diameter, and the polymer coating shall not be used when determining wire size. The allowed tolerance (see Section 11.1) shall be applied to the metallic-coated core wire diameter.

11.4 For Type III fabric, the specified diameter is the finished wire diameter.

Note 3—On metallic-coated wire, the tolerances apply to uniform areas of coated wire. Irregular deposits of coating shall be ignored.

12. HEIGHT OF FABRIC (FABRIC)

12.1 Chain-link fabric shall be furnished in the standard heights shown in Tables 3 and 4. The height of fabric shall be the overall dimension from ends of twists or knuckles. Permissible variation from the specified height shall be ±25.4 mm (±1 in.) for standard selvage.

13. SELVAGE (FABRIC)

13.1 Fabric with 50.8-mm (2-in.) mesh, and less than 1.8 mm (72 in.) high shall be knuckled at both selvages. Fabric 1.8 mm (72 in.) high or higher shall be knuckled at one selvage and twisted at the other.

13.2 Fabrics with mesh size less than 50.8 mm (2 in.) shall be knuckled at both selvages.

13.3 The selvages specified in Sections 13.1 and 13.2 are the standard selvages. Other selvages may be supplied only if specified by the purchaser. **Caution**—Twisted selvages for fences less than 1.8 m (72 in.) high are not recommended because of consumer safety considerations.

14. MASS OR THICKNESS OF COATING (FABRIC)

14.1 The mass of coating on Type I fabric shall be not less than as shown in Tables 7 and 8, as determined from the average of all specimens representing the lot and not less than 336 g/m^2 (1.1 oz/ft^2) on an individual specimen of Type I, Class C fabric or 549 g/m^2 (1.8 oz/ft^2) on an individual specimen of Type I, Class D fabric.

14.2 The mass of coating on Type II fabric shall be not less than as shown in Tables 7 and 8, as determined from the average of all specimens representing the lot and not less than 92 g/m^2 (0.30 oz/ft^2) on an individual specimen of 3.76- and 4.88-mm (0.148 and 0.192 in.) diameter wire or 76.3 g/m^2 (0.25 oz/ft^2) on an individual specimen of 3.05-mm (0.120-in.) diameter wire.

Table 7—Mass of Metallic Coating on Type I or II Fabric

Specified Diameter of Coated Wire		Mass of Coating of Uncoated Wire Surface		
		Type I Zinc		Type II Aluminum,
		Class C	Class D	
mm	Gauge	g/m^2	g/m^2	g/m^2
4.88	6	366	610	122.1
3.76	9	366	610	122.1
3.05	11	366	610	106.8

Table 8—Weight of Metallic Coating on Type I or II Fabric

Specified Diameter of Coated Wire		Weight of Coating of Uncoated Wire Surface		
		Type I Zinc		Type II Aluminum,
		Class C	Class D	
in.	mm	oz/ft^2	oz/ft^2	oz/ft^2
0.192	6	1.2	2.0	0.40
0.148	9	1.2	2.0	0.40
0.120	11	1.2	2.0	0.35

14.3 The minimum metallic mass of coating on the wire for Type IV fabric and the thickness of polymer shall be as specified in Tables 9 and 10 as determined from the average of all specimens representing the lot.

Table 9—Mass or Thickness of Type IV Coatings

Specified Diameter of Metallic-Coated Core Wire		Mass of Zinc Coating of Uncoated Wire Surface,	Mass of Aluminum Coating of Uncoated Wire Surface,	Polymer Thickness Range	
				Class A,	Class B,
mm	Gauge	g/m^2	g/m^2	mm	mm
4.88	6	122.1	61	0.38	0.15
				to	to
3.76	9	91.5	61	0.64	0.25
3.05	11	91.5	61	All gauges	All gauges

Note: The polymer coating shall not be used when determining wire size.

Table 10—Weight or Thickness of Type IV Coatings

Specified Diameter of Metallic-Coated Core Wire		Weight of Zinc Coating of Uncoated Wire Surface,	Weight of Aluminum Coating of Uncoated Wire Surface,	Polymer Thickness Range	
				Class A,	Class B,
in.	Gauge	oz/ft^2	oz/ft^2	in.	in.
0.192	6	0.40	0.20	0.015	0.006
				to	to
0.148	9	0.30	0.20	0.025	0.010
0.120	11	0.30	0.20	All gauges	All gauges

Note: The polymer coating shall not be used when determining wire size.

14.4 The mass or thickness of coating shall be determined on one or more pieces of wire removed from the fabric, as specified by the purchaser. These specimens may be of any length over 305 mm (12 in.), but preferably about 610 mm (24 in.), and shall include both bends and straight sections, but shall not include either twists or knuckles.

14.5 Test specimens of Type I or II fabric shall be free of lumps, beads, and drops of coating material, as determined by passing the specimen through a circular gauge, and no more than 1.3 mm (0.05 in.) thick having a diameter 0.56 ± 0.03 mm (0.022 ± 0.001 in.) greater than the specified diameter of coated wire. Any lumps or protrusions which will increase the diameter by more than

0.56 mm (0.022 in.) shall be removed with a knife or file to a size which will pass through the circular gauge.

14.6 The method of determining mass or thickness of coating shall be as follows:

14.6.1 *Type I or IV, Zinc Coating*—The mass of zinc coating shall be determined in accordance with T 65M/T 65.

14.6.2 *Type II, Aluminum Coating*—The mass of aluminum coating shall be determined in accordance with T 213M/T 213.

14.6.3 *Type IV, Polymer Coating, Class A*—Measure the minimum and the maximum thicknesses of the polymer coated wire with a suitable micrometer and record these dimensions. Then mechanically strip the polymer coating from the metallic-coated core wire and measure the diameter of the metal coated wire. The allowed tolerance in Section 11.1 shall be applied to the diameter of the metallic-coated core wire.

14.6.4 *Type IV, Polymer Coating, Class B*—Strip the polymer coating by chemical means and determine the diameter of the metallic-coated core wire. Scrape the coating from one side of the wire and measure the reduced diameter with a micrometer. The thickness of coating at this point is the difference between the measurement obtained and the measured diameter of the metallic-coated core wire. In a similar manner, determine the thickness of coating at right angles to the first determinations.

Note 4—When removing polymer coating by scraping, take care not to remove any of the metallic surface.

15. PROPERTIES OF TYPE IV, POLYMER-COATED WIRE (FABRIC)

15.1 The polymer-coated wire from which the fabric is woven shall have a demonstrated ability to conform to the following requirements:

15.2 *Adhesion Test*—Class A, extruded and bonded, must conform to the requirements of Section 15.2.1. Class B, bonded, must conform to the requirements of Section 15.2.2. Class A, extruded, is not subject to adhesion test.

15.2.1 Three specimens from each lot shall be tested. Measure a distance of 19 mm ($^3/_4$ in.) from the end of the specimen. With a regular hand grip wire stripper, exert maximum hand pull parallel to the axis of the wire. Attempt to remove the measured portion of the vinyl sleeve from the core wire. The lot shall be acceptable if the vinyl sleeve is not capable of being removed from the core wire on all three specimens.

15.2.2 Three specimens from each lot shall be tested. Make two cuts parallel to the axis of the wire through the coating, approximately 2 mm ($^1/_{16}$ in.) apart and at least 13 mm ($^1/_2$ in.) long. With a knife, peel back a section of the coating between 3 mm ($^1/_8$ in.) and 6 mm ($^1/_4$ in.) long to produce a tab. Attempt to remove the 2-mm ($^1/_{16}$-in.) strip of coating by pulling the tab. The lot shall be acceptable if the coating breaks rather than separates from the core wire on all three specimens.

15.3 *Accelerated Aging*—Polymer-coated wire from which the fabric is woven shall withstand exposure for 1000 hours when tested in accordance with ASTM G 152 Table X1.1 Cycle 1 or ASTM G 155 Table X3.1 Cycle 1. The product shall be construed to have failed the test if:

15.3.1 The wire fails to withstand the mandrel bend test described in Section 15.4.

15.3.2 Shrinkage of the polymer coating is greater than 5.2 mm/m ($^1/_{16}$ in./ft) of wire.

15.3.3 There is a significant change in color or gloss of the polymer surface as determined by visual inspection.

15.4 *Mandrel Bend*—The mandrel bend test shall be performed on an individual picket removed from the fabric. The specimen may be any length of wire over 305 mm (12 in.) and shall include both bends and straight sections, but shall not include either twists or knuckles. The polymer-coated wire when subjected to a single bend at –28.9ºC (–20ºF) around a mandrel no larger than 10 times the diameter of the wire shall not exhibit breaks or cracks in the polymer coating.

15.5 *Color*—Unless otherwise stipulated by the purchaser, the color of the polymer in both Class A and Class B fabric shall be in accordance with the standard colors contained in Table 11.

Table 11—Standard Polymer Colors

	Munsell Units (ASTM D 1535 and ASTM D 1729)		
	Medium Green	Dark Green	Black
Hue	7.5G to 2.5G	0.1G to 7.5G	See chroma tolerance
Value	3.5 to 4.5	2.3 to 3.3	1.3 to 2.1
Chroma	Greater than 6	1 to 4	Max = 0.5 (any hue)

15.5.1 Compliance with this requirement shall be determined by comparison of specimens of the polymer-coated wire to standard flat specimens of fused film of approximately the thickness specified for the polymer coating to be applied to the wire, and measuring at least 38 by 38 mm ($1^1/_2$ by $1^1/_2$ in.).

15.5.2 Standard flat specimens for the evaluation of color of Class A polymer coating shall be prepared by milling, calendering, or compression molding polymer pellets using temperatures approximating those to be used in the extrusion process.

15.5.3 Standard flat specimens for the evaluation of Class B polymer coatings shall be prepared by thermally fusing polymer powder onto a suitable base using temperatures approximating those to be used in the powder-coating process.

15.5.4 The color of the standard flat specimens shall be determined in accordance with ASTM D 1535 and ASTM D 1729.

16. WORKMANSHIP (FABRIC)

16.1 Chain-link fabric shall be produced by methods recognized as good commercial practices. Excessive roughness, blisters, sal-ammoniac spots, bruises, flaking, frozen knuckles, or other defects if present to any considerable extent shall provide a basis for rejection. Polymer coatings shall be without voids and without tears or cuts that reveal the substrate.

17. STANDARD LENGTH OF ROLLS (FABRIC)

17.1 The standard length of roll shall be 15.2 m (50 ft) ±1 percent except as otherwise agreed upon at the time of purchase.

17.2 The length of roll shall be determined by unrolling a roll of fabric on a flat surface and exerting tension by appropriate means to remove all slack. The tension applied shall not reduce the actual height of the fabric by more than 5.2 mm/m ($^1/_{16}$ in./ft) of height or by more than 12.7 mm ($^1/_2$ in.), whichever is less.

18. SAMPLING AND NUMBER OF TESTS (FABRIC)

18.1 A lot shall be 50 rolls or fraction thereof of chain-link fabric of the same size and type offered for inspection at one time. One roll from every lot shall be taken at random as a sample for test purposes. However, in no case shall fewer than two rolls from the entire quantity offered for inspection be sampled and tested, except when the entire quantity offered for inspection is fewer than 10 rolls; then only one roll shall be selected for the sample.

18.2 Sample rolls selected shall be inspected for weave (Section 8), size of mesh (Section 9), diamond count (Section 8.2), wire size (Section 11), height of fabric (Section 12), selvage (Section 13), and length of roll (Section 17).

18.3 Test specimens shall be taken from the outside end of the sample rolls and tested for breaking strength (Section 10) and, if applicable, mass or thickness of coating (Section 14).

18.4 If material tested fails to meet any of the requirements of this specification, the roll sampled shall be rejected, and two additional rolls shall be tested from the same lot, both of which shall meet the requirements in every respect or the lot represented by the samples will be rejected.

18.5 The manufacturer may elect to test for breaking strength and mass or thickness of coating before weaving the wire into fabric; however, the purchaser reserves the right to sample and test wire from the complete fabric for compliance.

19. INSPECTION (FABRIC)

19.1 The engineer, or his representative, shall have free entry, at all times, to all parts of the manufacturer's or fabricator's works that concern the manufacture or fabrication of materials furnished under this specification. Each product or article furnished under this specification shall be subject to inspection at the factory, fabricating plant, in laboratories of the purchaser's choosing or at the point of delivery. The engineer reserves the right to sample and test each product or article subsequent to acceptance at the place of manufacture or fabrication, to determine conformance with the requirements of this specification or to verify a certification.

20. CERTIFICATION AND REPORTS (FABRIC)

20.1 When specified by the purchaser in the contract or order, a manufacturer's certification that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements shall be furnished. When specified in the purchase order or contract, a report of the test results shall be furnished.

21. PACKAGING, MARKING, AND LOADING (FABRIC)

21.1 Each length of fabric shall be tightly rolled and firmly tied. Each roll of fabric shall carry a tag showing the length, kind of base metal, kind of coating, specified wire size, mesh size, height of fabric, and the name or mark of the manufacturer.

TENSION WIRE

22. MATERIALS AND MANUFACTURE (TENSION WIRE)

22.1 Tension wire shall be steel coil spring wire.

23. SIZE OF WIRE (TENSION WIRE)

23.1 The diameter of the metallic-coated wire shall be 4.50 ± 0.13 mm (0.177 in. ± 0.005 in.) as determined from the average of two readings taken at right angles to each other. The diameter shall be measured on any one of the test specimens or it may be taken on the unsampled length of wire furnished. The diameter shall be measured in an area with uniform coating.

24. BREAKING STRENGTH (TENSION WIRE)

24.1 The metallic coated wire shall have a breaking strength of 8.675 kN (1950 lbf) minimum and 14.2 kN (3200 lbf) maximum as determined from the average of the three specimens representing the lot. Breaking strength shall be determined in accordance with T 68 or T 68M.

25. MASS OF COATING (TENSION WIRE)

25.1 Zinc-coated tension wire shall be furnished with Class 1 zinc coating unless otherwise specified. The mass of coating shall be the average of the three specimens representing the lot. Mass of coating shall be determined in accordance with T 65M/T 65.

25.2 Aluminum-coated tension wire shall have a mass of aluminum coating not less than 37.2 g/m^2 (0.4 oz/ft^2) of uncoated wire surface as determined from the average of the three specimens representing the lot. Mass of coating shall be determined in accordance with T 213M/T 213.

25.3 Polymer coated tension wire shall conform to the requirements of ASTM F 1664.

26. SAMPLING AND NUMBER OF TESTS (TENSION WIRE)

26.1 A lot is defined as all the material of the same size and type presented at one time for inspection. Test specimens shall be any length over 305 mm (12 in.). Six specimens shall be taken, each from a different roll or piece, if possible. Three specimens shall be tested for breaking strength, and three shall be tested for mass of coating. Size of wire may be determined from any one of the six specimens.

26.2 If the material tested fails to meet any of the requirements of this specification, the lot shall be resampled with double the number of specimens taken from the lot. All retest specimens shall meet the requirements in all respects, or the lot represented will be rejected.

27. INSPECTION (TENSION WIRE)

27.1 The provisions of Section 19 shall apply to tension wire.

28. CERTIFICATION AND REPORTS (TENSION WIRE)

28.1 The provisions of Section 20 shall apply to tension wire.

POSTS, HARDWARE, AND FITTINGS

29. MATERIALS (POSTS, HARDWARE, AND FITTINGS)

29.1 Steel posts, rails, and gate frames shall be one of the following:

29.1.1 Grade 1 steel posts, rails, and gate frames shall be of a shape approved by the engineer and shall be of commercial quality or better, weldable steel produced by the open hearth, electric furnace, or basic oxygen process conforming to the requirements of ASTM F 1083.

29.1.2 Grade 2 steel posts, rails, and gate frames shall be round pipe or tubing manufactured by cold-rolling and electric resistance welding of steel strip conforming to the requirements of ASTM F 1043.

29.2 Aluminum-alloy posts, rails, and gate frames shall be produced of alloy 6063 and shall conform to the requirements of ASTM B 429, Schedule 40.

29.3 Miscellaneous fittings and hardware to be metallic coated shall be of commercial quality steel or better, or cast or malleable iron as appropriate to the article. The steel or iron shall have sufficient strength to provide a balanced design.

29.4 Miscellaneous aluminum-alloy fittings and hardware shall be of extruded wrought or cast aluminum alloy conforming to the requirements set forth in Table 12.

Table 12—Miscellaneous Aluminum-Alloy Fittings and Accessories

		Aluminum-Alloy	
Nomenclature	Type of Material	Alloy and Temper	ASTM Designation
Rail and brace ends, post tops and turnbuckles	Castings	356.0-T6, 712.0-T5, 713.0-T5, A360.0, 360.0, 413.0	B 26, B 85, B 108
Gate hinges, barbed wire extension arms, and other fittings	Castings	Same as above	
Stretcher bars and bands	Bar	6063-T6	B 221
Truss or brace rods		6061- T6	B 221
Flat band ties	Sheet	3003-H14	B 209
Bolts		6061-T6	F 468
Nuts		6061-T6	F 467

29.5 When agreed upon in writing between the purchaser and supplier, aluminum alloy fittings and hardware may be substituted for metallic-coated steel or cast or malleable iron fittings and hardware.

29.6 Zinc or polymer used for coating posts, rails, expansion sleeves, gate frames, hardware, or miscellaneous fittings shall comply with Section 6.

29.7 Zinc rich organic material for coating interior surfaces of Grade 2 pipe shall yield a dry film with a minimum total zinc content of 87 percent by mass of the total solids of the dried coating.

29.8 Material for coating the exterior of Grade 2 pipe shall be an organic material such as a cross-linked acrylic urethane or polyurethane.

30. BENDING STRENGTH (POSTS, HARDWARE, AND FITTINGS)

30.1 For any type and shape of post, rail, or gate frame, the product of the yield strength and the section modulus shall not be less than the product of the section modulus of size pipe specified in ASTM F 1083 schedule 40, Table 1 multiplied by 172 MPa (25000 psi).

30.2 The yield strength of Grade 2 pipe shall be determined in accordance with T 68 or T 68M, 0.2 percent offset method.

31. WEIGHT AND DIMENSION TOLERANCE (POSTS, HARDWARE, AND FITTINGS)

31.1 The following tolerances are permitted for round pipe or tubing used for steel posts, rails, or gate frames:

- Tolerance from specified weight ±10 percent
- Tolerance from specified dimensions ±5 percent
- Tolerance from specified wall thickness no more than –12.5 percent

31.2 A tolerance from the specified dimensions for aluminum-alloy posts, rails, and gate frames will be allowed in accordance with ANSI H35.2.

32. WEIGHT OR THICKNESS OF COATING (POSTS, HARDWARE, AND FITTINGS)

32.1 Hot-dip galvanized coating applied to Grade 1 steel posts and rails shall be applied uniformly to all surfaces. The mass of zinc coating shall be not less than 549 g/m^2 (1.8 oz/ft^2) as determined from the average results of two specimens taken for test in the manner prescribed in Section 35 and not less than 488 g/m^2 (1.6 oz/ft^2) on an individual specimen. The mass of coating shall be calculated by dividing the total mass of zinc, inside plus outside, by the total area, inside plus outside, of the surface coated.

32.2 Grade 2 posts and rails, furnished as steel pipe with a hot-dip galvanized zinc plus organic exterior coating, shall have the following masses or thicknesses of coating on the interior and exterior surfaces.

32.2.1 Hot-dip zinc on the exterior shall be not less than 274 g/m^2 (0.9 oz/ft^2) as determined from the average results of two specimens taken for test in the manner prescribed in Section 35 and not less than 244 g/m^2 (0.8 oz/ft^2) on an individual specimen. The mass of coating shall be calculated from the mass of zinc on the exterior surface only. The exterior zinc coating shall have a uniform chromate chemical treatment applied either as a separate treatment or simultaneously with the organic topcoat.

32.2.2 The hot-dip, zinc-coated exterior shall be topcoated with a clear organic coating such as urethane or polyurethane. The coating shall not be less than 0.3 mils dry film thickness at any point as determined on two specimens taken for test in the manner prescribed in Section 35. The organic coating material shall comply with the performance requirements as specified in Section 33.

32.2.3 The interior surface of this pipe shall have either a zinc-rich, organic coating or a hot-dip, galvanized zinc coating as follows:

32.2.3.1 The dry film thickness of zinc-rich, organic interior coatings shall be not less than 7.620 micrometers (0.3 mils) thick at any point as determined on two specimens taken for test in the manner prescribed in Section 35. The dried coating shall be not less than 87 percent total zinc by mass.

32.2.3.2 The mass of hot-dip, zinc interior coatings shall be not less than 107 g/m^2 (0.35 oz/ft^2) as determined from the average results of two specimens taken for test in the manner prescribed in Section 35 and not less than 76 g/m^2 (0.25 oz/ft^2) on an individual specimen.

32.3 Optional supplemental color coatings for Grade 1 and Grade 2 posts shall conform to the requirements of ASTM F 1043.

32.4 The zinc coating on all fittings and hardware shall conform to all the requirements of M 111M/M 111 or M 232M/M 232, whichever is applicable.

32.5 The method of determining mass or thickness of coating shall be as follows:

32.5.1 *Zinc-Coated*—The mass of coating shall be determined in accordance with T 65M/T 65.

32.5.2 *Aluminum-Coated*—The mass of aluminum coating shall be determined in accordance with T 213M/T 213.

32.5.3 *Organic Exterior Coating*—Existence of the organic coating can be verified by a 15-second contact with a copper sulfate solution (specific gravity 1.186) on three separate places of a sample in accordance with ASTM F 1043.

32.5.4 *Organic, Zinc-Rich Interior Coating*—Determine the thickness by magnetic gauge operated and calibrated in accordance with ASTM E 376.

33. PROPERTIES OF ORGANIC EXTERIOR COATINGS FOR GRADE 2 POSTS AND RAILS (POSTS, HARDWARE, AND FITTINGS)

33.1 Clear organic coating on the exterior of Grade 2 pipe, when placed over the specified zinc coating, shall meet the following requirements:

33.1.1 No film cracking at 500 hours exposure when tested in accordance with ASTM G 152 Table X1.1 Cycle 1 or G 155 Table X3.1 Cycle 1.

33.1.2 No red rust at 950 hours exposure to salt spray, in accordance with ASTM B 117.

33.1.3 No blistering or cracking at 500 hours when tested in accordance with ASTM D 2247.

34. WORKMANSHIP (POSTS, HARDWARE, AND FITTINGS)

34.1 Finished posts, rail, hardware, and fittings shall show good workmanship and be reasonably free from defects. All burrs at the ends of posts and rails shall be removed. Coatings shall be uniform and free of voids or excessive roughness.

35. SAMPLING AND NUMBER OF TESTS (POSTS, HARDWARE, AND FITTINGS)

35.1 All pipe or other shapes, other than aluminum alloy, shall be sampled and tested in lots of 500 pieces or less for the same shape and cross section offered for inspection at one time. For posts, rails, and miscellaneous accessories fabricated from aluminum alloy, the lot shall be as defined in the applicable specification. All fittings, hardware, etc., of the same type and material, offered for inspection at one time, shall be considered a lot.

35.2 All coated steel posts, rails, fittings, and hardware shall be sampled at the rate of one article per lot.

35.3 All aluminum-alloy posts, fittings, and hardware shall be sampled at the rate prescribed in the applicable specification.

35.4 Sample articles shall be inspected for dimensions and mass, if applicable to the item.

35.5 Two test specimens 100 mm (4 in.) long taken 150 mm (6 in.) from each end of the coated steel post or rail representing the lot shall be taken and tested for mass of coating (Section 32).

35.6 For zinc-coated fittings, hardware, etc., test the article for mass of coating (Section 32) as prescribed in M 111M/M 111 or M 232M/M 232, as applicable.

35.7 If any article tested fails to meet the requirements of this specification, two additional articles shall be tested from the same lot, both of which shall meet the requirements in every respect or the lot represented by the samples will be rejected.

36. INSPECTION (POSTS, HARDWARE, AND FITTINGS)

36.1 The provisions of Section 19 shall apply to posts, hardware, and fittings.

37. CERTIFICATION AND REPORTS (POSTS, HARDWARE, AND FITTINGS)

37.1 The provisions of Section 20 shall apply to posts, hardware, and fittings.

38. PACKAGING, MARKING, AND LOADING (POSTS, HARDWARE, AND FITTINGS)

38.1 Each bundle or container of posts, hardware, and fittings shall be identified with the name or mark of the manufacturer, type of material (steel, cast iron, aluminum alloy number, etc.), type of coating, and any additional data required for proper identification or to determine apparent conformance to specified quality requirements.

Standard Specification for

Turnbuckles and Shackles

AASHTO Designation: M 269-96 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Turnbuckles and Shackles

AASHTO Designation: M 269-96 (2008)

1. SCOPE

1.1. *Scope*—This specification covers forged turnbuckles, with and without jam nuts, and shackles for guardrail, sign supports, and similar uses. These items are considered to be available commercially. Not all classes, styles, and types of turnbuckles and shackles that are available commercially are covered by this specification.

1.2. *Classification*:

1.2.1. *Turnbuckles*:

1.2.1.1. *Type*—Turnbuckles covered by this specification shall be forged and of the design specified by the purchaser.

1.2.1.2. *Sizes*—Turnbuckles covered by this specification shall be of the sizes listed in Table 2, as specified.

1.2.2. *Shackles*:

1.2.2.1. Shackles shall be one of the classes in Table 1, as specified by the purchaser.

Table 1—Classes of Shackles

Class 1—Screw pin anchor shackles
Class 2—Screw pin chain shackles
Class 3—Oval pin chain shackles
Class 4—Round pin anchor shackles
Class 5—Round pin chain shackles
Class 6—Bolt type anchor shackles

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 102M/M 102, Steel Forgings, Carbon and Alloy, for General Industrial Use
- M 169, Steel Bars, Carbon and Alloy, Cold-Finished
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *National Institute of Standards and Technology (NIST) Standard*:

- Handbook H28, Screw Thread Standards for Federal Services

2.3. *ANSI Standard*:

- B18.22, Heavy Hex Jam Nuts

2.4. *Military Standard*:

- MIL-P-21035, Paint, High Zinc Dust Content, Galvanizing Repair (Metric)

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3. MATERIALS AND MANUFACTURE

3.1. *Materials*:

3.1.1. *Turnbuckles*—Unless otherwise specified, material for turnbuckles and end pulls shall comply with M 102M/M 102 and be of a grade which will meet the requirements of Table 2.

Table 2—Breaking Strength of Forged Turnbuckles (complete with end pulls)

	Strength Breaking, kN (lb) Min	Recommended Working Loads, kN (lb)
Size, Nominal Outside Diameter of Thread, mm (in.)	Eye or Stub End Pulls kN (lb)	Eye or Stub End Pulls kN (lb)
19.0 ($^{3}/_{4}$)	89.0 (20000)	17.8 (4000)
22.2 ($^{7}/_{8}$)	129.0 (29000)	25.8 (5800)
25.4 (1)	169.0 (38000)	33.8 (7600)
31.8 (1$^{1}/_{4}$)	266.9 (60000)	53.4 (12000)
34.9 (1$^{3}/_{8}$)	320.3 (72000)	64.0 (14400)
38.1 (1$^{1}/_{2}$)	378.1 (85000)	75.6 (17000)
44.4 (1$^{3}/_{4}$)	511.5 (115000)	102.3 (23000)
50.8 (2)	667.2 (150000)	133.4 (30000)
57.2 (2$^{1}/_{4}$)	876.3 (197000)	175.2 (39400)

3.1.2. *Shackles*—Each shackle, together with its pin or bolt, shall be forged at elevated temperature for final shape and size, in conformance with M 102M/M 102, Class AH.

3.2. *Construction*:

3.2.1. *Turnbuckles*:

3.2.1.1. *Method*—Each turnbuckle body and each end pull shall be forged at elevated temperature to final shape and size.

3.2.1.2. *Size*—Turnbuckles covered by this specification shall be furnished in the sizes shown in Table 3, clear opening between heads, as specified. The size of turnbuckle bodies shall be the nominal major diameter of the threads in the heads and the clear opening between heads (which is approximately equal to the take up); thus, for a 19 by 152-mm ($^{3}/_{4}$ by 6-in.) turnbuckle body, the heads shall be threaded for a 19-mm ($^{3}/_{4}$-in.) nominal major-diameter end pull, and the clear opening between heads shall be 152 mm (6 in.). The difference between the actual clear opening in the turnbuckle body and the nominal value given in Table 4 for the size specified shall not exceed five percent of the nominal value.

Table 3—Turnbuckles

	Size						
	Clear Opening Between Head, mm (in.)						
Thread, Nominal Outside Diameter, mm (in.)	152.4 (6)	228.6 (9)	304.8 (12)	457.2 (18)	609.6 (24)	914.4 (36)	1219.2 (48)
19.0 (${}^{3}/_{4}$)	X	X	X	X	X	—	—
22.2 (${}^{7}/_{8}$)	—	—	X	X	X	—	—
25.4 (1)	—	—	X	X	X	X	—
31.8 ($1^{1}/_{4}$)	—	—	X	X	X	X	—
38.1 ($1^{1}/_{2}$)	—	—	X	X	X	X	X
44.4 ($1^{3}/_{4}$)	—	—	—	X	X	X	X
50.8 (2)	—	—	—	—	X	X	X
57.2 ($2^{1}/_{4}$)	—	—	—	—	X	X	X

3.2.1.3. *Length of Head*—The length of the heads of the turnbuckle bodies shall be not less than 1.5 times the nominal outside diameter of the end pull for sizes up to 31.8 mm ($1^{1}/_{4}$ in.), and 1.25 times for sizes 31.8 mm ($1^{1}/_{4}$ in.) and above.

3.2.1.4. *Thread*—Turnbuckle bodies and end pulls shall be threaded after fabrication to final size and shape. The threads in the heads of the turnbuckle bodies and on the end pulls shall comply with NIST H28 (National Institute of Standards and Technology Specification H28, Screw-Thread Standards for Federal Services). Unified threads in the coarse (UNC) standard series (Table 5) should be used. If the standard diameter-pitch combinations are not suitable, the UNS threads with dimensions in accordance with NBS H28 should be used. Threads on the finished turnbuckle shall be not looser than Class 1A/1B fit. The female threads on the turnbuckle body may be oversized as necessary, so that after coating they will properly mate (not looser than Class 1A/1B fit) with the standard size male threads of the end pulls. The thread in one head of each turnbuckle body shall be right-hand and in the other head, left-hand. The threads on the end pulls shall be great enough so that the ends of the end pulls can be brought into contact with each other at the middle of the body length when jam nuts are not used.

3.2.1.5. *Breaking Strength*—The breaking strength of turnbuckles, equipped with end pulls, shall be not less than the value given in Table 2 for the required size, type, and form of end pull specified.

3.2.1.6. *Turnbuckle Bodies, Types*—Open turnbuckles shall be forged as specified. Forged turnbuckle bodies shall be similar to Figure 1. They shall be forged as specified. The shape of the head of the turnbuckle body shall be either round or hexagonal.

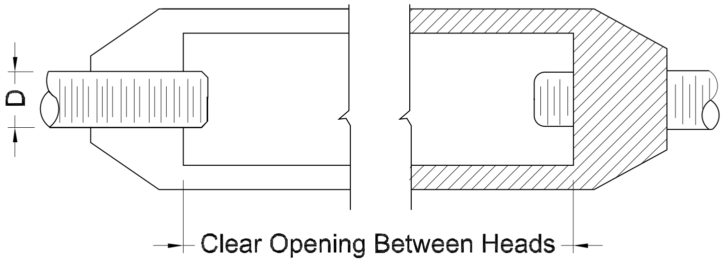

Figure 1—Open Turnbuckle Body, Forged

3.2.1.7. *Jam Nuts*—Jam nuts shall be right-hand or left-hand threaded, as required, made of carbon steel of a type selected from group 1016 to 1020 inclusive for M 169, and shall conform to the dimensional requirements of ANSI B18.2.2 Heavy Hex Jam Nuts.

3.2.1.8. *End Pulls*—Eye end pulls shall be forged, similar to Figure 2. The shape of the eye may be either oval or round. Minimum dimensions are as shown in Table 4.

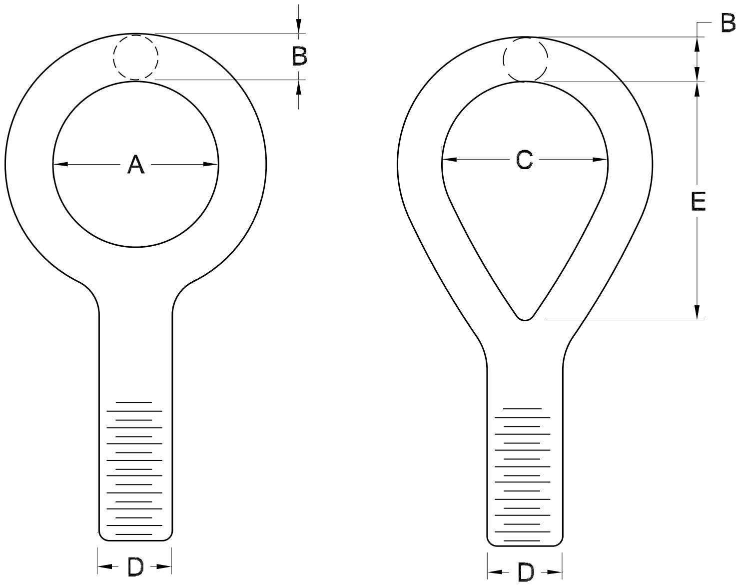

Figure 2—Forged-Eye End Pull

Table 4—Dimensions of Eye End Pulls, mm (in.)

D Nominal	A Minimum	B Minimum	C Minimum	E Minimum
19.0 ($^{3}/_{4}$)	38.1 ($1^{1}/_{2}$)	15.9 ($^{5}/_{8}$)	25.4 (1)	41.3 ($1^{5}/_{8}$)
22.2 ($^{7}/_{8}$)	44.4 ($1^{3}/_{4}$)	19.0 ($^{3}/_{4}$)	31.8 ($1^{1}/_{4}$)	47.6 ($1^{7}/_{8}$)
25.4 (1)	50.8 (2)	22.2 ($^{7}/_{8}$)	36.5 ($1^{7}/_{16}$)	57.2 ($2^{1}/_{4}$)
31.8 ($1^{1}/_{4}$)	54.0 ($2^{1}/_{8}$)	27.0 ($1^{1}/_{16}$)	42.9 ($1^{11}/_{16}$)	65.1 ($2^{9}/_{16}$)
38.1 ($1^{1}/_{2}$)	57.2 ($2^{1}/_{4}$)	31.8 ($1^{1}/_{4}$)	54.0 ($2^{1}/_{8}$)	82.6 ($3^{1}/_{4}$)
44.4 ($1^{3}/_{4}$)	63.5 ($2^{1}/_{2}$)	36.5 ($1^{7}/_{16}$)	60.3 ($2^{3}/_{8}$)	95.2 ($3^{3}/_{4}$)
50.8 (2)	76.2 (3)	41.2 ($1^{5}/_{8}$)	68.3 ($2^{11}/_{16}$)	111.1 ($4^{3}/_{8}$)
57.2 ($2^{1}/_{4}$)	82.5 ($3^{1}/_{4}$)	46.0 ($1^{13}/_{16}$)	74.6 ($2^{15}/_{16}$)	131.8 ($5^{3}/_{16}$)

3.2.2. *Shackles*:

3.2.2.1. *Threads*—Screw-pin shackles shall be threaded after fabrication to final size and shape. Threads shall conform to National Coarse Series as shown in Table 5. Appropriate portions of Section 3.2.1.4 shall apply to shackles.

3.2.2.2. *Size*—Shackles shall have the dimensions shown in Tables 6 through 17 for the appropriate class of shackle.

Table 5—Coarse Thread Series, Basic Dimensions, UNC

Nominal Size and Basic Major Diameter, *D* in.	Threads per Inch, *n*	Basic Pitch Diameter *E*, in.	Minor Diameter, External Threads, K_s, in.	Minor Diameter, Internal Threads, K_n, in.	Lead Angle at Basic Pitch Diameter λ, Deg.		Sectional Area at Minor Diameter at $D–2h_o$, Min., in.^{2}	Tensile Stress Area $\pi\left(\frac{E}{2}-\frac{3H}{16}\right)^2$, in.^{2}
0.500	13	0.4500	0.4056	0.4167	3	7	0.1257	0.1419
0.5625	12	0.5084	0.4603	0.4723	2	59	0.162	0.182
0.625	11	0.5660	0.5135	0.5268	2	56	0.202	0.226
0.750	10	0.6850	0.6273	0.6417	2	40	0.302	0.334
0.875	9	0.8028	0.7387	0.7547	2	31	0.419	0.462
1.000	8	0.9188	0.8466	0.8647	2	29	0.551	0.606
1.125	7	1.0322	0.9497	0.9704	2	31	0.693	0.763
1.250	7	1.1572	1.0747	1.0954	2	15	0.890	0.969
1.375	6	1.2667	1.1705	1.1946	2	24	1.054	1.155
1.500	6	1.3917	1.2955	1.3196	2	11	1.294	1.405
1.750	5	1.6201	1.5046	1.5335	2	15	1.74	1.90
2.000	4.5	1.8557	1.7274	1.7594	2	11	2.30	2.50
2.250	4.5	2.1057	1.9774	2.0094	1	55	3.02	3.25
2.500	4	2.3376	2.1933	2.2294	1	57	3.72	4.00
2.750	4	2.5876	2.4433	2.4794	1	46	4.62	4.93

3.3. *Finish*:

3.3.1. *Surface Condition*—Turnbuckle bodies and end pulls shackles shall be finished by grinding the flash smooth, where required, and removing the loose scale. They shall be free of cracks, flaws, seams, and other injurious imperfections.

3.3.2. *Zinc Coating*—Turnbuckles and shackles and accessories shall be galvanized (zinc coated) by the hot-dip process. The hot-dip process shall be applied in conformance with M 232M/M 232, and shall be adherent, smooth, and free from injurious lumps, blisters, dross, or flux. Coating shall be done on the end pulls and threaded pins after threading; coating for turnbuckle bodies, shackles and jam nuts may be done before or after tapping at the option of the purchaser.

3.3.3. *Galvanizing Repair*—Where the galvanizing on turnbuckles, shackles, end pulls, or pins has been damaged, the coating shall be repaired by regalvanizing, or the surface repaired by painting with two coats of zinc dust-zinc oxide paint conforming to MIL-P-21035.

3.4. *Physical Properties of Shackles*:

3.4.1. *Proof Loads*—Shackles shall be capable of withstanding the proof loads shown in the respective class tables when tested as specified in Section 5.1.1 without developing surface rupture or defects which interfere with serviceability or prevent disassembly of the pin. After proof loading, screw-pin shackles shall be capable of disassembly by hand after the first half turn.

3.4.2. *Breaking Loads*—Shackles shall be able to withstand, without breaking, the breaking loads shown in the respective class tables when tested as specified in Section 5.2.

3.4.3. *Ductility*—Shackles shall be sufficiently ductile that when fractured, the fractured member shall show a permanent distortion before breaking. If the pin fractures, it shall show a permanent bend of not less than 20 degrees. If the body fractures, it shall show a permanent mid-shackle set of not less than 15 percent of the original spread between bows.

3.4.4. *Class 1, Screw-Pin Anchor Shackles*—The screw-pin anchor shackles shall be similar to Figure 3, and shall conform to the dimensions and physical requirements shown in Tables 6 and 7.

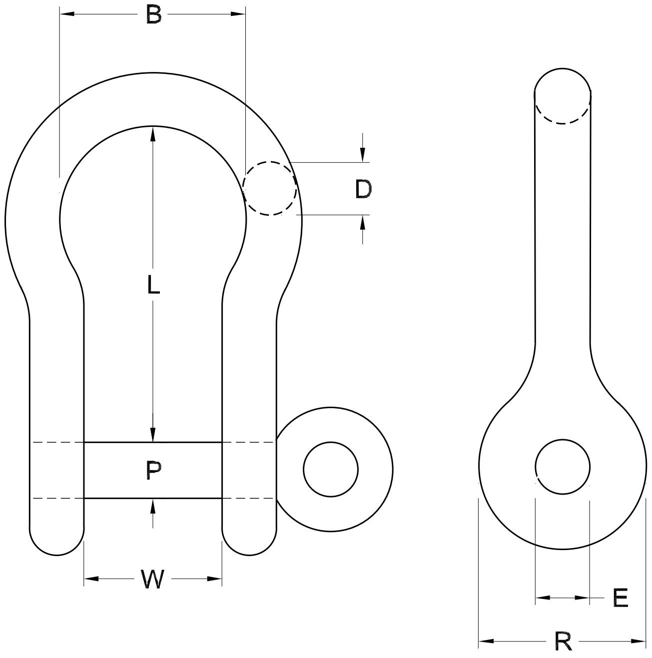

Figure 3—Class 1, Screw-Pin Anchor Shackles

Table 6—Class 1, Screw-Pin Anchor Shackles

Size *D*, mm	Diameter of Pin (*P*), mm (Min)	Width Between Eyes (*W*), mm	Tolerance in Width Between Eyes (*W*), mm	Length Inside (*L*), mm	Tolerance (Plus or Minus) in Inside Length (*L*), mm	Width Bow (*B*), mm	Major Diameter Threaded Eye, mm (Max)	Outside Diameter of Eye (*R*), mm (Max)	Diameter Unthreaded Eye (*E*), mm (Max)	Mass per 100 Shackles (Approx), kg	Proof Load, kN (Min)	Breaking Loads, kN (Min)
6.35	7.94	11.91	–0.8 + 2.4	28.58	1.59	19.05	8.73	22.22	10.32	5.4	4	16
7.64	9.52	13.49	–0.8 + 2.4	31.75	1.59	20.64	10.32	25.40	11.91	9.5	6	24
9.52	11.11	16.67	–0.8 + 2.4	36.51	1.59	23.18	11.91	28.58	13.49	14.5	9	35
11.11	12.70	18.26	–0.8 + 2.4	42.86	1.59	26.99	13.49	31.75	15.08	22.2	12	48
12.70	15.88	20.64	–1.6 + 2.4	49.21	1.59	30.16	16.67	34.92	18.26	33.1	18	63
14.29	15.88	22.22	–1.6 + 2.4	53.98	1.59	34.92	16.67	41.28	18.26	41.7	24	80
15.88	19.05	26.99	–1.6 + 2.4	63.50	3.18	38.10	19.84	47.62	21.43	68.5	27	98
19.05	22.22	31.75	–1.6 + 2.4	76.20	6.35	44.45	23.02	57.15	24.61	102.5	40	141
22.22	25.40	36.51	–1.6 + 2.4	82.55	6.35	50.80	26.19	60.32	27.78	154.2	53	192
25.40	28.58	42.86	–1.6 + 3.2	95.25	6.35	58.74	29.37	66.68	30.96	224.5	71	260
28.58	31.75	46.04	–1.6 + 3.2	107.95	6.35	66.68	32.94	76.20	34.13	313.4	96	298
31.75	34.92	50.80	–1.6 + 3.2	114.30	6.35	73.02	36.12	82.55	37.31	407.8	122	367
34.92	38.10	57.15	–3.2 + 4.8	133.35	6.35	82.55	39.29	88.90	41.28	552.9	149	444
38.10	41.28	60.32	–3.2 + 4.8	146.05	6.35	85.72	42.46	95.25	44.45	723.5	184	528
41.28	44.45	66.68	–3.2 + 4.8	158.75	6.35	104.78	45.64	104.78	47.62	866.4	222	620
44.45	50.80	73.02	–3.2 + 4.8	177.80	6.35	114.30	51.99	114.30	54.77	1247.4	264	718
50.80	57.15	82.55	–3.2 + 4.8	196.85	6.35	127.00	58.34	130.18	61.12	1769.0	310	939
57.15	63.50	98.42	–3.2 + 4.8	222.25	6.35	139.70	64.69	142.88	67.47	2562.8	359	1201
63.50	69.85	104.78	–3.2 + 4.8	254.00	6.35	152.40	71.04	149.22	73.82	3787.5	469	1503

Table 7—Class 1, Screw-Pin Anchor Shackles

Size *D*, in.	Diameter of Pin (*P*), in. (Min)	Width Between Eyes (*W*), in.	Tolerance in Width Between Eyes (*W*), in.	Length Inside (*L*), in.	Tolerance (Plus or Minus) in Inside Length (*L*), in.	Width Bow (*B*), in. (Min)	Major Diameter Threaded Eye, in. (Max)	Outside Diameter of Eye (*R*), in. (Max)	Diameter Unthreaded Eye (*E*), in. (Max)	Weight per 100 Shackles (Approx), lb	Proof Load, lb (Min)	Breaking Loads, lb (Min)
$^{1}/_{4}$	$^{5}/_{16}$	$^{15}/_{32}$	$-^{1}/_{32} + ^{3}/_{32}$	$1^{1}/_{8}$	$^{1}/_{16}$	$^{3}/_{4}$	$^{11}/_{32}$	$^{7}/_{8}$	$^{13}/_{32}$	12	900	3550
$^{5}/_{16}$	$^{3}/_{8}$	$^{17}/_{32}$	$-^{1}/_{32} + ^{3}/_{32}$	$1^{1}/_{4}$	$^{1}/_{16}$	$^{13}/_{16}$	$^{13}/_{32}$	1	$^{15}/_{32}$	21	1300	5300
$^{3}/_{8}$	$^{7}/_{16}$	$^{21}/_{32}$	$-^{1}/_{32} + ^{3}/_{32}$	$1^{7}/_{16}$	$^{1}/_{16}$	$^{15}/_{16}$	$^{15}/_{32}$	$1^{1}/_{8}$	$^{17}/_{32}$	32	2000	7950
$^{7}/_{16}$	$^{1}/_{2}$	$^{23}/_{32}$	$-^{1}/_{32} + ^{3}/_{32}$	$1^{11}/_{16}$	$^{1}/_{16}$	$1^{1}/_{16}$	$^{17}/_{32}$	$1^{1}/_{4}$	$^{19}/_{32}$	49	2750	10850
$^{1}/_{2}$	$^{5}/_{8}$	$^{13}/_{16}$	$-^{1}/_{16} + ^{3}/_{32}$	$1^{15}/_{16}$	$^{1}/_{16}$	$1^{3}/_{16}$	$^{21}/_{32}$	$1^{3}/_{8}$	$^{23}/_{32}$	73	3975	14150
$^{9}/_{16}$	$^{5}/_{8}$	$^{7}/_{8}$	$-^{1}/_{16} + ^{3}/_{32}$	$2^{1}/_{8}$	$^{1}/_{16}$	$1^{3}/_{8}$	$^{21}/_{32}$	$1^{5}/_{8}$	$^{23}/_{32}$	92	5425	17900
$^{5}/_{8}$	$^{3}/_{4}$	$1^{1}/_{16}$	$-^{1}/_{16} + ^{3}/_{32}$	$2^{1}/_{2}$	$^{1}/_{8}$	$1^{1}/_{2}$	$^{25}/_{32}$	$1^{7}/_{8}$	$^{27}/_{32}$	151	6100	22100
$^{3}/_{4}$	$^{7}/_{8}$	$1^{1}/_{4}$	$-^{1}/_{16} + ^{3}/_{32}$	3	$^{1}/_{4}$	$1^{3}/_{4}$	$^{29}/_{32}$	$2^{1}/_{4}$	$^{31}/_{32}$	226	8950	31800
$^{7}/_{8}$	1	$1^{7}/_{16}$	$-^{1}/_{16} + ^{3}/_{32}$	$3^{1}/_{4}$	$^{1}/_{4}$	2	$1^{1}/_{32}$	$2^{3}/_{8}$	$1^{3}/_{32}$	340	12000	43250
1	$1^{1}/_{8}$	$1^{11}/_{16}$	$-^{1}/_{16} + ^{1}/_{8}$	$3^{3}/_{4}$	$^{1}/_{4}$	$2^{5}/_{16}$	$1^{5}/_{32}$	$2^{5}/_{8}$	$1^{7}/_{32}$	495	15900	58550
$1^{1}/_{8}$	$1^{1}/_{4}$	$1^{13}/_{16}$	$-^{1}/_{16} + ^{1}/_{8}$	$4^{1}/_{4}$	$^{1}/_{4}$	$2^{5}/_{8}$	$1^{19}/_{64}$	3	$1^{11}/_{32}$	691	21625	66900
$1^{1}/_{4}$	$1^{3}/_{8}$	2	$-^{1}/_{16} + ^{1}/_{8}$	$4^{1}/_{2}$	$^{1}/_{4}$	$2^{7}/_{8}$	$1^{27}/_{64}$	$3^{1}/_{4}$	$1^{15}/_{32}$	899	27500	82500
$1^{3}/_{8}$	$1^{1}/_{2}$	$2^{1}/_{4}$	$-^{1}/_{8} + ^{3}/_{16}$	$5^{1}/_{4}$	$^{1}/_{4}$	$3^{1}/_{4}$	$1^{35}/_{64}$	$3^{1}/_{2}$	$1^{5}/_{8}$	1219	33400	99800
$1^{1}/_{2}$	$1^{5}/_{8}$	$2^{3}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$5^{3}/_{4}$	$^{1}/_{4}$	$3^{3}/_{8}$	$1^{43}/_{64}$	$3^{3}/_{4}$	$1^{3}/_{4}$	1595	41250	118700
$1^{5}/_{8}$	$1^{3}/_{4}$	$2^{5}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$6^{1}/_{4}$	$^{1}/_{4}$	$4^{1}/_{8}$	$1^{51}/_{64}$	$4^{1}/_{8}$	$1^{7}/_{8}$	1910	49900	139500
$1^{3}/_{4}$	2	$2^{7}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	7	$^{1}/_{4}$	$4^{1}/_{2}$	$2^{3}/_{64}$	$4^{1}/_{2}$	$2^{5}/_{32}$	2750	59350	161500
2	$2^{1}/_{4}$	$3^{1}/_{4}$	$-^{1}/_{8} + ^{3}/_{16}$	$7^{3}/_{4}$	$^{1}/_{4}$	5	$2^{19}/_{64}$	$5^{1}/_{8}$	$2^{13}/_{32}$	3900	69750	211100
$2^{1}/_{4}$	$2^{1}/_{2}$	$3^{7}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$8^{3}/_{4}$	$^{1}/_{4}$	$5^{1}/_{2}$	$2^{35}/_{64}$	$5^{5}/_{8}$	$2^{21}/_{32}$	5650	80800	270000
$2^{1}/_{2}$	$2^{3}/_{4}$	$4^{1}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	10	$^{1}/_{4}$	6	$2^{51}/_{64}$	$5^{7}/_{8}$	$2^{29}/_{32}$	8350	105500	338000

3.4.5. *Class 2, Screw-Pin Chain Shackles*—The screw-pin chain shackles shall be similar to Figure 4, and shall conform to the dimensions and physical requirements shown in Tables 8 and 9.

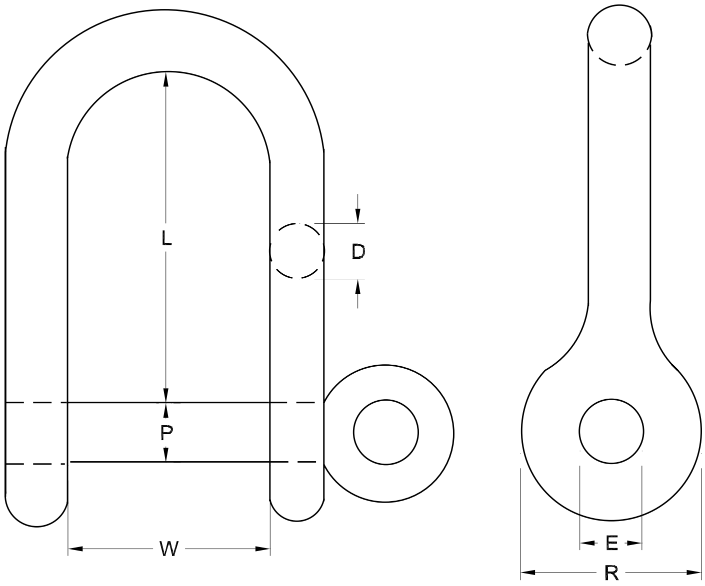

Figure 4—Class 2, Screw-Pin Chain Shackles

Table 8—Class 2, Screw-Pin Chain Shackles

Size *D*, mm	Diameter of Pin (*P*), mm (Min)	Width Between Eyes (*W*), mm	Tolerance in Width Between Eyes (*W*), mm	Length Inside (*L*), mm	Tolerance (Plus or Minus) in Inside Length (*L*), mm	Major Diameter Threaded Eye, mm (Max)	Outside Diameter of Eye (*R*), mm (Max)	Diameter Unthreaded Eye (*E*), mm (Max)	Mass per 100 Shackles (Approx), kg	Proof Load, kN (Min)	Breaking Loads, kN (Min)
6.35	7.94	11.91	–0.8 + 2.4	22.22	1.59	8.73	22.22	10.32	5.4	4	16
7.94	9.52	13.49	–0.8 + 2.4	25.40	1.59	10.32	25.40	11.91	8.2	6	24
9.52	11.11	16.67	–0.8 + 2.4	31.75	1.59	11.91	28.58	13.49	12.7	9	35
11.11	12.70	18.26	–0.8 + 2.4	38.10	1.59	13.49	31.75	15.08	20.0	12	48
12.70	15.88	20.64	–1.6 + 2.4	42.86	1.59	16.67	34.92	18.26	30.8	18	63
14.29	15.88	22.22	–1.6 + 2.4	46.04	1.59	16.67	41.28	18.26	39.9	24	80
15.88	19.05	26.99	–1.6 + 2.4	50.80	3.18	19.84	47.62	21.43	59.0	27	98
19.05	22.22	31.75	–1.6 + 2.4	58.74	6.35	23.02	57.15	24.61	91.2	40	141
22.22	25.40	36.51	–1.6 + 2.4	73.02	6.35	26.19	60.32	27.78	130.6	53	192
25.40	28.58	42.86	–1.6 + 3.2	82.55	6.35	29.37	66.68	30.96	200.0	71	252
28.58	31.75	46.04	–1.6 + 3.2	88.90	6.35	32.94	76.20	34.13	283.5	96	297
31.75	34.92	50.80	–1.6 + 3.2	93.66	6.35	36.12	82.55	37.31	362.9	122	367
34.92	38.10	57.15	–3.2 + 4.8	114.30	6.35	39.29	88.90	41.28	503.5	149	444
38.10	41.28	60.32	–3.2 + 4.8	127.00	6.35	42.46	95.25	44.45	622.3	184	528
41.28	44.45	66.68	–3.2 + 4.8	133.35	6.35	45.64	104.78	47.62	741.6	222	620
44.45	50.80	73.02	–3.2 + 4.8	149.22	6.35	51.99	114.30	54.77	1179.3	264	719
50.80	57.15	82.55	–3.2 + 4.8	171.45	6.35	58.34	130.18	61.12	1632.9	310	939
57.15	63.50	95.25	–3.2 + 4.8	180.98	19.05	64.69	142.88	67.47	2268.0	359	1201
63.50	69.85	104.78	–3.2 + 4.8	203.20	19.05	71.04	149.22	73.82	3356.6	469	1503

Table 9—Class 2, Screw-Pin Chain Shackles

Size *D*, mm	Diameter of Pin (*P*), in. (Min)	Width Between Eyes (*W*), in.	Tolerance in Width Between Eyes (*W*), in.	Length Inside (*L*), in.	Tolerance (Plus or Minus) in Inside Length (*L*), in.	Major Diameter Threaded Eye, in. (Max)	Outside Diameter of Eye (*R*), in. (Max)	Diameter Unthreaded Eye (*E*), in. (Max)	Weight per 100 Shackles (Approx), lb	Proof Load, lb (Min)	Breaking Loads, lb (Min)
1/4	5/16	15/32	–1/32 + 3/32	7/8	1/16	11/32	7/8	13/32	12	900	3550
5/16	3/8	17/32	–1/32 + 3/32	1	1/16	13/32	1	15/32	18	1300	5300
3/8	7/16	21/32	–1/32 + 3/32	1 1/4	1/16	15/32	1 1/8	17/32	28	2000	7950
7/16	1/2	23/32	–1/32 + 3/32	1 1/2	1/16	17/32	1 1/4	19/32	44	2750	10850
1/2	5/8	13/16	–1/16 + 3/32	1 11/16	1/16	21/32	1 3/8	23/32	68	3975	14150
9/16	5/8	7/8	–1/16 + 3/32	1 13/16	1/16	21/32	1 5/8	23/32	88	5425	17900
5/8	3/4	1 1/16	–1/16 + 3/32	2	1/8	25/32	1 7/8	27/32	130	6100	22100
3/4	7/8	1 1/4	–1/16 + 3/32	2 5/16	1/4	29/32	2 1/4	31/32	201	8950	31800
7/8	1	1 7/16	–1/16 + 3/32	2 7/8	1/4	1 1/32	3/8	1 3/32	288	12000	43250
1	1 1/8	1 11/16	–1/16 + 1/8	3 1/4	1/4	1 5/32	2 5/8	1 7/32	441	15900	56550
1 1/8	1 1/4	1 13/16	–1/16 + 1/8	3 1/2	1/4	1 19/64	3	1 11/32	625	21625	66800
1 1/4	1 3/8	2	–1/16 + 1/8	3 11/16	1/4	1 27/64	3 1/4	1 15/32	800	27500	82500
1 3/8	1 1/2	2 1/4	–1/8 + 3/16	4 1/2	1/4	1 33/64	3 1/2	1 5/8	1110	33400	99800
1 1/2	1 5/8	2 3/8	–1/8 + 3/16	5	1/4	1 43/64	3 3/4	1 3/4	1372	41250	118700
1 5/8	1 3/4	2 5/8	–1/8 + 3/16	5 1/4	1/4	1 51/64	4 1/8	1 7/8	1635	49900	139500
1 3/4	2	2 7/8	–1/8 + 3/16	5 7/8	1/4	2 3/64	4 1/2	2 5/12	2600	59350	161600
2	2 1/4	3 1/4	–1/8 + 3/16	6 3/4	1/4	2 19/64	5 1/8	2 13/32	3600	69750	211100
2 1/4	2 1/2	3 3/4	–1/8 + 3/16	7 1/8	3/4	2 35/64	5 5/8	2 21/32	5000	80800	270000
2 1/2	2 3/4	4 1/8	–1/8 + 3/16	8	3/4	2 51/64	5 7/8	2 29/32	7400	105500	338000

3.4.6. *Class 3, Oval-Pin Chain Shackles*—The oval-pin chain shackles shall be similar to Figure 5 and shall conform to the dimensions and physical requirements shown in Tables 10 and 11. This shackle shall be provided with a taper hole and a locking pin with a drive fit; the drive pin shall not extend beyond the bottom of the hole. The oval pin shall fit tight against the tension side of the eye when the taper locking pin is driven home.

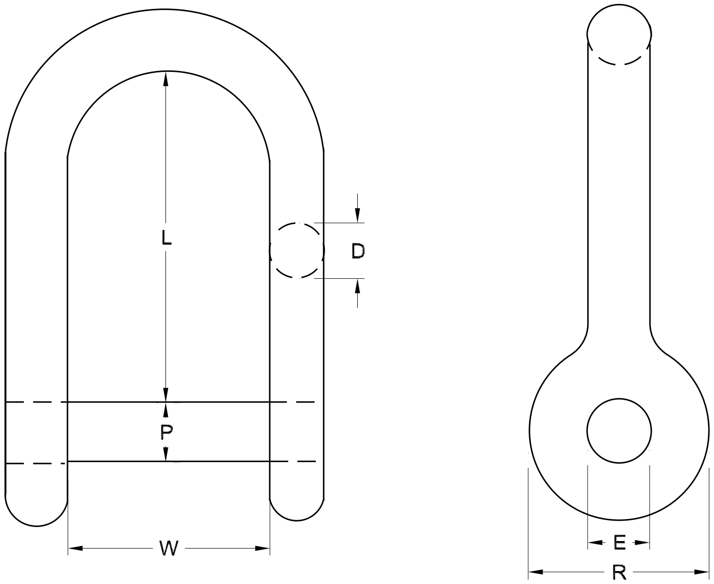

Figure 5—Class 3, Oval-Pin Chain Shackles

Table 10—Class 3, Oval-Pin Chain Shackles

Size *D*, mm	Thickness, mm	Width (*P*), mm	Width Between Eyes (*W*), mm	Tolerance in Width Between Eyes (*W*), mm	Length Inside (*L*), mm	Tolerance (Plus or Minus) in Inside Length (*L*), mm	Outside Width Eye (*R*), mm (Max)	Mass per 100 Shackles (Approx), kg	Proof Load, kN	Breaking Loads kN, (Min)
6.35	7.94	9.52	11.11	–0.8 + 2.4	20.64	1.59	25.40	4.5	4	20
7.94	9.52	11.11	12.70	–0.8 + 2.4	25.40	1.59	25.40	4.9	6	30
9.52	9.52	12.70	14.29	–0.8 + 2.4	30.16	1.59	28.58	13.1	9	41
11.11	11.11	15.08	15.88	–0.8 + 2.4	34.92	1.59	31.75	13.6	12	56
12.70	12.70	17.46	19.05	–1.6 + 2.4	39.69	1.59	34.92	31.8	18	73
14.29	12.70	17.46	22.22	–1.6 + 2.4	44.45	1.59	41.28	38.1	24	91
15.88	17.46	22.22	25.40	–1.6 + 2.4	47.62	3.18	47.62	61.7	27	111
19.05	18.26	25.40	31.75	–1.6 + 2.4	57.15	6.35	57.15	100.2	40	158
22.22	19.84	30.16	34.92	–1.6 + 2.4	63.50	6.35	60.32	140.2	53	214
25.40	23.81	34.92	38.10	–1.6 + 3.2	76.20	6.35	66.68	222.7	71	276
28.58	28.58	38.10	41.28	–1.6 + 3.2	88.90	6.35	76.20	254.5	96	347
31.75	31.75	45.24	52.39	–1.6 + 3.2	98.42	6.35	82.55	347.4	122	427
34.92	33.34	52.39	53.98	–3.2 + 4.8	123.82	6.35	88.90	503.5	149	512
38.10	33.34	52.39	57.15	–3.2 + 4.8	139.70	6.35	95.25	671.3	184	605
41.28	38.10	53.98	60.32	–3.2 + 4.8	142.88	6.35	104.78	748.4	222	—
44.45	38.10	53.98	63.50	–3.2 + 4.8	152.40	6.35	114.30	825.5	264	943
50.80	44.45	60.32	69.85	–3.2 + 4.8	177.80	6.35	130.18	1306.3	310	1139
57.15	47.62	63.50	76.20	–3.2 + 4.8	190.50	6.35	142.88	1949.1	359	1374
63.50	—	—	—	–3.2 + 4.8	—	—	149.22	—	469	1695

Table 11—Class 3, Oval-Pin Chain Shackles

Size of Pin			Width Between Eyes (*W*), in.	Tolerance in Width Between Eyes (*W*), in.	Length Inside (*L*), in.	Tolerance (Plus or Minus) in Inside Length (*L*), in.	Outside Width Eye (*R*), in. (Max)	Weight per 100 Shackles (Approx), lb	Proof Load, lb	Breaking Loads, lb (Min)
Size *D*, in.	Thickness, in.	Width (*P*), in.								
$^{1}/_{4}$	$^{5}/_{16}$	$^{3}/_{8}$	$^{7}/_{16}$	$-^{1}/_{32} + ^{3}/_{32}$	$^{13}/_{16}$	$^{1}/_{16}$	1	10	900	4500
$^{5}/_{16}$	$^{3}/_{8}$	$^{7}/_{16}$	$^{1}/_{2}$	$-^{1}/_{32} + ^{3}/_{32}$	1	$^{1}/_{16}$	1	11	1300	6800
$^{3}/_{8}$	$^{3}/_{8}$	$^{1}/_{2}$	$^{9}/_{16}$	$-^{1}/_{32} + ^{3}/_{32}$	$1^{3}/_{16}$	$^{1}/_{16}$	$1^{1}/_{8}$	29	2000	9300
$^{7}/_{16}$	$^{7}/_{16}$	$^{19}/_{32}$	$^{5}/_{8}$	$-^{1}/_{32} + ^{3}/_{32}$	$1^{3}/_{8}$	$^{1}/_{16}$	$1^{1}/_{4}$	30	2750	12500
$^{1}/_{2}$	$^{1}/_{2}$	$^{11}/_{16}$	$^{3}/_{4}$	$-^{1}/_{16} + ^{3}/_{32}$	$1^{9}/_{16}$	$^{1}/_{16}$	$1^{3}/_{8}$	70	3975	16500
$^{9}/_{16}$	$^{1}/_{2}$	$^{11}/_{16}$	$^{7}/_{8}$	$-^{1}/_{16} + ^{3}/_{32}$	$1^{3}/_{4}$	$^{1}/_{16}$	$1^{5}/_{8}$	84	5425	20500
$^{5}/_{8}$	$^{11}/_{16}$	$^{7}/_{8}$	1	$-^{1}/_{16} + ^{3}/_{32}$	$1^{7}/_{8}$	$^{1}/_{8}$	$1^{7}/_{8}$	136	6100	25000
$^{3}/_{4}$	$^{23}/_{32}$	1	$1^{1}/_{4}$	$-^{1}/_{16} + ^{3}/_{32}$	$2^{1}/_{4}$	$^{1}/_{4}$	$2^{1}/_{4}$	221	8950	35400
$^{7}/_{8}$	$^{25}/_{32}$	$1^{3}/_{16}$	$1^{3}/_{8}$	$-^{1}/_{16} + ^{3}/_{32}$	$2^{1}/_{2}$	$^{1}/_{4}$	$2^{3}/_{8}$	309	12000	48000
1	$^{15}/_{16}$	$1^{3}/_{8}$	$1^{1}/_{2}$	$-^{1}/_{16} + ^{1}/_{8}$	3	$^{1}/_{4}$	$2^{5}/_{8}$	491	15900	62000
$1^{1}/_{8}$	$1^{1}/_{8}$	$1^{1}/_{2}$	$1^{5}/_{8}$	$-^{1}/_{16} + ^{1}/_{8}$	$3^{1}/_{2}$	$^{1}/_{4}$	3	561	21625	78000
$1^{1}/_{4}$	$1^{1}/_{4}$	$1^{25}/_{32}$	$2^{1}/_{16}$	$-^{1}/_{16} + ^{1}/_{8}$	$3^{7}/_{8}$	$^{1}/_{4}$	$3^{1}/_{4}$	766	27500	96000
$1^{3}/_{8}$	$1^{5}/_{16}$	$2^{1}/_{16}$	$2^{1}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$4^{7}/_{8}$	$^{1}/_{4}$	$3^{1}/_{2}$	1110	33400	115000
$1^{1}/_{2}$	$1^{5}/_{16}$	$2^{1}/_{16}$	$2^{1}/_{4}$	$-^{1}/_{8} + ^{3}/_{16}$	$5^{1}/_{2}$	$^{1}/_{4}$	$3^{3}/_{4}$	1480	41250	136000
$1^{5}/_{8}$	$1^{1}/_{2}$	$2^{1}/_{8}$	$2^{3}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$5^{5}/_{8}$	$^{1}/_{4}$	$4^{1}/_{8}$	1650	49900	—
$1^{3}/_{4}$	$1^{1}/_{2}$	$2^{1}/_{8}$	$2^{1}/_{2}$	$-^{1}/_{8} + ^{3}/_{16}$	6	$^{1}/_{4}$	$4^{1}/_{2}$	1820	59350	212000
2	$1^{3}/_{4}$	$2^{3}/_{8}$	$2^{3}/_{4}$	$-^{1}/_{8} + ^{3}/_{16}$	7	$^{1}/_{4}$	$5^{1}/_{8}$	2880	69750	256000
$2^{1}/_{4}$	$1^{7}/_{8}$	$2^{1}/_{2}$	3	$-^{1}/_{8} + ^{3}/_{16}$	$7^{1}/_{2}$	$^{1}/_{4}$	$5^{5}/_{8}$	4297	80800	309000
$2^{1}/_{2}$	—	—	—	$-^{1}/_{8} + ^{3}/_{16}$	—	—	$5^{7}/_{8}$	—	105500	381000

3.4.7. *Class 4, Round-Pin Anchor Shackles*—The round-pin anchor shackles shall be similar to Figure 6, and shall conform to the dimensions and physical requirements shown in Tables 12 and 13.

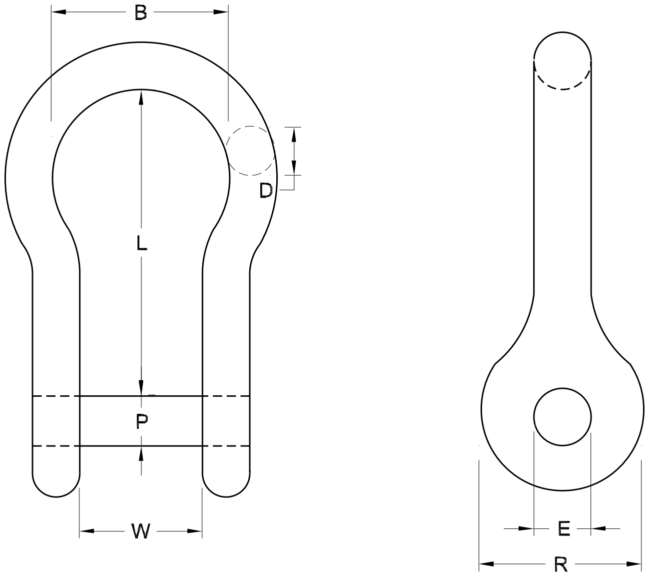

Figure 6—Class 4, Round-Pin Anchor Shackles

Table 12—Class 4, Round-Pin Anchor Shackles

Size *D*, mm	Length Inside (*L*), mm	Tolerance (Plus or Minus) in Inside Length (*L*), mm	Width Between Eyes (*W*), mm	Tolerance (Plus or Minus) in Width Between Eyes (*W*), mm	Diameter of Pin (*P*), mm	Diameter Outside Eye (*R*), mm (Max)	Diameter Eyes (*E*), mm (Max)	Mass per 100 Shackles (Approx), g	Proof Load, kN	Breaking Loads, kN (Min)
4.76	22.22	1.6	9.52	0.8	6.35	15.88	7.54	2.7	2	12
6.35	26.99	1.6	11.91	0.8	7.94	22.22	10.32	5.4	4	16
7.94	31.75	1.6	13.49	0.8	9.52	25.40	11.91	9.5	6	24
9.52	38.10	1.6	16.67	0.8	11.11	28.58	13.49	14.5	9	35
11.11	44.45	1.6	18.26	0.8	12.70	31.75	15.08	22.2	12	48
12.70	50.80	1.6	20.64	1.6	15.88	34.92	18.26	33.1	18	63
14.29	53.98	1.6	22.22	1.6	15.88	41.28	18.26	41.7	24	80
15.88	63.50	3.2	26.99	1.6	19.05	47.62	21.43	68.5	27	98
19.05	76.20	6.4	31.75	1.6	22.22	57.15	24.61	102.5	40	141
22.22	82.55	6.4	36.51	1.6	25.40	60.32	27.78	154.2	53	192
25.40	95.25	6.4	42.86	1.6	28.58	66.68	30.96	224.5	71	252
28.58	107.95	6.4	46.04	1.6	31.75	76.20	34.13	313.4	96	297
31.75	114.30	6.4	50.80	1.6	34.92	82.55	37.31	407.8	122	367
34.92	133.35	6.4	57.15	3.2	38.10	88.90	41.28	552.9	149	444
38.10	146.05	6.4	60.32	3.2	41.28	95.25	44.45	723.5	184	528
41.28	158.75	6.4	66.68	3.2	44.45	104.78	47.62	866.4	222	620
44.45	177.80	6.4	73.02	3.2	50.80	114.30	54.77	1247.4	264	719
50.80	196.85	6.4	82.55	3.2	57.15	130.18	61.12	1769.0	310	939
57.15	234.95	6.4	95.25	3.2	63.50	142.88	67.47	2562.8	359	1201
63.50	266.70	6.4	104.78	3.2	69.85	149.22	73.82	3801.1	469	1503

Table 13—Class 4, Round-Pin Anchor Shackles

Size *D*, in.	Length Inside (*L*), in.	Tolerance (Plus or Minus) in Inside Length (*L*), in.	Width Between Eyes (*W*), in.	Tolerance (Plus or Minus) in Width Between Eyes (*W*), in.	Diameter of Pin (*P*), in. (Min)	Diameter Outside Eye (*R*), in. (Max)	Diameter Eyes (*E*), in. (Max)	Weight per 100 Shackles (Approx), lb	Proof Load, lb	Breaking Loads, lb (Min)
3/16	7/8	1/16	3/8	1/32	1/4	5/8	19/64	6	550	2600
1/4	1 1/16	1/16	15/32	1/32	5/16	7/8	13/32	12	900	3550
5/16	1 1/4	1/16	17/32	1/32	3/8	1	15/32	21	1300	5300
3/8	1 1/2	1/16	21/32	1/32	7/16	1 1/8	17/32	32	2000	7950
7/16	1 3/4	1/16	23/32	1/32	1/2	1 1/4	19/32	49	2750	10850
1/2	2	1/16	13/16	1/16	5/8	1 3/8	23/32	73	3975	14150
9/16	2 1/8	1/16	7/8	1/16	5/8	1 5/8	23/32	92	5425	17900
5/8	2 1/2	1/8	1 1/16	1/16	3/4	1 7/8	27/32	151	6100	22100
3/4	3	1/4	1 1/4	1/16	7/8	2 1/4	31/32	226	8950	31800
7/8	3 1/4	1/4	1 7/16	1/16	1	2 3/8	1 3/32	340	12000	43250
1	3 3/4	1/4	1 11/16	1/16	1 1/8	2 5/8	1 7/32	495	15900	56550
1 1/8	4 1/4	1/4	1 13/16	1/16	1 1/4	3	1 11/32	691	21625	66800
1 1/4	4 1/2	1/4	2	1/16	1 3/8	3 1/4	1 15/32	899	27500	82500
1 3/8	5 1/4	1/4	2 1/4	1/8	1 1/2	3 1/2	1 5/8	1219	33400	99800
1 1/2	5 3/4	1/4	2 3/8	1/8	1 5/8	3 3/4	1 3/4	1595	41250	118700
1 5/8	6 1/4	1/4	2 5/8	1/8	1 3/4	4 1/8	1 7/8	1910	49900	139500
1 3/4	7	1/4	2 7/8	1/8	2	4 1/2	2 5/32	2750	59350	161600
2	7 3/4	1/4	3 1/4	1/8	2 1/4	5 1/8	2 13/32	3900	69750	211100
2 1/4	9 1/4	1/4	3 3/4	1/8	2 1/2	5 5/8	2 22/32	5650	80800	270000
2 1/2	10 1/2	1/4	4 1/8	1/8	2 3/4	5 7/8	2 29/32	8380	105500	338000

3.4.8. *Class 5, Round-Pin Chain Shackles*—The round-pin chain shackles shall be similar to Figure 7, and shall conform to the dimensions and physical requirements shown in Tables 14 and 15.

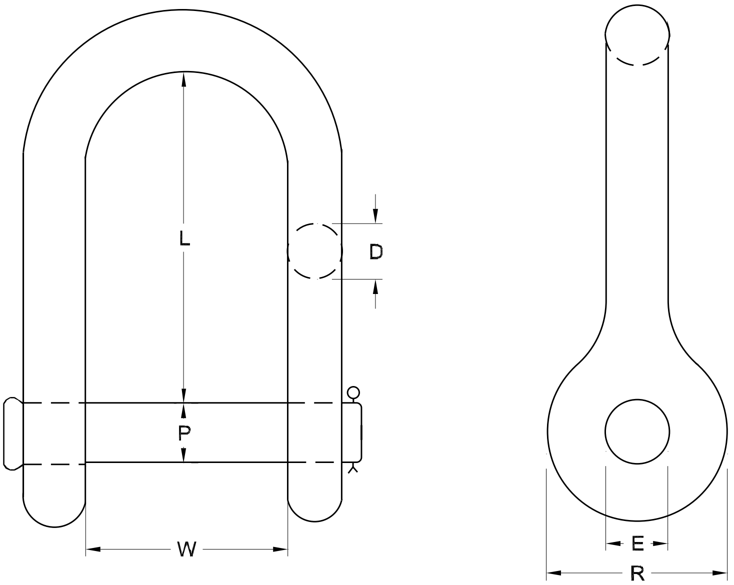

Figure 7—Class 5, Round-Pin Chain Shackles

Table 14—Class 5, Round-Pin Chain Shackles

Size *D*, mm	Diameter of Pin (*P*), mm (Min)	Width Between Eyes (*W*), mm	Tolerance in Width Between Eyes, (*W*), mm	Length Inside, (*L*), mm	(Plus or Minus) Tolerance Inside Length (*L*), mm	Diameter Outside Eye (*R*), mm (Max)	Diameter Eyes (*E*), mm (Max)	Mass per 100 Shackles (Approx), kg	Proof Load, kN (Min)	Breaking Loads, kN (Min)
6.35	7.94	11.91	–0.8 + 2.4	22.22	1.59	22.22	10.32	5.4	4	16
7.94	9.52	13.49	–0.8 + 2.4	25.40	1.59	25.40	11.91	8.2	6	24
9.52	11.11	16.67	–0.8 + 2.4	31.75	1.59	28.58	13.49	12.7	9	35
11.11	12.70	18.26	–0.8 + 2.4	38.10	1.59	31.75	15.08	20.0	12	48
12.70	15.88	20.64	–1.6 + 2.4	42.86	1.59	34.92	18.26	30.8	18	63
14.29	15.88	22.22	–1.6 + 2.4	46.04	1.59	41.28	18.26	40.0	24	76
15.88	19.05	26.99	–1.6 + 2.4	50.80	3.18	47.62	21.43	59.0	27	98
19.05	22.22	31.75	–1.6 + 2.4	58.74	6.35	57.15	24.61	91.2	40	141
22.22	25.40	36.51	–1.6 + 2.4	73.02	6.35	60.32	27.78	130.6	53	192
25.40	28.58	42.86	–1.6 + 12.7	82.55	6.35	66.68	30.96	200.0	71	252
28.58	31.75	46.04	–1.6 + 12.7	88.90	6.35	76.20	34.13	283.5	96	297
31.75	34.92	50.80	–1.6 + 12.7	93.66	6.35	82.55	37.31	362.9	122	367
34.92	38.10	57.15	–3.2 + 1.8	114.30	6.35	88.90	41.28	503.5	149	444
38.10	41.28	60.32	–3.2 + 4.8	127.00	6.35	95.25	44.45	622.3	184	528
41.28	44.45	66.68	–3.2 + 4.8	133.35	6.35	104.78	47.62	741.6	222	620
44.45	50.80	73.02	–3.2 + 4.8	149.22	6.35	114.30	54.77	1179.3	264	719
50.80	57.15	82.55	–3.2 + 4.8	171.45	6.35	130.18	61.12	1632.9	310	939
57.15	63.50	95.25	–3.2 + 4.8	180.98	6.35	142.88	67.47	2267.9	359	1201
63.50	69.85	104.78	–3.2 + 4.8	203.20	6.35	149.22	73.82	3356.6	469	1503

Table 15—Class 5, Round-Pin Chain Shackles

Size *D*, in.	Diameter of Pin (*P*), in. (Min)	Width Between Eyes (*W*), in.	Tolerance in Width Between Eyes (*W*), in.	Length Inside (*L*), in.	Plus or Minus Tolerance Inside Length (*L*), in.	Diameter Outside Eye (*R*), in. (Max)	Diameter Eyes (*E*), in. (Max)	Weight per 100 Shackles (Approx), lb	Proof Load, lb	Breaking Loads, lb (Min)
1/4	5/16	15/32	–1/32 + 3/32	7/8	1/16	7/8	13/32	12	900	3550
5/16	3/8	17/32	–1/32 + 3/32	1	1/16	1	15/32	18	1300	5300
3/8	7/16	21/32	–1/32 + 3/32	1 1/4	1/16	1 1/8	17/32	28	2000	7950
7/16	1/2	23/32	–1/32 + 3/32	1 1/2	1/16	1 1/4	19/32	44	2750	10850
1/2	5/8	13/16	–1/16 + 3/32	1 11/16	1/16	1 3/8	23/32	88	3975	14150
9/16	5/8	7/8	–1/16 + 3/32	1 13/16	1/16	1 5/8	23/32	88	5425	17000
5/8	3/4	1 1/16	–1/16 + 3/32	2	1/8	1 7/8	27/32	130	6100	22100
3/4	7/8	1 1/4	–1/16 + 3/32	2 5/16	1/4	2 1/4	31/32	201	9850	31800
7/8	1	1 7/16	–1/16 + 3/32	2 7/8	1/4	2 3/8	1 3/32	288	12000	43250
1	1 1/8	1 11/16	–1/16 + 1/2	3 1/4	1/4	2 5/8	1 7/32	441	15900	56550
1 1/8	1 1/4	1 13/16	–1/16 + 1/2	3 1/2	1/4	3	1 11/32	625	21625	66800
1 1/4	1 3/8	2	–1/16 + 1/2	3 11/16	1/4	3 1/4	1 15/32	800	27500	82500
1 3/8	1 1/2	2 1/4	–1/8 + 3/16	4 1/2	1/4	3 1/2	1 5/8	1110	33400	99800
1 1/2	1 5/8	2 3/8	–1/8 + 3/16	5	1/4	3 3/4	1 3/4	1372	41250	118700
1 5/8	1 3/4	2 5/8	–1/8 + 3/16	5 1/4	1/4	4 1/8	1 7/8	1635	49900	139500
1 3/4	2	2 7/8	–1/8 + 3/16	5 7/8	1/4	4 1/2	2 5/32	2600	59350	161600
2	2 1/4	3 1/4	–1/8 + 3/16	6 3/4	1/4	5 1/8	2 13/32	3600	69750	211100
2 1/4	2 1/2	3 3/4	–1/8 + 3/16	7 1/8	1/4	5 3/8	2 21/32	5000	80800	270000
2 1/2	2 3/4	4 1/8	–1/8 + 3/16	8	—	5 7/8	2 29/32	7400	105500	338000

3.4.9. *Class 6, Bolt-Type Anchor Shackles*—The bolt-type anchor shackle shall be similar to Figure 8, and shall conform to the dimensions and physical requirements shown in Tables 16 and 17. Bolt and nut shall have hexagon heads; cotter pin shall be provided.

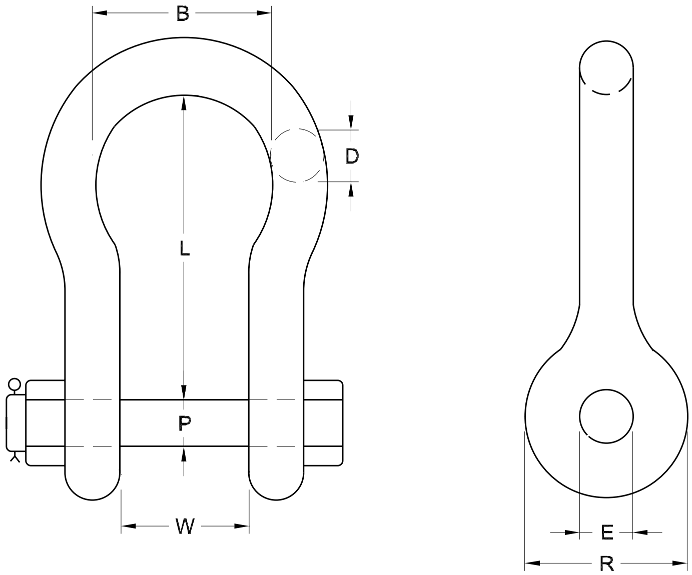

Figure 8—Class 6, Bolt-Type Anchor Shackles

Table 16—Class 6, Bolt-Type Anchor Shackles

Size *D*, mm	Diameter of Bolt (*P*), mm (Min)	Width Between Eyes (*W*), mm	Tolerance in Width Between Eyes (*W*), mm	Length Inside (*L*), mm	Tolerance (Plus or Minus) in Inside Length (*L*), mm	Width Bow (*B*), mm	Outside Diameter of Eye (*R*), mm (Max)	Diameter of Eye (*E*), mm (Max)	Mass per 100 Shackles (Approx), kg	Proof Load, kN (Min)	Breaking Loads, kN (Min)
28.58	31.75	46.04	–1.6 + 3.2	107.95	6.4	66.68	76.20	34.13	313.4	96	297
34.92	38.10	57.15	–3.2 + 4.8	133.35	6.4	82.55	88.90	41.28	552.9	149	444
38.10	41.28	60.32	–3.2 + 4.8	146.05	6.4	85.72	95.25	44.45	723.5	184	528
41.28	44.45	66.68	–3.2 + 4.8	158.75	6.4	104.78	104.78	47.62	866.4	222	620
44.45	50.80	73.02	–3.2 + 4.8	177.80	6.4	114.30	107.95	54.77	1247.4	264	719
50.80	57.15	82.55	–3.2 + 4.8	196.85	6.4	127.00	130.18	61.12	1769.0	310	939
57.15	63.50	98.42	–3.2 + 4.8	222.25	6.4	139.70	142.88	67.47	2562.8	359	1201
63.50	69.85	104.78	–3.2 + 4.8	254.00	6.4	152.40	149.22	73.82	3787.5	469	1503
69.85	76.20	114.30	–3.2 + 4.8	285.75	6.4	165.10	149.22	80.17	5216.3	592	1801

Table 17—Class 6, Bolt-Type Anchor Shackles

Size *D*, in.	Diameter of Bolt (*P*), in. (Min)	Width Between Eyes (*W*), in.	Tolerance in Width Between Eyes (*W*), in.	Length Inside (*L*), in.	Tolerance (Plus or Minus) in Inside Length (*L*), in.	Width Bow (*B*), in. (Max)	Outside Diameter of Eye (*R*), in. (Max)	Diameter of Eye (*E*), in. (Max)	Weight per 100 Shackles (Approx), lb	Proof Load, lb (Min)	Breaking Loads, lb (Min)
$1^{1}/_{8}$	$1^{1}/_{4}$	$1^{13}/_{16}$	$-^{1}/_{16} + ^{1}/_{8}$	$4^{1}/_{4}$	$^{1}/_{4}$	$2^{5}/_{8}$	3	$1^{11}/_{32}$	691	21625	66800
$1^{3}/_{8}$	$1^{1}/_{2}$	$2^{1}/_{4}$	$-^{1}/_{8} + ^{3}/_{16}$	$5^{1}/_{4}$	$^{1}/_{4}$	$3^{1}/_{4}$	$3^{1}/_{2}$	$1^{5}/_{8}$	1219	33400	99800
$1^{1}/_{2}$	$1^{5}/_{8}$	$2^{3}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$5^{3}/_{4}$	$^{1}/_{4}$	$3^{3}/_{8}$	$3^{3}/_{4}$	$1^{3}/_{4}$	1595	41250	118700
$1^{5}/_{8}$	$1^{3}/_{4}$	$2^{5}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$6^{1}/_{4}$	$^{1}/_{4}$	$4^{1}/_{8}$	$4^{1}/_{8}$	$1^{7}/_{8}$	1910	49900	139500
$1^{3}/_{4}$	2	$2^{7}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	7	$^{1}/_{4}$	$4^{1}/_{2}$	$4^{1}/_{4}$	$2^{5}/_{32}$	2750	59350	161600
2	$2^{1}/_{4}$	$3^{1}/_{4}$	$-^{1}/_{8} + ^{3}/_{16}$	$7^{3}/_{4}$	$^{1}/_{4}$	5	$5^{1}/_{8}$	$2^{13}/_{32}$	3900	69750	211100
$2^{1}/_{4}$	$2^{1}/_{2}$	$3^{7}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	$8^{3}/_{4}$	$^{1}/_{4}$	$5^{1}/_{2}$	$5^{5}/_{8}$	$2^{21}/_{32}$	5650	80800	270000
$2^{1}/_{2}$	$2^{3}/_{4}$	$4^{1}/_{8}$	$-^{1}/_{8} + ^{3}/_{16}$	10	$^{1}/_{4}$	6	$5^{7}/_{8}$	$2^{29}/_{32}$	8350	105500	338000
$2^{3}/_{4}$	3	$4^{1}/_{2}$	$-^{1}/_{8} + ^{3}/_{16}$	$11^{1}/_{4}$	$^{1}/_{4}$	$6^{1}/_{2}$	$5^{7}/_{8}$	$3^{5}/_{32}$	11500	133000	405000

4. QUALITY ASSURANCE PROVISIONS

4.1. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works. If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification, shall be the basis of acceptance of the materials. The manufacturer shall furnish the test results with the certification on request by the purchaser.

4.2. *Sampling*:

4.2.1. For the purpose of inspection and test, a lot shall consist of not more than 1000 pieces made from the same material of the same type and class offered for delivery at one time.

4.2.2. For the purpose of chemical analysis of steel, a lot shall consist of all turnbuckles or shackles made from the same material, from the same heat. In case heat cannot be identified, a lot shall consist of not more than 907 kg (2000 lb) of shackles or turnbuckles of the same type, class, and size.

4.2.3. *Specimens*—Specimens for inspection, and for required proof, breaking, and ductility tests shall be selected from each lot, in accordance with Table 18. Specimens used for proof test may be reused for breaking and ductility tests.

Table 18—Sampling Procedure for Inspection and Tests of Shackle or Turnbuckles

Number of Shackles or Turnbuckles in Lot	Number to Be Selected for Inspection and for Proof Test (When Proof Test Is Required)	Number to Be Used for Breaking Load and Ductility Tests
1 to 10	All	1
11 to 30	All	1
31 to 50	30	1
51 to 100	42	2
101 to 200	55	3
201 to 400	60	4
401 to 1000	65	5

4.3. *Chemical Analysis*—Analysis of material for shackles or turnbuckles shall be made from bars or from finished shackles or turnbuckles. One sample of not less than 60 g (2 oz.) of drillings or cuttings shall be taken from each lot of shackles or turnbuckles.

4.4. *Examination*—A random sample of shackles or turnbuckles taken in accordance with Table 18 shall be inspected to determine conformance with this specification regarding dimensions, masses, finish, and other requirements. Proof and breaking tests shall be made after zinc coating determinations.

4.4.1. *Rejection*—If one or more of the sample shackles or turnbuckles fail to conform to the requirements for appearance or coating, the entire lot shall be rejected. Each item in the rejected lot shall be reinspected by the manufacturer after removal or repair of noted deficiency. Normally, a lot shall be inspected in accordance with the sampling plan shown in Table 18; however, if a more stringent inspection of a resubmitted lot is required, the sampling procedure shall be in accordance with Table 19. If any sample from a resubmitted lot fails to pass the inspection, the entire lot shall be rejected.

Table 19—Sampling Procedure for Resubmitted Lots

Number of Shackles or Turnbuckles in Lot	Number of Samples to Be Inspected
1 to 100	All
101 to 1000	100

5. TESTS

5.1. *Proof Test*:

5.1.1. *Shackles*—Samples shall be subjected to proof loads shown in the applicable tables, either singly or in series. The diameter of the attachments used in proofing shall be not greater than the pin diameter of the shackle being tested and the application of the proof load shall be at the center of the pin. After releasing the proof load, each shackle shall be examined and disassembled to determine conformance with Section 3.3.1.

5.1.2. *Turnbuckles*—Each sample turnbuckle selected in accordance with Section 4.2.3 shall be subjected to a proof test of one-half the specified breaking strength for the end pull. Test load shall be applied at end pulls. Evidence of deformation or signs of incipient cracks in turnbuckle body or end pull shall be evidence of failure.

5.2. *Breaking and Ductility Tests*—After proof testing, the required number of samples shall be subjected to the breaking loads shown in the applicable table. For shackles, the diameter of the attachment used in the breaking test shall be not greater than the pin diameter of the shackle being tested; the application of the load shall be at the center of the pin. After breaking, the sample shall be inspected and measured to determine conformance with Section 3.4.2.

5.3. *Rejections*:

5.3.1. If any sample fails to pass the proof test, all shackles or turnbuckles in the lot shall be proofed and those failing to pass the test shall be rejected.

5.3.2. If any sample fails to pass the breaking or ductility test, triple the number of original sample shall be proofed and in addition triple the number of original samples shall be subject to the breaking and ductility test. If any retest sample fails in the breaking or ductility test, the lot shall be rejected.

5.4. *Galvanizing Test*—The galvanizing test shall be performed according to T 65M/T 65.

6. MARKING

6.1. Shackles or turnbuckles shall be shipped in boxes with marking identifying the following:

6.1.1. Size,

6.1.2. Type or class,

6.1.3. Number of units,

6.1.4. The number of this specification,

6.1.5. Production lot number, and

6.1.6. Other necessary identifying marks.

7. BASIS OF PURCHASE

7.1. Orders for material under this specification shall include the following information for each ordered item:

7.1.1. Quantity (number of units),

7.1.2. Name of product (turnbuckle or shackle),

7.1.3. Type or class (Section 1.2),

7.1.4. Size (Tables 2 or 6 through 17),

7.1.5. Grade of forging steel required,

7.1.6. Location of acceptance testing,

7.1.7. Test reports required, if any, and

7.1.8. AASHTO designation (M 269) and date of issue.

Standard Specification for

Metallic-Coated, Steel Woven Wire Fence Fabric

AASHTO Designation: M 279-09
ASTM Designation: A 116-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Metallic-Coated, Steel Woven Wire Fence Fabric

AASHTO Designation: M 279-09
ASTM Designation: A 116-05

1. SCOPE

1.1 This specification covers metallic-coated steel fence fabric having a series of horizontal (line) wires, with vertical (stay) wires either wrapped around the line wire (hinge joint) or fixed with another separate wire to the line wire (continuous stay fixed knot joint), forming rectangular openings. The fence fabric is suitable for use in fences for farm field enclosures (to keep domestic animals in or out), for wildlife and exotic animal control, for highway or railroad right-of-way fencing (to control access) and other similar uses.

1.2 This specification covers fence fabric in various designs, tensile strength grades, and metallic coating types and grades.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 120, Zinc
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 213M/T 213, Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles
- T 244, Mechanical Testing of Steel Products

2.2 *ASTM Standards*:

- A 641/A 641M, Standard Specification for Zinc–Coated (Galvanized) Carbon Steel Wire
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- A 809, Standard Specification for Aluminum-Coated (Aluminized) Carbon Steel Wire
- A 856/A 856M, Standard Specification for Zinc-5 % Aluminum-Mischmetal Alloy-Coated Carbon Steel Wire
- A 902, Standard Terminology Relating to Metallic Coated Steel Products

2.3 *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)

2.4 *Military Standards*:

- MLD-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products, Preparation for Shipment and Storage

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3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms used in this specification, refer to Terminology ASTM A 902.

3.2 *Description of Terms Specific to This Standard*:

3.2.1 *continuous stay fixed knot joint*—horizontal line wire and vertical stay wire joint made by fastening continuous stay wires to line wires by tying them together with a separate piece of knotwire at each joint.

3.2.2 *hinge joint*—horizontal line wire and vertical stay wire joint made by wrapping stay wire around line wires.

3.2.3 *intermediate wires*—line wires other than top and bottom wires.

3.2.4 *top and bottom wires*—line wires at the edge of the fence fabric (the top and bottom edges are erected).

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4. ORDERING INFORMATION

4.1 Orders for material purchased under this specification should include the following information, as necessary to describe each product ordered:

4.1.1 Name of material and joint style (woven steel fence fabric with hinge joint or continuous stay fixed knot joint);

4.1.2 Quantity (number of rolls);

4.1.3 Design Number describing standard sizes and construction of the fabric as listed in Table 1;

Note 1—The design numbers are related to the characteristics of the construction of the fence fabric. The design number indicates the number of the line wires, approximate height, stay wire spacing, and size (gauge) of the line and stay wires.

4.1.4 Fabric length (when length is not specified by the order, fabric is furnished to standard length of 10 m (330 ft)); and

4.1.5 Tensile strength grade (the fabric is available in strength grades of 60, 125, and 175 (see Table 1)).

Table 1—Design Numbers for Woven Wire Fence Fabric, Hinge Joint or Continuous Stay Fixed Knot Joint

Design Numbers	Number of Horizontal Wires	Nominal Fence Height	Spacing of Stay Wires, cm (in.)	Size, Steel Wire Gauge	
				Intermediate Line and Stay Wires	Top and Bottom Wires
No. 9 Grade 60					
1155-12-9	11	55	30 (12)	9	9
1047-12-9	10	47	30 (12)	9	9
939-12-9	9	39	30 (12)	9	9
832-12-9	8	32	30 (12)	9	9
726-12-9	7	26	30 (12)	9	9
949-12-9	9	49	30 (12)	9	9
845-12-9	8	45	30 (12)	9	9
635-12-9	6	35	30 (12)	9	9
1155-6-9	11	55	15 (6)	9	9
1047-6-9	10	47	15 (6)	9	9
726-6-9	7	26	15 (6)	9	9
No. 11 Grade 60					
1047-12-11	10	47	30 (12)	11	9
939-12-11	9	39	30 (12)	11	9
832-12-11	8	32	30 (12)	11	9
726-12-11	7	26	30 (12)	11	9
845-12-11	8	45	30 (12)	11	9
635-12-11	6	35	30 (12)	11	9
1047-6-11	10	47	15 (6)	11	9
939-6-11	9	39	15 (6)	11	9
832-6-11	8	32	15 (6)	11	9
726-6-11	7	26	15 (6)	11	9
No. 12 $^{1}/_{2}$ Grade 60					
1047-12-12 $^{1}/_{2}$	10	47	30 (12)	12 $^{1}/_{2}$	10
939-12-12 $^{1}/_{2}$	9	39	30 (12)	12 $^{1}/_{2}$	10
832-12-12 $^{1}/_{2}$	8	32	30 (12)	12 $^{1}/_{2}$	10
726-12-12 $^{1}/_{2}$	7	26	30 (12)	12 $^{1}/_{2}$	10
845-12-12 $^{1}/_{2}$	8	45	30 (12)	12 $^{1}/_{2}$	10
635-12-12 $^{1}/_{2}$	6	35	30 (12)	12 $^{1}/_{2}$	10
1047-6-12 $^{1}/_{2}$	10	47	15 (6)	12 $^{1}/_{2}$	10
939-6-12 $^{1}/_{2}$	9	39	15 (6)	12 $^{1}/_{2}$	10
832-6-12 $^{1}/_{2}$	8	32	15 (6)	12 $^{1}/_{2}$	10
726-6-12 $^{1}/_{2}$	7	26	15 (6)	12 $^{1}/_{2}$	10
No. 14 $^{1}/_{2}$ Grade 60					
939-6-14 $^{1}/_{2}$	9	39	15 (6)	14 $^{1}/_{2}$	11
832-6-14 $^{1}/_{2}$	8	32	15 (6)	14 $^{1}/_{2}$	11
726-6-14 $^{1}/_{2}$	7	26	15 (6)	14 $^{1}/_{2}$	11

Note 1—Design combinations other than listed in the table can be manufactured upon purchaser's request.

Note 2—Each design can be manufactured with hinge joint or continuous stay fixed knot joint.

Continued on next page.

Table 1—Design Numbers for Woven Wire Fence Fabric, Hinge Joint or Continuous Stay Fixed Knot Joint *(Continued)*

				Size, Steel Wire Gauge	
Design Numbers	Number of Horizontal Wires	Nominal Fence Height	Spacing of Stay Wires, cm (in.)	Intermediate Line and Stay Wires	Top and Bottom Wires
No. 12 $^{1}/_{2}$ Grade 125					
1047-12-12 $^{1}/_{2}$	10	47	30 (12)	12 $^{1}/_{2}$	10$^{1}/_{2}$
939-12-12 $^{1}/_{2}$	9	39	30 (12)	12 $^{1}/_{2}$	10$^{1}/_{2}$
832-12-12 $^{1}/_{2}$	8	32	30 (12)	12 $^{1}/_{2}$	10$^{1}/_{2}$
726-12-12 $^{1}/_{2}$	7	26	30 (12)	12 $^{1}/_{2}$	10$^{1}/_{2}$
1047-6-12 $^{1}/_{2}$	10	47	15 (6)	12 $^{1}/_{2}$	10$^{1}/_{2}$
939-6-12 $^{1}/_{2}$	9	39	15 (6)	12 $^{1}/_{2}$	10$^{1}/_{2}$
832-6-12 $^{1}/_{2}$	8	32	15 (6)	12 $^{1}/_{2}$	10$^{1}/_{2}$
726-6-12 $^{1}/_{2}$	7	26	15 (6)	12 $^{1}/_{2}$	10$^{1}/_{2}$
1478-6-12 $^{1}/_{2}$	14	78	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
No. 14 Grade 125					
1047-12-14	10	47	30 (12)	14	12 $^{1}/_{2}$
939-12-14	9	39	30 (12)	14	12 $^{1}/_{2}$
832-12-14	8	32	30 (12)	14	12 $^{1}/_{2}$
726-12-14	7	26	30 (12)	14	12 $^{1}/_{2}$
1047-6-14	10	47	15 (6)	14	12 $^{1}/_{2}$
939-6-14	9	39	15 (6)	14	12 $^{1}/_{2}$
832-6-14	8	32	15 (6)	14	12 $^{1}/_{2}$
726-6-14	7	26	15 (6)	14	12 $^{1}/_{2}$
No. 14 $^{1}/_{2}$ Grade 125					
1047-12-14 $^{1}/_{2}$	10	47	30 (12)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
939-12-14 $^{1}/_{2}$	9	39	30 (12)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
832-12-14 $^{1}/_{2}$	8	32	30 (12)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
726-12-14 $^{1}/_{2}$	7	26	30 (12)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
1047-6-14 $^{1}/_{2}$	10	47	15 (6)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
939-6-14 $^{1}/_{2}$	9	39	15 (6)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
832-6-14 $^{1}/_{2}$	8	32	15 (6)	14 $^{1}/_{2}$	12 $^{1}/_{2}$
726-6-14 $^{1}/_{2}$	7	26	15 (6)	14 $^{1}/_{2}$	12 $^{1}/_{2}$

Note 1—Design combinations other than listed in the table can be manufactured upon purchaser's request.

Note 2—Each design can be manufactured with hinge joint or continuous stay fixed knot joint.

Continued on next page.

Table 1—Design Numbers for Woven Wire Fence Fabric, Hinge Joint or Continuous Stay Fixed Knot Joint *(Continued)*

				Size, Steel Wire Gauge	
Design Numbers	Number of Horizontal Wires	Nominal Fence Height	Spacing of Stay Wires, cm (in.)	Intermediate Line and Stay Wires	Top and Bottom Wires
No. 12 $^{1}/_{2}$ Grade 175 *(For continuous stay fixed knot joint style fabric, stay wire minimum tensile strength is 100 ksi, ties wire diameter is minimum 13.5 GA)*					
1375-12-12 $^{1}/_{2}$	13	75	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1047-12-12 $^{1}/_{2}$	10	47	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
2096-12-12 $^{1}/_{2}$	20	96	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1796-12-12 $^{1}/_{2}$	17	96	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1886-12-12 $^{1}/_{2}$	18	86	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1775-12-12 $^{1}/_{2}$	17	75	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1584-12-12 $^{1}/_{2}$	15	84	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1561-12-12 $^{1}/_{2}$	15	61	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1348-12-12 $^{1}/_{2}$	13	48	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1060-12-12 $^{1}/_{2}$	10	60	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
949-12-12 $^{1}/_{2}$	9	49	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
842-12-12 $^{1}/_{2}$	8	42	30 (12)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1047-9-12 $^{1}/_{2}$	10	47	23 (9)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
23120-6-12 $^{1}/_{2}$	23	120	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
2096-6-12 $^{1}/_{2}$	20	96	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1796-6-12 $^{1}/_{2}$	17	96	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1886-6-12 $^{1}/_{2}$	18	86	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1584-6-12 $^{1}/_{2}$	15	84	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1348-6-12 $^{1}/_{2}$	13	48	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1060-6-12 $^{1}/_{2}$	10	60	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
949-6-12 $^{1}/_{2}$	9	49	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
842-6-12 $^{1}/_{2}$	8	42	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
735-6-12 $^{1}/_{2}$	7	35	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1047-6-12 $^{1}/_{2}$	10	47	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1775-6-12 $^{1}/_{2}$	17	75	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1561-6-12 $^{1}/_{2}$	15	61	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1375-6-12 $^{1}/_{2}$	13	75	15 (6)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
2096-3-12 $^{1}/_{2}$	20	96	7.5 (3)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1775-3-12 $^{1}/_{2}$	17	75	7.5 (3)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1561-3-12 $^{1}/_{2}$	15	61	7.5 (3)	12 $^{1}/_{2}$	12 $^{1}/_{2}$
1348-3-12 $^{1}/_{2}$	13	48	7.5 (3)	12 $^{1}/_{2}$	12 $^{1}/_{2}$

Note 1—Design combinations other than listed in the table can be manufactured upon purchaser's request.

Note 2—Each design can be manufactured with hinge joint or continuous stay fixed knot joint.

Table 2—Minimum Weight of Metallic Coating

Size, Steel Wire Gauge	Diameter, mm (in.)	Minimum Mass (Weight) of Coating, g/m^2 (oz/ft^2)					
		Type A Grade 60	Type Z Class 1 Grade 60	Type Z Class 3 Grades 60, 125, and 175	Type ZA Class 20 Grade 60	Type ZA Class 40 Grade 60, 125, and 175	Type ZA Class 80 Grade 60, 125, and 175
No. 9	3.76 (0.148)	122 (0.40)	107 (0.35)	275 (0.90)	61 (0.20)	122 (0.40)	244 (0.80)
No. 10	3.43 (0.135)	107 (0.35)	92 (0.30)	259 (0.85)	61 (0.20)	122 (0.40)	244 (0.80)
No. 10 $^1/_2$	3.25 (0.128)			259 (0.85)		122 (0.40)	244 (0.80)
No. 11	3.05 (0.120)	107 (0.35)	92 (0.30)	259 (0.85)	61 (0.20)	122 (0.40)	244 (0.80)
No. 12 $^1/_2$	2.51 (0.099)	98 (0.32)	85 (0.28)	244 (0.80)	61 (0.20)	122 (0.40)	244 (0.80)
No. 13 $^1/_2$	2.18 (0.086)		76 (0.25)	229 (0.75)	61 (0.20)	122 (0.40)	244 (0.80)
No. 14	2.03 (0.080)			214 (0.70)		122 (0.40)	244 (0.80)
No. 14 $^1/_2$	1.93 (0.076)	92 (0.30)	76 (0.25)	214 (0.70)	61 (0.20)	122 (0.40)	244 (0.80)

4.1.6 *Metallic Coating Type*:

4.1.6.1 *Coating Type A*—Made from aluminum-coated wire.

4.1.6.2 *Coating Type Z*—Made from zinc-coated wire.

4.1.6.3 *Coating Type ZA*—Made from ZN-5% Al-mischmetal alloy (Zn-5Al-MM) coated wire.

4.1.7 *Metallic Coating Class*—See Table 2.

4.1.8 Certification, or test report, or both, if required (see Section 10).

Note 2—A typical ordering description is as follows: Woven steel fence fabric, 60 rolls, Design Number 1047-6-12.5, Grade 60, Coating Type Z, Coating Class 3, to AASHTO M 279-03, with certification.

4.2 All rolls of fence fabric accepted by the purchaser shall be billed on the basis of the original length of the rolls before sampling unless changed by contractual agreement.

Table 3—Breaking Strength of Line Wires

Size, Steel Wire Gauge	Tensile Strength Grade, (ksi)	Nominal Diameter, mm (in.)	Minimum Breaking Strength Line Waves Only, N (lbf)
9	60 (60)	3.77 (0.148)	4590 (1030)
10	60 (60)	3.43 (0.135)	3820 (860)
10 $^1/_2$	125 (125)	3.25 (0.128)	7160 (1610)
11	60 (60)	3.05 (0.120)	3050 (685)
12 $^1/_2$	60 (60)	2.51 (0.099)	2050 (460)
12 $^1/_2$	100 (100)	2.51 (0.099)	3493 (770)
12 $^1/_2$	125 (125)	2.51 (0.099)	4280 (960)
12 $^1/_2$	175 (175)	2.51 (0.099)	5990 (1345)
14	125 (125)	2.03 (0.080)	2800 (630)
14 $^1/_2$	60 (60)	1.93 (0.076)	1210 (270)
14 $^1/_2$	125 (125)	1.93 (0.076)	2520 (565)

Note: There is no breaking strength requirement for stay wires.

5. MATERIALS

5.1 *Wire*—The steel wire shall be coated prior to fabrication, to the coating class specified in the order, the coating weight (mass) conforming to the requirements of Table 3. Coated wire shall be produced to the following applicable specifications:

5.1.1 *Coating Type A*—ASTM A 809,

5.1.2 *Coating Type Z*—ASTM A 641/A 641M,

5.1.3 *Coating Type ZA*—ASTM A 856/A 856M.

5.2 *Coated Wire Size*—Coated wire gauge sizes shown in Table 1, Table 2, and Table 3 correspond to steel wire gauge sizes listed in ASTM A 510, within tolerances stated in Section 7.

6. GENERAL REQUIREMENTS

6.1 *Construction*—The sizes and constructions for fence fabric furnished under this specification shall be in accordance with the requirements of Table 1 for the design number specified in the order, within the tolerances stated in Section 7. Designs other than specified in the table can be manufactured upon agreement between purchaser and producer. Each design can be manufactured with hinge joint or continuous stay fixed knot joint.

6.2 *Horizontal Wire*—Horizontal wires of all woven fencing shall be furnished with tension curves, at least one tension curve per each 229 mm (9 in.) of horizontal (line) wire.

6.3 *Splices*—Splicing of individual line wires by means of a wrap joint, mechanical fasteners, or an electric butt weld is permitted. The maximum number of line wire splices or joints shall not exceed one-half of the number of line wires in any 101 m (330 ft) (20-rod) roll of fabric. Such splices or joints shall be made in a workmanlike, manner and welded joints shall be coated with the corresponding Type A, Z, or AZ coating material to provide corrosion protection equivalent to the type coated wire being used.

6.4 *Stay Wires*—Stay wires shall be uniformly spaced and substantially perpendicular to the line wires. Tie wire used for the continuous stay fixed knot joint style fabric shall be minimum 13.5 gauge and of the same coating type and class as stay wire.

6.5 *Fence Fabric Length*—The length of the fence fabric in a roll shall be 101 m (330 ft) (20 rod). Fabric length other than 101 m can be manufactured upon agreement between purchaser and producer.

6.6 *Breaking Strength*—The breaking strength of line wires shall conform to the requirements of Table 3 for the grade specified in the order. There is no strength requirement for the stay wires for hinge joint style fabric. For Grade 175 continuous stay fixed knot joint style fabric, stay wire minimum tensile strength is 100 ksi (Grade 100).

7. PERMISSIBLE VARIATIONS IN DIMENSIONS

7.1 *Wire Diameter*—The permissible variation of the wire, from the nominal diameter shown in Table 3, shall be ±0.127 mm (±0.005 in.). Determine the diameter using a micrometer or other suitable measuring instrument, based on the greatest and least measurement at the same cross-section, with measurement to the nearest 0.025 mm (0.001 in.) The average of the two measurements shall be considered the diameter of the test specimen.

7.1.1 *Out-of-Roundness*—Due to the mechanics of the manufacture, a certain amount of out-of-roundness is expected on stay wires of the finished fence fabric. No limits are placed on out-of-roundness of the stay wires.

7.2 *Fabric Height*—The height of the woven wire fence fabric (center-to-center distance between top and bottom wires) shall not vary more than ±25 mm (±1 in.) from the specified height shown in Table 1. The specified height of fence fabric is based on the sum of the line wire spacing shown in Figures 1, 2, or 3.

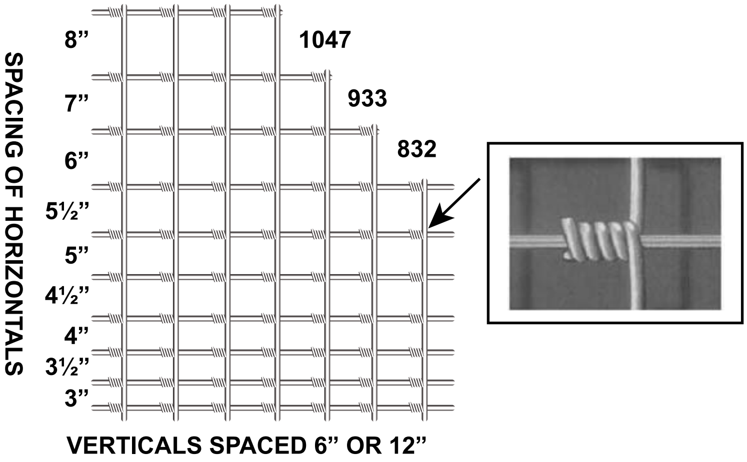

Figure 1—Typical Hinge Joint Fence Fabric Dimensions and Design Numbers[1]

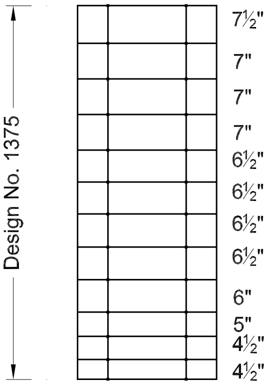

Figure 2—Fence Fabric Dimensions for Design No. 1375[1]

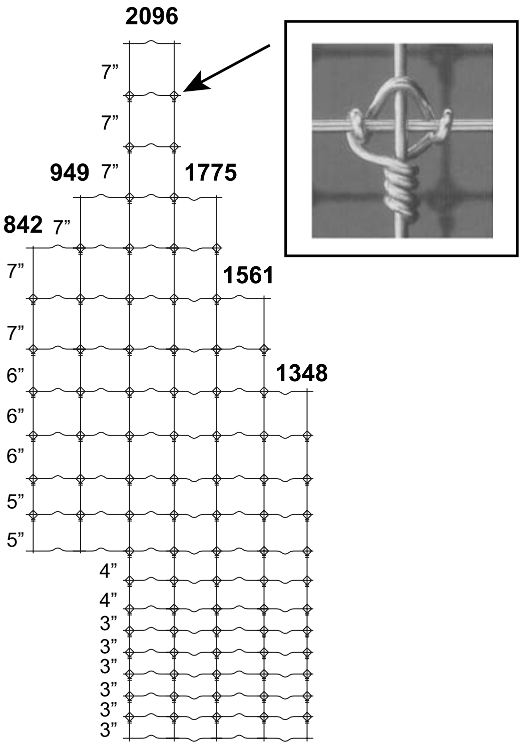

Figure 3—Continuous Stay Fixed Knot Joint Fence Fabric Dimensions and Design Numbers[1]

7.3 *Stay Wire Spacing*—The spacing between individual parts of line wires, or individual pairs of stay wires, shall not vary from the nominal dimensions more than 10 mm ($^3/_8$ in.) for 3 in. and 6 in. spacing and no more than 19 mm ($^3/_4$ in.) for 12 in. spacing product.

7.4 *Horizontal (Line) Wire Spacing—*The spacing between horizontal wires shall be as illustrated in Figures 1, 2, and 3 and is acceptable for given design number when agreed upon between purchaser and producer, providing that the total number of line wires remains unchanged. The spacing between individual pairs of horizontal wires shall not vary from the accepted nominal dimensions by more than 10 mm ($^3/_8$ in.). The tolerance of the line wires spacing shall not alter the tolerance on the overall height of the fence fabric.

7.5 *Fence Fabric Length*—The length of fence fabric in a roll shall be the specified length within a tolerance of –0 and +3 percent.

8. SAMPLING AND TESTING

8.1 Unless otherwise specified in the purchase order or contract, the manufacturer is responsible for the performance of all inspection and test requirements specified in this specification. Except as otherwise specified in the purchase order or contract, the manufacturer may use any suitable facilities for the performance of the inspection and test requirements unless disapproved by the purchaser at the time the order is placed. The purchaser shall have the right to perform any of the inspection and tests set forth in this specification when such inspections and tests are deemed necessary to assure that the material conforms to prescribed requirements.

8.2 *Sampling*—For the purpose of tests, select one roll at random from every 50 rolls, or fraction thereof, in a lot or a total of seven rolls, whichever is less. A lot shall consist of all rolls of a single design, grade, coating type, and coating class offered for delivery at the same time. A sample for physical tests is a length of fence fabric, at least 1 m (3 ft) long, cut from the end of the sample roll to include at least three of the vertical (stay) wires.

8.3 *Testing for Weight of Coating*—Coating weight for Types Z and ZA shall be determined in accordance with T 65M/T 65. Coating weight for Type A shall be determined in accordance with T 213M/T 213.

8.3.1 A test specimen for weight of coating determination shall consist of a number of lengths cut from a single wire, excluding all wire knots, wraps, and welded sections, such that the total length of wire tested is a minimum of 305 mm (12 in.). Test at least six test specimens for weight of coating, selected as follows:

8.3.1.1 One specimen from the top or bottom line wires,

8.3.1.2 Three specimens from different intermediate line wires, and

8.3.1.3 Two specimens from different vertical (stay) wires.

8.4 *Tests for Breaking Strength*—Cut specimens approximately 305 mm (12 in.) in length from the line wires, excluding knots, wraps, and welds. Test for breaking strength in accordance with T 244. Test at least four specimens, with one specimen from the top or bottom line wires, and three specimens from intermediate line wires.

8.5 *Pretesting of Wire*—Instead of testing wire for breaking strength and weight of coating from the completed fence fabric in accordance with Sections 8.3 and 8.4, the manufacturer, at his election, shall establish compliance with the requirements in Sections 5 and 6 by test made on wire prior to fabrication. If the manufacturer makes this election, the purchaser still has the right to test wire from the completed fence fabric for compliance.

8.6 *Inspection for General Workmanship*—For the purpose of inspection, a maximum of two rolls from the lot, as described in Section 8.2, shall be subjected to observations for the line and stay wire spacing, overall length, and workmanship.

8.6.1 Instead of inspecting for length by unrolling full rolls, the purchaser and the manufacturer have the option of agreeing on a weight per roll related to the fabric design, or measuring tools employed during manufacturing. The purchaser still reserves the right to confirm the length by actual measurement.

9. RETEST AND REJECTION

9.1 If one or more of the test specimens from a sample roll of fence fabric fail the weight-of-coating test or breaking strength test, the lot shall be subjected to retests. For retest purposes, four additional rolls for each 50 rolls offered shall be sampled. The lot size than becomes 50. Test specimens shall be cut in accordance with Section 8.3 or Section 8.4, as appropriate.

9.2 If more than four of the 24 retest specimens for weight-of-coating fail to meet the requirements of Table 2, or if any of the retest specimens has less than 75 percent of the specified coating weight, the entire lot represented by the retest specimens may be rejected.

9.3 If more than three of 16 retest specimens for breaking strength fail to meet the requirements of Table 3, or if any of the retest specimens has less than 90 percent of the specified strength, the entire lot represented by the retest specimens may be rejected.

9.4 If instead of rejecting the entire lot as provided for in Section 9.2 or Section 9.3, the producer may test specimens from every roll as provided for in Section 8.3 or Section 8.4 and resubmit those rolls meeting specification requirements.

9.5 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make a claim for a rehearing.

10. CERTIFICATION

10.1 When specified in the purchase order or contract, a producer's or supplier's certification shall be furnished to the purchaser that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements. When specified in the purchase order or contract, a report of the test results shall be furnished.

11. PACKAGING AND PACKAGE MARKING

11.1 Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

11.2 When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, when Level A is specified, preservation, packaging, and packing shall be in accordance with the Level A requirement of MIL-STD-163.

11.3 When specified in the contract or order, and for the direct procurement by or direct shipment to the U.S. Government, marking for shipment in addition to requirements specified in the contract or order shall be in accordance with MIL-STD-129 for U.S. military agencies and in accordance with Fed. Std. No. 123 for U.S. Government civil agencies.

12. KEYWORDS

12.1 Fence fabric; fencing material; metallic-coated steel wire; steel wire; wire.

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[1] Figures appear courtesy of ASTM International.

Standard Specification for

Metallic-Coated (Carbon) Steel Barbed Wire

AASHTO Designation: M 280-09
ASTM Designation: A 121-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Metallic-Coated (Carbon) Steel Barbed Wire

AASHTO Designation: M 280-09
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1. SCOPE

1.1. This specification covers metallic-coated steel barbed wire, consisting of a strand of two wires.

1.2. The barbed wire is available with aluminum, zinc, and zinc-5 percent aluminum-mischmetal alloy coatings, with a number of coating weights, in a number of different construction (designs), and in two grades. Not all designs are available in all coating types.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. The text of this specification references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of the specification.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *ASTM Standards*:

- A 428/A 428M, Standard Test Method for Weight [Mass] of Coating on Aluminum-Coated Iron or Steel Articles
- A 641/A 641M, Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- A 809, Standard Specification for Aluminum-Coated (Aluminized) Carbon Steel Wire
- A 856/A 856M, Standard Specification for Zinc-5% Aluminum-Mischmetal Alloy-Coated Carbon Steel Wire
- A 902, Standard Terminology Relating to Metallic Coated Steel Products

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for use of the International System of Units (SI): The Modern Metric System

2.4. *Federal Standard*:

- Fed. Std. 123, Marking for Shipment (Civil Agencies)

2.5. *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products Preparation for Shipment and Storage

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms used in this specification, refer to Terminology, ASTM A 902.

4. CLASSIFICATION

4.1. The barbed wire covered by this specification is classified as described in this section.

4.2. *Design Number*—Numbers describing standard sizes and constructions, as listed in Table 1.

4.3. *Metallic Coating Type*:

4.3.1. *Coating Type A*—made from aluminum-coated strand wire.

4.3.2. *Coating Type Z*—made from zinc-coated strand wire.

4.3.3. *Coating Type ZA*—made from zinc-5 percent aluminum-mischmetal alloy (Zn-5Al-MM) coated strand wire.

4.4. *Metallic Coating Class*—the specified amount of coating (coating weight [mass]) on the strand wire.

4.4.1. For coating Type A, see Section 6.3. (Only one coating weight for each wire size.)

4.4.2. For coating Type Z, see Table 2.

4.4.3. For coating Type ZA, see Table 3.

4.5. *Grades*:

4.5.1. *Standard Grade*—barbs spaced on 102 or 127 mm (4 or 5 in.) centers as indicated in Table 1.

4.5.2. *High-Security Grade*—barbs spaced on 76 mm (3 in.) centers (for Coating Type A only).

Note 1—The design numbers are related to the characteristics of the construction of the barbed wire, with the number groups related, in order, to the steel wire gauge of the strand wires, number of barb points, spacing of barbs, steel wire gauge of the barbs, and a letter indicating the shape of the barbs.

5. ORDERING INFORMATION

5.1. Orders for material under this specification shall include the following information, as necessary to describe the desired product:

5.1.1. Name of the material (steel barbed wire);

5.1.2. Quantity (number of spools and length of barbed wire on each, or total length) (see Section 7.5 for standard size of spools);

5.1.3. Metallic coating type, (see Section 4.3);

5.1.4. Metallic coating class (for Types Z and ZA) (see Table 2 or Table 3);

5.1.5. Design number (see Table 1);

5.1.6. For Coating Type A barbed wire, whether aluminum-alloy barbs are required or prohibited (see Section 6.2.1). If not stated, the choice shall be at the manufacturer's option;

5.1.7. AASHTO designation and year of issue; and

5.1.8. Certification or test report, or both, if required.

Note 2—A typical ordering description is as follows: Steel barbed wire, 20 spools of 80 rods each, Coating Type Z, Coating Class 3, Design Number 12-2-4-14R, to M 280-____ with certification.

5.2. All spools of barbed wire accepted by the purchaser shall be billed on the basis of the original length of the spools before sampling unless changed by contractual arrangement.

Table 1—Standard Sizes and Constructions for Barbed Wire

Design Number	Size, Steel Wire Gauge	Nominal Diameter of Coated Wire, mm (in.)	Number of Barb Points	Spacing of Barbs, mm (in.)	Dia of Barbs, Steel Wire Gauge[a]	Shape of Barbs
			Metallic Coating Type A			
12-4-3-14R	$12^{1}/_{2}$	2.51 (0.099)	4	76 (3)	14	Round
12-4-5-14R	$12^{1}/_{2}$	2.51 (0.099)	4	127 (5)	14	Round
12-4-3-12R[b]	$12^{1}/_{2}$	2.51 (0.099)	4	76 (3)	14	Round
			Metallic Coating Type Z and Type ZA			
12-2-4-12F	$12^{1}/_{2}$	2.51 (0.099)	2	102 (4)	$12^{1}/_{2}$[c]	Flat
12-2-4-13F	$12^{1}/_{2}$	2.51 (0.099)	2	102 (4)	13	Flat
12-2-4-14R	$12^{1}/_{2}$	2.51 (0.099)	2	102 (4)	14	Round
12-2-5-12F	$12^{1}/_{2}$	2.51 (0.099)	2	127 (5)	$12^{1}/_{2}$[c]	Flat
12-2-5-14R	$12^{1}/_{2}$	2.51 (0.099)	2	127 (5)	14	Round
12-4-5-14H	$12^{1}/_{2}$	2.51 (0.099)	4	127 (5)	14[c]	Half-Round
12-4-5-14R	$12^{1}/_{2}$	2.51 (0.099)	4	127 (5)	14	Round
13-2-4-14R	$13^{1}/_{2}$	2.18 (0.086)	2	102 (4)	14	Round
13-4-5-14R	$13^{1}/_{2}$	2.18 (0.086)	4	127 (5)	14	Round
14-2-5-14F	14	2.03 (0.080)	2	127 (5)	14	Flat
14-4-5-14F	14	2.03 (0.080)	4	127 (5)	14	Flat
14-2-5-14R	14	2.03 (0.080)	2	127 (5)	14	Round
14-4-5-14R	14	2.03 (0.080)	4	127 (5)	14	Round
15-2-5-13F	$15^{1}/_{2}$	1.70 (0.067)	2	127 (5)	$13^{3}/_{4}$[c]	Flat
15-2-5-14R	$15^{1}/_{2}$	1.70 (0.067)	2	127 (5)	14	Round
15-4-5-16R	$15^{1}/_{2}$	1.70 (0.067)	4	127 (5)	$16^{1}/_{2}$	Round

[a] Nominal diameter of wire used in making barbs shall be as follows:

$12^{1}/_{2}$ gauge	2.51 mm (0.099 in.)
13 gauge	2.32 mm (0.092 in.)
$13^{3}/_{4}$ gauge	2.11 mm (0.083 in.)
14 gauge	2.03 mm (0.080 in.)
$16^{1}/_{2}$ gauge	1.47 mm (0.058 in.)

[b] Design Number 12-4-3-12R, Metallic Coating Type A, is High-Security Grade. All other design numbers are for standard grade.

[c] The gauge of the half-round and flat barbs is designated by the gauge of the round wire from which the barbs are rolled.

Table 2—Minimum Mass of Coating on Type Z Barbed Wire

Size, Steel Wire Gauge	Nominal Diameter of Type Z		Minimum Weight of Coating of Uncoated Wire Surface, g/m^2 (oz/ft^2)	
	mm	(in.)	Class 1	Class 3
$12^{1}/_{2}$	2.51	0.099	85 (0.28)	245 (0.80)
13	2.32	0.092	85 (0.28)	230 (0.75)
$13^{1}/_{2}$	2.18	0.086	75 (0.25)	215 (0.70)
$13^{3}/_{4}$	2.11	0.083	[a]	215 (0.70)
14	2.03	0.080	75 (0.25)	215 (0.70)
$15^{1}/_{2}$	1.70	0.067	[a]	200 (0.65)
$16^{1}/_{2}$	1.47	0.058	[a]	200 (0.60)

[a] These sizes only furnished Class 2 Coating (Section 8).

Table 3—Minimum Mass of Coating on Type ZA Barbed Wire

Size, Steel Wire Gauge	Nominal Diameter of Type ZA		Min Weight of Coating of Uncoated Wire Surface, $g/m^2(oz/ft^2)$ Class[a]					
	mm	(in.)	20	40	60	80	100	120
$12^{1}/_{2}$	2.51	0.099	X[b]	X	X	X	X	X
13	2.32	0.092	X	X	X	X	X	X
$13^{1}/_{2}$	2.18	0.086	X	X	X	X	X	X
$13^{3}/_{4}$	2.11	0.083	X	X	X	X	X	X
14	2.03	0.080	X	X	X	X	X	X
$15^{1}/_{2}$	1.70	0.067	X	X	X	X	X	X
$16^{1}/_{2}$	1.47	0.058	X	X	X	X	X	X

[a]

Coating Class	20	40	60	80	100	120
Coating Weight:						
(g/m^2)	0.20	0.40	0.60	0.80	1.00	1.20
(oz/ft^2)	61	122	183	244	305	366

[b] X denotes availability.

6. MATERIAL

6.1. *Base Metal*—The base metal of the steel strand wires and steel barbs shall be of a good commercial quality carbon steel, capable of meeting the breaking strength requirement in Section 7.7. The base metal for aluminum barbs (permitted with metallic Coating Type A) shall be aluminum alloy wire conforming to alloy 5000-H38, Alloy 6061-T94, or equal.

6.1.1. For Coating Type A barbed wire, the choice of whether aluminum-coated steel wire or aluminum alloy wire for the barbs shall be that of the manufacturer, unless otherwise specified by the purchaser. If aluminum alloy wire is used, the particular alloy shall be agreed upon between the manufacturer and the purchaser at the time the order is placed.

6.2. *Coating Materials*—the coating on the wire shall conform with the requirements of the following specifications:

6.2.1. *Coating Type A*—aluminum-coated wire in accordance with ASTM A 809.

6.2.2. *Coating Type Z*—zinc-coated wire in accordance with ASTM A 641/A 641M.

6.2.3. *Coating Type ZA*—zinc-5 percent aluminum-mischmetal alloy (Zn-5Al-MM) coated wire in accordance with ASTM A 856/A 856M.

6.3. *Coated Wire*—the steel wire shall be coated before fabrication.

6.3.1. *Weight of Coating Requirements for Strand Wires*—The strand wires for Types Z and ZA barbed wire, as represented by the test specimens, shall conform to the requirements of Tables 2 and 3 respectively for the minimum coating weight for the type and class ordered. The strand wire for Type A barbed wire, as represented by the test specimens, shall have a minimum coating weight of 90 g/m^2 (0.30 oz/ft^2) on the $12^{1}/_{2}$-gauge wire.

6.3.2. *Weight of Coating Requirements for Barbs*—The wire for barbs for Types Z and ZA barbed wire, as represented by the test specimens, shall conform to the same coating class requirements as the strand wire. The steel wire for barbs for Type A barbed wire, as represented by the test specimens, shall have a minimum coating weight of 75 g/m^2 (0.25 oz/ft^2) on the 14-gauge wire.

7. GENERAL REQUIREMENTS

7.1. The sizes and constructions for barbed wire furnished under this specification shall be in accordance with the requirements of Table 1 for the design number specified in the order, within the tolerances stated in Section 8.

7.2. The barbs shall be sharp, well-formed, and tightly wrapped. The barb length, measured from the center of the two strand wires, shall be 9.5 mm ($^3/_8$ in.) minimum.

7.3. The strand wires shall be twisted with a uniform length of lay. Type Z and Type ZA barbed wire shall have the twisting consistently in one direction (left or right) or alternating between the left and right directions. Type A barbed wire shall have the twisting consistently in either the left or right direction, with alternating of the twisting prohibited.

7.4. Splicing of the individual wires by means of a wrap joint or an electric butt weld is permitted. Not more than three splices or joints shall be made in a workmanlike manner.

7.5. The barbed wire, for the various types, shall be packaged on spools in lengths as follows:

7.5.1. *Type A*—80 rods (402 m) (1320 ft) or 305 m (1000 ft), and

7.5.2. *Types Z and ZA*—80 rods (402 m) (1320 ft) or 80 rods plus additional increments of 10 rods (50 m) (165 ft).

7.6. *Breaking Strength*—The breaking strength of the stranded barbed wire, for all types, shall not be less than 4230 N (950 lbf). This breaking strength reflects that of both strand wires tested together as one unit.

8. PERMISSIBLE VARIATIONS IN DIMENSIONS

8.1. *Diameter*—The permissible variation from the nominal diameter of the wire, for both line wires and barbs, for all types, shall be ±0.13 mm (±0.005 in.).

8.1.1. Due to the mechanics of manufacture when forming the barbs, a certain amount of out-of-roundness can be expected. The size and the condition precludes barbs from being subjected to diameter checks.

8.2. *Barb Spacing*—The nominal spacing of the barbs shall be as noted in Table 1. The individual barb spacing shall be measured from the edge of one barb at the strand to the corresponding edge of the adjacent barb. Cumulative spacing is established by counting the total number of barbs in a 7.6-m (25-ft) length of barbed wire. Barbs are subject to relocation during fabrication and handling, potentially leading to rejections with rigid interpretation of the spacing requirement. Therefore, barb spacing shall be considered acceptable under the following conditions:

8.2.1. The sample has 93.5 percent of the individual barb spacings conforming to the specified spacing ±19 mm (±$^3/_4$ in.), and

8.2.2. A sample length of 7.6 m (25 ft) of barbed wire contains:

8.2.2.1. A minimum of 86 barbs for 76-mm (3-in.) spacing,

8.2.2.2. A minimum of 69 barbs for 102-mm (4-in.) spacing, or

8.2.2.3. A minimum of 55 barbs for 127-mm (5-in.) spacing.

9. SAMPLING AND TESTING

9.1. *Sampling*—For the purpose of tests, select one spool at random from every 50 spools or fraction thereof in a lot, or a total of seven samples, whichever is less. A lot shall consist of all the spools of a single construction (design number) of barbed wire offered for delivery at the same time.

9.2. *Test Specimens for Physical Tests*—Cut a 1.2-m (4-ft) length of barbed wire from the end of each spool for the tests prescribed in Sections 6 and 7. Determine the breaking strength by testing the twisted strand as a composite. Test each strand wire individually for mass of coating.

9.3. *Testing for Mass of Coating*—Coating mass for Types Z and ZA shall be determined in accordance with ASTM A 90/A 90M. Coating mass for Type A shall be determined in accordance with ASTM A 428/A 428M. Perform testing either before or after fabrication for the strand wires and for Type A steel barbs. Perform testing prior to fabrication for Type Z and ZA barbs, and certify the test results.

9.4. *Pretesting of Wire*—Instead of testing wire for breaking strength and mass of coating from the completed barbed wire in accordance with Section 9.2, the manufacturer, at his election, shall establish compliance with the requirements in Sections 6 and 7, by tests made on wire prior to fabrication. If the manufacturer makes this election, the purchaser still has the right to test wire from the completed barbed wire for compliance. It is recognized that during fabrication, the barb is mechanically deformed and scraped, and some differences are likely in coating mass results on barbs tested before and after fabrication.

9.5. *Inspection for General Workmanship*—For the purpose of inspection, a maximum of two spools from the lot, as described in Section 9.1, shall be subjected to observations for barb length and spacing, overall length, and workmanship.

9.5.1. Instead of inspecting for length by unrolling full spools, the purchaser and manufacturer have the option of agreeing on a mass per spool related to wire size or measuring tools employed during manufacturing. The purchaser still reserves the right to confirm length by actual measurement.

9.5.2. Inspection for barb spacing is normally performed on the outer 7.6-m (25-ft) length of a spool, which permits repackaging of the spool. Any other selection shall be as agreed upon between the manufacturer and the purchaser.

10. RETESTS

10.1. *Lot Size for Retests*—If one or more of the individual wire specimens fails the coating mass test, or if a strand specimen fails the breaking strength test, the lot shall be subjected to retest. For retest purposes, four additional spools of barbed wire for each 50 spools offered shall be sampled. The lot size then becomes 50 spools, except variation in lot size is permitted to accommodate pallet count when the barbed wire is palletized.

10.2. *Retesting for Coating Mass*—If more than two of the individual strand wires of the retest specimens fail to meet the requirements of Section 6.3, or if any of the retest specimens has less than 75 percent of the specified coating mass, the entire lot represented by the retest will be rejected.

10.3. *Retesting for Breaking Strength*—If any of the retest specimens fail to meet the minimum breaking strength value in Section 7.7, the entire lot represented by the specimens will be rejected.

10.4. *Re-Inspection for Barb Spacing, Barb Length, and Overall Length*—If either of the sample spools fails to meet the requirements of these dimensions within the tolerances of Section 8, two additional spools shall be selected for inspection. If either of these spools fails to meet the requirements, the lot will be rejected.

11. INSPECTION

11.1. Unless otherwise specified in the purchase order or contract, the manufacturer is responsible for the performance of all inspection and test requirements specified in this specification. Except as otherwise specified in the purchase order or contract, the manufacturer shall use his own or any other suitable facilities for the performance of the inspection and test requirements unless disapproved by the purchaser at the time the order is placed. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification when such inspections and tests are deemed necessary to ensure that the material conforms to prescribed requirements.

12. REJECTION AND REHEARING

12.1. Material that fails to conform to the requirements of this specification shall be rejected. Rejection shall be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or supplier shall make claim for a rehearing.

12.2. Instead of rejecting the entire lot as provided in Section 10, the manufacturer has the option of testing specimens from every spool and rejecting only those spools failing the mass of coating or breaking strength requirements.

13. CERTIFICATION

13.1. When specified in the purchase order or contract, a manufacturer's or supplier's certification that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements shall be furnished to the purchaser. When specified in the purchase order or contract, a report of the test results shall be furnished.

14. PACKAGING AND MARKING

14.1. Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

14.2. When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, when Level A is specified, preservation, packaging, and packing shall be in accordance with the Level A requirement of MIL-STD-163.

14.3. When specified in the contract or order, and for the direct procurement by or direct shipment to the U.S. Government, marking for shipment, in addition to the requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U.S. military agencies and in accordance with Fed. Std. No. 123 for U.S. Government civil agencies.

15. KEYWORDS

15.1. Barbed wire; carbon steel wire; metallic-coated steel wire; steel barbed wire; wire.

Standard Specification for

Steel Fence Posts and Assemblies, Hot-Wrought

AASHTO Designation: M 281-96 (2008)
ASTM Designation: A 702-89 (1994)$^{\in 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Fence Posts and Assemblies, Hot-Wrought

AASHTO Designation: M 281-96 (2008)

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1. SCOPE

1.1 This specification covers steel fence posts and assemblies manufactured from hot-wrought sections and intended for use in field and line fencing.

1.2 The posts are available in tee, channel or U, and Y-bar shapes, or angle shapes, and are furnished painted or galvanized, unless otherwise specified.

1.3 The values stated in inch-pound units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 111M/M 111, Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware

2.2 *ASTM Standards*:

- A 29/A 29M, Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for
- A 36/A 36M, Standard Specification for Carbon Structural Steel
- A 499, Standard Specification for Steel Bars and Shapes, Carbon Rolled from “T” Rails
- A 641/A 641M, Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment

2.3 *Federal Standard*:

- Fed Std. No. 123, Marking for Shipment (Civil Agencies)

2.4 *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products, Preparation for Shipment or Storage

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *assemblies*—angle section post components for installation of gates, fence ends, or corners, and intermediate bracing.

3.1.2 *line posts*—posts that support the straight-line body of the fence.

4. ORDERING INFORMATION

4.1 Orders for products under this standard should include the following:

4.1.1 Quantity (number of pieces) of line posts, end, or gate assemblies, corner or intermediate brace assemblies (It is customary to order line posts in multiples of five of the required length and the required number of end or corner assemblies.),

4.1.2 Type of section (if a specific section is required) (Section 6.2 and Figure 1),

4.1.3 Length or lengths required (Section 7.2),

4.1.4 Finish: galvanized or painted,

4.1.5 AASHTO designation and date of issue,

4.1.6 Anchor plates, if required (Section 6.4.3), and

4.1.7 Wire fasteners (state weight of zinc coating if other than Class 1) (Sections 6.6.2 and 6.6.3).

Note 1—A typical ordering description is as follows: 500 line posts; painted 8 ft long; M 281-____; omit anchor plates.

5. GENERAL REQUIREMENTS

5.1 Material furnished under this ASTM specification shall conform to the general requirements of the current edition of ASTM A 29/A 29M unless otherwise provided herein.

6. MATERIALS AND MANUFACTURE

6.1 *Material*:

6.1.1 Line post shall be fabricated from Steels A or B and assemblies from Steels A, B, or C as specified in Table 1.

6.1.2 Except as provided in Section 6.1.3, the finished line post and assemblies shall conform to the tensile properties specified in Table 1 for the applicable steel.

6.1.3 At the manufacturer's option, a Brinell or Rockwell B hardness test may be substituted for the tensile requirements in Table 1. In such cases the material shall conform to the Brinell or Rockwell B hardness specified in Table 2.

Table 1—Materials for Line Posts and Assemblies

		Line Posts		Assemblies	
Steel	Steel Description	Yield Point, Min, ksi (MPa)	Tensile Strength, Min, ksi (MPa)	Yield Point, Min, ksi (MPa)	Tensile Strength, Min, ksi (MPa)
A	Hot-wrought carbon steel 0.35 percent carbon, min	40 (275)	70 (485)	40 (275)	70 (485)
B	Hot-wrought carbon steel , or hot-wrought rail steel [a]	50 (345)	80 (550)	50 (345)	80 (550)
C	Structural steel[b]	—	—	36 (250)	58 (400)

[a] In accordance with ASTM A 499.

[b] In accordance with ASTM A 36/A 36M.

Table 2—Brinell Hardness

Steel	Description	Brinell Hardness, Min	Rockwell B Hardness, Min
A	Hot-wrought carbon steel, 0.35 percent carbon, min	143	79
B	Hot-wrought carbon steel or rail steel[a]	156	83
C	Structural steel [b]	116	68

[a] In accordance with ASTM A 499.

[b] In accordance with ASTM A 36/A 36M.

6.2 *Line Post Section*:

6.2.1 The posts shall be furnished as T, channel or U, or Y sections as illustrated in Figure 1. The cross section of T posts shall be approximately $1^{3}/_{8}$ in. (35 mm) wide, $1^{3}/_{8}$ in. deep, and $^{1}/_{8}$ in. (3.2 mm) thick. Unless otherwise specified by the purchaser, the line post type is at the manufacturer's option.

6.2.2 Dimensions may vary slightly in individual design in maintaining the control weight per foot.

6.3 *Wire Attachments*—Line posts shall have corrugations, knobs, notches, holes, or studs so placed and formed as to engage a substantial number of fence line wires in proper positions.

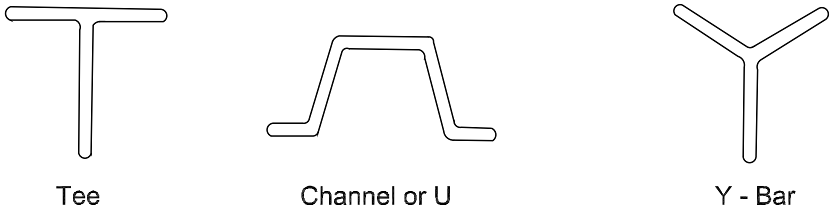

Figure 1—Typical Cross Sections of Line Post Types

6.4 *Anchor Plates*:

6.4.1 Each line post shall be manufactured with an anchor plate, unless otherwise specified. The anchor plate shall be made from carbon steel and shall be swaged or riveted to the post in such a manner as to prevent displacement when the posts are driven.

6.4.2 The placement of the anchor plate shall be nominally 14 in. (350 mm), 16 in. (400 mm), or 18 in. (450 mm) from the bottom of the post to the uppermost portion of the anchor plate.

6.4.3 Anchor plates shall be tapered to facilitate driving, shall have a minimum area of 18 in.^2 ($11600\ \text{mm}^2$), and shall weigh 0.67 lb (0.3 kg) ±5 percent.

6.4.4 When specified, line posts may be furnished without anchor plates.

6.4.5 Anchor plates shall be manufactured from Type A or B materials.

6.5 *Post Assemblies*:

6.5.1 Uprights shall consist of angles with a nominal size $2^1/_2$ by $2^1/_2$ by $^1/_4$ in. (65 by 65 by 6.4 mm) weighing 4.10 lb/ft (6.1 kg/m) prior to fabrication.

6.5.2 Braces shall consist of angles with a nominal size 2 by 2 by $^1/_4$ in. (50 by 50 by 6.4 mm) weighing 3.19 lb/ft (4.75 kg/m) prior to fabrication, or an alternative angle of equivalent weight.

6.5.3 Uprights and braces shall be furnished with the necessary holes and galvanized hardware for the required assembly.

6.5.4 All assemblies shall be furnished with one upright. End and gate assemblies shall be furnished with one brace, and corner and intermediate braces with two braces.

6.6 *Wire Fasteners*:

6.6.1 Unless otherwise specified by the purchaser, each line post shall be provided with not less than five suitable fasteners for attaching fence wire to the posts.

6.6.2 The fasteners shall be formed from zinc-coated steel wire not less than 0.120-in. (3.05-mm) diameter zinc coated in accordance with ASTM A 641. Class 1 coating shall be furnished unless otherwise specified by the purchaser.

6.6.3 When line posts are intended for range type western fencing using three line wires, it is satisfactory to provide only three fasteners for each post.

7. DIMENSIONS, MASS, AND PERMISSIBLE VARIATIONS

7.1 *Nominal Weights and Tolerances*:

7.1.1 *Nominal Weight*—Prior to fabrication by punching, drilling, attaching anchors, or finish coating, the line post sections shall have a nominal weight of 1.33 lb/ft (1.98 kg/m) of length.

7.1.2 The weight of line posts plus anchor plates (if specified), prior to fabrication, drilling, or finish coating shall not vary from nominal weights specified in Table 3 by more than ±5 percent. Weight shall be determined in lots of five line posts.

7.1.3 The weight of assembly components prior to fabrication, drilling, or finish coating shall not vary from the nominal weights specified in Table 4 by more than ±5 percent. Single assembly components shall be used to determine weight.

Table 3—Nominal Weights of (Raw) Line Posts

Post Length		Weight[a]	
ft	m	lb	kg
5	1.52	7.32	3.32
5 1/2	1.68	7.99	3.61
6	1.83	8.65	3.92
6 1/2	1.98	9.32	4.22
7	2.13	9.98	4.53
7 1/2	2.28	10.64	4.83
8	2.44	11.31	5.13
9	2.74	12.64	5.74
10	3.05	13.97	6.34

[a] Includes weight of anchor plate.

Table 4—Nominal Weights of (Raw) Assemblies

	Length		Weight[a]	
	ft	m	lb	kg
Upright and one brace, each (end or gate)	7	2.13	51	23
Upright and two braces, each (corner of intermediate brace)	7	2.13	73	33
Upright and one brace, each	8	2.44	58	26
Upright and two braces, each	8	2.44	84	38
Upright and one brace, each	9	2.74	66	30
Upright and two braces, each	9	2.74	94	43

[a] Includes weight of bolts.

7.2 *Standard Lengths and Tolerances*:

7.2.1 Line posts shall be furnished in standard lengths of 5 to 10 ft (1525 to 3050 mm) inclusive, as specified by the purchaser. Standard length increments are shown in Table 3.

7.2.2 The length of line posts, uprights, and braces shall not vary from that specified more than –1.0 in. (–25 mm) or +2 in. (+50 mm).

7.2.3 The placement of the anchor plate shall not vary from the nominal by more than ±3 in. (76 mm).

8. WORKMANSHIP, FINISH, AND APPEARANCE

8.1 Line posts, uprights, and braces shall be furnished painted or galvanized as specified by the purchaser.

8.2 When specified to be painted, the posts shall be cleaned of all loose scale prior to finishing, and painted with one or more coats, of weather resistant, air drying or baking, paint, or enamel.

8.3 When specified to be galvanized, the posts and post assemblies shall be zinc-coated by the hot-dip process in accordance with M 111M/M 111. The assembly hardware (Section 6.5.3) shall be zinc-coated in accordance with M 232M/M 232.

9. SAMPLING

9.1 One item from each lot shall be selected at random for testing. A lot shall consist of all posts or assemblies, or both, of the same length offered for delivery at the same time.

9.2 The post or assembly selected in accordance with Section 9.1 shall be tested for tensile strength or hardness, weight, and zinc coating, if applicable.

9.3 For purposes of visual inspection, length determinations, and dimensional examination, one post or assembly from each 400, or a total of seven, or whichever is less, shall be selected at random.

9.4 Visual inspection shall include examination for such features as excessive bow, camber, twist, or other injurious imperfections in surface or coating. Such imperfections may be considered cause for rejection of individual posts or assemblies.

10. INSPECTION

10.1 Unless otherwise specified in the purchase order or contract, the manufacturer is responsible for the performance of all inspection and test requirements specified in this specification. Except as otherwise specified in the purchase order or contract, the manufacturer may use his own or any other suitable facilities for the performance of the inspection and test requirements unless disapproved by the purchaser at the time the order is placed. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification when such inspections and tests are deemed necessary to assure that the material conforms to prescribed requirements.

11. REJECTION AND RETESTS

11.1 Should the post or assembly fail to meet any of the requirements of Section 9.2, the lot size shall become 400. One test shall be selected from each lot, and failure of the test shall result in rejection of that particular lot.

11.2 Should two or more posts or assemblies fail to meet any of the requirements of Section 9.3, the lot size shall become 400. Seven items shall be examined from each lot for compliance with the requirements of Section 9.3 causing initial failure. If two or more items fail, the entire lot shall be rejected.

11.3 Any individual post or assembly failing to meet the requirements of Sections 9.2 or 9.3 shall be rejected.

12. REJECTION AND REHEARING

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier may make claim for a rehearing.

13. CERTIFICATION

13.1 When specified in the purchase order or contract, a producer's or supplier's certification that the material was manufactured in accordance with this specification and has been found to meet the requirements shall be furnished to the purchaser.

14. PACKAGING

14.1 Line posts shall be bound in bundles of five posts, and by agreement with the purchaser, may be supplied in master bundles containing up to 250 posts.

14.2 Orders are customarily on piece count rather than on weight of posts or assemblies. The nominal weights establish the basis for weight tolerance and transportation data (Tables 3 and 4 for nominal weights).

15. PACKAGING, MARKING, AND LOADING FOR SHIPMENT

15.1 Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

15.2 When specified in the contract or order and for direct procurement by or direct shipment to the U.S. Government when Level A is specified, preservation, packaging, and packing shall be in accordance with Level A requirements of MIL-STD-163.

15.3 When specified in the contract or order and for direct procurement by or direct shipment to the U.S. Government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U.S. military agencies and in accordance with Fed. Std. No. 123 for U.S. Government civil agencies.

Standard Specification for

Portland Cement

AASHTO Designation: M 85-09
ASTM Designation: C 150-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Portland Cement

AASHTO Designation: M 85-09
ASTM Designation: C 150-09

1. SCOPE

1.1 This specification covers ten types of portland cement as follows (Note 1):

1.1.1 *Type I*—For use when the special properties specified for any other type are not required;

1.1.2 *Type IA*—Air-entraining cement for the same uses as Type I, where air-entrainment is desired;

1.1.3 *Type II*—For general use, more especially when moderate sulfate resistance is desired;

1.1.4 *Type IIA*—Air-entraining cement for the same uses as Type II, where air-entrainment is desired;

1.1.5 *Type II(MH)*—For general use, more especially when moderate heat of hydration and moderate sulfate resistance are desired.

1.1.6 *Type II(MH)A*—Air-entraining cement for the same uses as Type II(MH), where air-entrainment is desired.

1.1.7 *Type III*—For use when high early strength is desired;

1.1.8 *Type IIIA*—Air-entraining cement for the same use as Type III, where air-entrainment is desired;

1.1.9 *Type IV*—For use when low heat of hydration is desired; and

1.1.10 *Type V*—For use when high sulfate resistance is desired.

Note 1—Some cements are designated with a combined type classification, such as Type I/II, indicating that the cement meets the requirements of the indicated types and is being offered as suitable for use when either type is desired.

1.2 When both SI and inch-pound units are present, the SI units are the standard. The inch-pound units are approximations listed for information only.

1.3 The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 327, Processing Additions for Use in the Manufacture of Hydraulic Cements
- T 98, Fineness of Portland Cement by the Turbidimeter
- T 105, Chemical Analysis of Hydraulic Cement
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 107, Autoclave Expansion of Hydraulic Cement
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 131, Time of Setting of Hydraulic Cement by Vicat Needle
- T 137, Air Content of Hydraulic Cement Mortar
- T 153, Fineness of Hydraulic Cement by Air Permeability Apparatus
- T 154, Time of Setting of Hydraulic Cement Paste by Gillmore Needles
- T 186, Early Stiffening of Hydraulic Cement (Paste Method)

2.2 *ASTM Standards*:

- C 33, Standard Specification for Concrete Aggregates
- C 186, Standard Test Method for Heat of Hydration of Hydraulic Cement
- C 226, Standard Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Hydraulic Cement
- C 452, Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
- C 563, Standard Test Method for Approximation of Optimum SO_3 in Hydraulic Cement Using Compressive Strength
- C 1038, Standard Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *portland cement*—a hydraulic cement produced by pulverizing clinker, consisting essentially of hydraulic calcium silicates, and usually containing one or more of the following:

- water,
- calcium sulfate,
- up to 5 percent limestone, and
- processing additions.

3.1.2 *air-entraining portland cement*—a portland cement containing an interground air-entraining addition.

3.1.3 *hydraulic cement*—a cement that sets and hardens by chemical interaction with water and is capable of doing so underwater.

4. ORDERING INFORMATION

4.1 Orders for material under this specification shall include the following:

4.1.1 This specification number and date;

4.1.2 Type or types allowable. If no type is specified, Type I shall be supplied;

4.1.3 Any optional chemical requirements from Table 2, if desired; and

4.1.4 Any optional physical requirements from Table 4, if desired.

Note 2—Cement conforming to the requirements for all types are not carried in stock in some areas. In advance of specifying the use of other than Type I cement, determine whether the proposed type of cement is, or can be made, available.

5. INGREDIENTS

5.1 The cement covered by this specification shall contain no ingredients except as follows:

5.1.1 *Portland Cement Clinker.*

5.1.2 *Water or Calcium Sulfate or Both*—The amounts shall be such that the limits shown in Table 1 for sulfur trioxide and loss-on-ignition shall not be exceeded.

Table 1—Standard Chemical Requirements[a]

Cement Type	Applicable Test Method	I and IA	II and IIA	II(MH) and II(MH)A	III and IIIA	IV	V
Aluminum oxide (Al_2O_3), max, percent	T 105	—	6.0	6.0	—	—	—
Ferric oxide (Fe_2O_3), max, percent	T 105	—	6.0[c]	6.0[b, c]	—	6.5	—
Magnesium oxide (MgO), max, percent	T 105	6.0	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3),[d] max, percent	T 105						
When (C_3A)[f] is 8 percent or less		3.0	3.0	3.0	3.5	2.3	2.3
When (C_3A)[f] is more than 8 percent		3.5	[e]	[e]	4.5	[e]	[e]
Loss on ignition, max, percent	T 105	3.0	3.0	3.0	3.0	2.5	3.0
Insoluble residue, max, percent	T 105	0.75	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (C_3S)[f], max, percent	See Annex A1	—	—	—	—	35[b]	—
Dicalcium silicate (C_2S)[f], min, percent	See Annex A1	—	—	—	—	40[b]	—
Tricalcium aluminate (C_3A)[f], max, percent	See Annex A1	—	8	8	15	7[b]	5[c]
Sum of $C_3S + 4.75C_3A$, max, percent[g]		—	—	100[h]	—	—	—
Tetracalcium aluminoferrite plus twice the tricalcium Aluminate ($C_4AF + 2(C_3A)$), or solid solution ($C_4AF + C_2F$), as applicable, maximum, percent	See Annex A1	—	—	—	—	—	25[c]

[a] See Note 2.

[b] Does not apply when the heat of hydration limit in Table 4 is specified.

[c] Does not apply when the sulfate resistance limit in Table 4 is specified.

[d] It is permissible to exceed the values in the table for SO_3 content, provided it has been demonstrated by ASTM C 1038 that the cement with the increased SO_3 will not develop expansion exceeding 0.020 percent at 14 days. When the manufacturer supplies cement under this provision, supporting data shall be supplied to the purchaser. See Note 5.

[e] Not applicable.

[f] See Annex A1 for calculation.

[g] See Note 4.

[h] In addition, 7-day heat of hydration testing by ASTM C 186 shall be conducted at least once every 6 months. Such testing shall not be used for acceptance or rejection of the cement, but results shall be reported for informational purposes.

5.1.3 *Limestone*—The amount shall be not more than 5.0 percent by mass such that the chemical and physical requirements of this standard are met (See Note 3). The limestone, defined in ASTM C 51, shall be naturally occurring and consist of at least 70 percent by mass of one or more of the mineral forms of calcium carbonate.

Note 3—The standard permits up to 5 percent by mass of the final cement product to be naturally occurring, finely ground limestone, but does not require that limestone be added to the cement. Cement without ground limestone can be specified in the contract or order.

5.1.4 *Inorganic Processing Additions*—The amount shall not be more than 5.0 percent by mass of cement. Not more than one inorganic processing addition shall be used at a time. For amounts greater than 1 percent, they shall have been shown to meet the requirements of M 327 for inorganic processing additions in the amount used or greater. If an inorganic processing addition is used, the manufacturer shall report the amount (or range) used, expressed as a percentage of cement mass, along with the oxide composition of the processing addition.

5.1.5 *Organic Processing Additions*—They shall have been shown to meet the requirements of M 327 in the amounts used or greater, and the total amount of organic processing additions used shall not exceed 1 percent of the weight of portland cement clinker.

5.1.6 *Air-Entraining Addition (for Air-Entraining Portland Cement Only)*—The interground addition shall conform to the requirements of ASTM C 226.

6. CHEMICAL COMPOSITION

6.1 Portland cement of each of the ten types shown in Section 1 shall conform to the respective standard chemical requirements prescribed in Table 1. In addition, optional chemical requirements are shown in Table 2.

Note 4—The limit on the sum, $C_3S + 4.75\ C_3A$, in Table 1 provides control on the heat of hydration of the cement and is consistent with an ASTM C 186 7-day heat of hydration limit of 335 kJ/kg (80 cal/g).

Note 5—There are cases where performance of a cement is improved with SO_3 in excess of the Table 1 limits in this specification. ASTM C 563 is one of several methods a manufacturer can use to evaluate the effect of sulfate content on cement characteristics. Whenever SO_3 content of a cement exceeds Table 1 limits, ASTM C 1038 results provide evidence that excessive expansion does not occur at this higher sulfate content.

Table 2—Optional Chemical Requirements[a]

Cement Type	Applicable Test Method	I and I A	II and II A	II(MH) and II(MH)A	III and III A	IV	V	Remarks
Tricalcium aluminate (C_3A),[b] max, percent	See Annex A1	—	—	—	8	—	—	for moderate sulfate resistance
Tricalcium aluminate (C_3A),[b] max, percent	See Annex A1	—	—	—	5	—	—	for high sulfate resistance
Equivalent alkalies (Na_2O + 0.658K_2O), max, percent	T 105	0.60[c]	0.60[c]	0.60[c]	0.60[c]	0.60[c]	0.60[c]	low-alkali cement

[a] These optional requirements apply only if specifically requested. Availability should be verified. See Note 2 in Section 4.

[b] See Annex A1 for calculation.

[c] Specify this limit when the cement is to be used in concrete with aggregates that are potentially reactive and no other provisions have been made to protect the concrete from deleteriously reactive aggregates. Refer to ASTM C 33 for information on potential reactivity of aggregates.

7. PHYSICAL PROPERTIES

7.1 Portland cement of each of the ten types shown in Section 1 shall conform to the respective standard physical requirements prescribed in Table 3. In addition, optional physical requirements are shown in Table 4.

Table 3—Standard Physical Requirements

Cement Type[a]	Applicable Test Method	I	IA	II	IIA	II (MH)	II (MH)A	III	IIIA	IV	V
Air content of mortar, volume, percent:[b]	T 137										
Max		12	22	12	22	12	22	12	22	12	12
Min		—	16	—	16	—	16	—	16	—	—
Fineness, specific surface, m2/kg											
(alternative methods):[c]											
Turbidimeter test:	T 98										
Min		150	150	150	150	150	150	—	—	150	150
Max						245[d]	245[d]	—	—	245	—
Air permeability test:	T 153										
Min		260	260	260	260	260	260	—	—	260	260
Max						430[d]	430[d]	—	—	430	—
Autoclave expansion, max, percent	T 107	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Strength, not less than the value shown for the ages indicated below:[e]											
Compressive strength, MPa (psi)	T 106M/ T 106										
1 day		—	—	—	—	—	—	12.0 (1740)	10.0 (1450)	—	—
3 days		12.0 (1740)	10.0 (1450)	10.0 (1450)	8.0 (1160)	10.0 (1450) 7.0[f] (1020)[f]	8.0 (1160) 6.0[f] (870)[f]	24.0 (3480)	19.0 (2760)	—	8.0 (1160)
7 days		19.0 (2760)	16.0 (2320)	17.0 (2470)	14.0 (2030)	17.0 (2470) 12.0[f] (1740)[f]	14.0 (2030) 9.0[f] (1310)[f]	—	—	7.0 (1020)	15.0 (2180)
28 days		—	—	—	—	—	—	—	—	17.0 (2470)	21.0 (3050)
Time of setting (alternative methods):[g]											
Gillmore test:	T 154										
Initial set, min, not less than		60	60	60	60	60	60	60	60	60	60
Final set, min, not more than		600	600	600	600	600	600	600	600	600	600
Vicat test:[h]	T 131										
Time of setting, min, not less than		45	45	45	45	45	45	45	45	45	45
Time of setting, min, not more than		375	375	375	375	375	375	375	375	375	375

[a] See Note 2.

[b] Compliance with the requirements of this specification does not necessarily ensure that the desired air content will be obtained in concrete.

[c] Either of the two alternative fineness methods may be used at the option of the testing laboratory. However, when the sample fails to meet the requirements of the air-permeability test, the turbidimeter test shall be used, and the requirements in this table for the turbidimetric method shall govern.

[d] Maximum fineness limits do not apply if the sum of $C_3S + 4.75C_3A$ is less than or equal to 90.

[e] The strength at any specified test age shall be not less than that attained at any previous specified test age.

[f] When the optional heat of hydration in Table 4 is specified..

[g] The purchaser should specify the type of setting-time test required. In case he does not so specify, the requirements of the Vicat test only shall govern.

[h] The time of setting is that described as initial setting time in T 131.

Table 4—Optional Physical Requirements[a]

Cement Type	Applicable Test Method	I and II	IA and IIA	II(MH)	II(MH)A	III and IIIA	IV	V
False set, final penetration, min, percent	T 186	50	50	50	50	50	50	50
Heat of hydration:	ASTM C 186							
7 days, max, kJ/kg (cal/g)		—	—	290 (70)[b]	290 (70)[b]	—	250 (60)[c]	—
28 days, max, kJ/kg (cal/g)		—	—	—	—	—	290 (70)[c]	—
Strength, not less than the values shown:								
Compressive strength,	T 106M/ T 106	28.0	22.0	28.0	22.0	—	—	—
MPa (psi), 28 days		(4060)	(3190)	(4060)	(3190)			
				22.0[b]	18.0[b]			
				(3190)[b]	(2610)[b]			
Sulfate resistance, 14 days, max, percent expansion[d]	ASTM C 452	—[e]	—[e]	—[e]	—[e]	—	—	0.040

[a] These optional requirements apply only if specifically requested. Availability should be verified. See Note 2 in Section 4.

[b] The limit for the sum of the tricalcium silicate and 4.75 times the tricalcium aluminate in Table 1 shall not apply when this optional limit is requested. These strength requirements apply when the optional heat of hydration requirement is requested.

[c] When the heat of hydration limit is specified, it shall be used instead of the limits of C_3S, C_2S, C_3A, and Fe_2O_3 listed in Table 1.

[d] When the sulfate resistance is specified, it shall be used instead of the limits of C_3A, $C_4AF + 2(C_3A)$, and Fe_2O_3 listed in Table 1.

[e] Cement meeting the high sulfate resistance limit for Type V are deemed to meet the moderate sulfate resistance required of Type II and Type II(MH).

8. SAMPLING

8.1 When the purchaser desires that the cement be sampled and tested to verify compliance with this specification, sampling and testing should be performed in accordance with T 127.

8.2 Method T 127 is not designed for manufacturing quality control and is not required for manufacturer's certification.

9. TEST METHODS

Determine the applicable properties enumerated in this specification in accordance with the following methods:

9.1.1 *Air Content of Mortar*—T 137;

9.1.2 *Chemical Analysis*—T 105;

9.1.3 *Strength*—T 106M/T 106;

9.1.4 *False Set*—T 186;

9.1.5 *Fineness by Air Permeability*—T 153;

9.1.6 *Fineness by Turbidimeter*—T 98;

9.1.7 *Heat of Hydration*—ASTM C 186;

9.1.8 *Autoclave Expansion*—T 107;

9.1.9 *Time of Setting by Gillmore Needles*—T 154;

9.1.10 *Time of Setting by Vicat Needles*—T 131;

9.1.11 *Sulfate Expansion*—ASTM C 452;

9.1.12 *Calcium Sulfate (Expansion of) Mortar*—ASTM C 1038.

10. INSPECTION

10.1 Inspection of the material shall be made as agreed upon between the purchaser and the seller as part of the purchase contract.

11. REJECTION

11.1 The cement may be rejected if it fails to meet any of the requirements of this specification.

11.2 At the option of the purchaser, retest, before using, cement remaining in bulk storage for more than 6 months or cement in bags in local storage in the custody of a vendor for more than 3 months after completion of tests; reject the cement if it fails to conform to any of the requirements of this specification. Cement so rejected shall be the responsibility of the owner of record at the time of resampling for retest.

11.3 Packages shall identify the mass contained as net weight. At the option of the purchaser, packages more than 2 percent below the mass marked thereon shall be rejected. If the average mass of packages in any shipment, as shown by determining the mass of 50 packages selected at random, is less than that marked on the packages, the entire shipment shall be rejected.

12. MANUFACTURER'S STATEMENT

12.1 At the request of the purchaser, the manufacturer shall state in writing the nature, amount, and identity of any air-entraining addition, and of any processing addition that may have been used, and also, if requested, shall supply test data showing compliance of such air-entraining addition with the provisions of ASTM C 226, and of any such processing addition with M 327.

12.2 When limestone is used, the manufacturer shall state in writing the amount thereof and, if requested by the purchaser, shall supply comparative test data on chemical and physical properties of the cement with and without the limestone (see Note 6). The comparative tests do not supersede the normal testing to confirm that the cement meets chemical and physical requirements of this standard. The amount of limestone in cement shall be determined in accordance with Annex A2.

Note 6—Comparative test data may be from qualification tests performed by the manufacturer during formulation of the cement with limestone.

13. PACKAGING AND PACKAGE MARKING

13.1 When the cement is delivered in packages, the words "portland cement," the type of cement, the name and brand of the manufacturer, and the mass of the cement contained therein shall be plainly marked on each package. When the cement is an air-entraining type, the words "air-entraining" shall be plainly marked on each package. Similar information shall be provided in the shipping documents accompanying the shipment of packaged or bulk cement. All packages shall be in good condition at the time of inspection.

Note 7—With the change to SI units, it is desirable to establish a standard SI package for portland cements. To that end, 42 kg (92.6 lb) provides a convenient, even-numbered mass reasonably similar to the traditional 94-lb (42.6 kg) package.

14. STORAGE

14.1 The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building that will protect the cement from dampness and minimize warehouse set.

15. MANUFACTURER'S CERTIFICATION

15.1 Upon request of the purchaser in the contract or order, a manufacturer's report shall be furnished at the time of shipment stating the results of tests made on samples of the material taken during production or transfer and certifying that the cement conforms to applicable requirements of this specification.

Note 8—Guidance on preparing the manufacturer's report is provided in Appendix X1.

16. KEYWORDS

16.1 Hydraulic cement; portland cement; specification.

ANNEX

(Mandatory Information)

A1. CALCULATION OF POTENTIAL CEMENT PHASE COMPOSITION

A1.1. All values calculated as described in this annex shall be rounded according to ASTM E 29. When evaluating conformance to a specification, round values to the same number of places as the corresponding table entry before making comparisons. The expressing of chemical limitations by means of calculated assumed phases does not necessarily mean that the oxides are actually or entirely present as such phases.

A1.2. When expressing phases, C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3. For example, C_3A = $3CaO \cdot Al_2O_3$. Titanium dioxide and phosphorus pentoxide (TiO_2 and P_2O_5) shall not be included with the Al_2O_3 content. See Note A1.

Note A1—When comparing oxide analyses and calculated phases from different sources or from different historic times, be aware that they may not have been reported on exactly the same basis. Chemical data obtained by Reference and Alternate Test Methods of T 105 (wet chemistry) may include titania and phosphorous as alumina unless proper correction has been made (see T 105), while data obtained by rapid instrumental methods usually do not. This can result in small differences in the calculated phases. Such differences are usually within the precision of the analytical methods, even when the methods are properly qualified under the requirements of T 105.

A1.3. When the ratio of percentages of aluminum oxide to ferric oxide is 0.64 or more, the percentages of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite shall be calculated from the chemical analysis as follows:

$$\text{Tricalcium silicate } (C_3S) = (4.071 \times \%\ CaO) - (7.600 \times \%\ SiO_2) - (6.718 \times \%\ Al_2O_3) - (1.430 \times \%\ Fe_2O_3) - (2.852 \times \%\ SO_3) \qquad (A1.1)$$

$$\text{Dicalcium silicate } (C_2S) = (2.867 \times \%\ SiO_2) - (0.7544 \times \%\ C_3S) \qquad (A1.2)$$

$$\text{Tricalcium aluminate } (C_3A) = (2.650 \times \%\ Al_2O_3) - (1.692 \times \%\ Fe_2O_3) \qquad (A1.3)$$

$$\text{Tetracalcium aluminoferrite } (C_4AF) = 3.043 \times \%\ Fe_2O_3 \qquad (A1.4)$$

A1.3.1. When the alumina-ferric oxide ratio is less than 0.64, a calcium aluminoferrite solid solution (expressed as ss(C_4AF + C_2F)) is formed. No tricalcium aluminate will be present in cements of this composition. Dicalcium silicate shall be calculated as in Equation A1.2. Contents of this solid solution and of tricalcium silicate shall be calculated by the following formulas:

$$ss(C_4AF + C_2F) = (2.100 \times \%\ Al_2O_3) + (1.702 \times \%\ Fe_2O_3) \qquad (A1.5)$$

$$\text{Tricalcium silicate } (C_3S) = (4.071 \times \%\ CaO) - (7.600 \times \%\ SiO_2) - (4.479 \times \%\ Al_2O_3) - (2.859 \times \%\ Fe_2O_3) - (2.852 \times \%\ SO_3) \qquad (A1.6)$$

A1.4. If no limestone or inorganic processing additions are used in the cement, or in the absence of information on limestone or inorganic processing additions used in the cement, phases shall be calculated using procedures in Equations A1.1 to A1.6 without adjustment.

A1.5. In absence of information on limestone or inorganic processing additions content, results shall note that no adjustment has been made for possible use of limestone or inorganic processing additions.

A1.6. When inorganic processing additions, limestone, or both are used with the base cement (portland cement clinker and any added calcium sulfate), the contents of C_3S, C_2S, C_3A, and C_4AF, shall be adjusted as follows:

A1.6.1. The percentage of C_3S, C_2S, C_3A, and C_4AF in the base cement shall be determined based on chemical analyses using methods in T 105 and using equations A1.1 to A1.6 as appropriate. The contents of each of these phases shall be adjusted to account for the use of limestone or inorganic processing additions as follows:

$$X_f = X_b \times \frac{(100 - L - P)}{100} \qquad (A1.7)$$

where:

X_b = the percentage by mass of C_3S, C_2S, C_3A, or C_4AF in the base cement (portland cement clinker and any calcium sulfate),

L = the percentage by mass of limestone,

P = the percentage by mass of inorganic processing addition, and

X_f = the percentage by mass of C_3S, C_2S, C_3A, or C_4AF in the finished cement.

The adjusted values for the finished cement shall be reported on the manufacturer's report.

Note A2—For example, where the cement includes 3.5 percent limestone and 3.0 percent of an inorganic processing addition and the base cement has 60 percent C_3S, 15 percent C_2S, 7 percent C_3A, and 10 percent C_4AF, the adjusted phase composition is:

$$C_3S_f = \frac{60 \times (100 - 3.5 - 3.0)}{100} = 56\ \%$$

$$C_2S_f = \frac{15 \times (100 - 3.5 - 3.0)}{100} = 14\ \%$$

$$C_3A_f = \frac{7 \times (100 - 3.5 - 3.0)}{100} = 7\ \%$$

$$C_4AF_f = \frac{10 \times (100 - 3.5 - 3.0)}{100} = 9\ \%$$

A2. LIMESTONE CONTENT OF PORTLAND CEMENT

A2.1. When limestone is used, the limestone content in portland cement shall be derived from the determination of CO_2 in the finished cement. Analysis of CO_2 shall be based on methods described in T 105. The percent limestone in the cement is calculated from the CO_2 analysis based on the CO_2 content of the limestone used. The limestone content of the cement is calculated as follows:

$$\frac{\%CO_2 \text{ in the cement}}{\%CO_2 \text{ in the limestone}} \times 100 = \%\text{ limestone in cement} \qquad (A2.1)$$

Note A3—For example, where the determined CO_2 content in the finished cement equals 1.5 percent and the CO_2 content of the limestone equals 43 percent ($CaCO_3$ in limestone equals 98 percent), then:

$$\frac{1.5}{43} \times 100 = 3.5\%\text{ limestone content in cement}$$

A2.2. This specification requires that the limestone to be used must contain a minimum of 70 percent $CaCO_3$. The manufacturer shall include the $CaCO_3$ content of the limestone on the manufacturer's report. Calculate the $CaCO_3$ content of the limestone as follows: % $CaCO_3$ = 2.274 × % CO_2.

Note A4—For verification of limestone content of cement, the purchaser must analyze for CO_2 content and make a correction for the content of $CaCO_3$ in the limestone in order for the data to be comparable to the manufacturer's report.

A2.3. Portland cements that do not contain limestone can contain baseline levels of CO_2 inherent in manufacture, for example, due to carbonation. This baseline CO_2 content is included as part of any calculated limestone content.

APPENDIX

(Nonmandatory Information)

X1. MANUFACTURER'S CERTIFICATION (MILL TEST REPORT)

X1.1. To provide uniformity for reporting the results of tests performed on cements under this specification, as required by Section 15 of M 85, Manufacturer's Certification, an example Mill Test Report is shown in Figure X1.1.

X1.2. The identity information given should unambiguously identify the cement production represented by the Mill Test Report and may vary, depending on the manufacturer's designation and purchaser's requirements.

X1.3. The Manufacturer's Certification statement may vary, depending on the manufacturer's procurement order or legal requirements, but should certify that the cement shipped is represented by the certificate and that the cement conforms to applicable requirements of the specification at the time it was tested (or retested) or shipped.

X1.4. The sample Mill Test Report has been developed to reflect the chemical and physical requirements of this specification and recommends reporting all analyses and tests normally performed on cements meeting M 85. Purchaser reporting requirements should govern if different from normal reporting by the manufacturer or from those recommended here.

X1.5. Cements may be shipped prior to later-age test data being available. In such cases, the test value may be left blank. Alternatively, the manufacturer can generally provide estimates based on historical production data. The report should indicate if such estimates are provided.

X1.6. In reporting limits from the tables in M 85 on the Mill Test Report, only those limits specifically applicable should be listed. In some cases, M 85 table limits are superseded by other provisions.

X1.7. When limestone or inorganic processing additions or both are used in the cement, additional data are reported by the manufacturer. An example additional data report is shown in Figure X1.2.

ABC Portland Cement Company
Qualitytown, NJ

Plant: Example	Cement Type: II(MH)	Date: March 9, 2002
Production Period: March 2, 2002–March 8, 2002

STANDARD REQUIREMENTS
M 85, Tables 1 and 3

CHEMICAL

Item	Spec. Limit	Test Result
SiO_2 (%)	[a]	20.6
Al_2O_3 (%)	6.0 max	4.4
Fe_2O_3 (%)	6.0 max	3.3
CaO (%)	[a]	62.9
MgO (%)	6.0 max	2.2
SO_3 (%)	3.0 max	3.2
Loss on ignition (%)	3.0 max	2.7
Na_2O (%)	[a]	0.19
K_2O (%)	[a]	0.50
Insoluble residue (%)	0.75 max	0.27
CO_2 (%)	[a]	1.5
Limestone (%)	5.0 max	3.5
$CaCO_3$ in limestone (%)	70 min	98
Inorganic processing addition (ground, granulated blast-furnace slag)	5.0 max	3.0
Potential phase compositions (%)[d]		
C_3S	[a]	59
C_2S	[a]	11
C_3A	8 max	6
C_4AF	[a]	10
$C_4AF + 2(C_3A)$	[a]	20
$C_3S+4.75\ C_3A$, (%)	100 max	83

PHYSICAL

Item	Spec. Limit	Test Result
Air content of Mortar (volume %)	12 max	8
Fineness (m^2/kg)	260 min	377
(Air permeability)	430 max	
Autoclave expansion (%)	0.80 max	0.04
Compressive strength (MPa)	Min:	
1 day	[a]	
3 days	7.0	23.4
7 days	12.0	29.8
28 days	[a]	
Time of setting (minutes)		
(Vicat)		
Initial	Not less than 45	124
	Not more than 375	
Heat of hydration (kJ/kg)	[b]	300
7 days		
ASTM C1038 mortar bar expansion (%)	[c]	0.010[e]

[a] Not applicable.

[b] Test result represents most recent value and is provided for information only.

[c] Required only if percent SO3 exceeds the limit in Table 1, in which case expansion shall not exceed 0.020% at 14 days.

[d] Adjusted per Annex A1.6.

[e] Test result for this production period not available. Most recent test result provided.

OPTIONAL REQUIREMENTS
M 85, Tables 2 and 4

CHEMICAL

Item	Spec. Limit	Test Result
Equivalent alkalies (%)	[f]	0.52

[f] Limit not specified by purchaser. Test result provided for information only.

PHYSICAL

Item	Spec. Limit	Test Result
False set (%)	50 min	82
Compressive strength (MPa)		
28 days	28.0 min	39.7[e]

We certify that the above-described cement, at the time of shipment, meets the chemical and physical requirements of M 85-xx or (other) ____________________ specification.

Signature: ______________________________ Title: ______________________________

Figure X1.1—Example Mill Test Report

ABC Portland Cement Company
Qualitytown, NJ

Plant: Example Cement Type: II(MH) Date: March 9, 2002
Production Period: March 2, 2002–March 8, 2002

Additional Data

Inorganic Processing Addition Data

Type	Ground, granulated blast furnace slag
Amount (%)	3.0
SiO_2 (%)	33.1
Al_2O_3 (%)	10.9
Fe_2O_3 (%)	1.1
CaO (%)	44.4
SO_3 (%)	0.2

Base Cement Phase Composition

C_3S (%)	63
C_2S (%)	12
C_3A (%)	5
C_4AF (%)	11

We certify that the above-described data represents the materials used in the cement manufactured during the production period indicated.

Signature: ______________________ Title: ______________________

Figure X1.2—Example Additional Data Report

Standard Specification for

Blended Hydraulic Cement

AASHTO Designation: M 240-10[1]
ASTM Designation: C 595-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Blended Hydraulic Cement

AASHTO Designation: M 240-10[1]
ASTM Designation: C 595-09

1. SCOPE

1.1 This specification pertains to blended hydraulic cements for both general and special applications, using slag or pozzolan, or both, with portland cement or portland cement clinker or slag with lime.

Note 1—This specification prescribes ingredients and proportions with some performance requirements, whereas ASTM C 1157 is a blended cement specification in which performance criteria alone govern the products and their acceptance.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Values in SI units [or inch-pound units] shall be obtained by measurement in SI units [or inch-pound units] or by appropriate conversion, using the Rules for Conversion and Rounding given in IEEE/ASTM SI 10, of measurements made in other units [or SI units]. Values are stated in only SI units when inch-pound units are not used in practice.

1.3 The text of this standard refers to notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) are not requirements of the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 85, Portland Cement
- M 327, Processing Additions for Use in the Manufacture of Hydraulic Cements
- T 105, Chemical Analysis of Hydraulic Cement
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 107, Autoclave Expansion of Hydraulic Cement
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 129, Normal Consistency of Hydraulic Cement
- T 131, Time of Setting of Hydraulic Cement by Vicat Needle
- T 133, Density of Hydraulic Cement
- T 137, Air Content of Hydraulic Cement Mortar
- T 153, Fineness of Hydraulic Cement by Air Permeability Apparatus
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete
- T 192, Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve

2.2 *ASTM Standards*:

- C 186, Standard Test Method for Heat of Hydration of Hydraulic Cement
- C 219, Standard Terminology Relating to Hydraulic Cement
- C 226, Standard Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Hydraulic Cement
- C 227, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
- C 265, Standard Test Method for Water-Extractable Sulfate in Hydrated Hydraulic Cement Mortar
- C 311, Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- C 563, Standard Test Method for Approximation of Optimum SO_3 in Hydraulic Cement Using Compressive Strength
- C 688, Standard Specification for Functional Additions for Use in Hydraulic Cements
- C 821, Standard Specification for Lime for Use with Pozzolans
- C 1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
- C 1157, Standard Performance Specification for Hydraulic Cement
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3 *IEEE/ASTM Standard*:

- SI 10, American National Standard for use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1 *Definitions*—The terms used in this specification are defined in ASTM C 219 except for the following terms:

3.1.1 *binary blended cement*—a blended hydraulic cement consisting of portland cement with either a slag cement or a pozzolan.

3.1.2 *ternary blended cement*—a blended hydraulic cement consisting of portland cement with either a combination of two different pozzolans, or slag cement and a pozzolan.

4. CLASSIFICATION

4.1 This specification applies to the following types of blended cement that generally are intended for use as directed.

4.1.1 *Blended hydraulic cements for general concrete construction.*

4.1.1.1 *Type IS*—Portland blast-furnace slag cement.

4.1.1.2 *Type IP*—Portland-pozzolan cement.

4.1.1.3 *Type IT*—Ternary blended cement.

4.2 *Reporting:*

4.2.1 The naming practice for blended cements shall be made by adding the suffix (X) to the type designation under Section 4.1.1. where (X) equals the targeted percentage of slag or pozzolan in the product expressed as a whole number by mass of the final blended product, within the allowable variation as stated in Section 14.3.

4.2.2 The naming practice for ternary blended cements shall be made by adding the suffixes (AX) and (BY) to the Type IT designation under Section 4.1.1. where:

4.2.2.1 A is either “S” for slag cement, or “P” for pozzolan, whichever is present in larger amount by mass, and

4.2.2.2 X is the targeted percentage by mass of constituent A, and

4.2.2.3 B is either “S” for slag cement, or “P” for pozzolan, and

4.2.2.4 Y is the targeted percentage by mass of constituent B.

4.2.2.5 Both X and Y values are expressed as a whole number by mass of the final blended product, within the allowable variation as stated in 14.3. If X and Y are the same, the order is interchangeable.

Note 2—Examples of the naming practice per 4.2.1 and 4.3 are shown below (all percentages by mass):

Binary blended cement with 80 percent portland cement and 20 percent slag cement = IS (20)

Binary blended cement with 85 percent portland cement and 15 percent pozzolan = IP (15)

Ternary blended cement with 70 percent portland cement, 20 percent slag cement, and 10 percent pozzolan = IT (S20)(P10)

Ternary blended cement with 65 percent portland cement, 25 percent of one pozzolan, and 10 percent of another pozzolan = IT (P25)(P10).

4.2.3 A simplified naming practice is used in this standard for practicality and clarity when referring to specific requirements for binary and ternary blended cements that are applicable to a range of products or in ternary blended cements when requirements are applicable to only one constituent within a specific range (percent). (See Note 3.)

Note 3—Examples of the simplified naming practices per 4.2.3 are shown below:

An example when requirements are applicable to a range of products can be found in Table 1, where the maximum SO_3 content of 3 percent applies to: binary blended cements with slag cement contents <70 percent, indicated as IT (P <S <70).

1. An example when requirements are applicable to only one constituent within a specific range (percent) of that constituent can be found in 8.2, where testing is required only when the slag cement content is <25 percent. Because the requirement is based on the slag cement content only with no relation to the pozzolan content, a simplified naming practice is employed and the range of ternary blended cements are indicated as Type IT(S <25).

4.3 *Special Properties*:

4.3.1 Air-entraining cement, when desired by the purchaser, shall be specified by adding the suffix (A) to any of the above types. The air-entraining option is specified in combination with any of the other special properties where required.

Note 4—A given mass of blended cement has a larger absolute volume than the same mass of portland cement. This should be taken into consideration in purchasing cements and in proportioning concrete mixtures.

4.3.2 Moderate sulfate resistance or moderate heat of hydration, or both, when desired by the purchaser, shall be specified by adding the suffix (MS) or (MH), respectively, to the type designation under Section 4.1.1.

4.3.3 High sulfate resistance, when desired by the purchaser, shall be specified by adding the suffix (HS) to the type designation under Section 4.1.1.

Note 5—Special characteristics attributable to slag or pozzolan will vary based on quantities contained within the blended cements.

4.3.4 Low heat of hydration, when desired by the purchaser, shall be specified by adding the suffix (LH) to the type designation under Section 4.1.1.

5. ORDERING INFORMATION

5.1 Orders for material under this specification shall include the following:

5.1.1 Specification number,

5.1.2 Type or types required, and

5.1.2.1 Indicate allowable slag or pozzolan percent maximum or minimum, or both, if required.

5.1.3 Optional special properties required (see Section 4.3):

5.1.3.1 MS if moderate sulfate resistance is required;

5.1.3.2 HS if high sulfate resistance is required;

5.1.3.3 MH if moderate heat of hydration is required;

5.1.3.4 LH if low heat of hydration is required;

5.1.3.5 A if air entraining is required;

5.1.3.6 Accelerating addition, if required;

5.1.3.7 Retarding addition, if required;

5.1.3.8 Water reducing addition, if required;

5.1.3.9 Water reducing and accelerating addition, if required; and

5.1.3.10 Water reducing and retarding addition, if required.

5.1.4 Certification, if desired. (See Section 14.)

Note 6—It is important to check for availability of various options. Some multiple options are mutually incompatible or unattainable.

6. MATERIALS AND MANUFACTURE

6.1 *Blast-Furnace Slag*—Blast-furnace slag shall be the nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium and other bases that are developed in a molten condition simultaneously with iron in a blast furnace.

6.2 *Granulated Blast-Furnace Slag*—Granulated blast-furnace slag shall be the glassy granular material formed when molten blast-furnace slag is rapidly chilled, as by immersion in water.

6.3 *Slag Cement*—See terminology ASTM C 219.

6.4 *Portland Cement*—See terminology ASTM C 219. For purposes of this specification, portland cement meeting the requirements of M 85 is suitable. Portland cement or other hydraulic materials, or both, containing high free lime are not prohibited as long as the autoclave test limits for the blended cement are met.

6.5 *Portland Cement Clinker*—Portland cement clinker shall be partially fused clinker consisting primarily of hydraulic calcium silicates.

6.6 *Pozzolan*—Pozzolan shall be a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

6.7 *Hydrated Lime*—Hydrated lime used as part of a blended cement shall meet the requirements of ASTM C 821, except that when interground in the production process there shall be no minimum fineness requirement.

6.8 *Air-Entraining Addition*—When air-entraining cement is specified, an addition meeting the requirements of ASTM C 226 shall be used.

6.9 *Processing Additions*—When processing additions are used in the manufacture of cement, they shall have been shown to meet the requirements of M 327 in the amounts used or greater. (See Section 14.2.)

6.10 *Functional Additions*—When functional additions (used at the sole option of the purchaser, and in amounts not to exceed 0.50 percent by mass of the cement) are used, they shall be shown to meet the requirements of ASTM C 688 when tested with the cement to be used in the amount used or greater. (See Section 14.2 and Note 5.)

Note 7—The 0.50 percent by mass is an arbitrarily selected value.

6.11 *Other Additions*—The cement covered by this specification shall contain no additions except as provided for above except that water or calcium sulfate (see ASTM C 219), or both, if added, shall be in amounts so that the limits shown in Table 1 for sulfate reported as SO_3 and loss on ignition are not exceeded.

6.12 *Binary Blended Cement*—Binary blended cement shall be a hydraulic cement consisting of an intimate and uniform blend (see Note 7) produced either by intergrinding portland cement clinker with a pozzolan or a granulated blast-furnace slag, or a slag cement, or by blending portland cement with a pozzolan or a slag cement, or a combination of intergrinding and blending. The maximum constituent requirements of Sections 6.14 and 6.16 shall apply.

6.13 *Ternary Blended Cement*—Ternary blended cement shall be a hydraulic cement consisting of an intimate and uniform blend (see Note 7) produced either by intergrinding portland cement clinker with (1) two different pozzolans, or (2) granulated blast-furnace slag, or a slag cement and a pozzolan; or by blending portland cement with (1) two different pozzolans, or (2) slag cement and a pozzolan, or (3) a combination of intergrinding and blending. The maximum constituent requirements of 6.14 and 6.16 shall apply.

6.14 *Portland Blast-Furnace Slag Cement*—Portland blast-furnace slag cement shall be a hydraulic cement in which the slag cement constituent is up to 95 percent by mass of the blended cement. Binary or ternary blended cement, with a slag cement content equal to or exceeding 70 percent by mass, is permitted to contain hydrated lime.

Note 8—The attainment of an intimate and uniform blend of two or more types of fine materials is difficult. Consequently, adequate equipment and controls must be provided by the manufacturer. The purchaser should assure himself of the adequacy of the blending operation.

6.15 *Air-Entraining Portland Blast-Furnace Slag Cement*—Air-entraining portland blast-furnace slag cement shall be portland blast-furnace slag cement to which sufficient air-entraining addition has been added so that the resulting product complies with the air content of mortar requirements.

6.16 *Portland-Pozzolan Cement*—Portland-pozzolan cement shall be a hydraulic cement in which the pozzolan constituent is up to 40 percent by mass of the blended cement.

6.17 *Air-Entraining Portland-Pozzolan Cement*—Air-entraining portland-pozzolan cement shall be portland-pozzolan cement to which sufficient air-entraining addition has been added so that the resulting product complies with the air content of mortar requirements.

7. CHEMICAL COMPOSITION

7.1 Cement of the type specified shall conform to the applicable chemical requirements prescribed in Table 1.

Table 1—Chemical Requirements

Cement Type[a]	Applicable Test Method	IS (<70) IT (P < S < 70)	IS (≥70) IT (S > 70)	IP IT (P > S)
Magnesium oxide (MgO), max, percent	T 105	—	—	6.0
Sulfur reported as sulfate (SO_3), max, percent[b]	T 105	3.0	4.0	4.0
Sulfide sulfur (S), max, percent	T 105	2.0	2.0	—
Insoluble residue, max, percent	T 105	1.0	1.0	—
Loss on ignition, max, percent	T 105	3.0	4.0	5.0

[a] The chemical requirements in this table are applicable to all air-entrained cement equivalents.

[b] When it has been demonstrated by ASTM C 563 that the optimum SO_3 exceeds a value of 0.5 percent less than the specification limit, an additional amount of SO_3 is permissible provided that, when the cement with the additional calcium sulfate is tested by ASTM C 265, the calcium sulfate in the hydrated mortar at 24 ± $^1/_4$ h, expressed as SO_3, does not exceed 0.50 g/L. When the manufacturer supplies cement under this provision, upon request, supporting data shall be supplied to the purchaser.

7.2 If the purchaser has requested the manufacturer to state in writing the composition of the blended cement purchased, the composition of the cement furnished shall conform to that shown in the statement within the following tolerances. (See Note 8.)

	Tolerance, ± percent
Silicon dioxide (SiO_2)	3
Aluminum oxide (Al_2O_3)	2
Calcium oxide (CaO)	3

Note 9—This means that if the manufacturer's statement of the composition says "SiO_2: 32 percent," the cement when analyzed shall be found to contain between 29 and 35 percent SiO_2.

8. PHYSICAL PROPERTIES

8.1 *Blended Cement*—Blended cement of the type specified shall conform to the applicable physical requirements prescribed in Table 2.

Table 2—Physical Requirements

Cement Type[a]	Applicable Test Method	IS (<70), IT(P < S < 70), IP, IT(P > S)	IS (<70) (MS), IT(P < S < 70) (MS), IP(MS), IT(P > S) (MS)	IS (<70) (HS), IT(P <S < 70) (HS), IP (HS), IT(P > S) (HS)	IS (≥70), IT (S ≥ 70)	IP (LH),[c] IT(P > S) (LH)[c]
Fineness	T 153, T 192	[D]	[D]	[D]	[D]	[D]
Autoclave expansion max, percent	T 107	0.80	0.80	0.80	0.80	0.80
Autoclave contraction max, percent[E]	T 107	0.20	0.20	0.20	0.20	0.20
Time of setting, Vicat test:[F]	T 131					
Set, minutes, not less than		45	45	45	45	45
Set, h, not more than		7	7	7	7	7
Air content of mortar, volume percent[a]	T 137	12 max	12 max	12 max	12 max	12 max
Compressive strength, min,[a] MPa (psi):	T 106					
3 days		13.0	11.0	11.0	—	—
		(1890)	(1600)	(1600)	—	
7 days		20.0	18.0	18.0	5.0	11.0
		(2900)	(2610)	(2610)	(720)	(1600)
28 days		25.0	25.0	25.0	11.0	21.0
		(3620)	(3620)	(3620)	(1600)	(3050)
Heat of hydration:[G]	ASTM C 186					
7 days, max, kJ/kg		290	290	290		250
(cal/g)		(70)	(70)	(70)		(60)
28 days, max, Kj/kg		330	330	330		290
(cal/g)		(80)	(80)	(80)		(70)
Water requirement, max mass percent of cement	T 106	—	—	—	—	64
Drying shrinkage, max, percent	T 160	—	—	—	—	0.15
Mortar expansion:[h]	ASTM C 227					
14 days, max, percent		0.020	0.020	0.020	0.020	0.020
8 weeks, max, percent		0.060	0.060	0.060	0.060	0.060
Sulfate resistance[i]	ASTM C 1012					
Expansion at 180 days, max, percent		(0.10)[i]	0.10	0.05		(0.10)[i]
Expansion at 1 year, max, percent				0.10		

[a] Air-entrained cements shall have a mortar content of 19 ± 3 percent by volume and the minimum compressive strength shall be no less than 80 percent of the comparable non-air-entrained cement type.

[b] The requirements of Type IT(P >S), including MS, HS, or LH, as appropriate, shall apply to ternary blended cements with equal pozzolan and slag cement contents.

[c] Applicable only when higher strengths at early ages are not required or when low heat is required.

[d] Both amounts retained when wet sieved on 45-µm (No. 325) sieve and specific surface by air permeability apparatus, m^2/kg, shall be reported on all mill test reports requested under Section 14.4.

[e] The specimens shall remain firm and hard and show no signs of distortion, cracking, checking, pitting, or disintegration when subjected to the autoclave expansion test.

[f] Time of setting refers to initial setting time in T 131. The time of setting of cements containing a user-requested accelerating or retarding functional addition need not meet the limits of this table, but shall be stated by the manufacturer.

[g] Applicable only when moderate (MH) or low (LH) heat of hydration is specified, in which case the strength requirements shall be 80 percent of the values shown in the table.

[h] The test for mortar expansion is an optional requirement to be applied only at the purchaser's request and should not be requested unless the cement will be used with alkali-reactive aggregate.

[i] In the testing of HS cement, testing at one year shall not be required when the cement meets the 180-day limit. An HS cement failing the 180-day limit shall not be rejected unless it also fails the one-year limit.

[j] Optional sulfate resistance criterion that applies only if specifically invoked.

8.2 *Pozzolan or Slag*—Pozzolan or granulated blast-furnace slag or slag cement that is to be blended with cement shall be tested in the same state of subdivision as that in which it is to be blended. Pozzolan shall conform to the fineness requirement and the activity index requirement of Table 3. Slag cement that is to be used for Portland blast-furnace slag cements Type IS (<25) or ternary blended cements Type IT(S <25) shall conform to the slag activity requirement of Table 3. Such pozzolan or granulated blast-furnace slag or slag cement that is to be interground with portland cement clinker shall, before testing for conformance with requirements of Table 3, be ground in the laboratory to a fineness at which it is believed to be present in the finished cement. It is the manufacturer's responsibility to decide on the fineness at which the testing is to be carried out, and when requested to do so by a purchaser, to report the information upon which the decision was based.

Table 3—Requirements for Pozzolan for Use in Blended Cements and for Slag for Use in Portland Blast-Furnace Slag Cement Type IS (<25) and Ternary Blended Cement Type IT(S <25)

Pozzolan	Applicable Test Method	
Fineness: Amount retained when wet-sieved on 45-µm (No. 325) sieve, max, percent	T 192	20.0
Alkali reactivity of pozzolan for use in types IP(<15); IT(P<15) and IP(<15)-A cements, 6 tests, mortar bar expansion at 91days, max, percent	ASTM C 227	0.05
Slag or pozzolan activity index with portland cement, at 28 days, min, percent	See Annex A1	75.0

8.3 Pozzolan for use in the manufacture of portland-pozzolan cement, Type IP (<15) and IP(<15)-A, or ternary blended cements Type IT(P < 15) and Type IT(P <15)-A, shall meet the requirements of Table 3 when tested for mortar expansion of pozzolan as described in Section 10.1.13. If the alkali content of the clinker to be used for the production lots changes by more than 0.2 percent total as equivalent Na_2O, calculated as $Na_2O + 0.658\ K_2O$, from that of the clinker with which the acceptance tests were carried out, the pozzolan shall be retested to show compliance with the requirements of Table 3.

9. SAMPLING

9.1 Sample the materials in accordance with the following methods:

9.1.1 *Sampling Blended Cements*—T 127:

9.1.1.1 When the purchaser desires that the cement be sampled and tested to verify compliance with this specification, perform sampling and testing in accordance with T 127.

9.1.1.2 T 127 is not designed for manufacturing quality control and is not required for manufacturer's certification.

9.1.2 *Sampling Pozzolan*—ASTM C 311. One 2-kg (4-lb) sample shall be taken from approximately each 360 Mg (400 tons) of pozzolan.

10. TEST METHODS

10.1 Determine the applicable properties enumerated in this specification in accordance with the following test methods:

10.1.1 *Chemical Analysis*—T 105, with the special provisions noted therein applicable to blended cement analyses.

10.1.2 *Fineness by Sieving*—T 192.

10.1.3 *Fineness by Air-Permeability Apparatus*—T 153.

10.1.4 *Autoclave Expansion*—T 107, except that, in the case of portland blast-furnace slag cement IS (≥70) or ternary blended cement IT(S ≥70), the test specimens shall remain in the moist cabinet for a period of 48 hours before being measured for length, and the neat cement shall be mixed for not less than 180 seconds nor more than 210 seconds.

10.1.5 *Time of Setting*—T 131.

10.1.6 *Air Content of Mortar*—T 137, using the actual specific gravity of the cement, if it differs from 3.15 by more than 0.05, in calculating the air content.

10.1.7 *Compressive Strength*—T 106M/T 106.

10.1.8 *Heat of Hydration*—ASTM C 186.

10.1.9 *Normal Consistency*—T 129, except that in the case of portland blast-furnace slag cement IS (≥70) or ternary blended cement IT(S ≥70) the paste shall be mixed for not less than 180 seconds or more than 210 seconds.

10.1.10 *Specific Gravity*—T 133.

10.1.11 *Water Requirement*—The mass of mixing water added to the six-cube batch in accordance with T 106M/T 106, as a percentage of the total cementing ingredients.

10.1.12 *Mortar Expansion of Blended Cement*—ASTM C 227, using crushed Pyrex Glass No. 7740[2] as aggregate and the grading prescribed in Table 4.

Table 4—Aggregate Grading Requirements for Mortar Expansion Test

Sieve Size		Mass, Percent
Passing	Retained on	
4.75-mm (No. 4)	2.36-mm (No. 8)	10
2.36-mm (No. 8)	1.18-mm (No. 16)	25
1.18-mm (No. 16)	600-µm (No. 30)	25
600-µm (No. 30)	300-µm (No. 50)	25
300-µm (No. 50)	150-µm (No. 100)	15

10.1.13 *Mortar Expansion of Pozzolan for Use in Pozzolan-Modified Portland Cement Types IP(<15) and IP(<15)-A or Ternary Blended Cement Types IT(P <15) and IT(P <15)-A*—Using the pozzolan and the clinker or cement that are to be used together in the production of the blended cement, prepare portland-pozzolan cements Types IP(<15) and IP(<15)-A or Ternary Blended Cement Types IT(P <15) and IT(P <15)-A containing 2.5, 5, 7.5, 10, 12.5, and 15 mass percent of the pozzolan. These blends shall be tested in accordance with ASTM C 227 using a sand judged to be a nonreactive by the mortar bar test in ASTM C 227. The expansion of the mortar bars shall be measured at 91 days, and all six blends shall meet the expansion requirement in Table 3.

10.1.14 *Drying Shrinkage*—T 160. Make three specimens using the proportion of dry materials of 1 part of cement to 2.75 parts of T 106M/T 106, graded Ottawa sand. Use a curing period of 6 days and an air storage period of 28 days. Report the linear contraction during air storage based on an initial measurement after the 6-day water-curing period.

10.1.15 *Activity Index with Portland Cement*—Test in accordance with Annex A1.

10.1.16 *Sulfate Resistance*—See ASTM C 1012.

11. TESTING TIME REQUIREMENTS

11.1 The following periods from time of sampling shall be allowed for the completion of testing:

3-day test	8 days
7-day test	12 days
14-day test	19 days
28-day test	33 days
8-week test	61 days

12. INSPECTION

12.1 Facilities shall be provided to the purchaser for careful inspection and sampling of the finished cement. Inspection and sampling of finished cement shall be at the mill or distribution site controlled by the manufacturer, or at any other location agreed upon between the purchaser and the seller.

12.2 The manufacturer shall provide suitable facilities to enable the inspector to check the relative masses of the constituents used, and the intergrinding or blending operation used to produce the cement. The plant facilities for intergrinding or blending and inspection shall be adequate to ensure compliance with the provisions of this specification.

13. REJECTION

13.1 At the option of the purchaser, cement shall be rejected if it fails to meet any of the requirements of this specification applicable to the cement. Such rejection shall apply to an optional requirement only if that option has been invoked for the cement.

13.2 When the purchaser requires, cement in bulk storage for a period greater than 6 months shall be resampled and retested and, at the option of the purchaser, shall be rejected if it fails to meet any of the applicable requirements of this specification. Cement so rejected shall be the responsibility of the owner of record at the time of sampling for retest.

13.3 When the purchaser requires, packages more than 2 percent below the mass marked thereon shall be rejected; or if the average mass of packages in any shipment, as shown by determining the mass of 50 packages taken at random, is less than that marked on the packages, the entire shipment, at the option of the purchaser, shall be rejected.

14. CERTIFICATION

14.1 At the request of the purchaser, the manufacturer shall state in writing the source, amount, and composition of the essential constituents used in manufacture of the finished cement and the composition of the blended cement purchased.

14.2 At the request of the purchaser, the manufacturer shall state in writing the nature, amount, and identity of any processing, functional, or air-entraining addition used; and also, if requested, shall supply test data showing compliance of any such processing addition with the provisions of ASTM C 465, of any such functional addition with the provisions of ASTM C 688, and of any such air-entraining addition with the provisions of ASTM C 226.

14.3 At the request of the purchaser, the manufacturer shall also state in writing that the amount of pozzolan or slag in the finished cement will not vary more than ±5.0 mass percent of the finished cement from lot to lot or within a lot.

14.4 Upon request of the purchaser in the contract or order, a manufacturer's certification shall be furnished indicating that the material was tested during production or transfer in accordance with this specification, that it complies with this specification, and a report of the test results shall be furnished at the time of shipment (to include both amount retained on the 45-μm (No. 325) sieve and specific surface by the air permeability method).

15. PACKAGING AND PACKAGE MARKING

15.1 When the cement is delivered in packages, the words, "portland blast-furnace slag cement," "portland-pozzolan cement," or "ternary blended cement" as appropriate; the type of cement, name and brand of the manufacturer, and the mass of the cement contained therein shall be plainly marked on each package. When the cement contains a functional addition listed in Sections 5.1.3.5 to 5.1.3.10, the type of functional addition shall be plainly marked on each package. Similar information shall be provided in the shipping documents accompanying the shipment of packaged or bulk cement. All packages shall be in good condition at the time of inspection.

16. STORAGE

16.1 The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weather-tight building that will protect the cement from dampness and minimize warehouse set.

17. KEYWORDS

17.1 Blended hydraulic cement; fly ash cement; granulated blast-furnace slag; hydraulic cement; portland blast-furnace slag cement; portland-pozzolan cement; pozzolanic cement; slag cement; ternary blended cement.

ANNEX

(Mandatory Information)

A1. ACTIVITY INDEX WITH PORTLAND CEMENT PROCEDURE

A1.1. *Specimen Preparation*:

A1.1.1. Mold, cure, and test the specimens from a control mix and from a test mix in accordance with T 106M/T 106. The portland cement used in the control mix shall meet the requirements of M 85 and shall be the type, and if available, the brand of cement to be used in the work. In the test mix, replace 35 percent of the absolute volume of the amount of cement used in the control mix by an equal absolute volume of the test sample. Make 3-cube batches as follows (For 6- or 9-cube batches, double or triple, respectively, the amounts of dry ingredients.):

A1.1.1.1. *Control Mix*:

- 250 g of portland cement
- 687.5 g of graded Ottawa sand
- X mL of water required for flow of 100 to 115

A1.1.1.2. *Pozzolan Test Mix*:

- 162.5 g of portland cement
- g of pozzolan: 87.5 × sp gr of the sample/sp gr of the portland cement g of sample
- 687.5 g of graded Ottawa sand
- Y mL of water required for flow of 100 to 115

A1.1.1.3. *Slag Test Mix:*

- 75 g of portland cement
- g of slag: 175 × sp gr of the slag/sp gr of the portland cement
- 687.5 g of graded Ottawa sand
- Z mL of water required for flow of 100 to 115

A1.2. *Storage of Specimens*:

A1.2.1. After molding, place the specimens and molds (on the base plates) in the moist room or closet at 23 ± 2.0°C [73.5 ± 3.5 °F] for 20 to 24 hours. While in the moist room or closet, protect the surface from dripping water. Remove the molds from the moist room or closet and remove the cubes from the molds. Place the cubes in close-fitting metal or glass containers (Note A1), seal the containers airtight, and store at 38 ± 2.0°C [100.0 ± 3.5 °F] for 27 days. Allow the specimens to cool to 23 ± 2.0°C [73.5 ± 3.5 °F] before testing.

Note A1—Use any metal container having a capacity of three cubes if it can be sealed airtight by soldering. Containers of light-tinned sheet metal with inside dimensions of 52 by 52 by 160 mm [2 by 2 by 6.25 in.] have been found to be satisfactory. Wide-mouth Mason jars of 1-L capacity have been found to be satisfactory, provided care is taken to prevent breakage. (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.)[3]

A1.3. *Compressive Strength Test*:

A1.3.1. Determine the compressive strength of the three specimens of the control mix and of the test mix at an age of 28 days in accordance with T 106M/T 106.

A1.4. *Calculation*:

A1.4.1. Calculate the activity index with portland cement as follows:

$$\text{Activity index with portland cement} = (A/B) \times 100$$

where:

A = average compressive strength of test mix cubes, MPa, and

B = average compressive strength of control mix cubes, MPa.

A1.5. *Precision and Bias*:

A1.5.1. *Precision*—Single operator precision, on blended cements using fly ash is essentially the same as on fly ash/cement blends in Research Report C09-1001[4] and it was found to have 3.8 percent coefficient of variation (1s percent). This indicates that results of two properly conducted tests by the same operator should not differ by more than 10.7 percent (d2s) of the average of two results. Since the test is performed solely for the purpose of manufacturer certification of raw material quality, no multilaboratory precision is applicable.

A1.5.2. *Bias*—Because there are no standard reference materials, bias cannot be determined.

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[1] In essential equivalence with ASTM C 595-09.

[2] Pyrex Glass No. 7740 is available as lump cullet from the Corning Glass Works, Corning, NY; this is the sole source of supply of the apparatus known to the ASTM committee at this time. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

[3] Section on Safety, Manual of Cement Testing, *Annual Book of ASTM Standards*, Volume 04.01.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: C09-1001.

Standard Specification for

Silica Fume Used in Cementitious Mixtures

AASHTO Designation: M 307-07
ASTM Designation: C 1240-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

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1. SCOPE

1.1. This specification covers silica fume for use in concrete and other systems containing hydraulic cement.

1.2. In the cases of slurried or densified silica fume, perform the tests on the raw silica fume from which these products have been made.

1.3. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4. The following safety hazards caveat pertains only to the test methods portions, Section 10, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.* Read the material safety data sheets for materials used.

1.5. The text of this standard references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of this standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 194M/M 194, Chemical Admixtures for Concrete
- T 105, Chemical Analysis of Hydraulic Cement
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 137, Air Content of Hydraulic Cement Mortar
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete
- T 192, Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve

2.2. *ASTM Standards*:

- C 109/C 109M, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
- C 114, Standard Test Methods for Chemical Analysis of Hydraulic Cement
- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates

- C 157/C 157M, Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
- C 183, Standard Practice for Sampling and the Amount of Testing of Hydraulic Cement
- C 185, Standard Test Method for Air Content of Hydraulic Cement Mortar
- C 219, Standard Terminology Relating to Hydraulic Cement
- C 311, Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- C 430, Standard Test Method for Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve
- C 441, Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
- C 494, Standard Specification for Chemical Admixtures for Concrete
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- C 1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
- C 1069, Standard Test Method for Specific Surface Area of Alumina or Quartz by Nitrogen Adsorption
- C 1157, Standard Performance Specification for Hydraulic Cement
- C 1437, Standard Test Method for Flow of Hydraulic Cement Mortar

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *silica fume*—a very fine pozzolanic material, composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferro-silicon alloys (also known as condensed silica fume and microsilica).

3.1.2. Other terms in this specification are defined in ASTM C 125 and C 219.

4. ORDERING INFORMATION

4.1. The purchaser shall specify any optional chemical or physical requirements.

5. CHEMICAL REQUIREMENTS

5.1. Silica fume shall conform to the requirements for chemical composition prescribed in Table 1.

Table 1—Chemical Requirements

Silicon dioxide (SiO_2), min percent	85.0
Moisture content, max percent	3.0
Loss on ignition, max percent	6.0

6. PHYSICAL REQUIREMENTS

6.1. Silica fume shall conform to the physical requirements prescribed in Table 2. Optional physical requirements are shown in Table 3.

Table 2—Physical Requirements

Oversize:	
Percent retained on 45-µm (No. 325) sieve, max percent[a]	10
Percent retained on 45-µm (No. 325) sieve, max variation from average, percentage points[b]	5
Accelerated pozzolanic strength activity index:[c]	
With portland cement at 7 days, min percent of control	105
Specific surface, min, m^2/g	15

[a] Exercise care to avoid retaining agglomerations of extremely fine material.

[b] The average shall consist of the ten preceding tests or all of the preceding tests if the number is less than 10.

[c] Accelerated pozzolanic strength activity index is not to be considered a measure of the compressive strength of concrete containing the silica fume. This is a measure of the reactivity of a given silica fume with a given cement and may vary with the source of both the silica fume and the cement.

Table 3—Optional Physical Requirements[a]

Uniformity requirements:	
When air-entraining concrete is specified, the quantity of air-entraining agent required to produce an air content volume of 18 percent of the mortar shall not vary from the average established by the 10 preceding tests, or by all preceding tests if less than 10, by more than, percent	20
Reactivity with cement alkalies:[b]	
Reduction of mortar expansion at 14 days, min, percent[a]	80
Sulfate resistance expansion:[c]	
(moderate resistance) 6 months, max, percent	0.10
(high resistance) 6 months, max, percent	0.05
(very high resistance) one year, max, percent	0.05

[a] Optional physical requirements will be made only at the request of the purchaser.

[b] The indicated tests for reactivity with cement alkalies should not be requested unless the material is to be used with an aggregate that is regarded as deleteriously reactive with alkalies in hydraulic cement. The test for reduction of mortar expansion may be made using any high-alkali cement in accordance with ASTM C 113 if the cement to be used in the work is not known or is not available at the time of the test. The test for mortar expansion should be performed by each of the high-alkali cements to be used in the work.

[c] Only one limit shall be specified.

7. SAMPLING

7.1. When the purchaser desires that the silica fume be sampled and tested to verify compliance with this specification, perform the sampling and testing in accordance with T 127 or ASTM C 183, modified as described in Section 7.3.

Note 1—Exercise caution in the interpretation of T 127 or ASTM C 183 because there is a difference between the continuous manufacture of hydraulic cement and the generation and collection of silica fume. To a great extent, storage is dictated by the design of the silica fume collection system. The design of silica fume collection systems may not have provided for sampling points and practices.

7.2. T 127 or ASTM C 183, as modified, is not designed for manufacturing quality control and is not required for manufacturer's certification.

7.3. The following modification of T 127 or ASTM C 183 is necessary to render it applicable to silica fume:

7.3.1. Replace the words "hydraulic cement" and "cement" with the words "silica fume" every time they appear in the text.

7.3.2. All samples, whether grab or composite, shall have a mass of at least 1 kg (2 lb).

7.3.3. When compliance verification tests of silica fume are required to be made at a laboratory other than that of the silica fume manufacturer or marketer, coordinate the silica fume sampling schedule, sample transportation time, and sample testing schedule among the purchaser, manufacturer, and testing laboratory so the test results will be available when the decision to accept or reject the silica fume must be made.

7.3.4. The section entitled "Sampling" is modified as follows:

7.3.4.1. Take two grab samples or two composite samples for the first 100 Mg (110 tons) of silica fume. Take a grab sample or a composite sample for each subsequent 100 Mg (110 tons) of silica fume, but not less than two samples shall be taken in any sampling program.

7.3.4.2. *From Bulk Storage at Points of Discharge*—Withdraw silica fume from the discharge openings in a steady stream until sampling is completed. In sampling bulk storage at points of discharge, while the silica fume is flowing through the openings, take samples at such intervals so that, at a minimum, the sampling requirements of Section 7.3.4.1 are met.

7.3.5. The section entitled "Amount of Testing" is modified by deleting the first paragraph, "General."

8. FREQUENCY OF TESTS

8.1. Except for the tests listed in Section 8.2, make all chemical determinations and physical tests on composite samples representing no more than 400 Mg (440 tons) each. Prepare each composite sample by combining portions from the samples representing each 100 Mg (110 tons) so that each 100 Mg (110 tons) is represented equally.

8.2. Test for specific surface, density, and accelerated pozzolanic strength activity index using composite samples that represent 3200 Mg (3520 tons) or 3 months of production, whichever gives the highest frequency. Prepare each composite sample by combining portions from the samples representing each 400 Mg (440 tons) or 1 month, whichever gives the highest frequency, so that each sample is represented equally.

9. PREPARATION OF SAMPLE

9.1. Prepare composite samples for tests, as required in Section 8, by arranging all test samples in groups, with each group representing the number of megagrams required by the test or tests for which the composite sample is intended. From each of the samples in a group, take equal portions, sufficient in amount to form a composite sample large enough to permit making the required physical or chemical determinations.

9.2. Prior to testing, mix grab samples and composite samples thoroughly. A clean and dry laboratory concrete drum mixer provides adequate mixing for this purpose. Take care to limit the volume of silica fume in the drum mixer to the range of 10 to 50 percent of the drum's total capacity. If necessary, secure a sheet of polyethylene film on the drum with an elastic tiedown to keep the material in the drum. Limit the mixing action to 5 ± 1 minute.

9.2.1. When a small sample size precludes the use of a concrete mixer, use a heavy plastic bag, of a capacity at least five times larger than the sample volume, to mix the sample thoroughly. After placing the sample in the bag, close the bag by tying the bag opening tightly, and mix the material by rolling the bag around for 5 ±1 minute.

9.3. Take material for specific tests from a thoroughly mixed sample by using a sampling device (sampling tube, scoop, etc.) of appropriate size to make a test specimen. Make this test specimen from at least six random subsamples.

TEST METHODS–CHEMICAL ANALYSIS

10. SILICON DIOXIDE AND TOTAL ALKALIES

10.1. *Reference Method*—Use the reference method in T 105 for cements with insoluble residue greater than one percent. Analysts performing sodium oxide and potassium oxide determinations shall observe the precautions outlined in the applicable section of ASTM C 1157 (refer to the section on Test Methods). Most pozzolans dissolve completely in lithium borate fluxes.

11. MOISTURE CONTENT AND LOSS ON IGNITION

11.1. Make these determinations following applicable provisions of ASTM C 311.

TEST METHODS–PHYSICAL TESTS

12. DENSITY

12.1. *Equipment*:

12.1.1. Two 500-mL Volumetric Flasks, Class A;

12.1.2. Balance, with an accuracy of at least 0.01 g;

12.1.3. Constant temperature bath, capable of being regulated within ±0.5°C (1.0°F).

12.2. *Deionized water*:

12.3. *Procedure*:

12.3.1. Determine the density of the material as received, unless otherwise specified, as follows. If density determination on an ignited sample is required, first ignite the sample as described in the test for loss on ignition in the applicable section given in T 105.

12.3.2. Determine the mass (W_f) of a 500-mL volumetric flask, to an accuracy of 0.01 g. Add 30 g of silica fume. Determine the mass of the flask and the contents (W_a) to the nearest 0.01 g. Add water to the flask to fill it one-half full, and shake it to ensure thorough wetting of the material. Fill to the mark with water. Remove air bubbles by shaking the flask at 15-minute intervals until the liquid is free of air or by applying a vacuum to the flask. After all of the air bubbles are removed, place the flask in a constant temperature bath at 23 ± 0.5°C until the flask and its contents reach a constant temperature. Remove the flask from the water bath; immediately add or remove water, at the same temperature, to the flask to get the meniscus on the mark. Wipe dry the exterior of the flask and determine the mass of the flask and its contents (W_s).

12.3.3. Empty, clean, and determine the mass of the 500-mL volumetric flask, used above, filled to the mark with water (W_t) stabilized at 23 ± 0.5°C.

12.4. *Calculation*:

$$D_{sf} = \frac{\left(W_a - W_f\right)}{500\ mL - \left[(W_s - W_a)/D_w\right]} \tag{1}$$

where:

D_{sf} = density of silica fume, Mg/m^3;

W_f = mass of 500-mL volumetric flask, g;

W_a = mass of 500-mL volumetric flask plus approximately 30 g of silica fume, g;

W_s = mass of 500-mL volumetric flask plus silica fume plus water to the mark, g;

W_t = mass of 500-mL volumetric flask plus water to the mark, g; and

D_w = ($W_t - W_f$)/500-mL, Mg/m^3.

12.5. Report the average of two density determinations.

13. OVERSIZE, AMOUNT RETAINED WHEN WET-SIEVED ON A 45-μM (NO. 325) SIEVE

13.1. Use T 192. Calibrate the sieves in accordance with T 192.

Note 2—Oversize is used to determine the amount of contaminating material retained on the 45-μm (No. 325) sieve. See Appendix X2 (ASTM C 1240: Appendix X2).

14. SPECIFIC SURFACE

14.1. Determine the specific surface by the BET, nitrogen adsorption method, in accordance with ASTM C 1069.

Note 3—Manufacturers and examples of nitrogen adsorption instrumentation include Horiba Instruments, Inc. Irvine, CA, 5A-9600; Micromeritics Instrument Corporation, Norcross Georgia, FlowSorb-II 2300; Quantachrome Corporation, Boynton Beach, FL, Quantasorb Jr.; and JUWE Laborgerate Service GmbH, Korschenbroich, Germany, Stroehlein AREAmeter II. National Institute of Standards and Technology (NIST) Standard Reference Material SRM^{R} 2696 (22.92 m^2/g) for specific surface is available for use in comparison and evaluation of laboratory equipment and procedures.

15. AIR-ENTRAINMENT OF MORTAR

15.1. Follow the applicable provisions of ASTM C 311, except use the following test mixture and equation for W_c:

	Test Mixture
Portland cement, g	300
Silica fume, g	30
20-30 Standard Ottawa sand, g	1170
Water, mL, sufficient to give a flow of 80 percent to 95 percent	Y
Neutralized Vinsol resin solution, mL, sufficient to produce an air content of 18 ± 3 percent	Z

$$W_c = \frac{300 + 1170 + 30 + \left(300 \times P \times 0.01\right)}{300/3.15 + 1170/2.65 + 30/D + \left[\left(300 \times P \times 0.01\right)/1\right]} \qquad (2)$$

Then calculate:

Air content, volume % = $100[1–(M/W_c)]$ $M = W/400$ *(3)*

where:

M = actual mass per unit of volume of mortar as determined by T 137, g/mL;

W = mass of the specified 400 mL of mortar (see T 137), g;

W_c = theoretical mass per unit volume, calculated on an air-free basis and using the values for density and quantities of the materials in the mixture, g/mL;

P = percent of mixing water plus Vinsol resin solution based on mass of cement; and

D = density of silica fume used in the mixture, Mg/m^3.

15.2. Determine the flow in accordance with the applicable provisions of T 106M/T 106.

16. ACCELERATED POZZOLANIC STRENGTH ACTIVITY INDEX WITH PORTLAND CEMENT

16.1. Use the applicable section on strength activity index with portland cement of ASTM C 311, except change to reflect testing at constant water to cementitious materials ratio. Prepare test specimens from the batch proportions of the control mixture and the test mixture, molding three cubes from both the control mix and the test mix.

16.1.1. *Control Mixture*:

16.1.1.1. 500 g of portland cement,

16.1.1.2. 1375 g of graded standard sand, and

16.1.1.3. 242 mL of water.

16.1.2. *Test Mixture*:

16.1.2.1. 450 g of portland cement,

16.1.2.2. 50 g of silica fume,

16.1.2.3. 1375 g of graded standard sand, and

16.1.2.4. 242 mL of water.

16.1.2.5. *X* grams of dry high-range water reducer, meeting specification M 194 Type F, required to produce a flow of 100 to 115 percent. Add the high-range water reducer directly to the mixing water in the mixing bowl. Then add the cement or the cement-silica fume mixture and start the mixing cycle.

16.1.3. Determine the flow in accordance with the applicable provisions of ASTM C 1437.

16.1.4. *Storage of Specimens*—After 24 hours of initial curing in the moist room (23 ± 2°C and relative humidity of not less than 95 percent), place the cubes in airtight glass containers and store at 65 ± 2°C for 6 days.

16.1.5. Determine the compressive strength, as specified in T 106, of the three specimens of the control mixture and the three specimens of the test mixture at 7 days after molding.

17. REACTIVITY WITH CEMENT ALKALIES

17.1. Determine the reduction of mortar expansion in accordance with ASTM C 441, except that the amount of silica fume in the test mixture shall be 10 percent by mass of cementitious material.

18. SULFATE RESISTANCE

18.1. Determine the sulfate resistance according to ASTM C 1012, except that the amount of microsilica in the test mixture shall be 10 percent by mass of cementitious material.

19. BULK DENSITY

19.1. The bulk density of silica fume is defined as the mass of a unit volume of loose silica fume.

19.2. This test method covers determination of the bulk density of silica fume as silica fume is transferred from one container to another with controlled minimum compaction. Its particular usefulness is in connection with identifying material form (as produced or densified), silo or truck storage capacity, material handling, and transportation characteristics.

19.3. *Equipment*:

19.3.1. *Balance*—meeting ASTM C 1005, with a sensitivity of 0.1 g.

19.3.2. *Vibrating Table, Table Top*[1]—electromagnetic vibrating table with a controlled low amplitude that does not exceed 1-mm linear vibration. Approximate deck size is 175 × 250 mm with a 5-kg capacity. The amplitude of the vibration shall be capable of being regulated to suit the characteristics of the material being handled.

19.3.3. *Stainless Steel Beaker*—of known volume, not less that 1 L calibrated to the nearest ±1 mL, without a spout.

19.4. *Procedure*:

19.4.1. Determine the mass of the clean dry beaker to the nearest 1 g.

19.4.2. Fill the beaker with silica fume and compact by use of the vibrating table at a mid-range setting for 15 s, adding materials as needed.

19.4.3. Screed or strike off the measure with a straightedge or spatula to produce a flat, even surface that is level with the rim or edge of the beaker. Wipe off any excess silica fume that may adhere to the sides.

19.4.4. Place the filled measure on the balance and determine the mass of the silica fume to the nearest 1 g.

19.5. *Calculation*:

19.5.1. Divide the net mass of the silica fume in grams by the volume of the container in milliliters. Multiply by 1,000 to express the density in kilograms per cubic meter. To convert the value in kilograms per cubic meter to pounds per cubic foot, divide by 16.01846.

20. REPORT

20.1. Report the following information:

20.1.1. SiO_2 content, percent;

20.1.2. Moisture content, percent;

20.1.3. Loss on ignition, percent;

20.1.4. Oversize, percent; retained

20.1.5. Bulk density, kg/m^3;

20.1.6. Density, Mg/m^3;

20.1.7. Name of manufacturer and brand, if applicable;

20.1.8. Accelerated Pozzolanic Strength Activity Index;

20.1.9. Specific surface, m^2/g; and

20.1.10. Total alkalies, as equivalent Na_2O, percent;

20.2. Report the following information when specifically requested by the purchaser:

20.2.1. The quantity of air-entraining agent compared to the 10 preceding tests, percent;

20.2.2. Reduction of mortar expansion, percent; and

20.2.3. Sulfate resistance expansion, percent.

21. PRECISION AND BIAS

21.1. *Precision*:

21.1.1. *Accelerated Pozzolanic Strength Activity Index Test*:

21.1.1.1. *Single-Operator Precision*—The precision of this test will be evaluated using ASTM C 670.

21.1.1.2. *Multilaboratory Precision*—The precision of this test will be evaluated using ASTM C 670.

21.1.2. *Density Test*:

21.1.2.1. *Single-Operator Precision*—The single-operator standard deviation among single test results (a test result is defined in this specification as the average of two separate measurements) has been found to be 0.035 Mg/m^3. Therefore, results of two properly conducted tests by the same operator should not differ by more that 0.099 Mg/m^3 on the same silica fume.[2]

21.1.2.2. *Multilaboratory Precision*—The multilaboratory standard deviation among single test results (a test result is defined in this specification as the average of two separate measurements) has been found to be 0.047 Mg/m^3. Therefore, results of two properly conducted tests in different laboratories on the same silica fume should not differ by more that 0.132 Mg/m^3 of their average.[2]

21.1.3. *Bulk Density*:

21.1.3.1. *Precision*—The precision of this test method will be evaluated using ASTM C 670.

21.1.3.2. *Bias*—Since there is no accepted reference material suitable for determining any bias that might be associated with this test method, no statement on bias is being made.

21.2. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedures for measuring the accelerated pozzolanic strength activity index and the density, no statement on bias is being made.

22. REJECTION AND RETESTING

22.1. The purchaser has the right to reject material that fails to conform to the requirements of this specification. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the tests, the producer or supplier is not prohibited from making a claim for retesting.

23. CERTIFICATION

23.1. When specified in the purchase order or contract, the purchaser shall be furnished certification that samples have been tested as directed in this specification and that the specified requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished.

24. PACKAGING AND PACKAGE MARKING

24.1. When silica fume is delivered in packages, the name and brand, if applicable, of the manufacturer or distributor and the mass of the silica fume contained therein shall be clearly marked on each package. Similar information shall be provided in the shipping invoices accompanying the shipment of packaged or bulk silica fume in dry or slurried forms. All packages shall be in good condition at the time of inspection.

25. STORAGE AND INSPECTION

25.1. Silica fume shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment. Facilities for inspection and sampling shall be provided at the point from which the material is to be shipped.

APPENDIXES

(Nonmandatory Information)

X1. SILICA CONTENT

X1.1. Since the quantity of amorphous silica is one of the primary characteristics that determines the pozzolonic activity of silica fume, determination of the total silicon content is important Gravimetric (“wet method”) determinations can be accomplished using sodium carbonate (Na_2CO_3) fusion as described in Test Method C114 and similar procedures. Instrumental methods successfully used for determination of total silicon in high silica materials include X-ray fluorescence spectrometry, inductively coupled plasma, optical emission spectrometry, and atomic absorption spectrophotometry. Silica Fume SRM^R 2696 is available from NIST for use in evaluating chemical and instrumental methods of analysis of silica fume used in conjunction with the product specifications. Because silica (SiO_2) required in this specification has to be at least 85 percent by mass of silica fume, additional silica reference manuals, such as SRM^R 1413 high alumina sand (82.77 percent) and silica flour (99 percent), may be suitable for use with instrumental methods of analysis. Analysts should note that the gravimetric method determines all chemical forms of silicon in the material as silica (SiO_2), whereas the instrumental test methods determine all chemical forms of silicon in the material as total silicon (Si), which is reported as SiO_2. Typically, it is assumed that all or nearly all of the Si that is present in silica fume is SiO_2.

X2. OVERSIZE

X2.1. The 45-µm (No. 325) sieve specification is to be used to determine the amount of foreign material present. Since silica fume is much finer than cement or fly ash, the particles will all pass through the sieve except for foreign material. Extremely fine materials tend to form agglomerations; good judgment must be exercised to differentiate between easily dispersible agglomerates and foreign materials.

X3. PROBLEM OF MIXTURE PROPORTION FOR VARIOUS TEST MIXTURES

X3.1. Such test methods as accelerated pozzolanic strength activity index with portland cement, reactivity with cement alkalies, and sulfate resistance require mixtures where the silica fume being tested replaces a given amount of cement. For specification purposes, 10 percent by mass replacement of cement by silica fume will be used rather than that which is stated in the present methods, Water-to-cementitious materials ratio will be replaced by a flow of between 100 and 115 percent. As the percent replacement with silica fume increases, the mixture becomes unworkable, and either more water is necessary or a water reducer is necessary to have a workable mixture. By limiting the mixtures to 10 percent by mass replacement, the addition of water to a certain flow is a viable alternative, even though the addition of water reducer would probably produce a higher strength. Since this is a specification, the interest is in comparing material under similar conditions, rather than in maximum strength.

X4. SULFATE RESISTANCE

X4.1. Satisfactory reductions of expansion in laboratory mixtures have been obtained with silica fume replacement levels of 5 to 15 percent. Each source of silica fume must be tested with high-C_3A portland cement to establish appropriate replacement levels for adequate sulfate resistance.

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[1] A suitable vibrating table is the Syntron Paper Jogger, Model J-1, manufactured by F.M.C. Corporation, 57 Cooper Ave., Homer City, PA 15748.

[2] These measurements represent, respectively, the (1s) and (d2s) limits in accordance with ASTM C 670.

Standard Specification for

High-Reactivity Pozzolans for Use in Hydraulic-Cement Concrete, Mortar, and Grout

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AASHTO Designation: M 321-04 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

High-Reactivity Pozzolans for Use in Hydraulic-Cement Concrete, Mortar, and Grout

AASHTO Designation: M 321-04 (2008)

1. SCOPE

1.1. This specification covers high-reactivity pozzolans for use as a mineral admixture in portland cement concrete and mortar to fill small voids and/or where pozzolanic action is desired. High-reactivity pozzolans are microsilica products with a particle size typically one to two orders of magnitude smaller than portland cement. These materials are usually supplied in undensified or densified dry form. If the material is supplied in a densified form, the tests should be performed on the as-collected undensified material before being processed into densified form.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.* Read the material safety data sheets for materials used. This standard is not intended for specifying silica fume as defined in Section 3.3. It is recommended that M 307 or ASTM C 1240 be used for that purpose.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 307, Silica Fume Used in Cementitious Mixtures
- T 105, Chemical Analysis of Hydraulic Cement

2.2. *ASTM Standards*:

- C 219, Standard Terminology Relating to Hydraulic Cement
- C 311, Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- C 1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
- C 1240, Standard Specification for Silica Fume Used in Cementitious Mixtures
- C 441, Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. DEFINITIONS

3.1. *pozzolan*—a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

3.2. *high-reactivity pozzolan*—an amorphous silica of high silica content and purity possessing high pozzolanic activity, meeting the requirements of this standard specification.

Note 1—Materials such as metakaolin, rice hull ash, zirconium fume, ultra-fine fly ash, and fume from the production of 50 percent ferrosilicon (with SiO_2 less than 85 percent) are examples of high-reactivity pozzolans.

3.3. *silica fume*—a very fine pozzolanic material composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferro silicon alloys (also known as condensed silica fume and microsilica), meeting the requirements of M 307 and ASTM C 1240.

4. ORDERING INFORMATION

4.1. Orders for material meeting this specification shall include the following information as necessary to adequately describe the desired product:

4.1.1. Name of material (high-reactivity pozzolan material);

4.1.2. AASHTO designation and year of issue;

4.1.3. Applicable optional chemical and/or physical requirements;

4.1.4. *Product form*—densified or undensified in kilograms per cubic meter (lb/ft^3)—dry.

5. CHEMICAL REQUIREMENTS

5.1. High-reactivity pozzolan shall conform to the chemical requirements prescribed in Table 1. Optional chemical requirements are shown in Table 2.

Table 1—Chemical Requirements

Reactive Oxides (SiO_2 + Al_2O_3 + Fe_2O_3), min percent	75.0
Sulfur trioxide (SO_3), max percent	3.0
Loss on ignition, max percent	6.0
Moisture content, max percent	3.0

Table 2—Optional Chemical Requirements[a]

Available alkalies, as Na_2O, max percent[b]	
Report value only %[b]	

[a] Optional chemical requirements will be made only at the request of the purchaser.

[b] Applicable only when specifically required for mineral admixture to be used in concrete containing reactive aggregate and cement to meet a limitation on content of alkalies.

6. PHYSICAL REQUIREMENTS

6.1. High-reactivity pozzolan shall conform to the physical requirements prescribed in Table 3. Optional physical requirements are shown in Table 4.

Table 3—Physical Requirements

Accelerated Pozzolanic Strength Activity Index:	
With portland cement, as percent of control, determine at seven days	85
Fineness: maximum percent retained on the 45-μm No. 325) sieve[a]	10

[a] Exercise care to avoid retaining agglomerations of extremely fine materials.

Table 4—Optional Physical Requirements[a]

Increase of drying shrinkage of mortar bars at 28 days, max, percent	0.10
Uniformity requirements:	
In addition, when air-entrained concrete is specified, the quantity of air-entraining admixture required to produce an air content volume of 18 percent of the mortar shall not vary from the average established by the 10 preceding tests, or by all preceding tests if less than 10, by more than, percent	20
Reactivity with cement alkalies:	
Reduction of mortar expansion at 14 days, min, percent[b]	80
Sulfate expansion 14 days, max, percent	0.045
Pozzolanic Strength Activity Index (non-accelerated curing):	
With portland cement, as percent of control, determined at 28 days	100

[a] Optional physical requirements will be made only at the request of the purchaser.

[b] The indicated tests for reactivity with cement alkalies in accordance with ASTM C 441 should not be requested unless the material is to be used with an aggregate that is regarded as deleteriously reactive with alkalies in cement. The test for reduction of mortar expansion may be made using any high-alkali cement in accordance with ASTM C 441 if the portland cement to be used in the mix is not known or is not available at the time of the test.

7. METHODS OF SAMPLING AND TESTING

7.1. High-reactivity pozzolan shall be sampled at the purchaser's option in accordance with ASTM C 311.

7.2. Testing of the high-reactivity pozzolan in accordance with the requirements of Section 8 shall be conducted at the option of the purchaser.

8. TEST METHODS

8.1. *Chemical Analysis*:

8.1.1. *Silicon Dioxide, Aluminum Oxide, Iron Oxide, and Sulfur Trioxide*—Determine in accordance with T 105 for cements with insoluble residue greater than one percent. Rapid test methods referenced in T 105 may be used.

8.1.2. *Moisture Content, Loss on Ignition, and Available Alkalies*—Make these determinations following applicable provisions of ASTM C 311.

8.2. *Physical Tests*:

8.2.1. *Density*—ASTM C 311, record only.

8.2.2. *Increase of Drying Shrinkage of Mortar Bars*—ASTM C 311, except use 500 g portland cement, 50 g high-reactivity pozzolan, and 1325 g of sand in test mixture. The 50 g of high-reactivity pozzolan replaces the 125 g of mineral admixture prescribed in ASTM C 311.

8.2.3. *Reactivity with Cement Alkalies*—ASTM C 441, except that the amount of high-reactivity pozzolan in the test mixture shall be 10 percent by mass of cementitious material.

8.2.4. *Accelerated Pozzolanic Strength Activity Index with Portland Cement*—ASTM C 311, with the procedure as modified in M 307 or ASTM C 1240, Section 16. A set of samples shall be evaluated at seven days of age. As an optional test, Pozzolanic Strength Activity Index with Portland Cement, ASTM C 311, with the procedure as modified in M 307 or ASTM C 1240, Section 16, except with curing on a non-accelerated basis as in ASTM C 109. A set of samples shall be evaluated at 28 days of age.

8.2.5. *Air-Entrainment of Mortar*—ASTM C 311, except use 300 g of portland cement, 30 g of high-reactivity pozzolan, and 1170 g of standard Ottawa sand in the test mixture. Use sufficient water, ml, to give a flow of 80 to 95 percent and sufficient neutralized vinsol resin solution, ml, to produce an air content of 18 ± 3 percent.

8.2.6. Also, use the following equation for W_c:

$$W_c = \frac{300 + 1170 + 30 + (300 \times P \times 0.01)}{300/3.15 + 1170/2.65 + 30/D + \left[(300 \times P \times 0.01)/1\right]} \tag{1}$$

8.2.7. Then calculate:

Air content, volume % = 100 $[1 - (W_a / W_c)] W_a = W/400$ (2)

where:

W_a = actual mass per unit of volume of mortar as determined by ASTM C 185, g/mL,

W = mass of the specified 400 mL of mortar (see Test Method ASTM C 185), g,

W_c = theoretical mass per unit volume, calculated on an air-free basis and using the values for density and quantities in the material in the mixture, g/mL,

P = percent passing of mixing water plus vinsol resin solution based on mass of cement, and

D = density of silica fumes used in the mixture, $\mathrm{Mg/m^3}$.

8.2.7.1. *Sulfate Expansion*—ASTM C 1012, except that the amount of high-reactivity pozzolan in the test mixture shall be 10 percent by mass of cementitious material.

9. STORAGE AND INSPECTION

9.1. The high-reactivity pozzolan shall be stored in such a manner as to permit easy access for proper inspection and identification. Every facility shall provide the purchaser access for sampling and inspection, either at the source or at the site of the work.

10. REJECTION

10.1. Materials that fail to conform to the requirements of this specification shall be rejected. Rejections shall be reported to the producer or supplier promptly.

11. CERTIFICATION

11.1. Upon request of the purchaser in the contract or order, a manufacturer's certification shall be furnished stating the results of tests made on samples of the material taken during production or transfer, and indicating conformance with applicable requirements of this specification. Information on incorporated admixtures shall also be required.

12. PACKAGING AND PACKAGE MARKING

12.1. When high-reactivity pozzolan is delivered in packages, the name and brand of the manufacturer, the loose bulk density, manufacturing lot number (incorporating manufacturing date) and the mass of the high-reactivity pozzolan contained therein shall be clearly marked on each package/pallet. Similar information shall be provided in the shipping invoices accompanying the shipment of the high-reactivity pozzolan. All packages shall be in good condition at the time of delivery.

Standard Specification for

Preformed Expansion Joint Filler for Concrete (Bituminous Type)

AASHTO Designation: M 33-99 (2007)
ASTM Designation: D 994-98 (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Preformed Expansion Joint Filler for Concrete (Bituminous Type)

AASHTO Designation: M 33-99 (2007)
ASTM Designation: D 994-98 (2003)

1. SCOPE

1.1. This specification covers bituminous preformed expansion joint filler for use in concrete construction.

Note 1—Attention is called to M 153 and M 213.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 153, Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
- M 213, Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
- T 42, Preformed Expansion Joint Filler for Concrete Construction

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 545, Standard Test Methods for Preformed Expansion Joint Fillers for Concrete Construction (Nonextruding and Resilient Types)

3. MANUFACTURE

3.1. This product shall consist of a bituminous (asphalt or tar) mastic composition, formed and encased between two layers of bituminous impregnated felt or two layers of glass-fiber felt. The mastic shall comprise mineral fillers and reinforcing fibers, and may contain thin strips of reinforcing sheet material.

4. GENERAL REQUIREMENTS

4.1. Preformed strips of expansion joint filler shall be of such character as not to be deformed or broken by ordinary handling when exposed to atmospheric conditions and shall not become brittle in cold weather. Pieces of the joint filler that have been damaged shall be rejected.

5. PROPERTIES

5.1. *Distortion at 52°C*—The joint filler shall not show a deflection of more than 25 mm when tested in accordance with Section 8.1.

5.2. *Brittleness*—The joint filler shall not crack or shatter when tested in accordance with Section 8.2.

Note 2—Expansion joint filler having a nominal thickness of 6 mm or less shall not be subject to a requirement for brittleness.

5.3. *Water Absorption*—The water absorption of the joint filler, when tested in accordance with Section 8.3, shall not exceed the following values:

Nominal Thickness of Joint, mm	Absorption, max percent
25	2.5
19	3
13	4
9.5	5

Note 3—Expansion joint filler having a nominal thickness of less than 9.5 mm shall not be subject to a requirement for water absorption.

5.4. *Compression*—The load required to compress the test specimen to 50 percent of its thickness before test shall be not less than 690 kPa nor more than the following values when the joint filler is tested in accordance with Section 8.4.

Nominal Thickness of Joint, mm	Load Requirements, min–max, kPa
25	690–5200
19	690–5800
13	690–6400

Note 4—Expansion joint filler having a nominal thickness of less than 13 mm shall not be subject to a requirement for compression.

6. DIMENSIONS AND PERMISSIBLE VARIATIONS

6.1. The preformed strips shall conform to the dimensions specified or shown on the plans. Strips of the joint filler that do not conform to the specified dimensions, within the permissible variations of +1.6 mm to –0 mm in thickness, ±3 mm in depth, and ±6 mm in length, shall be rejected.

7. SAMPLING

7.1. *Size of Samples*—Each sample shall consist of sufficient material to provide at least three test specimens measuring 50 by 150 mm and at least one test specimen measuring 100 by 100 mm.

7.2. *Number of Samples*—One representative sample shall be selected from each shipment of 100 m^2 or fraction thereof of each thickness ordered.

7.3. Samples shall be packed for transportation in such a manner that there will be no danger of distortion or breakage.

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8. TEST METHODS

8.1. *Distortion at 52ºC*—Cut a test specimen 50 by 150 mm, substantially flat and straight, with the 150-mm dimension parallel to the machine direction of the strip. Clamp the specimen between two blocks so that the expansion joint forms a cantilever of 90-mm length. Place the clamp and joint assembly in a force-draft oven maintained at 52 ± 1.1ºC, with the specimen in a horizontal position, for 2 hours. Measure the deflection of the specimen from the horizontal.

8.2. *Brittleness*—Cut a test specimen 50 by 150 mm with the 150-mm dimension parallel to the machine direction of the strip. Maintain the specimen at a temperature of 4 to 6ºC in water for at least 2 hours prior to testing. Clamp the specimen between two boards so that the expansion joint forms a cantilever of 90-mm length and holds in a horizontal position by a suitable rigid support. Suspend a spherical cast iron ball, weighing 400 g and having a diameter of 48 mm, by a cord tied to an eyelet fastened to the ball. For specimens having a thickness of 14 mm or less, suspend the ball 300 mm above the center of the projecting portion of the specimen. For specimens greater than 14 mm in thickness, suspend the ball 600 mm above the specimen. Release the ball by burning the cord above the eyelet. Other suitable suspension and release devices may be used.

8.3. *Water Absorption*—Cut a test specimen 50 by 150 mm from the joint filler material, in such a manner that all edges are freshly cut, and determine the mass. Immerse the specimen in water for 24 hours, remove, and wipe off the surface water with a slightly dampened cloth. Measure the mass of the specimen quickly and calculate the gain in mass and express as mass percent of water absorbed.

8.4. *Compression*—Test the joint filler in accordance with Sections 7.2 to 7.2.5 of T 42, except make only a single application of the load required to compress the specimen to 50 percent of its thickness before test; and do not measure the recovery.

Note 5—The distortion and brittleness tests are used to determine the handling characteristic of the material. The water absorption and compression tests are used to determine the suitability of the material as an expansion joint filler.

8.5. *Precision and Bias*:

8.5.1. Precision statement for single operator was calculated per ASTM C 670, Table 2, maximum acceptable range of individual measurements. No precision statement is necessary for brittleness since this property is qualified as an attribute. Precision statements are listed in Table 1.

8.5.2. Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

Table 1—Single-Operator Precision Statements

Property	Property as a Function of Nominal Thickness				
Thickness, nominal, mm	25	19	13	9.5	6.4
Distortion, max mm	25	25	25	25	25
Precision, max accept range	2.93	2.30	5.92	6.03	6.84
Brittleness	Pass[a]	Pass[a]	Pass[a]	Pass[a]	—
Precision, max accept range	[b] [b] [b] [b]				—
Water absorption, wt % max	2.5	3	4	5	—
Precision, max accept range	0.057	0.087	0.400	1.187	—
Compression, kPa, min–max	690–5200	690–5800	690–6400	—	—
Precision, max accept range	204.2	180.1	416.5	—	—

Precision, max accept range per C 670, Table 2. Maximum acceptable range between high and low individual measurements.

[a] Not crack or shatter.

[b] No precision statement is necessary for this attribute.

9. KEYWORDS

9.1. Asphalt; bituminous; construction; expansion; joint; paving; preformed.

APPENDIXES

(Nonmandatory Information)

X1. STANDARD TEST METHODS AND CONDITIONS

X1.1. *Size of Samples*—Sample sizes were used as required for each test property.

X1.2. *Number of Specimens*—For each test, three specimen were used.

X1.3. *Test Conditions*—Standard test conditions were used as required in each test section and per Section 8, Test Methods.

X2. SINGLE-OPERATOR PRECISION STATEMENTS

X2.1. ASTM C 670, “Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials,” was used to develop the single-operator precision statement.

X2.2. Windows 95 function categories were used to calculate the average (avg) values and the one-sigma (1s) limits. Data was graphed using Windows 95 Chart Wizard.

X2.3. Acceptance of individual measurement values was based on the calculated difference of two-sigma (d2s) limits as the appropriate index of test precision. Maximum acceptance range of the measurements was calculated per Table 1 of C 670 and, for a given test, the individual results of the measurements were accepted if the results were within the calculated maximum acceptable range.

X2.4. Single-operator precision was calculated per Table 2 of C 670. Results of three specimens were used to calculate the average values and the 1s limits. From C 670, Table 2, for the average of three measurements, the multiplier is 5.7 for the maximum acceptable range of individual measurements. The precision statement, then, for a single operator is calculated as follows:

Precision Statement = (1s) × 5.7.

X2.5. Calculated precision statements for the various properties are given in Table 1.

X2.6. Single-operator precision for the average compression load values, for each thickness, is also presented in Figure X2.1 (URL—upper range limit, LRL—lower range limit).

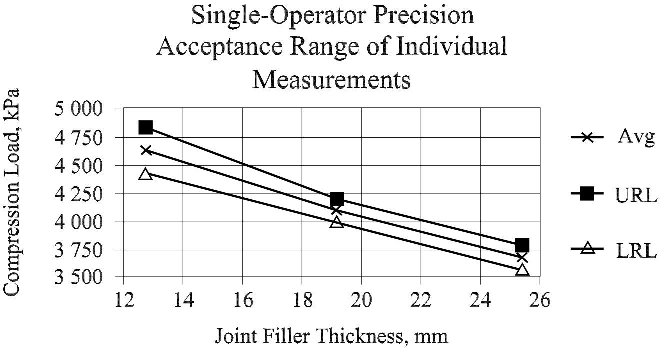

Figure X2.1—Graph I

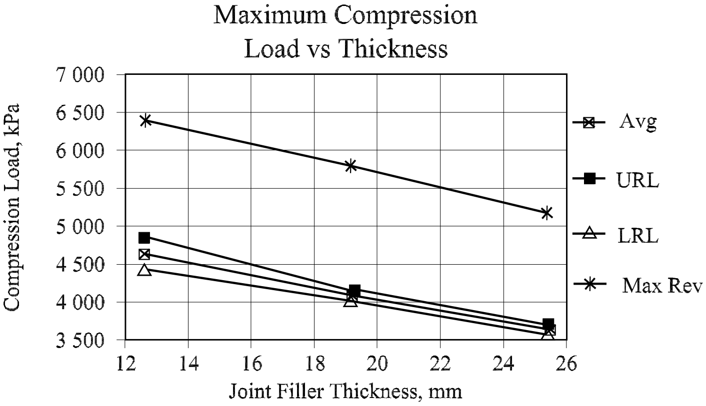

Figure X2.2—Graph II

COMPRESSION LOAD VALUES

X2.7. It was found that the compression load values are dependent on the thickness of the preformed expansion joint filler. As the thickness of the expansion filler increased, the resultant compression load values decreased as shown in Figures X2.1 and X2.2.

X2.8. Starting with the compression load value of 5200 kPa maximum for 25-mm thick joint filler, as a starting point, then by graphic analysis, the maximum compression load values were plotted for each joint filler thickness as shown in Figure X2.2 and as stated in Table 1.

Standard Specification for

Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

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AASHTO Designation: M 153-06[1]
ASTM Designation: D 1752-04a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction

AASHTO Designation: M 153-06[1]
ASTM Designation: D 1752-04a

1. SCOPE

1.1. This specification covers preformed expansion joint fillers of the following four types for use in concrete, brick, or stone construction:

1.1.1. *Type I*—sponge rubber,

1.1.2. *Type II*—cork,

1.1.3. *Type III*—self-expanding cork, and

1.1.4. *Type IV*—polyurethane-bonded recycled rubber.

Note 1—Attention is called to M 213 and M 33.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 33, Preformed Expansion Joint Filler for Concrete (Bituminous Type)
- M 213, Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
- T 42, Preformed Expansion Joint Filler for Concrete Construction

3. ORDERING INFORMATION

3.1. Products conforming to this specification are manufactured in sheet form to a range of thicknesses: namely, 6, 9.5, 13, 19, and 25 mm. Sheet sizes may be 900 or 1200 mm in width and lengths of 900, 1500, 1800, 3000, or 3700 mm. Purchaser must specify sheet sizes when ordering.

3.2. Joint filler in strip form is cut from the sheets as manufactured. When ordering joint filler strips, the purchaser must specify thickness, widths, and length; strip widths are available from 50 mm in increments of 13 mm.

4. MATERIALS

4.1. *Sponge Rubber*—The joint filler shall consist of preformed strips of a durable, elastic sponge rubber compound, using synthetic rubber or natural rubber as a base and containing no reclaimed rubber or factice. Unless otherwise specified, the sponge rubber shall have a cement gray color to blend with concrete in appearance.

4.2. *Cork and Self-Expanding Cork*—The joint filler shall consist of preformed strips that have been formed from clean granulated cork particles securely bound together by a synthetic resin of an insoluble nature.

4.3. *Polyurethane-Bonded Recycled Rubber*—The joint filler shall consist of preformed strips of a durable composite of ground recycled rubber from automobile tires bonded together with a polyurethane adhesive.

4.4. Preformed strips of expansion joint fillers shall be of such character as not to be deformed or broken by ordinary handling when exposed to atmospheric conditions. Pieces of the joint filler that have been damaged shall be rejected.

5. PHYSICAL REQUIREMENTS

5.1. *Test Specimen*—The sample to be tested shall be cut from the sheet as manufactured, and shall be representative of the sheet stock.

5.2. *Recovery*—The test specimen shall be compressed to 50 percent of its thickness before test. The load shall be released immediately after application. At the end of 10 minutes after release of application of the load, the specimen shall have recovered to at least 90 percent of its thickness before test.

5.2.1. In case of failure to comply with the above requirements, the test specimen shall be given three applications of a load sufficient to compress the material to 50 percent of its thickness before test. The load shall be released immediately after each application. At the end of 1 hour after the third application, the specimen shall have recovered at least 90 percent of its thickness before the test.

5.3. *Compression*—The load required to compress the test specimen to 50 percent of its thickness before test shall be not less than 340 nor greater than 10 350 kPa.

5.4. *Extrusion*—The test specimen shall be compressed to 50 percent of its thickness before test with three of the edges restrained. The amount of extrusion of the free edge shall not exceed 6 mm.

5.5. *Expansion*—In the case of self-expanding cork (Type III) expansion joint filler only, the test specimen, after being immersed in boiling water for 1 hour, shall have a final thickness not less than 140 percent of the thickness before test. Discoloration of the water shall not be considered an indication of failure.

5.6. *Boiling in Hydrochloric Acid*—In the case of cork and self-expanding cork (Types II and III) expansion joint fillers only, the test specimen shall show no evidence of serious disintegration. Discoloration or a small amount of swelling shall not be considered as failure. The test specimens shall be examined immediately after the end of the boiling period and shall be rejected for any of the following evidences of disintegration: (1) particles of cork are dislodged during the boiling period (Note 2), (2) specimen lacks resiliency, is very friable, and is easily broken to pieces, or (3) surface of specimen appears porous and particles of cork are easily dislodged by rubbing with fingers.

Note 2—Particles of cork dislodged from edges cut during preparation of the specimen should not be considered as constituting failure under this requirement.

5.7. *Density*—In the case of sponge rubber (Type I) expansion joint filler only, the density of the air-dry filler shall be not less than 480 kg/m^3.

6. DIMENSIONS AND PERMISSIBLE VARIATIONS

6.1. The preformed strips shall conform to the dimensions specified or shown on the plans. Strips of the joint filler that do not conform to the specified dimensions, within the permissible variations of ±1.5 mm in thickness, ±3 mm in depth, and ±6 mm in length, shall be rejected.

7. SAMPLING

7.1. *Size and Number of Samples*—Each sample shall consist of sufficient material to provide at least five test specimens measuring 114 by 114 mm. One representative sample approximately 0.2 m^2 shall be selected from each shipment of 100 m^2 or fraction thereof.

7.2. For self-expanding cork joint filler, a minimum of five 114 by 114 mm square specimens properly banded and plastic wrapped at the point of manufacture shall be submitted for testing.

7.3. Samples shall be packaged for safe transportation to the testing agency in such a manner that there will be no danger of distortion or breakage.

8. TEST METHODS

8.1. Determine the properties prescribed in this specification in accordance with T 42.

9. REJECTION AND RETEST

9.1. Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or supplier may request retesting.

10. PACKAGING

10.1. Preformed expansion joint filler in sheets or strips should be stored and transported on pallets or a suitable flat surface to prevent breakage and permanent deformation due to weather conditions.

10.2. Self-expanding cork filler shall be wrapped in waterproof paper—sealed—in a manner that will prevent the entrance of moisture, and packaged in sizes convenient for handling on the job.

11. KEYWORDS

11.1. Construction; cork; expansion; joint; paving; preformed; rubber; sponge; structural.

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[1] Except for the Type IV Polyurethane-Bonded Recycled Rubber Joint Filler and any reference to Type IV, this specification agrees with ASTM D 1752-04a.

Standard Specification for

Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)

AASHTO Designation: M 213-01 (2010)
ASTM Designation: D 1751-04 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)

AASHTO Designation: M 213-01 (2010)
ASTM Designation: D 1751-04 (2008)

1. SCOPE

1.1. This specification covers preformed expansion joint fillers having relatively little extrusion and substantial recovery after release from compression.

1.2. The values stated in SI units are to be regarded as the standard.

Note 1—Attention is called to M 153 and to M 33.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 33, Preformed Expansion Joint Filler for Concrete (Bituminous Type)
- M 153, Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
- T 42, Preformed Expansion Joint Filler for Concrete Construction

3. ORDERING INFORMATION

3.1. Products conforming to this specification are manufactured in sheet form to a range of thicknesses; namely, 6.4, 9.5, 13, 19, and 25 mm. Sheet sizes may be 900 or 1200 mm in width and standard length of 3 m. Purchaser must specify sheet sizes when ordering.

3.2. Joint filler in strip form is cut from the sheets as manufactured. When ordering joint filler strips, the purchaser must specify thickness, width, and length; strip widths are available from 50 mm in increments of 13 mm.

4. MANUFACTURE

4.1. This product shall consist of preformed *sheets* or strips made of one of the following:

4.1.1. Cane or other suitable fibers of a cellular *cellulosic* nature securely bound together and then uniformly saturated with asphalt;

4.1.2. Strips formed from clean granulated cork securely bound together by a suitable asphalt binder and encased between two layers of saturated felt or two layers of glass-fiber felt; or

4.1.3. Strips of a durable composite of ground recycled rubber from automobile tires bonded together with a polyurethane adhesive.

4.2. Preformed strips of expansion joint filler shall be of such character as not to be deformed or broken by twisting, bending, or other ordinary handling when exposed to atmospheric conditions.

5. REQUIREMENTS

5.1. *Test Specimen*—The sample to be tested shall be cut from the sheet, as manufactured, and shall be representative of the sheet stock.

5.2. *Compression*—The load required to compress the test specimen to 50 percent of its thickness before test shall be not less than 690 kPa and not more than 5200 kPa. If the nominal thickness of the specimen is less than 13 mm, a maximum load of 8600 kPa will be permitted. The sample after compression shall not show a loss of more than 3 percent of its original mass.

5.3. *Extrusion*—The test specimen shall be compressed to 50 percent of its thickness before test with three of its edges restrained. The amount of extrusion of the free edge shall not exceed 6 mm.

5.4. *Recovery*—The test specimen shall be compressed to 50 percent of its thickness before test. The load shall be released immediately after application. At the end of the 10 minutes after release of application of the load, the specimen shall have recovered to at least 70 percent of its thickness before test.

5.4.1. In case of failure to comply with the above requirements, the test specimen shall be given three applications of a load sufficient to compress the material to 50 percent of its thickness before test. The load shall be released immediately after each application. At the end of 1 hour after the third application, the specimen shall have recovered to at least 70 percent of its thickness before test.

5.5. *Density*—For fiber joint only, oven dry the specimen at 104 ± 3ºC for 2 hours or to a constant weight. After oven drying, cool the specimen to room temperature in a covered desiccator and weigh to the nearest 0.1 g. The density of air-dried filler material shall not be less than 304 kg/m^3. The density of oven-dried fiber filler shall not be less than 288 kg/m^3.

5.6. *Water Absorption*—A standard expansion joint filler test specimen with four square cut edges, when submerged horizontally under 25 mm of water at 21 ± 3ºC, shall absorb not more than 15 percent by volume in 24 hours for nominal thickness of 13 mm and over, and 20 percent by volume for all other thicknesses.

5.7. *Asphalt Content*—For materials manufactured as described in Sections 4.1.1 and 4.1.2, at least 35 percent by mass of the finished product shall be asphalt uniformly distributed throughout the cross-section of the material.

6. DIMENSIONS AND PERMISSIBLE VARIATIONS

6.1. The preformed strips shall conform to the dimensions specified or shown on the plans. Strips of the joint filler that do not conform to the specified dimensions, within the permissible variation of ±1.5 mm in thickness, ±3 mm in depth, and ±6 mm in length, shall be rejected.

7. SAMPLING

7.1. *Size of Samples*—Each sample shall consist of sufficient material to provide at least five test specimens measuring 114 by 114 mm. One representative sample, approximately 200 mm^2, shall be selected from each shipment of 100 m^2 or fraction thereof.

7.2. Individual samples are to be taken from separate sheets of preformed expansion joint filler.

7.3. Samples shall be packaged for transportation in such a manner that there will be no danger of distortion or breakage.

8. TEST METHODS

8.1. Determine the properties prescribed in this specification in accordance with T 42.

9. REJECTION AND RETEST

9.1. Material that fails to conform to the requirements of this specification shall be rejected. Rejection should be reported to the manufacturer and supplier promptly and in writing. In case of dissatisfaction with the test results, the manufacturer or supplier may request retesting.

10. PACKAGING

10.1. Preformed expansion joint filler in sheets or strips should be stored and transported on pallets or suitable flat surface to prevent breakage and permanent deformation.

11. KEYWORDS

11.1. Bituminous; expansion joint; filler; joint; preformed.

Standard Specification for

Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements

AASHTO Designation: M 220-84 (2007)
ASTM Designation: D 2628-91 (2005)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements

AASHTO Designation: M 220-84 (2007)
ASTM Designation: D 2628-91 (2005)

AASHTO M 220-84 (2007) is identical to ASTM D 2628-91 (2005).

Standard Specification for

Plain and Laminated Elastomeric Bridge Bearings

AASHTO Designation: M 251-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Plain and Laminated Elastomeric Bridge Bearings

AASHTO Designation: M 251-06

1. SCOPE

1.1. This specification covers the material requirements for plain and laminated elastomeric bridge bearings. Elastomeric bearings furnished under this specification shall adequately provide for thermal expansion and contraction, rotation, camber changes, and creep and shrinkage, where applicable, of structural members. Elastomeric bearings as herein defined shall include plain pads (consisting of elastomer only) and laminated bearings with steel or fabric laminates.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Publications*:

- *Standard Specifications for Highway Bridges*
- *LRFD Bridge Design Specifications*

2.2. *ASTM Standards*:

- A 36/A 36M, Standard Specification for Carbon Structural Steel
- A 1011M, Standard Specification for Steel, Sheet and Strip
- D 412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers—Tension
- D 746, Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact
- D 751, Standard Test Method for Coated Fabrics
- D 3183, Standard Practice for Rubber—Preparation of Pieces for Test Purposes from Products
- D 4014, Standard Specification for Plain and Steel-Laminated Elastomeric Bearings for Bridges
- E 4, Standard Practices for Force Verification of Testing Machines
- E 29, Standard Method for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3. *ANSI Standard*:

- ANSI B46.1, Surfaces and Surfacing

2.4. *Rubber Manufacturers Association, Inc. Standards*:

- RMA F 3
- RMA T.063
- RMA F 2

2.5. *The Society for Protective Coatings Specification*:[1]

- SSPC-VIS 1-01, Visual Standard for Abrasive Blast Cleaned Steel

3. GENERAL REQUIREMENTS

3.1. All bearings shall be designed in accordance with specifications contained in the latest edition of the AASHTO's *Standard Specifications for Highway Bridges* or the *AASHTO LRFD Bridge Design Specifications*.

3.2. The dimensions of the furnished bearings shall be the dimensions required by the design documents within the tolerances shown in Section 6 of this specification. The bearings shall be composed of the specified materials; shall be tested at the appropriate level; and shall satisfy any special requirements of the purchaser.

3.3. The contractor shall provide the purchaser with written notification 30 days prior to the start of bearing production. This notification shall include the contract number, quantity, and size of bearings being produced, manufacturer's name, location, and the representative who will coordinate production, inspection, sampling, and testing with the purchaser.

3.4. Testing for the physical properties of the elastomer may require the destruction of one or more bearings from a lot. In these instances, the cost of providing additional bearings for testing purposes shall be borne by the supplier.

3.5. At the owner's discretion, bearings specified by hardness and designed in accordance with Method A of the *AASHTO LRFD Bridge Design Specifications* or the *Standard Specifications for Highway Bridges* may be tested and accepted in accordance with Appendix X1 in lieu of Section 8.

3.6. In addition to material requirements for the bearing's individual components, this specification provides acceptance criteria for finished bearings.

4. MATERIALS

4.1. *Properties of the Elastomer*—The elastomer compound used in the construction of these bearings shall contain only virgin crystallization resistant polychloroprene (neoprene) or virgin natural polyisoprene (natural rubber) as the raw polymer. All materials shall be new with no reclaimed material incorporated in the finished bearing. The elastomer compounds shall be classified as being of low-temperature Grade 0, 2, 3, 4, or 5 as specified by the minimum grade requirements of Table 14.7.5.2-2, "Low Temperature Zones and Minimum Grade of Elastomer," of the *AASHTO LRFD Bridge Design Specifications*. Low temperature zones used in this table are as defined in Figure 14.7.5.2-1, "Temperature Zones," of the same publication.

4.2. The cured elastomer shall meet the minimum requirements of Table 1. The properties of the cured elastomeric compound material listed in Table 1 shall be determined using samples taken from actual bearings.

Table 1—Elastomer Properties

Material Property	ASTM Standard	Test Requirement	Polyisoprene (Natural Rubber)	Polychloroprene (Neoprene)	Units
Physical Properties	See Section 8.8.4				
	D 412	Min Shear Modulus	0.55 (79.7707)	0.55 (79.7707)	MPa (psi)
		Min Tensile Strength	15.5 (2248.085)	15.5 (2248.085)	MPa (psi)
		Min Ultimate Elongation	450	400	Percent
Low Temperature Brittleness	D 746 Procedure B	Grades 0 and 2—No Test Required	—	—	
		Grade 3—Test at –40ºC (–40°F)	Passes	Passes	
		Grade 4—Test at –48ºC (–54.4°F)	Passes	Passes	
		Grade 5—Test at –57ºC (–70.6°F)	Passes	Passes	

4.3. All material tests shall be carried out at 23 ± 2ºC (73.4 ± 3.6°F) unless otherwise noted.

4.4. For the purpose of determining conformance with this specification, an observed or calculated value shall be rounded off to the nearest 100 kPa (14.5038 psi) for tensile strength, to the nearest 10 percent for elongation, and to the nearest 0.01 MPa (1.4504 psi) for shear modulus.

4.5. *Steel Laminates*—Steel laminates used for reinforcement shall be made from rolled mild steel conforming to ASTM A 36/A 36M, ASTM A 1011M, or equivalent, unless otherwise specified by the purchaser. The laminates shall be of the thickness specified by the purchaser or, if left unspecified, have a minimum nominal thickness of 1.52 mm (0.0598 in.). Holes in plates for manufacturing purposes shall not be permitted unless considered in the design of the bearing.

4.6. External load bearing plates shall conform to the requirements of ASTM A 36/A 36M, ASTM A 1011M, or equivalent, unless otherwise specified in the contract documents. Except as noted, all bearings surfaces of external load plates shall be finished or machined flat within 0.25 mm (0.0098 in.). The bottom surfaces of external load plates (masonry plates) designed to rest on bearing pads shall not exceed an out-of-flatness value of 1.59 mm (0.0626 in.). The external load bearing plates shall be protected from rust until all exposed surfaces can be field painted. Any rust inhibitor utilized must be removed from all surfaces to be welded prior to welding.

4.7. *Fabric Laminates*—Fabric laminates shall be woven from 100 percent glass fibers of "E" type yarn with continuous fibers. The minimum thread count in either direction shall be 10 threads per cm. The fabric shall have either a crowfoot or an eight-harness satin weave. Each ply of fabric shall have a minimum tensile strength of 140 kN/m (799.4208 lbf/in.) of width in each thread direction, which shall be determined by ASTM D 751.

5. FABRICATION

5.1. Bearings with steel laminates shall be cast as a unit in a mold and bonded and vulcanized under heat and pressure. The molds shall have standard shop practice mold finish. The internal steel laminates shall be blast cleaned to a condition matching that of SSPC-Vis 1-01, Pictorial Standard BSP6 or CSP6, and additionally cleaned of any oil or grease before bonding. Plates shall be free of sharp edges and burrs, and shall have a minimum edge cover of 6 mm (0.2363 in.). External load plates (sole plates) shall be protected from rusting by the manufacturer, and shall be hot bonded to the bearing during vulcanization. Bearings with steel laminates that are designed to act as a single unit with a given shape factor must be manufactured as a single unit.

5.2. Fabric-laminated bearings may be molded and vulcanized in large sheets and cut to size. Cutting shall be performed so as to avoid heating the materials and produce a smooth finish with no separation of the fabric from the elastomer. Fabric shall be free of folds and ripples and shall be parallel to the top and bottom surfaces. If external steel plates are required, a cold bonding process that will yield the strengths required in Section 8.8 of this specification may be used in lieu of hot bonding.

5.3. Plain pads may be molded or extruded and vulcanized in large sheets and cut to size. Cutting shall not heat the materials, and shall produce a smooth finish to ANSI B46.1, 6.3 μm (248 μin.). Plain pads shall be molded or extruded to the finished thickness. Fabricators will not be allowed to make pads of finished thickness by plying pads of lesser thickness together. External load plates, when used, shall be protected from rusting by the manufacturer and shall be hot bonded by vulcanization during the primary molding process.

5.4. Flash tolerance, finish, and appearance of bearings shall meet the requirements of the latest edition of the *Rubber Handbook* as published by the Rubber Manufacturers Association, Inc., RMA F 3 and T.063 for molded bearings and RMA F 2 for extruded bearings.

6. TOLERANCES

6.1. Plain pads and laminated bearings shall be manufactured to the design dimensions tolerances listed in Table 2, unless other tolerances are shown on the design drawings. Use the following equation to define alignment tolerance limits for steel laminate when tolerance #3 (±3 mm) (± 0.1181 in.) is exceeded: $7.5\theta + v/h_r \leq 0.35$ provided $\theta \leq 0.02$ where θ (radians) and v (mm) (in) are absolute values of steel laminate rotation and vertical displacement. If the specified layer elastomeric layer thickness is h_r, the bearing length is L, and H_1 and H_2 are the measured maximum and minimum thicknesses at the edges of the layer, then $v = |h_r - 0.5\,(H_1 + H_2)|$ and $\theta = |(H_1 - H_2)/2L|$ for interior layers and $\theta = |(H_1 - H_2)/L|$ for top and bottom layers provided that the minimum elastomer layer thickness $H_2 \geq 5$ mm (0.1968 in.). Bearings with tolerances that satisfy this equation must also satisfy the compression test in Section 8.8 or the inclined compression test in Annex A1.

Table 2—Tolerances

	mm (in.)
1. Overall vertical dimensions:	
Design thickness 32 mm (1.2598 in.) or less	–0, +3 (0.1181)
Design thickness over 32 mm (1.2598 in.)	–0, +6 (0.2362)
2. Overall horizontal dimensions:	
For measurements 914 mm (35.9842 in.) and less	–0, +6 (0.2362)
For measurements greater than 914 mm (35.9842 in.)	–0, +12 (0.4724)
3. Thickness of individual layers of elastomer (laminated bearings only) at any point within the bearing	±3 mm (0.1181)
4. Variation from a plane parallel to the theoretical surface (as determined by measurements at the edge of the bearings):	
Top	Slope relative to the bottom of no more than 0.005 radians
Sides	6 (0.2362)
5. Position of exposed connection members	±3 (0.1181)
6. Edge cover of embedded laminates of connection members	–0, +3 (0.1181)
7. Size of holes, slots, or inserts	±3 (0.1181)
8. Position of holes, slots, or inserts	±3 (0.1181)

7. MARKING

7.1. Each elastomeric bearing shall be marked in indelible ink or flexible paint. The marking shall consist of the order number, lot number, bearing identification number, and elastomer type and grade. Unless otherwise specified in the contract documents, the marking shall be on a face that is visible after the bridge is erected.

8. BEARING TESTING AND ACCEPTANCE CRITERIA

8.1. All test apparatus used to determine conformance with these specifications shall be calibrated annually in accordance with T 67.

8.2. Sampling, testing, and acceptance consideration will be made on a lot basis. A lot of bearings shall be considered to be a group of 100 or fewer bearings that are manufactured in a reasonably continuous manner from the same batch of elastomer, cured under the same conditions, and are all the same size and type (plain, fabric-laminated, or steel-laminated). A lot may include 100 or fewer fabric-laminated bearings of different plan size if cut from a large sheet or sheets meeting these requirements.

8.3. The manufacturer shall designate the bearings in each lot and certify that each of the bearings in the lot was manufactured in a reasonably continuous manner from the same batch of elastomer, and cured under the same conditions. In addition, the manufacturer shall certify that each bearing in the lot satisfies the requirements of the design specification and meets the dimensional tolerances of Section 6 of this specification.

8.4. The dimensions of each bearing shall be checked. If any dimension is outside the limits listed in Section 6 of this specification, the lot shall be rejected.

8.5. The purchaser shall select sample bearings from the lot for testing in accordance with this specification. Sampling rate shall be as follows:

- *Plain Bearings*—Two full size bearings per lot.
- *Laminated Bearings*—One full size bearing per every ten per lot, a minimum of two bearings.

8.6. Elastomer taken from the sampled bearings shall be tested for conformance with the requirements of Sections 4.1 through 4.4 of this specification. If the sampled elastomer fails to meet any of these requirements, the lot shall be rejected.

8.7. Tests may be performed by the manufacturer, by the purchasing agency, or by an outside independent laboratory subject to the approval of the purchaser. If testing is performed by the manufacturer or an independent laboratory, certified test results shall be provided. Regardless of the agency designated to test the pads, the purchaser reserves the right to obtain test samples from the bearings for confirming test results.

8.8. Bearing criteria shall include the following:

8.8.1. Each sampled bearing shall be tested to determine compressive strain at the maximum design dead plus live service compressive load in accordance with Section 9.1 of this specification if the structural designer has specified a maximum value for compressive strain at that load. If the specified strain is exceeded, the lot shall be rejected.

8.8.2. Each sampled bearing shall be subjected to a compressive load equal to 1.5 times the maximum design dead plus live service compressive load. The load shall be held for 5 minutes, removed, and reapplied for a second period of 5 minutes. The bearing shall be visually examined while under the second loading. If the bearing exhibits three separate surface cracks that are greater than 2 mm (0.0787 in.) wide and 2 mm (0.0787 in.) deep or a single crack 3 mm (0.1181 in.) deep or wider than 6 mm (0.2363 in.), the lot shall be rejected. For laminated bearings, if bulging patterns imply laminate placement that does not satisfy design criteria and manufacturing tolerances, or if bulging suggests poor laminate bond, the lot shall be rejected.

8.8.3. A minimum of one sampled bearing per lot shall be tested for creep and shear bond strength in accordance with Annex A2 of this specification. The percent creep at 25 years shall be reported to the purchaser, when the designer specifies an allowable value. If the allowable value is exceeded, the lot shall be rejected. If the selected samples for shear bond fail the criteria of Annex A2.6.1, two additional samples shall be selected for testing in accordance with Annex A2.6.1. If the two samples fail, the lot shall be rejected.

8.8.4. The shear modulus of the elastomer shall be determined at 23 ± 1ºC (73.4 ± 1.8°F) in accordance with either Annex A1 or Annex A2 of this specification or ASTM D 4014 Annex A1 modified as follows: the initial cycles shall be taken to a strain of 0.7 and, on the last cycle, the shear modulus shall be determined at 0.5 strain. Shear modulus may be determined with either Annex A1, Annex A2, or the modified ASTM D 4014 Annex A1 for plain or laminated elastomeric pads designed according to Method A of the *AASHTO LRFD Bridge Design Specifications* or the *Standard Specifications for Highway Bridges*. Shear modulus shall be determined with Annex A1 or the modified ASTM D 4014 Annex A1 for laminated pads designed according to Method B. If the shear modulus is not within ±15 percent of the value specified, the lot shall be rejected. If shear modulus does not meet the specified minimum value from Table 1, the lot shall be rejected.

8.9. Optional test procedures, when required by the purchaser.

8.9.1. For elastomer Grades 2 through 5, additional shear modulus testing shall be performed on elastomer from the sampled bearings in accordance with Section 9.2 of this specification. If the measured stiffness at the specified temperature exceeds four times the stiffness measured at 23 ± 2ºC (73.4 ± 3.6°F), the lot shall be rejected.

8.9.2. Elastomer from the sampled bearings shall be tested for compression stiffness in accordance with Annex A3. The elastomer stiffness shall be measured at 23 ± 2ºC (73.4 ± 3.6°F) and at a lower temperature corresponding to the specified grade of elastomer. The lower test temperatures for the various grades of elastomer shall be as follow:

- Grades 0 and 2—Test at –32 ± 2˚C (-25.6 ± 3.6°F)
- Grade 3—Test at –40 ± 2˚C (-40 ± 3.6°F)
- Grade 4—Test at –46 ± 2˚C (-50.8 ± 3.6°F)
- Grade 5—Test at –54 ± 2˚C (-65.2 ± 3.6°F)

8.9.2.1. If the stiffness of the elastomer measured at the specified lower temperature is more than four times the stiffness of the elastomer measured at 23 ± 2ºC (73.4 ± 3.6°F), the lot shall be rejected.

8.9.3. The purchaser may require more severe tests of pads, such as fatigue or test to failure.

9. TESTS

9.1. *Determination of Compression Strain at Maximum Design Load*:

9.1.1. The bearing to be tested shall be placed in a test machine capable of applying a compressive load equal to the bearings' maximum design dead plus live service load.

9.1.2. A pair of deflectometers shall be placed on opposite sides of the bearing in the test machine. The deflectometers shall be located as near as possible to the center of the bearing.

9.1.3. The bearing shall be loaded at a rate of 520 kPa/min (75.4196 psi/min) to a compression stress equal to 5 percent of the bearing's maximum design dead plus live service compressive load. The 5 percent load shall be maintained for 2 minutes. At the end of the 2 minutes, the deflectometer readings shall be recorded.

9.1.4. The compressive load shall be increased at a rate of 520 kPa/min (75.4196 psi/min) to a compressive stress equal to the bearing's maximum design dead plus live service load. The load shall be maintained for a period of 2 minutes, at the end of which the deflectometer readings shall be recorded.

9.1.5. The total compressive deflection between the two loadings shall be calculated for each deflectometer. The bearing's compressive strain shall be calculated as the average of the compressive deflections indicated by the two deflectometers divided by the design effective rubber thickness of the tested bearing.

9.2. *Additional Shear Modulus Testing for Elastomer Grades 2 through 5*:

9.2.1. Shear modulus testing shall be performed as described in Annex A1 of ASTM D 4014 except as modified below.

9.2.2. The test specimens shall be taken from sampled bearings. After preparing the test specimen, it shall be conditioned for a period of time at a specified temperature. Conditioning times and temperatures for the various elastomer grades shall be as follow:

- Grade 2—7 days at –18 ± 2˚C (-0.4 ± 3.6°F)
- Grade 3—14 days at –26 ± 2˚C (-14.8 ± 3.6°F)
- Grade 4—21 days at –37 ± 2˚C (-34.6 ± 3.6°F)
- Grade 5—28 days at –37 ± 2˚C (-34.6 ± 3.6°F)

9.2.3. Shear modulus testing shall be performed with the test specimen in an enclosed freezer unit capable of maintaining the specified conditioning temperature. A ±25 percent strain cycle shall be applied with a period of 100 seconds. The first three-quarter cycle of strain shall be discarded and the stiffness shall be determined by the slope of the force deflection curve for the next half cycle of loading.

ANNEXES

(Mandatory Information)

A1. INCLINED COMPRESSION TEST FOR SHEAR MODULUS

A1.1. *Scope*:

A1.1.1. This method determines the shear modulus of full-size elastomeric bearings from the compressive force-displacement curve after three conditioning cycles to 65 percent strain.

A1.2. *Apparatus*:

A1.2.1. A compression test machine shall be used to apply the load to a pair of test bearings between three inclined platens as shown in Figure A1.1.

A1.2.2. The inclined platens shall be made out of steel or aluminum. The surface inclination can vary between 1:10 and 1:20. All platens shall have the same surface inclination. The platen dimensions shall be greater than the dimensions of the bearings tested. The minimum thickness of the aluminum platens shall be 12 mm (0.4724 in.). The top and bottom platens shall be attached to the testing machine.

A1.2.3. The platen surfaces, or facing plates attached to the platens, that are in contact with the bearings shall be roughened to prevent bearing slip during the test. The roughening can be performed by impacting with a tool that is used to roughen concrete surfaces, blasting with grit, or other equivalent means. Milled grooves no deeper than 1 mm (0.0394 in.) can also be used to provide a no-slip surface.

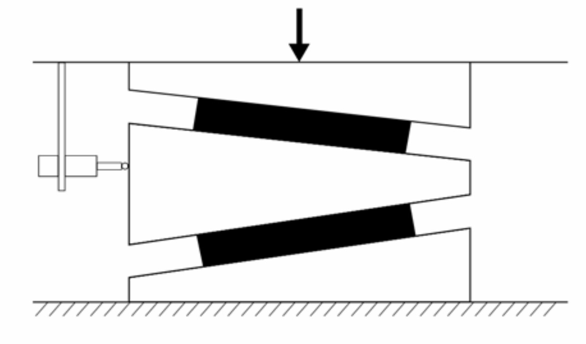


Figure A1.1—Inclined Compression Test Setup

A1.3. *Test Specimen*:

A1.3.1. The elastomeric bearings shall be of uniform thickness and of rectangular or circular in cross-section. The thickness shall not be less than 6 mm (0.2363 in.). The length and width of each bearing shall not be less than four times the thickness.

A1.3.2. Plain elastomeric pads must be bonded to rigid plates on both the top and bottom surfaces. The bonding system must not require a curing temperature greater than 40ºC (104ºF). The plates shall be of rectangular section and may be of mild steel. Plate dimensions shall be slightly larger than bearing dimensions. A thickness ≥5 mm (0.1968 in.) can be used for the plates.

A1.3.3. Measure the length, width, and total elastomer thickness of the bearings to determine the average cross-sectional area (*A*) and average elastomer thickness (*T*) of a bearing.

A1.3.4. Laminated pads shall be tested with or without any sole plates attached.

A1.3.5. The contact surfaces of bearings that are not bonded to steel plates shall be cleaned to remove any kind of residue.

A1.4. *Test Procedure*:

A1.4.1. Allow time for any bonds to achieve adequate strength and condition the specimen at a test temperature of 23 ± 2ºC (73.4 ±3.6ºF) at least eight hours prior to testing unless another test temperature is specified.

A1.4.2. Bearings shall be sandwiched between the platens until the surfaces are in contact with each other.

A1.4.3. Two deflectometers shall be attached to monitor the horizontal displacement of the middle platen. The deflectometers shall be accurate to a least 0.025 mm (0.000984 in.).

A1.4.4. Carry out four successive loading and unloading cycles to a deformation equal to 65 percent of the average bearing thickness, and at such a loading rate that the time per cycle is within a range of 4 to 6 minutes. In all the unloading cycles, the minimum load shall be 5 kN (1124.045 lbf) or 2 percent of the maximum load, whichever is less.

A1.4.5. If there is any indication of slip of the bearings relative to the rigid plates or of bond failure during the test, prepare new specimens and repeat the test.

A1.4.6. If the middle platen does not come back to the same approximate position after the last two successive unloading cycles, a slip may have occurred between the bearing and the platens. This condition must be remedied for a valid test.

A1.5. Determination of Shear Modulus:

A1.5.1. The shear modulus shall be determined from the fourth cycle of compressive load versus average displacement curve as shown in Figure A1.2.

A1.5.2. Take an effective origin at force F_1, extension X_1 where F_1 is 5 kN (1124.045 lbf) or 2 percent of the maximum force on the fourth cycle, whichever is smaller. Determine the force F_2 at an extension X_2 given by $X_1 + 0.5T$, where T is the average total elastomer thickness of the pad (overall pad thickness minus the thicknesses of all the laminates within the bearing).

A1.5.3. The shear modulus is calculated as follows:

$$\text{Shear Modulus} = \frac{2(F_2 - F_1)}{A \times n}$$

For 1:*n* sloped platens. The factor *n* converts the vertical compressive force to a horizontal shear force.

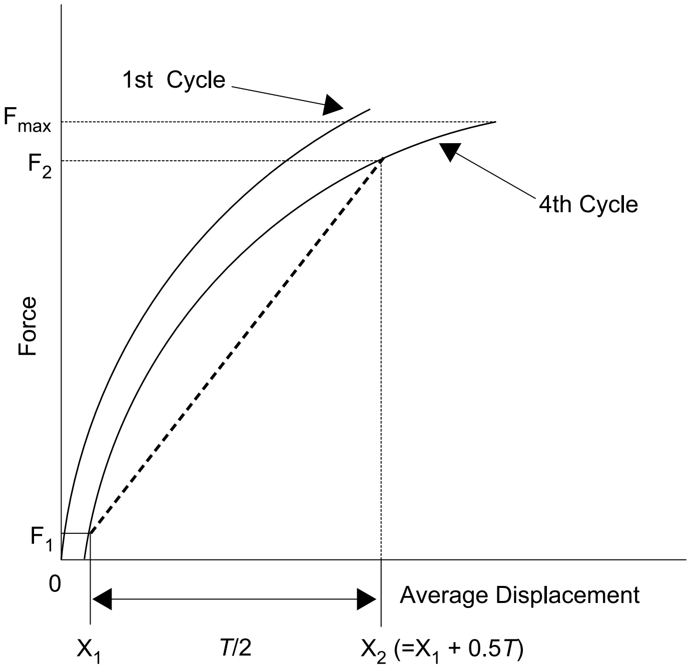


Figure A1.2—Compression Force vs. Shear Displacement

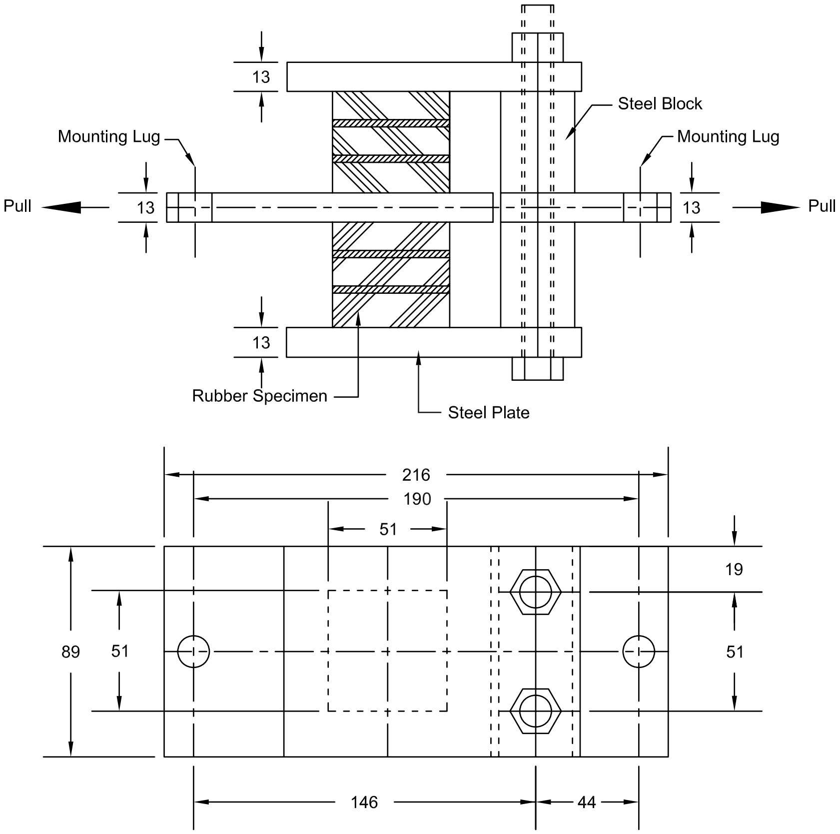
A2. A TEST METHOD FOR CREEP AND SHEAR BOND IN ELASTOMERIC BEARINGS

A2.1. *Scope*:

A2.1.1. This document describes a procedure to estimate creep and shear bond of elastomeric bridge bearings. It also describes a procedure for estimating shear modulus of elastomeric bearings as allowed in Section 8.8.4.

A2.1.2. The values stated in SI units are to be regarded as the standard.

A2.1.3. *This document does not purport to address the details of the test setup or safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to using the test summarized in this document.*



Equivalent U.S. Customary Units

mm	in.	mm	in.
13	0.5118	89	3.5039
19	0.7480	146	5.7480
44	1.7323	190	7.4803
51	2.0079	216	8.5039

Figure A2.1—Test Setup (mm)

A2.2. *Referenced Documents*:

- ASTM D 3183, Standard Practice for Rubber-Preparation of Pieces for Test Purposes from Products

A2.3. *Test Specimen*:

A2.3.1. The standard test specimen shall consist of two 51 by 51 mm (2.0079 by 2.0079 in.) square pieces of rubber bonded to steel plates as shown in Figure A2.1. The aspect ratio, height to width, should be between 0.75 and 1.25. If the subject bearing is laminated, the test specimens should have a minimum of at least two to three layers of elastomers.

A2.3.2. The rubber pieces shall be cut from one of the subject bearings per ASTM D 3183.

A2.3.3. The adherence of rubber to steel plate can be cold or hot, using an appropriate adhesive system and surface preparation adequate to keep the bond fully intact for 8 hours while the test specimen is subjected to a sustained shear strain of 50 percent at room temperature.

Note A1—When testing fabric-reinforced laminated bearings, which utilizes a bonded external load plate, the adhesive system for the cold bond between the elastomer and the steel plate shall be the same as that used in the actual manufactured bearings.

A2.3.4. The total height of the rubber piece shall be greater than 12 mm (0.4724 in.) and less than 45 mm (1.7717 in.). If the rubber piece consists of alternate layers of rubber and either metal or fabric reinforcements cut from actual bearing as shown in Figure A2.1, the total height of each rubber piece shall be limited to 51 mm (2.0079 in.).

A2.4. *Test Procedure*:

A2.4.1. Mount the test specimen in a displacement controlled loading system (MTS or equivalent) with appropriate load cell connected to a data acquisition system (automatic or manual).

A2.4.2. Load the specimen to 50 percent shear strain ten times at 1 percent strain per second. Shear strain is defined as the ratio of shearing displacement to the total thickness of rubber in the test piece. If the rubber thickness in one piece is R_{thk}, then for 50 percent strain, the specimen needs to be displaced $0.5R_{thk}$.

A2.4.3. Load the specimen to 50 percent shear strain in 1 second and keep the strain constant for a minimum of 6 hours.

A2.4.4. Record the load after 30 minutes of initial loading with further measurements after every 5 minutes for 360 minutes, minimum.

A2.4.5. For each time measurement, use Equation A2.1 to convert the load to shear modulus:

$$G(t) = \frac{load(t)}{51 \times 51 \times 2 \times 0.5} \qquad (A2.1)$$

where $load(t)$ is the load at time t (min) and $G(t)$ is the shear modulus (MPa) (psi) at time t. Note that (51 by 51) is the area of test piece and 0.5 is the shear strain. Since there are two test pieces in the test specimen, the load is divided by two.

A2.4.6. A power law of the form shown in Equation A2.2 can be conservatively used to predict $G(t)$ at times greater than 30 minutes.

$$G(t) = at^b \qquad (A2.2)$$

Where a and b are constants that are calculated by regression analysis of the data obtained in Section A2.4.5 as described in Section A2.4.7.

A2.4.7. Plot $\log(G(t))$ versus $\log(t)$ and fit a straight line using the least-squares method. The constant b is the slope of this line and $\log(a)$ is the intercept of the straight line on the $\log(G(t))$ axis.

A2.5. *Creep Estimate for Full-Size Bearing*:

A2.5.1. Let T be the time at which creep deflection needs to be estimated (e.g., 25 years).
Calculate $G(t)$ = 60 minutes and at $t = T$ using Equation A2.2.

A2.5.2. Calculate percent creep using Equation A2.3.

$$\text{Creep (\%)} = \left(\frac{G(60)}{G(T)} - 1 \right) \times 100 \qquad (A2.3)$$

A2.6. *Shear Bond*:

A2.6.1. After completion of the 6-hour stress relaxation test, load the specimen to 150 percent strain at 1 percent strain per second. Hold the specimen at 150 percent strain for 5 minutes and observe any failure in the rubber or debonding at the interface of the rubber layers and laminates or steel plate. Failure will be defined as separation of the elastomer from the laminate or steel plate in any one interface area, which exceeds either 2 mm (0.0787 in.) deep or 10 mm (0.3937 in.) long. Report the type of failure. Failures in the cold bond (when used) are not important unless they affect the ability to reach 150 percent strain, in which case a new specimen must be fabricated.

A3. COMPRESSION STIFFNESS TEST METHOD

A3.1. *Compression Stiffness Test Method*:

A3.1.1. This test determines the compressive stiffness of elastomeric bridge bearings over a wide temperature range by direct measurements of compressive loads and displacements. The test method is useful for determining the relative changes in stiffness over a wide range of temperatures as well as determining the compressive stiffness over a wide range of temperatures.

A3.2. *Test Setup*:

A3.2.1. A compression testing machine shall be used that is capable of exerting a compressive load of 500 kN (1124404.5 lbf) to a pair of bearing specimens as shown in Figure A3.1.

A3.2.2. Four displacement transducers or other devices with an accuracy of 0.005 mm (0.000197 in.) shall be used to record the displacements. Load shall be monitored with a load cell or other equivalent device with an accuracy of 1 percent of the test load.

A3.2.3. The specimens and loading plates shall be conditioned and tested in an enclosed unit capable of controlling temperatures down to −30 ± 2°C (−22 ± 3.6°F). Depending on the temperature ranges and conditioning time involved, mechanical refrigeration or a dry-ice chest or both will be advantageous.

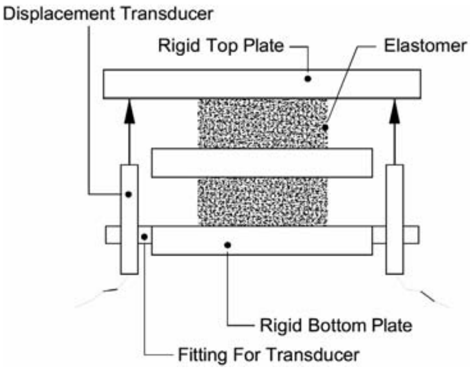


Figure A3.1—Test Setup

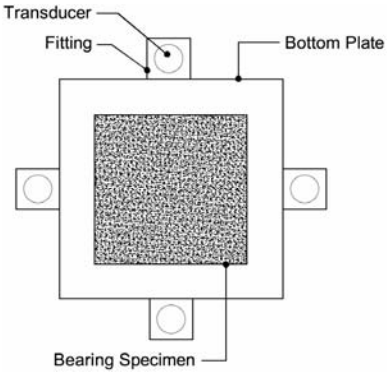


Figure A3.2—Location of Transducers

A3.3. *Test Specimen*:

A3.3.1. The test specimen in Figure A3.1 shall consist of two identical blocks of elastomer sandwiched between rigid plates. The elastomer blocks shall be of uniform thickness, preferably equal to the original thickness of the full-size bearing and of square or rectangular cross-section, the length and width each being not less than four times the thickness.

A3.3.2. The steel rigid plates shall be of square or rectangular section, a larger width and length than the elastomer block. Suitable plate dimensions for use with 40-mm (1.5748-in.) thick elastomeric pads are a thickness of 25 mm (0.9843 in.) and a plan dimension at least 25 mm (0.9843 in.) larger than each block dimension.

A3.4. *Test Procedure*:

A3.4.1. Measure the length, width, and thickness of the blocks and determine the average cross-sectional area, plan area (A), and the average total elastomer thickness (T), of the specimen.

A3.4.2. Attach four displacement transducers between the top and bottom plate such that the relative displacement between the top and bottom plate can be measured at four points as shown in Figure A3.2. The center points of each side of the bottom plate are appropriate locations for the transducers.

A3.4.3. Place the specimens inside the environmental chamber (or freezer), and bring the freezer to the desired test temperature. Condition the specimens at the specified test temperature for the specified period of time.

A3.4.4. Attach the specimens to the compression machine. Carry out three successive loading and release cycles to a deformation equal to 10 percent of the total elastomer thickness of the two blocks, $2T$, at a rate such that the time per cycle is within the range of 30 to 120 seconds.

A3.4.5. Measure both the load and the displacement at $0.02T$ increments only for the third cycle.

A3.5. *Determination of Stiffness*:

A3.5.1. The compressive modulus E_s shall be determined from the load-displacement curve on the third cycle as shown in Figure A3.3.

A3.5.2. Draw a best-fit straight line using the least-squares method through the data points between displacements $0.02T$ and $0.2T$. The line must pass through the $0.02T$ data point. Determine the slope K_1, of the best-fit straight line.

A3.5.3. Determine E_s from Equation A3.1.

$$E_s = K_1 \frac{2T}{A} \qquad (A3.1)$$

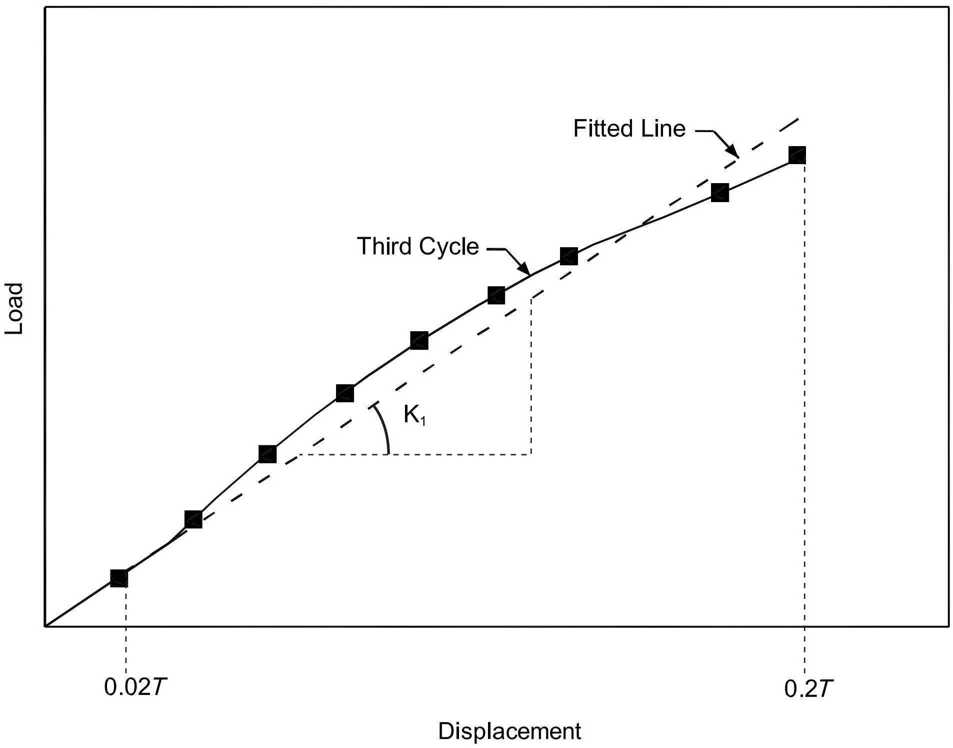


Figure A3.3—Load Displacement Curve

APPENDIXES

(Nonmandatory Information)

X1. OPTIONAL TEST AND ACCEPTANCE CRITERIA FOR METHOD A DESIGN ELASTOMERIC BRIDGE BEARINGS

X1.1. *General*:

X1.1.1. This Appendix is intended to be an alternative for use in conjunction with M 251 for elastomeric bridge bearings, which are specified by hardness and designed in accordance with AASHTO's *LRFD Bridge Design Specifications* or the *Standard Specifications for Highway Bridges*. The optional materials test methods of Appendix X1 may be used in lieu of the materials test methods of Table 1, when specified by the purchaser.

X1.2. The materials specifications remain as listed in M 251-06 as noted.

X1.3. Table 1 in Section 4 is replaced by the following tests:

Table X1. Optional Materials Test Procedures for Elastomeric Bridge Bearing Elastomers

			Polyisoprene (Natural Rubber)			Polychloroprene (Neoprene)			Units
Material Property	ASTM Standard	Test Requirements	50	60	70	50	60	70	
Physical Properties	D 2240	Hardness	50 ± 5	60 ± 5	70 ± 5	50 ± 5	60 ± 5	70 ± 5	Shore “A” points
	D412	Min tensile strength	15.5 (2248.085)	15.5 (2248.085)	15.5 (2248)	15.5 (2248.085)	15.5 (2248)	15.5 (2248.085)	MPa (psi)
		Min ultimate elongation	450	400	300	400	350	300	Percent
Heat Resistance	D 573 at specified temp	Specific temperature of the test	70 (158)	70 (158)	70 (158)	100 (212)	100 (212)	100 (212)	ºC (ºF)
		Aging time	168	168	168	70	70	70	Hours
		Max change in durometer hardness	+10	+10	+10	+15	+15	+15	Shore “A” points
		Max change in tensile strength	–25	–25	–25	–15	–15	–15	Percent
		Max change in ultimate elongation	–25	–25	–25	–40	–40	–40	Percent
Compression Set	D 395	Specific temperature of test	70 (158)	70 (158)	70 (158)	100 (212)	100 (212)	100 (212)	ºC (ºF)
	Method B at specified temp	Max permissible change (after 22 hours)	25	25	25	35	35	35	Percent
Low Temperature Brittleness	D 746	Grades 0 and 2—No test required							
	Procedure B	Grades 3—test at –40ºC (–40ºF)	Pass	Pass	Pass	Pass	Pass	Pass	
		Grade 4—test –48ºC (–54.4ºF)	Pass	Pass	Pass	Pass	Pass	Pass	
		Grade 5—test at –57ºC (–70.6ºF)	Pass	Pass	Pass	Pass	Pass	Pass	

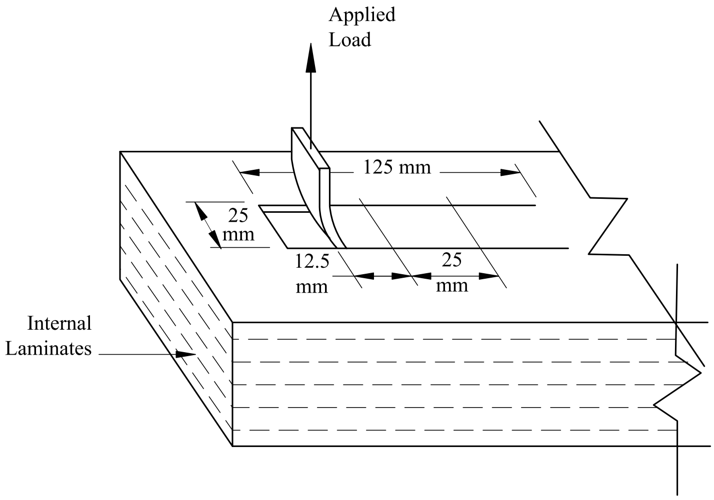
X2. BEARING TESTING AND ACCEPTANCE CRITERIA

X2.1. *Bearing Testing and Acceptance Criteria*—Sections 8.1 through 8.8.2 shall apply.

X2.2. For laminated bearings, a minimum of one sampled bearing per lot shall be tested for bond strength. Fabric-reinforced pads shall have a minimum bond strength of 5.2 kN/m (1169.006 lbf/min) and steel-reinforced pads, a strength of 6.9 kN/m (1551.182 lbf/min). If the test bearing fails to meet the required minimum bond strength, the lot shall be rejected.

X2.2.1. Bond strength shall be determined in accordance with ASTM 429 Method B as modified herein.

X2.2.2. The bond test shall be performed on sampled bearings by cutting the required strip from an elastomer layer bonded to an internal laminate. The strip size shall be 25 mm (0.9843 in.) wide, 125 mm (4.9213 in.) long, and at least 6.3 mm (0.2480 in.) thick.



Equivalent U.S. Customary Units

mm	in.
12.5	0.4921
25	0.9843
125	4.9212

Figure X2.1—Preparation of Bond Strength Specimens (mm)

X2.2.3. Peeling of the elastomer strip from the internal laminate shall be initiated by carefully cutting the elastomer back to create a tab long enough to install in the grips of the testing machine.

X2.2.4. Draw lines across the strip 12.5 mm (0.4921 in.) and 37.5 mm (1.4764 in.) from where the peeled portion of the strip meets the internal laminate. Install the specimen in the grips so that the angle between the elastomer tab and the surface of the bearing will be approximately 90 degrees for the duration of the test.

X2.2.5. Apply the tensile load at the required rate until the elastomer peels back beyond the 37.5 mm (1.4764 in.) mark while recording the load as required. If the load reaches 270 N (60.6984 lbf) without the elastomer starting to peel from the laminate surface, end the test and record the bond strength as 10.8 kN/m (61.6696 lbf/in.) +. If the elastomer peels back to the 37.5 mm (1.4764 in.) mark without reaching 270 N (60.6984 lbf) of load, record the bond strength as the average load in kN/m (lbf/in.) of width required to peel the elastomer between the marks. If the elastomer tab rips off the bearing before reaching the 37.5 mm (1.4764 in.) mark or reaching 270 N (60.6984 lbf) of load, retest in another area of the bearing.

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[1] The Society for Protective Coatings, 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656.

Standard Specification for

Joint Sealants, Hot-Poured, Elastomeric-Type, for Portland Cement Concrete Pavements

AASHTO Designation: M 282-99 (2007)
ASTM Designation: D 3406-95 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Joint Sealants, Hot-Poured, Elastomeric-Type, for Portland Cement Concrete Pavements

AASHTO Designation: M 282-99 (2007)
ASTM Designation: D 3406-95 (2006)

AASHTO M 282-99 (2007) is identical to ASTM D 3406-95 (2006).

Standard Specification for

Preformed Polychloroprene Elastomeric Joint Seals for Bridges

AASHTO Designation: M 297-10
ASTM Designation: D 3542-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Preformed Polychloroprene Elastomeric Joint Seals for Bridges

AASHTO Designation: M 297-10
ASTM Designation: D 3542-08

AASHTO M 297-10 is identical to ASTM D 3542-08 except for the following provisions:

1. Replace the last sentence of Section 6.1.1 of ASTM D 3542-08 with the following:

   "The relationship of a seal's height to its depth is significant to its performance. Thus, the height shall be as agreed upon between the purchaser and the supplier."

2. The last two sentences of Section 6.2.3 of ASTM D 3542-08 are not included in M 297-10.
3. The last four sentences of Section 8.1 of ASTM D 3542-08 are not included in M 297-10.
4. Replace Section 10.1.2 of ASTM D 3542-08 with the following:

   10.1.2 A certification of test results by an independent testing agent and a statement that the material has been sampled, tested, and inspected in accordance with the provisions of the specification. Each certification so furnished shall be signed by an authorized agent of the testing agency.

Standard Specification for

Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements

AASHTO Designation: M 324-08
ASTM Designation: D 6690-06a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements

AASHTO Designation: M 324-08
ASTM Designation: D 6690-06a

AASHTO M 324-08 is identical to ASTM D 6690-06a.

Standard Practice for

Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures

AASHTO Designation: R 50-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures

AASHTO Designation: R 50-09[1]

1. SCOPE

1.1. This standard practice provides guidance to pavement designers interested in incorporating geosynthetics for the purpose of reinforcing the aggregate base course of flexible pavement structures. Geosynthetic reinforcement is intended to provide structural support of traffic loads over the life of the pavement.

1.1.1. For the purpose of this guide, base reinforcement is the use of a geosynthetic within, or directly beneath, the granular base course.

1.1.2. When referring to geosynthetics, the discussion is limited to geotextiles, geogrids, or geogrid/geotextile composites.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 288, Geotextile Specification for Highway Applications

2.2. *Other References*:

- Geosynthetics Materials Association (GMA) White Paper I—"Geosynthetics in Pavement Systems Applications," May 1999. Available at www.bookstore@ifai.com.
- Geosynthetic Materials Association (GMA) White Paper II—"Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures," June 2000. Available at www.bookstore@ifai.com.
- National Highway Institute (NHI) Participant Notebook—*Geosynthetic Design and Construction Guidelines*, April 1999. Available at www.nhi.fhwa.dot.gov.

3. INTRODUCTION

3.1. Because the benefits of geosynthetic reinforced pavement structures may not be derived theoretically, test sections are necessary to obtain benefit quantification. Studies have been done that demonstrate the value added by a geosynthetic in a pavement structure. These studies, necessarily limited in scope, remain the basis for design in this field.

3.2. This standard practice is very empirical in nature and restricted to applications already demonstrated to be useful. The practitioner will need to consult the references and locate a tested section similar to that which is expected in their own design. In that way, the experimentally determined benefit may be applied to the project being designed.

4. TERMINOLOGY

4.1. *Definitions*:

4.1.1. *base course reduction (BCR)*—percentage of the base or subbase thickness in a reinforced pavement, as compared to the base or subbase thickness in an unreinforced pavement with the same material components, such that equal life cycles for a defined failure state result between the two.

4.1.2. *separation*—use of a geotextile to prevent the mixing of a subgrade soil and an overlying aggregate material.

4.1.3. *stabilization*—use of a geotextile in wet, saturated conditions to provide the functions of separation and drainage.

4.1.4. *traffic benefit ratio (TBR)*—ratio of the number of load cycles of a reinforced pavement structure to reach a defined failure state to the number of loads for the same unreinforced section to reach the same defined failure state.

4.2. *Discussion*—Use of geotextiles for separation and stabilization applications is covered in M 288 and, therefore, is not included in this guide.

5. SUMMARY OF DESIGN METHOD

5.1. The purpose of this guide is to provide the practitioner with general information regarding the use of a geosynthetic for reinforcement in a pavement structure. The guide will not provide step-by-step procedures for the design of the geosynthetic in this application; instead, overall design considerations are outlined.

5.2. Design procedures use experimentally derived input parameters that are often geosynthetic specific. Thus, computed engineering designs and economic benefits are not easily translated to other geosynthetics. Therefore, users of this document are encouraged to affirm their designs with field verification of the reinforced pavement performance, both in engineering design and economic benefits.

6. SIGNIFICANCE AND USE

6.1. Geosynthetics are used in the pavement structure for structural support of traffic loads over the design life of the pavement. The geosynthetic is expected to provide one or both of these benefits: (1) improved or extended service life of the pavement, or (2) reduced thickness of the structural section.

6.2. Service life improvement may be in the form of extended performance periods or increased reliability (1) so that the constructed pavement will support the actual versus designed equivalent single-axle loads, or (2) to account for actual subgrade strengths lower than assumed designed subgrade strength.

7. GENERAL DESIGN STEPS

7.1. In general terms, the design steps to be followed in determining the applicability of incorporating geosynthetic reinforcement in a pavement design are shown below.

7.1.1. General design procedures may be found in the NHI Participant Notebook on this topic.

7.1.2. A general design procedure for the reinforcement application, detailing the steps summarized below, is contained in GMA White Paper II.

7.1.3. Make an initial assessment of the applicability of a geosynthetic. This is based on an assessment of the subgrade strength and the past performance in similar soils. Consideration should be given to each type of geosynthetic appropriate for the installation.

7.1.4. Design the thickness of an unreinforced pavement section based on representative material parameters for a pavement design unreinforced by geosynthetics.

7.1.5. Determine the benefits of using a geosynthetic. Refer to Section 6.1 to determine what the target benefit or benefits should be.

7.1.6. The target benefits should indicate whether a TBR or BCR, or both, needs to be identified.

7.1.6.1. The TBR is defined as the ratio of the number of load cycles of a reinforced pavement structure to reach a defined failure state, to the number of loads for the same unreinforced section to reach the same defined failure state.

7.1.6.2. The BCR is defined as the percentage of the base or subbase thickness in a reinforced pavement, as compared to the base or subbase thickness in an unreinforced pavement with the same material components, such that equal life cycles for a defined failure state result between the two.

7.1.7. Develop a trial reinforced pavement design that reflects the desired target benefits. Though the design procedures mentioned in Sections 7.1.1 and 7.1.2 can be used to estimate the potential benefit of geosynthetic reinforcement, the accuracy of these methods for specific applications is yet to be determined; hence, construction and performance monitoring as discussed in Sections 7.1.11 and 7.1.12 is recommended. Similar case histories of pavement reinforcement should also be used to help estimate the potential benefit of geosynthetic reinforcement for the specific application being considered.

7.1.8. Perform a life-cycle cost analysis. A knowledge of the initial construction costs for both the unreinforced and the reinforced options, the life-cycle costs for both options, and other benefits, which may not be easily quantifiable, is needed in order to complete a life-cycle cost analysis.

7.1.9. Prepare material specifications. Based on the results of the above process, the engineer may want to develop an approved list of products that are considered appropriate for this application, based on successful past applications. The construction contractor then has the option, based on the results of the design, to select products based on suitability, availability, and economics.

7.1.10. Prepare contract documents, specifications, and construction drawings. Specific attention needs to be paid to installation guidelines, location within the pavement section, and quality assurance procedures when preparing these documents and drawings.

7.1.11. Monitor the construction sequences to ensure that the correct geosynthetic is installed in the correct locations, both vertically within the pavement section and horizontally along the project. The installation procedures should also be monitored to eliminate any construction damage to the geosynthetic and to ensure proper performance of the material.

7.1.12. Monitor long-term performance. Formal documentation of the pavement's performance is recommended to allow for a complete evaluation of the geosynthetic's performance in relation to the benefits that the section was designed to provide.

7.1.13. Users of this guide are encouraged to prepare an annual assessment regarding the performance of the geosynthetic.

7.1.14. Based on the above assessment of performance, design procedures and/or material specifications may be developed or revised to reflect the results of the study.

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[1] This standard was first published in 2001 as PP 46.

Standard Specification for

Steel Forgings, Carbon and Alloy, for General Industrial Use

AASHTO Designation: M 102M/M 102-06
ASTM Designation: A 668/A 668M-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249,
Washington, D.C. 20001

Standard Specification for

Steel Forgings, Carbon and Alloy, for General Industrial Use

AASHTO Designation: M 102M/M 102-06
ASTM Designation: A 668/A 668M-04

1. SCOPE

1.1. This specification covers untreated and heat-treated carbon and alloy steel forgings for general industrial use. ASTM specifications for forgings are available for specific applications such as pressure vessels, railroad use, turbine generators, gearing, and others involving special temperature requirements.

1.2. Hot-rolled or cold-finished bars are not within the scope of this specification.

1.3. Six classes of carbon steel and seven classes of alloy steel forgings are listed (Section 7), which indicates their required heat-treatments as well as mechanical properties.

1.4. Provision, with the suffix H for certification and marking, for the supply of forgings after hardness testing only.

1.5. Supplementary requirements, including those in ASTM A 788, of an optional nature, are provided. These shall apply only when specified by the purchaser.

1.6. Appendix X1 lists the current classes corresponding to the various classes of ASTM A 235, A 237, and A 243, which have been superseded by this specification.

1.7. The values stated in either SI units or inch-pound units are to be regarded separately as the standard; within the text and tables, the inch-pound units are shown in brackets. The values stated in each system are not exactly equivalent; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 275/A 275M, Standard Practice for Magnetic Particle Examination of Steel Forgings
- A 388/A 388M, Standard Practice for Ultrasonic Examination of Steel Forgings
- A 788, Standard Specification for Steel Forgings, General Requirements
- E 381, Standard Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

3. TERMINOLOGY

3.1. The terminology section of ASTM A 788 is applicable to this specification.

3.2. *Definition of Terms Specific to This Standard*:

3.2.1. *hollow cylindrical forging*—a forging the length of which, as measured on its longitudinal axis, is more than its diameter shall be considered as a hollow cylinder within the scope of this specification if it has been lengthened by extrusion or forged in a manner similar to that of a ring; namely, expanded in diameter on a mandrel.

3.2.2. *ring-shaped or disk-shaped forging*—a forging the length of which, as measured on its longitudinal axis, is less than its diameter or main transverse dimension is considered a ring or disk within the meaning of this specification.

4. ORDERING INFORMATION

4.1. Material supplied to this specification shall conform to the requirements of ASTM A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

4.1.1. If the requirements of this specification are in conflict with the requirements of ASTM A 788, the requirements of this specification shall prevail.

4.2. When this specification is to be applied to an inquiry, contract, or order, the purchaser shall furnish the following information:

4.2.1. The ordering information required by ASTM A 788;

4.2.2. The class of forging desired as listed in Table 1;

4.2.3. Location(s) of areas of significant loading if test specimens are to be located in accordance with Section 7.1.4.5;

4.2.4. The options that may be selected as found in Sections 5.4.2, 7.6.3, and 7.7; and

4.2.5. Any applicable supplementary requirements.

5. MATERIALS AND MANUFACTURE

5.1. *Discard*—Sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

5.2. *Forging Process*:

5.2.1. The forging shall be brought as close as practical to finished shape and size by hot mechanical work.

5.2.2. Supplementary requirements S2, S14, and S15 may be specified by the purchaser to satisfy concerns about the utility of the proposed forging.

5.3. *Heat Treatment*:

5.3.1. All forgings, other than Class A, shall be heat-treated. See Section 7.

5.3.2. Where options exist within a class, the choice of heat treatment shall be left to the discretion of the manufacturer, unless the purchaser specifies one of the available options.

6. CHEMICAL COMPOSITION

6.1. The steel shall conform to the requirements for chemical composition prescribed in Table 1.

Table 1—Chemical Requirements

	Composition, max, percent	
Elements	Classes A to F and AH to FH	Classes G to N and GH to NH
Manganese	1.35	—
Phosphorus	0.050	0.040
Sulfur	0.050	0.040

6.2. The choice of chemical composition is left to the discretion of the manufacturer, unless otherwise specified by the purchaser.

6.3. *Heat Analysis*—An analysis of each heat shall be made by the manufacturer.

6.4. *Product Analysis*—An analysis may be made by the purchaser according to the requirements of ASTM A 788. If a standard grade has been used to manufacture the forging, the permissible variations in composition of ASTM A 788 shall apply. If a nonstandard grade of steel has been used, and composition limits have not been supplied, the product analysis can be used only to confirm the type of steel supplied.

7. MECHANICAL PROPERTIES

7.1. *Tensile Requirements*:

7.1.1. The material shall conform to the tensile properties prescribed in Table 2.

7.1.2. *Size Classification*—The dimensions of the forging at time of heat-treatment determine the size classification. (See Table 2.)

7.1.2.1. *Solid Forgings*—Either the as-forged or rough-machined diameter or thickness of solid forgings, disregarding large ends, collars, flanges, and journals, at time of heat-treatment shall determine the size classification.

7.1.2.2. *Ring or Hollow Cylinder Forging*—The size classification shall be determined by its wall thickness or width, whichever is the smaller dimension of either the as-forged or rough-machined forging at time of heat-treatment.

Table 2—Tensile Requirements

Class	Size, mm [in.]		Tensile Strength, Min	Yield Point, Yield Strength 0.2 percent Offset, Min	Elongation in 50 mm [2 in.], Min Percent	Reduction of Area, Min Percent	Brinell Hardness
	Over	Not Over	MPa [psi]	MPa [psi]			
				Carbon Steel			
A (AH) (untreated)	—	510 [20]	324 [47000] 414 [60000]	—	—	—	183 max
B (BH) (Annealed or normalized, or normalized and tempered	—	510 [20]	414 [60000]	207 [30000]	24	36	120–174
C (CH) (Annealed or normalized, or normalized and tempered)	—	305 [12]	455 [66000]	227 [33000]	23	36	137–183
	305 [12]	510 [20]	455 [66000]	227 [33000]	22	34	137–183
D (DH) (Normalized, annealed, or normalized and tempered)	—	205 [8]	517 [75000]	259 [37500]	24	40	149–207
	205 [8]	305 [12]	517 [75000]	259 [37500]	22	35	149–207
	305 [12]	510 [20]	517 [75000]	259 [37500]	20	32	149–207
	510 [20]		517 [75000]	259 [37500]	19	30	149–207
E (EH) (Normalized and tempered, or double normalized and tempered)	—	205 [8]	586 [85000]	303 [44000]	25	40	174–217
	205 [8]	305 [12]	572 [83000]	296 [43000]	23	37	174–217
	305 [12]	510 [20]	573 [83000]	296 [43000]	22	35	174–217
F (FH) (Quenched and tempered, or normalized, quenched and tempered)	—	100 [4]	621 [90000]	379 [55000]	20	39	187–235
	100 [4]	180 [7]	586 [85000]	345 [50000]	20	39	174–217
	180 [7]	255 [10]	586 [85000]	345 [50000]	19	37	174–217
	255 [10]	510 [20]	565 [82000]	331 [48000]	19	36	174–217
				Alloy Steel			
G (GH) (Annealed or normalized, or normalized and tempered)	—	305 [12]	552 [80000]	345 [50000]	24	40	163–207
	305 [12]	510 [20]	552 [80000]	345 [50000]	22	38	163–207
H (HH) (Normalized and tempered)	—	180 [7]	621 [90000]	414 [60000]	22	44	187–235
	180 [7]	255 [10]	621 [90000]	400 [58000]	21	42	187–235
	254 [10]	508 [20]	620 [90000]	400 [58000]	18	40	187–235
J (JH) (Normalized and tempered, or normalized, quenched and tempered)	—	180 [7]	655 [95000]	483 [70000]	20	50	197–255
	180 [7]	255 [10]	621 [90000]	448 [65000]	20	50	187–235
	254 [10]	508 [20]	620 [90000]	450 [65000]	18	48	207–255
K (KH) (Normalized, quenched and tempered)	—	180 [7]	724 [105000]	552 [80000]	20	50	212–269
	180 [7]	255 [10]	689 [100000]	517 [75000]	19	50	207–269
	254 [10]	508 [20]	690 [100000]	515 [75000]	18	48	207–269
L (LH) (Normalized, quenched and tempered)	—	100 [4]	862 [125000]	724 [105000]	16	50	255–321
	100 [4]	180 [7]	793 [115000]	655 [95000]	16	45	235–302
	180 [7]	255 [10]	758 [110000]	586 [85000]	16	45	223–293
	254 [10]	508 [20]	760 [110000]	585 [85000]	14	40	223–293
M (MH) (Normalized, quenched and tempered)	—	100 [4]	1000 [145000]	827 [120000]	15	45	293–352
	100 [4]	180 [7]	965 [140000]	793 [115000]	14	40	285–341
	180 [7]	255 [10]	931 [135000]	758 [110000]	13	40	269–331
	254 [10]	508 [20]	930 [135000]	758 [110000]	12	38	269–341
N (NH) (Normalized, quenched and tempered)	—	100 [4]	1172 [170000]	965 [140000]	13	45	331–401
	100 [4]	180 [7]	1138 [165000]	931 [135000]	12	35	331–401
	180 [7]	255 [10]	1103 [160000]	896 [130000]	11	35	321–388
	254 [10]	508 [20]	1105 [160000]	905 [130000]	11	35	321–402

7.1.3. *Number of Tests*—Unless the purchaser specifies that forgings shall be furnished in accordance with the requirements of Section 7.3, the number of tension tests performed shall be as follows:

7.1.3.1. For all classes of heat-treated forgings with rough-machined masses less than 2250 kg [5000 lb] each, one test shall be made from each size classification represented in each heat in each annealing or normalizing charge, or from each size classification in each heat in each normalizing or quenching charge represented in each tempering charge. For untreated forgings (Class A) with a mass of less than 2250 kg [5000 lb] each, one test from each heat shall be made.

7.1.3.2. On all classes, for forgings with rough-machined masses of 2250 kg [5000 lb] or more, at least one test from each forging shall be made.

7.1.3.3. On all classes, for forgings with rough-machined masses of 3200 kg [7000 lb] or more, two tests will be taken: on ring and disk forgings 180 degrees apart; on shafts and long hollow cylinders more than 2.0 m [80 in.] in length (excluding test material), one from each end and offset 180 degrees. Shaft and cylinder forgings 2.0 m [80 in.] or less in length (excluding test material) may have both tests located at one end 180 degrees apart.

7.1.3.4. When forgings are made in multiple as a single forging, that is, forged as one piece and divided after heat-treatment, the multiple forging shall be considered as one forging, and the number of tests required shall be designated in Sections 7.1.3.1, 7.1.3.2, and 7.1.3.3.

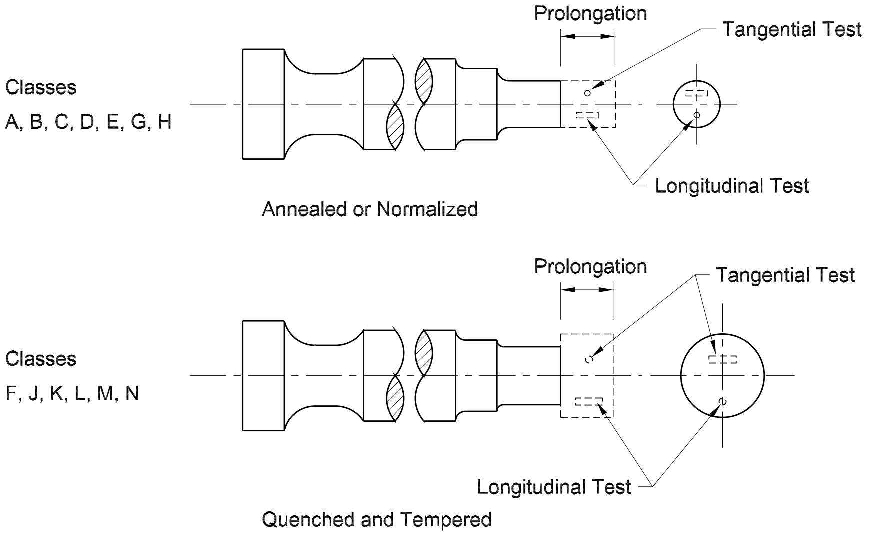
7.1.4. *Prolongations*:

7.1.4.1. A sufficient number of the forgings shall have prolongations for extracting specimens for testing. Locations of test specimens for various types of forgings shall be as shown in Figure 1.

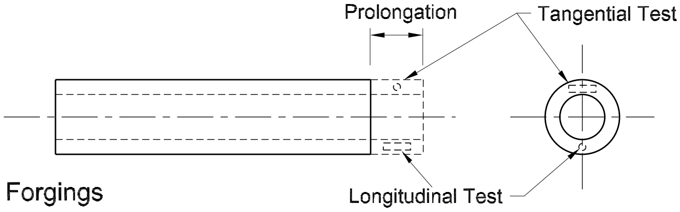
7.1.4.2. The nominal or principal outside rough-machine diameter or thickness of the forgings, disregarding large ends, collars, flanges, and journals shall determine the size of the prolongations for test specimens; however, the prolongations on annealed, normalized, or normalized and tempered shafts may be extensions of the small diameter end of the shaft, as shown in Figure 1.

7.1.4.3. For quenched forgings in Classes F, J, K, L, M, and N, the prolongations shall be sufficiently long so that the center of the gauge length (for longitudinal specimens) or axis (for tangential specimens) of the tension test specimen shall be at the following locations:

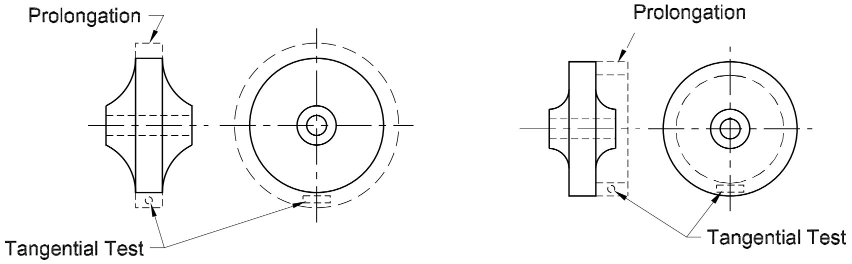
1. On solid round forgings, bars, or billets (Figure 1(a)), at mid-radius and from the end, 90 mm [$3^1/_2$ in.] or $^1/_2$ the diameter, whichever is less.
2. On solid rectangular forgings, bars, or billets, at $^1/_4$ the thickness and the width from the end, 90 mm [$3^1/_2$ in.] or $^1/_4$ the thickness, whichever is less.
3. On disk forgings (Figure 1(c)) (with prolongation on OD), at mid-thickness and from the OD 90 mm [$3^1/_2$ in.], or $^1/_2$ the thickness, whichever is less.
4. On disk forgings (Figure 1(c)) (with prolongation on the width or thickness), 90 mm [$3^1/_2$ in.] or $^1/_2$ the thickness, whichever is less, from any heat-treated surface.
5. On ring forgings (Figure 1(d)) (with prolongation on width), at mid-wall and from the ring face 90 mm [$3^1/_2$ in.] or $^1/_2$ the wall thickness, whichever is less.
6. On ring forgings (Figure 1 (d)) (with prolongation on the OD), at mid-width and from the OD 90 mm [$3^1/_2$ in.] or $^1/_2$ the width, whichever is less.



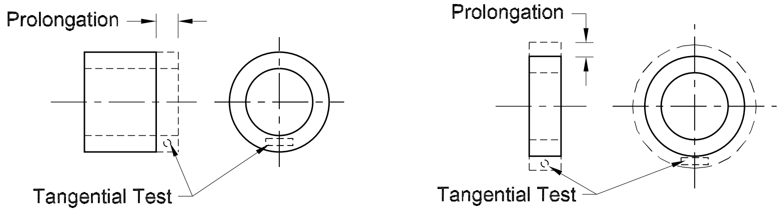
(a) Shafts and Rotors



(b) Hollow Forgings



(c) Disk Forgings



(d) Ring Forgings

Figure 1—Locations of Test Specimens for Various Types of Forgings

7.1.4.4. In place of prolongs, the manufacturer may elect to (1) submit an extra forging(s) to represent each test lot; in this event, the representative forging must be made from the same heat of steel, have received the same reduction and type of hot working, be of the same nominal thickness, and have been heat-treated in the same furnace charge as the forging(s) it represents; or (2) obtain the test specimen from the trepanned material of transverse or radial holes, provided depth is equal to or greater than the minimum depth required by Section 7.1.4.3.

7.1.4.5. With prior purchaser approval, test specimens may be taken at a depth (*t*) corresponding to the distance from the area of significant stress to the nearest heat-treated surface and at least twice this distance (2*t*) from any second surface. However, the test depth shall not be nearer to one heat-treated surface than 19 mm [$^3/_4$ in.] and to the second heat-treated surface than 38 mm [$1^1/_2$ in.]. Sketches showing the exact test locations shall be approved by the purchaser when this method is used.

7.1.5. Tests for acceptance shall be made after final heat-treatment of the forgings.

7.1.6. Test specimens shall be parallel to the axis of the forging in the direction in which the metal is most drawn out except that rings, hollow forgings which were expanded by forging, and disks shall be tested in the tangential direction.

7.1.7. Yield point shall be determined on carbon steel Grades A through F, and yield strength on alloy steel Grades G through N. For carbon steel grades not showing a yield point, the yield strength on 0.2 percent offset shall be reported.

7.2. *Hardness Tests*—Brinell hardness tests shall be performed after heat-treatment (except on Class A forgings) and rough machining on each forging having a mass under 3200 kg [7000 lb] and each multiple forging made in accordance with Section 7.1.3.4 weighing under 3200 kg [7000 lb]. For exceptions, see Sections 7.1.3.3 and 7.2.3.

7.2.1. The average value of the hardness readings on each forging shall fall within the hardness ranges specified in Table 2. The permissible variation in hardness in any forging over 110 kg [250 lb] shall not exceed 30 HB for Classes A through E, 40 HB for Classes F through J, and 50 HB for Classes K through N.

7.2.2. At least two hardness tests shall be taken on each flat face of disks, rings, and hollow forgings over 110 kg [250 lb] approximately at mid-radius and 180 degrees apart; for example, at the 3:00 and 9:00 positions on one face and the 6:00 and 12:00 positions on the opposite face. On solid forgings over 110 kg [250 lb], at least four tests shall be taken on the periphery of the forging, two at each end 180 degrees apart.

7.2.3. For forgings 110 kg [250 lb] and less, Brinell testing shall be performed on the broken test specimens representing the heat or heats included in each heat-treating charge, or in the case of untreated forgings (Class A), on the test specimen representing each heat. The results shall meet the requirements of Table 2. If the purchaser desires Brinell testing of each forging, Supplementary Requirement S11 may be used.

7.3. If so specified by the purchaser, forgings may be supplied on the basis of hardness tests alone. If this option is exercised, the class shall be identified in certification and marking with the suffix “H,” that is, “AH,” “BH,” “CH,” etc.

8. RETREATMENT

8.1. When heat-treated forgings are specified and the mechanical test results of any test lot do not conform to the requirements specified, the manufacturer may retreat the lot not more than three additional times, and retests shall be made according to Section 7. Retreatment is defined as complete re-austenization. Multiple retempering is not precluded by this requirement.

8.2. When untreated forgings (Class A) are specified and the mechanical test results of any test lot do not conform to the requirements specified, the manufacturer may anneal, normalize, or normalize and temper, one or more times, but not more than three times; and retests shall be made in accordance with Section 7. The tensile properties shall conform to the requirements for the class of forgings ordered (Class A).

9. INSPECTION, REJECTION, AND CERTIFICATION

9.1. Facilities for inspection at the place of manufacture, rejection of forgings, and certification shall comply with ASTM A 788.

10. PRODUCT MARKING

10.1. The marking requirements of ASTM A 788 shall be augmented as follows.

10.2. Each forging over 110 kg [250 lb] shall be legibly stamped by the manufacturer with the manufacturer's name or trademark, the manufacturer's serial number, the specification identification number followed by the appropriate class number, and, where applicable, a standard Grade designation.

10.3. For forgings 110 kg [250 lb] and under, the purchaser may indicate the nature and location of identification marks.

10.4. The type of stamps to be used shall be round-nosed or "interrupted-dot" die stamps having a minimum radius of 0.79 mm [$^1/_{32}$ in.].

11. KEYWORDS

11.1. Alloy steel forgings; carbon steel forgings; general industrial applications; heat-treatment classifications; strength classifications.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. CHEMICAL COMPOSITION

S1.1. The supplier shall obtain approval of the grade of steel he proposes to apply to the order and reach agreement with the purchaser on the ranges of each element specified in the composition.

S2. SPECIAL FORGING TECHNIQUES

S2.1. Special forging techniques are required to produce metal flow during the hot-working operation in the direction most favorable for resisting the stresses encountered in service. Verification of forging flow lines shall be by macroetch testing of sample forgings in accordance with ASTM E 381.

S3. ROUGH TURNING AND BORING

S3.1. The position of any rough turning or boring in the sequence of manufacturing operations.

S4. CARBON CONTENT FOR WELDING

S4.1. For forgings intended for welding, the carbon content (product analysis) shall be limited to 0.35 max percent.

S5. BEND TESTS

S5.1. The test specimen shall withstand being bent at room temperature through 180 degrees without cracking on the outside of the bent portion of an inside diameter of 40 mm [$1^1/_2$ in.].

S6. MAGNETIC PARTICLE TEST

S6.1. Forgings shall be magnetic particle tested in accordance with the latest issue of ASTM A 275/A 275M.

S7. ULTRASONIC TEST

S7.1. Forgings shall be ultrasonically tested in accordance with the latest issue of ASTM A 388/A 388M.

S8. VACUUM TREATMENT

S8.1. Vacuum degassed steel shall be supplied.

S9. TENSILE REQUIREMENTS

S9.1. When sizes larger than permitted in Table 2 are required, ductility values may be reduced from the specified values.

S9.2. Yield strengths higher than those listed in Table 2 for quenched and tempered grades may be specified.

S10. HEAT TREATMENT

S10.1. A minimum tempering temperature shall be specified.

S11. ADDITIONAL TESTS

S11.1. Tests in addition to those prescribed in Section 7 may be specified.

S12. ADDITIONAL MARKING

S12.1. Additional identification marking or the locations of the stamping or both may be specified.

S13. FORGE PROCEDURE

S13.1. The forge procedure shall be submitted by the manufacturer to the purchaser for approval prior to production of the forging.

S14. ROUGH FORGING SKETCHES

A dimensional sketch or drawing of the proposed rough forging shall be supplied by the producer for approval before the forging is produced. This drawing or sketch shall indicate also the proposed heat-treatment contour, including bores, if any, and the position of the required mechanical test coupons.

APPENDIXES

(Nonmandatory Information)

X1. COMPARISON OF AASHTO M 102 VS. SUPERSEDED ASTM SPECIFICATIONS A 235, A 237, AND A 243.

X1.1. See specification comparison in Table X1.1.

Table X1.1—Specification Comparison

Superseded ASTM Specification and Class	Use M 102, Class
A 235, A	A
A 235, C	B
A 235, C1	C
A 235, E	D
A 235, F	—
A 235, F1	E
A 235, G	F
A 237, A	G
A 237, B	—
A 237, C	H
A 237, C1	—
A 237, D	J
A 237, E	K
A 237, F	L
A 237, G	M
A 237, H	N
A 243, A	A
A 243, C	B
A 243, C1	C
A 243, E	D
A 243, F	—
A 243, F1	E
A 243, G	F
A 243, H	G
A 243, I	—
A 243, J	H
A 243, K	J
A 243, L	K
A 243, M	L
A 243, N	M
A 243, O	N

X2. TYPICAL GRADES OF STEEL USED FOR A 668/A 668M CLASSES

X2.1. See chemical composition and class/grade guide for typical grades of steel in Tables X2.1 and X2.2, respectively.

TABLE X2.1—Chemical Composition (Maximum Weight Percentage)

Element	Grade X1[a]	Grade X2[b]	Grade X3[c]	Grade X4[d]	Grade X5[e]	Grade X6[f]
Carbon	0.30	0.45	0.40	0.45	0.45	0.40
Manganese	0.90	0.90	0.85	1.10	0.90	0.90
Phosphorous	0.04	0.04	0.025	0.025	0.025	0.015
Sulfur	0.04	0.04	0.025	0.025	0.025	0.015
Silicon	0.35	0.35	0.35	0.35	0.35	0.35
Nickel	—	—	3.75	—	2.00	2.50
Chromium	—	—	—	1.10	1.00	1.25
Molybdenum	—	—	—	0.25	0.30	0.60
Vanadium	—	—	—	—	—	0.20

[a] Grade X1 is equivalent to SAE 1030.

[b] Grade X2 is equivalent to SAE 1045.

[c] Grade X3 is equivalent to SAE 4840.

[d] Grade X4 is equivalent to SAE 6145.

[e] Grade X5 is equivalent to SAE 4535.

[f] There is no SAE equivalent to Grade X6.

TABLE X2.2—Class/Grade Guide

Class	Brinell Hardness	Applicable Grades
Carbon Steel		
A	183 max	X1
B	120–174	X1
C	137–183	X1,X2
D	149–207	X1,X2
E	174–217	X2
F	187–235	X2
Alloy Steel		
G	163–207	X3,X4
H	187–235	X3,X4
J	197–255	X3,X4,X5
K	212–269	X3,X5
L	255–321	X4,X5
M	293–352	X5,X6
N	331–401	X6

Standard Specification for

Steel Castings, Carbon, for General Application

AASHTO Designation: M 103M/M 103-06
ASTM Designation: A 27/A 27M-05

American Association of State Highway and Transportation Officials
444 North Capitol Street NW, Suite 249
Washington, DC 20001

Standard Specification for

Steel Castings, Carbon, for General Application

AASHTO Designation: M 103M/M 103-06
ASTM Designation: A 27/A 27M-05

1. SCOPE

1.1. This specification covers carbon steel castings for general applications that require up to 485 MPa [70 ksi] minimum tensile strength.

Note 1—The grades covered by this specification represent materials that are suitable for assembly with other steel castings or wrought steel parts by fusion welding. It is not intended to imply that all these grades possess the same degree of weldability or that the same welding techniques can be used on all castings. It is the responsibility of the purchaser to establish for himself a suitable welding technique.

1.2. Several grades and two classes of steel castings are covered, as indicated below. The grade and class desired shall be specified by the purchaser.

1.2.1. *Grade N-1*—Chemical analysis only.

1.2.2. *Grade N-2*—Heat-treated but not mechanically tested.

1.2.3. *Grade U-415-205 [60-30]*—Mechanically tested but not heat-treated.

1.2.4. *Grades 415-205 [60-30], 450-240 [65-35], 485-250 [70-36], and 485-275 [70-40]*—Heat treated and mechanically tested.

1.2.5. Class 1 and Class 2 steel castings shall be specified in accordance with Section 9.2.

1.3. This specification is applicable to orders in either SI units (as M 103M) or inch-pound units (as M 103). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 103.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 732/A 732M, Standard Specification for Castings, Investment, Carbon and Low Alloy Steel for General Application, and Cobalt Alloy for High Strength at Elevated Temperatures
- A 781/A 781M, Standard Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use

- E 527, Standard Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

3. GENERAL CONDITIONS FOR DELIVERY

3.1. Material furnished to this specification shall conform to the requirements of ASTM A 781/A 781M, including any supplementary requirements that are indicated on the purchase order. Failure to comply with the general requirements of ASTM A 781/A 781M constitutes nonconformance with this specification. In case of conflict between this specification and ASTM A 781/A 781M, this specification shall prevail.

4. ORDERING INFORMATION

4.1. Orders for material under this specification should include the following information in proper sequence.

4.1.1. Quantity;

4.1.2. Specification, grade (Section 1.2), and class (Section 9.2);

4.1.3. Description of the casting by pattern number or drawing;

4.1.4. Options in the specification; and

4.1.5. Supplementary requirements desired, including standards of acceptance.

5. HEAT TREATMENT

5.1. All castings of Grades N-2, 415-205 [60-30], 450-240 [65-35], 485-250 [70-36], and 485-275 [70-40] shall be heat-treated by full annealing, normalizing, normalizing and tempering, or quenching and tempering. Unless otherwise specified in the inquiry, contract, or order, the castings may be heat-treated by any one or combination of these heat-treatments at the option of the manufacturer.

5.1.1. Heat-treatment shall be performed after castings have been allowed to cool from the pouring temperature to below the transformation range.

5.2. Furnace temperatures for heat-treating shall be regulated by the use of pyrometers.

6. CHEMICAL COMPOSITION

6.1. The steel shall conform to the requirements regarding chemical composition prescribed in Table 1. Product analysis tolerances shall conform to the Product Analysis Tolerances shown in ASTM A 781/A 781M. When residual element chemical content is of interest to the purchaser, S54 may be considered.

Table 1—Chemical Requirements

Grade (UNS No.)[a]	Composition, percent Carbon,[b] Max	Manganese,[b] Max	Silicon, Max	Sulfur, Max	Phosphorus, Max
Grade N-1 (J02500)	0.25	0.75	0.80	0.06	0.05
Grade N-2 (J03500)	0.35	0.60	0.80	0.06	0.05
Grade U-415-205 [60-30] (J02500)	0.25	0.75	0.80	0.06	0.05
Grade 415-205 [60-30] (J03000)	0.30	0.60	0.80	0.06	0.05
Grade 450-240 [65-35] (J03001)	0.30	0.70	0.80	0.06	0.05
Grade 485-250 [70-36] (J03501)	0.35	0.70	0.80	0.06	0.05
Grade 485-275 [70-40] (J02501)	0.25	1.20	0.80	0.06	0.05

[a] Specify Class 1 or Class 2 in addition to grade designation. (See Section 9.2.)

[b] For each reduction of 0.01 percent carbon below the maximum specified, an increase of 0.04 percent manganese above the maximum specified will be permitted to a maximum of 1.40 percent for Grade 485-275 [70-40] and 1.00 percent for the other grades.

7. TENSILE PROPERTIES

7.1. Except for Grades N-1 and N-2, one tension test shall be performed on each heat, and the mechanical properties thus determined shall conform to the requirements specified in Table 2. The tension test shall be performed in accordance with T 244.

Table 2—Tensile Requirements

Grade [a]	Tensile Strength, Min, MPa [ksi]	Yield Strength, Min, MPa [ksi]	Elongation in 50 mm [2 in.], Min, percent[b]	Reduction of Area, Min, percent
Grade U-415-205 [60-30]	415 [60]	205 [30]	22	30
Grade 415-205 [60-30]	415 [60]	205 [30]	24	35
Grade 450-240 [65-35]	450 [65]	240 [35]	24	35
Grade 485-250 [70-36]	485 [70]	250 [36]	22	30
Grade 485-275 [70-40][c]	485 [70]	275 [40]	22	30

[a] Specify Class 1 or Class 2 in addition to grade designation. (See Section 9.2.)

[b] When ICI test bars are used in tensile testing as provided for in this specification, the gauge length to reduced section diameter ratio shall be 4:1.

[c] Grade 485-275 [70-40] may be used to meet the requirement of Grade 485-250 [70-36], when agreed upon between the manufacturer and the purchaser.

7.2. Test bars shall be poured in special blocks similar to those shown in Figure 1 of ASTM A 781/A 781M and from the same heat as the casting represented.

7.3. Test coupons may be cut from the heat-treated (if required) castings or cast integrally with the castings at the producer's option.

7.4. The test bars for heat-treated castings shall be heat-treated in production furnaces to the same procedure as the castings they represent. When specified by the purchaser, the test bars shall be heat-treated with the castings.

7.5. Test specimens shall be machined to the form and dimensions shown in Figure 4 of T 244, with the ends machined to fit the grips on the tensile testing machine to be used. Suggested types of ends for standard round tension test specimens are shown in Figure 5 of T 244.

7.6. If any specimen is machined improperly or if flaws are revealed by machining or during testing, the specimen may be discarded and another substituted from the same heat.

7.7. When this specification is applied to investment castings, test coupons and tension test specimens shall be obtained and prepared as directed in S3.2 of ASTM A 732/A 732M. Test coupons shall be heat-treated as prescribed in Section 7.4.

8. RETESTS

8.1. If the results of the mechanical tests for any heat, lot, or casting do not conform to the requirements specified, retests are permitted as outlined in T 244. At the manufacturer’s option, castings may be reheat-treated and retested. When castings are reheat-treated, they may not be reaustenitized more than three times without the approval of the purchaser. Testing after reheat treatment shall consist of the full number of specimens taken from locations complying with the specification or order.

9. REWORK AND RETREATMENT

9.1. All welds shall be inspected to the same quality standards as were used to inspect the casting.

9.2. If postweld heat-treatment is required, Class 1 must be specified along with the grade, and the welds to be heat-treated must be defined. If postweld heat-treatment is not required, Class 2 must be specified along with the grade.

10. KEYWORDS

10.1. Castings; general applications; steel.

SUPPLEMENTARY REQUIREMENTS

A list of standardized supplementary requirements for use at the option of the purchaser is described in ASTM A 781/A 781M. Those which are considered suitable for use with this specification are listed below by title only. Additional supplementary requirements suitable for use with this specification at the option of the purchaser are described below. One or more of the supplementary requirements indicated below may be included in the purchaser’s order or contract. When so included, a supplementary requirement shall have the same force as if it were in the body of the specification. Supplementary requirements' details not fully described shall be agreed upon between the purchaser and the supplier, but shall not negate any of the requirements in the body of the specification.

S1. MAGNETIC PARTICLE EXAMINATION

S2. RADIOGRAPHIC EXAMINATION

S3. LIQUID PENETRANT EXAMINATION

S4. ULTRASONIC EXAMINATION

S6. CERTIFICATION

S8. MARKING

S9. CHARPY IMPACT TEST

S10. HARDNESS TEST

S12. TEST REPORT

S13. UNSPECIFIED ELEMENTS

S14. TENSION TEST FROM CASTINGS

S51. PERMISSIBLE VARIATIONS IN DIMENSIONAL TOLERANCES FOR CASTINGS MADE FROM MOUNTED PATTERNS

S51.1. Tolerances for commercial steel castings (Section S51.1.1) made from mounted patterns and the surfaces that are not to be machined shall be in accordance with Table 3. Metal match plate patterns and precise molding methods can produce closer tolerances than the values shown in Table 3. Complex casting designs may require permissible variations different from those listed in Table 3.

S51.1.1. The term "commercial castings" does not cover castings requiring special fixtures for gauging, or finishing castings by grinding to special tolerance gauges beyond the normal requirements as listed in Table 3.

Table 3—Normally Expected Deviation of Linear Casting Dimensions from Design Dimensions

Blueprint Dimensions, mm [in.]	Tolerances, mm [in.]	
Up to 75 [3], incl	+3 [+$^4/_{32}$]	–2 [–$^3/_{32}$]
Over 75 to 175 [3 to 7], incl	+4 [+$^5/_{32}$]	–3 [–$^4/_{32}$]
Over 175 to 500 [7 to 20], incl	+5 [+$^6/_{32}$]	–4 [–$^5/_{32}$]
Over 500 to 2500 [20 to 100], incl	+6 [+$^8/_{32}$]	–5 [–$^6/_{32}$]

S52. GATE AND RISER PROJECTIONS FOR CASTINGS MADE FROM MOUNTED PATTERNS

S52.1. Castings shall have gates and risers removed in a manner such that no riser or gate stub projects or a depression is made beyond or below the casting design contour in an amount that would exceed the values given in Table 4.

Table 4—Gate and Riser Projection Tolerances

Riser or Gate, Max Dimension, mm [in.]	Max Projection, mm [in.]	Max Depression, mm [in.]
Up to 100 [4], incl	3 [$^1/_8$]	3 [$^1/_8$]
Over 100 to 200 [4 to 8], incl	6 [$^1/_4$]	3 [$^1/_8$]
Over 200 to 500 [8 to 20], incl	10 [$^3/_8$]	3 [$^1/_8$]
Over 500 to 750 [20 to 30], incl	13 [$^1/_2$]	6 [$^1/_4$]
Over 750 [30]	19 [$^3/_4$]	6 [$^1/_4$]

S53. MASS DEVIATION FOR CASTINGS MADE FROM MOUNTED PATTERNS

S53.1. The allowable deviations from the average casting mass are shown in Table 5.

Table 5—Allowable Deviation[a] from Average Casting Mass

Casting Mass, kg [lb]	Positive Deviation, percent	Negative Deviation, percent
Up to 45 [100], incl	8.0	8.0
Over 45 to 230 [100 to 500], incl	6.5	5.0
Over 230 to 4540 [500 to 10000], incl	5.0	3.0
Over 4540 [10000]	3.0	2.5

[a] Deviations do not apply to mass as calculated from a design drawing.

S54. CHEMICAL ANALYSIS FOR RESIDUAL ELEMENTS

S54.1. The manufacturer shall determine the percentage of elements specified as follows, using procedures specified in ASTM A 781/A 781M. The chemical analysis thus determined shall conform to the following requirements:

Copper, max, percent	0.50
Nickel, max, percent	0.50
Molybdenum, max, percent	0.25
Chromium, max, percent	0.50

S54.2. Total content of these residual elements, maximum percent 1.00.

Standard Specification for

Gray Iron Castings

AASHTO Designation: M 105-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Gray Iron Castings

AASHTO Designation: M 105-09

1. SCOPE

1.1. This specification covers gray iron castings intended for general engineering use where tensile strength is a major consideration. Castings are classified on the basis of the tensile strength of the iron in cast test bars.

1.1.1. This specification subordinates chemical composition to tensile strength.

1.2. Castings produced to this specification are graded on the basis of minimum tensile strength obtained in special test coupons designed to standardize cooling rate. The tensile strength developed in certain casting sections may vary from test coupon values. (See Appendix X1.2.)

1.3. The values stated in SI units are to be regarded as the standard.

1.4. AASHTO M 306 may be specified for drainage structure castings such as frames, grates, rings, and covers for inlets, manholes, and other structures if loading requirements exceed normal highway loading or if more restrictive dimensional tolerances are required.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 306, Drainage, Sewer, Utility, and Related Castings
- T 68M/T 68, Tension Testing of Metallic Materials (Discontinued)

2.2. *ASTM Standards*:

- A 644, Standard Terminology Relating to Iron Castings
- A 48, Standard Specification for Gray Iron Castings
- E 8/E 8M, Standard Test Methods for Tension Testing of Metallic Materials

2.3. *Military Standard*:

- MIL-STD-129, Marking for Shipment and Storage[1]

2.4. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)[1]

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *manufacturer*—a producing foundry/facility where iron is melted and poured into molds.

3.1.2. *supplier*—an agent, representative, or organization that provides castings that it did not manufacture.

3.1.3. *purchaser*—the end user of the casting.

3.2. The preceding terms and definitions are specific to this specification. ASTM A 644 contains other terms and definitions relating to gray iron castings.

4. CLASSIFICATION

4.1. Castings ordered and produced in accordance with this specification are classified into a number of grades based on the properties of cast test bars (Table 1). Each class is designated by a number followed by a letter. The number indicates the minimum tensile strength of the cast test bar, and the letter indicates the size of the test bar. Examples of proper designations are as follows:

- Gray Iron Castings, M 105, Class 30B
- Gray Iron Castings, M 105, Class 40C

5. ORDERING INFORMATION

5.1. Orders for material to this specification shall include the following information:

5.1.1. AASHTO designation number and year of issue;

5.1.2. Class of iron required (Section 4.1 and Table 1);

5.1.3. The size of the cast test bar (letter classification—A, B, C, or S) that best represents the thickness of the controlling section of the casting (Table 3);

5.1.4. The tension test specimen (B or C) to be machined from test bar C (Section 11.3, Table 2, and Figure 2);

5.1.5. The tension test specimen to be machined from test bar S (Section 11.4, Table 2, and Figure 2);

5.1.6. Lot size (Section 14);

5.1.7. Special requirements (Section 7);

5.1.8. Saving tested specimens or unbroken test bars (Section 16.4); and

5.1.9. Special preparation for delivery (Section 18).

6. TENSILE REQUIREMENTS

6.1. Test bars representing castings conforming to this specification shall meet the requirements for tensile strength as described in Table 1.

Table 1—Requirements for Tensile Strength of Gray Cast Irons in Cast Test Bars

Class	Tensile Strength, Min, MPa [ksi]	Nominal Test Bar, Dia, mm [in.]	Class	Tensile Strength, Min, MPa [ksi]	Nominal Test Bar, Dia, mm [in.]
No. 20A	138 [20]	22.4 [0.88]	No. 45A	310 [45]	22.4 [0.88]
No. 20B		30.5 [1.2]	No. 45B		30.5 [1.2]
No. 20C		50.8 [2.0]	No. 45C		50.8 [2.0]
No. 20S		Bar S[a]	No. 45S		Bar S[a]
No. 25A	172 [25]	22.4 [0.88]	No. 50A	345 [50]	22.4 [0.88]
No. 25B		30.5 [1.2]	No. 50B		30.5 [1.2]
No. 25C		50.8 [2.0]	No. 50C		50.8 [2.0]
No. 25S		Bar S[a]	No. 50S		Bar S[a]
No. 30A	207 [30]	22.4 [0.88]	No. 55A	379 [55]	22.4 [0.88]
No. 30B		30.5 [1.2]	No. 55B		30.5 [1.2]
No. 30C		50.8 [2.0]	No. 55C		50.8 [2.0]
No. 30S		Bar S[a]	No. 55S		Bar S[a]
No. 35A	241 [35]	22.4 [0.88]	No. 60A	414 [60]	22.4 [0.88]
No. 35B		30.5 [1.2]	No. 60B		30.5 [1.2]
No. 35C		50.8 [2.0]	No. 60C		50.8 [2.0]
No. 35S		Bar S[a]	No. 60S		Bar S[a]
No. 40A	276 [40]	22.4 [0.88]			
No. 40B		30.5 [1.2]			
No. 40C		50.8 [2.0]			
No. 40S		Bar S[a]			

[a] All dimensions of test bar S shall be as agreed upon between the manufacturer and the purchaser.

7. SPECIAL REQUIREMENTS

7.1. When agreed upon in writing between the manufacturer and the purchaser, it may be necessary for the castings to meet special requirements regarding hardness, chemical composition, microstructure, pressure tightness, radiographic soundness, dimensions, surface finish, etc.

8. DIMENSIONAL REQUIREMENTS

8.1. The castings shall conform to the dimensions or drawings furnished by the purchaser, or, if there are no drawings, to the dimensions predicted by the pattern equipment supplied by the purchaser.

9. WORKMANSHIP AND FINISH

9.1. The surface of the casting shall be free of adhering sand, scale, cracks, and hot tears, as determined by visual examination.

9.2. No repairing by plugging or welding of any kind shall be permitted unless written permission is granted by the purchaser.

10. CAST TEST BARS

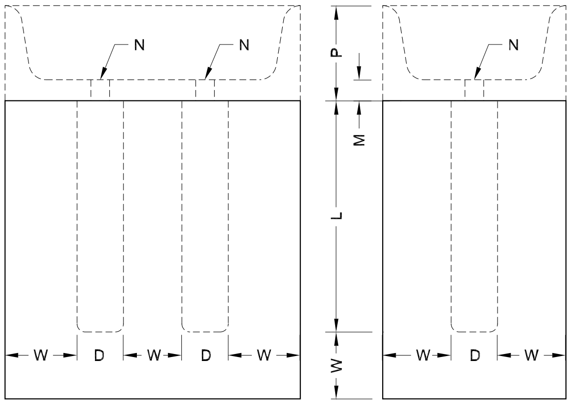
10.1. Test bars shall be poured from the same lot as the castings they represent, and shall have dimensions as shown in Table 2. Allowance may be made for reasonable pattern draft within the tolerances shown in Table 2. Test bars A, B, and C are all standard test bars in the form of simple cylinders. Test bar S is special and is intended for use where the standard bars are not satisfactory.

Table 2—Diameters and Lengths of Cast Test Bars

	As-Cast Diameter, mm [in.]			Length, mm [in.]	
Test Bar	Nominal (Mid-Length)	Min (Bottom)	Max (Top)	Min (Specified)	Max (Recommended)
A	22.4 [0.88]	21.6 [0.85]	24.4 [0.96]	125 [5.0]	150 [6.0]
B	30.5 [1.20]	29.0 [1.14]	33.5 [1.32]	150 [6.0]	230 [9.0]
C	50.8 [2.00]	48.3 [1.90]	53.3 [2.10]	175 [7.0]	255 [10.0]
S[a]					

[a] All dimensions of test bar S shall be as agreed upon by the manufacturer and the purchaser.

10.2. The separately cast test bars shall be cast in dried, baked, or chemically bonded molds made mainly of an aggregate of siliceous sand with appropriate binders. The average grain size of the sand shall approximate that of the sand in which the castings are poured. Molds for the test bars shall be approximately at room temperature when poured. More than one test bar may be cast in a single mold, but each bar in the mold shall be surrounded by a thickness of sand that is not less than the diameter of the bar. A suitable design for a separately cast test bar mold is shown in Figure 1.



	Required Features		Optional Features
1.	Material—Aggregate of dry siliceous sand.	1.	Number of test bars in a single mold—Two suggested.
2.	Position—Bars vertical.	2.	Design of pouring cup.
3.	*L*—See Table 3.	3.	*P*—50 mm (2 in.), suggested.
4.	*D*—See Table 3.	4.	*N*—8 mm ($^{5}/_{16}$ in.) in diameter, suggested.
5.	*W*—Not less than diameter, *D*.	5.	*M* = 1.5 *N*, suggested.

Figure 1—Suitable Design and Dimensions for Mold for Separately Cast Cylindrical Tension Test Bars for Gray Iron

10.3. Test bars that are intended to represent castings that are cooled in the mold to less than 480ºC (900ºF), before shakeout, shall be cooled in their molds to a temperature less than 480ºC (900ºF). Then they may be cooled in still air to room temperature.

10.4. Test bars that are intended to represent castings that are hotter than 480ºC (900ºF) when shaken out of their molds shall be cooled as described in Section 10.3 or (by agreement between the manufacturer and the purchaser) may be shaken out of their molds at approximately the same temperature as the castings they represent.

10.5. When castings are stress-relieved, annealed, or otherwise heat-treated, test bars shall receive the same thermal treatment and shall be treated adjacent to the castings they represent.

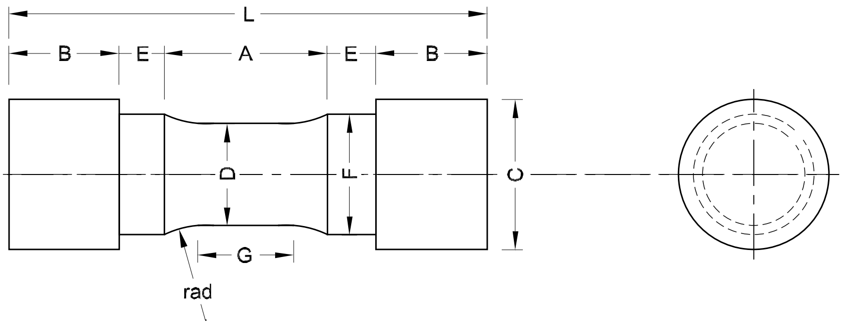
Note 1—The intent of these provisions is as follows: to prohibit the casting of test bars in molds of metal, graphite, zircon, lightweight aggregates, or other materials which would affect significantly the tensile strength of the iron; to prohibit control of tensile strength of the test bars by manipulation of the grain size of the sand; and to prohibit the casting of test bars in molds preheated substantially above room temperature.

Table 3—Cast Test Bars for Use When a Specific Correlation Has Not Been Established Between the Test Bar and the Casting

Thickness of the Wall of the Controlling Section of the Casting, mm (in.)	Test Bar
Under 6 (0.25)	S
6 to 12 (0.25 to 0.50)	A
13 to 25 (0.51 to 1.00)	B
26 to 50 (1.01 to 2)	C
Over 50 (2)	S

11. TENSION TEST SPECIMENS

11.1. *For Test Bar A*—the tension test specimen A, as shown in Figure 2, shall be machined concentric with the axis of the test bar.



Dimensions, mm (in.)	Tension Test, Specimen A	Tension Test, Specimen B	Tension Test, Specimen C
G—Length of parallel, min	13 (0.50)	19 (0.75)	32 (1.25)
D—Diameter	12.7 ± 0.25 (0.500 ± 0.010)	19.1 ± 0.4 (0.750 ± 0.015)	31.7 ± 0.050 (1.25 ± 0.025)
R—Radius of fillet, min	25 (1)	25 (1)	50 (2)
A—Length of reduced section, min	32 ($1^1/_4$)	38 ($1^1/_2$)	57 ($2^1/_4$)
L—Overall length, min	95 ($3^3/_4$)	100 (4)	160 ($6^3/_8$)
C—Dia of end section, approx	22.2 ($^7/_8$)	31.8 ($1^1/_4$)	47 ($1^7/_8$)
E—Length of shoulder, min	6 ($^1/_4$)	6 ($^1/_4$)	8 ($^5/_{16}$)
F—Dia of shoulder	16 ± 0.5 ($^5/_8$ ± $^1/_{64}$)	25 ± 0.5 ($^5/_{16}$ ± $^1/_{64}$)	36 ± 0.5 ($1^7/_{16}$ ± $^1/_{64}$)
B—Length of end section	[a]	[a]	[a]

[a] Optional to fit holders on testing machine. If threaded, root diameter shall not be less than dimension, *F*.

Figure 2—Tension Test Specimens

11.2. *For Test Bar B*—the tension test specimen B, as shown in Figure 2, shall be machined concentric with the axis of the test bar.

11.3. *For Test Bar C*—tension test specimens B or C, as shown in Figure 2, shall be machined concentric with the axis of the test bar. Unless the size of the tension test specimen to be machined from test bar C is specified in writing by the purchaser, the decision whether to use tension test specimen B or C shall be made by the manufacturer of the castings.

11.4. *For Test Bar S*—the nature and dimensions of the tension test specimen shall be determined by agreement between the manufacturer and the purchaser.

12. TENSION TEST

12.1. Tension test specimens shall fit the holders of the testing machine in such a way that the load shall be axial.

12.2. The elapsed time from the beginning of loading in the tension test to the instant of fracture shall be not less than 15 seconds for test specimen A and not less than 20 seconds for specimens B and C.

13. NUMBER OF TESTS AND RETESTS

13.1. The tension test shall be conducted in accordance with T 68.

13.2. One tension test shall be performed on each lot and shall conform to the tensile requirements specified.

13.3. If the results of a valid test fail to conform to the requirements of this specification, two retests shall be made. If either retest fails to meet the specification requirements, the castings represented by these test specimens shall be rejected. A valid test is one wherein the specimen has been properly prepared and appears to be sound and on which the approved test procedure has been followed.

13.4. If sufficient cast test pieces are not available, the manufacturer shall have the option of removing a test specimen from a location of representative casting, as agreed upon between the manufacturer and purchaser.

13.5. If the first test results indicate that a heat-treatment is needed to meet the test requirements, the entire lot of castings and the representative test specimens shall be heat-treated together. Testing shall proceed in accordance with Sections 13.1 through 13.4.

13.6. If, after testing, a test specimen shows evidence of a defect, the results of the test may be invalidated and another test made on a specimen from the same lot.

14. SAMPLING

14.1. A lot shall consist of one of the following:

14.1.1. All the metal poured from a single heating in a batch type melting furnace.

14.1.2. All the metal from two or more batch type melting furnaces poured into a single ladle or a single casting.

14.1.3. All the metal poured from a continuous melting furnace for a given period of time between changes in charge, processing conditions, or aim-for chemistry, or 4 hours, whichever is the shorter period.

The purchaser may agree to extend the four-hour time period to eight hours if the manufacturer can demonstrate sufficient process control to warrant such an extension.

14.1.4. One ladle of iron having a mass of more than 910 kg (2000 lb).

14.2. When an individual casting is poured from more than one ladle of iron, or when the iron for that casting is melted in more than one melting unit or from a different melt or a different type of charge in the same melting unit, or both, the iron from each melting unit, melt, or type of charge shall be considered a different lot.

14.3. When more than one lot of iron is used to pour a single casting, the iron in each lot must conform to this specification.

14.4. When an individual casting is poured with iron melted in more than one melting unit or from more than one melt or type of charge in the same melting unit, and when the irons from the different sources are mixed together thoroughly in a ladle before the casting is poured, the mixed iron in that ladle may be considered a lot.

15. INSPECTION

15.1. Unless otherwise specified in the contract or purchase order, the supplier/manufacturer shall be responsible for carrying out all the tests and inspections required by this specification, using purchaser approved reliable facilities, and shall maintain complete records of all such tests and inspections. Such records shall be available for review by the purchaser.

Two separate and alternative bases of acceptance are permitted. If the producing foundry is located within the United States of America, and operates in accordance with an acceptable Quality System approved by the purchaser, all castings must adhere to the inspection criteria listed in Section 15.1.1. If the producing foundry is not located within the United States of America, or if the producing foundry is located within the United States of America and it is not operating in accordance with an acceptable Quality System approved by the purchaser, all castings must adhere to the inspection criteria listed in Section 15.1.2.

15.1.1. *Acceptance on the Basis of Separately Cast Test Bars*—Before supplying any castings to a purchaser, the manufacturer must first submit to the purchaser for acceptance, documentation that a Quality System is in place to ensure material compliance. Thereafter, acceptability of the castings produced in accordance with this specification shall be by certification of the results of material tests conducted on separately cast test bars, and by inspection of the finished castings for freedom from defects. The manufacturer shall provide certification that the test bars furnished for the testing represent the castings furnished for the order. If there are more than three test bar failures in one calendar year, the producing facility shall immediately report the three failing test results to the purchaser and shall discontinue supplying product. In order for the producing foundry to resume supplying product, documentation that a new Quality System is in place to ensure material compliance must be submitted to and accepted by the purchaser. The purchaser shall also have the option of allowing production under Section 15.1.2.

15.1.2. *Acceptance on the Basis of Cast-On Test Bars*—A test bar for determining the class of iron shall be cast on each member at a place where it can be easily broken off with a breakage pattern remaining on the member. Test bars are only to be removed after receipt of permission from the purchaser. Test bars shall be of sufficient size to produce a machined test specimen complying with the dimensional requirements for a Type B test bar as shown in Table 2. For lots of 15 or fewer, 30 percent of the test bars selected at random from castings shall be tested by the supplier/manufacturer. For lots of 16 to 100, 10 percent or a minimum of 5 test bars, whichever is greater, selected at random from castings shall be tested by the supplier/manufacturer. For lots greater than 100, a minimum of 10 percent of all test bars selected at random from castings shall be tested by the supplier/manufacturer. All test bars shall conform to the strength requirements specified. If any of those test bars fails to conform to the strength requirements herein specified because of surface or internal defects, additional testing shall be performed at the direction of the purchaser. For lots of 15 or fewer, all remaining test bars must be tested. For larger lots, an additional 10 or 10 percent, whichever is greater, of the remaining test bars selected at random from the entire lot must be tested. All test results from this additional testing must conform to the strength requirements of this specification for the lot of castings to be acceptable. Each casting that has a test bar removed from it and evaluated must be inspected for mass (weight) and dimensions by the supplier/manufacturer. If the casting does not conform to the mass (weight) and dimensional requirements, the casting will be rejected. If a casting fails to conform to the mass (weight) or dimensional requirements, all remaining castings shall be inspected and all must conform to the requirements for the lot of castings to be acceptable.

If the purchaser elects to select a casting for verification of test results, the member shall be furnished by the supplier/manufacturer at no cost to the purchaser. All test specimen preparation and testing shall be paid for by the supplier/manufacturer.

16. CERTIFICATION

16.1. When specified by the purchaser's order or contract, a manufacturer's certification or compliance statement that the casting or lot of castings was made, sampled, tested, and inspected in accordance with this specification, including a report of test results signed by an authorized agent of the manufacturer, shall be furnished at the time of shipment, and such certification or compliance statement shall be the basis for acceptance of the casting or lot of castings.

16.2. A signature is not required on the certification or test report. However, the document shall clearly identify the organization submitting the certification and the authorized agent of the manufacturer who certified the test results. Notwithstanding the absence of a signature, the organization submitting the certification is responsible for its content.

16.3. When castings are produced at one manufacturer and labeled with the name of another organization or manufacturer, the original certifications shall be from the foundry that produced the casting. The certification shall clearly identify the manufacturer, the physical location of the facility that produced the casting, and the organization the castings were produced for. The document shall clearly identify the authorized agent for the manufacturer and the authorized agent of the organization the castings were produced for. Any testing conducted by the supplier shall be certified by the supplier and provided to the purchaser.

16.4. All test results as required by this specification shall be maintained by the manufacturer for seven years and shall be made available to the purchaser upon request. All unbroken test bars shall be stored and maintained by the manufacturer or supplier for a minimum of three years and shall be made available to the purchaser upon request.

16.5. Records of casting certifications issued by the manufacturer shall be maintained by the manufacturer for seven years and shall be made available to the purchaser upon request.

17. PRODUCT MARKING

17.1. When the size of the casting permits, each individual casting shall be identified by the following: name of the manufacturer, country of manufacture, AASHTO or ASTM designation, class by number followed by a letter indicating the minimum tensile strength and size of test bar, heat identification and cast date (MM/DD/YY), casting lettering as required by the purchaser, and the markings as required to meet federal requirements.

17.2. If iron for the casting is melted and poured at one foundry and labeled with the name of another organization, manufacturer, or foundry, the casting shall include the name of the producing foundry and the organization the casting is produced for. The name of the producing foundry shall be cast onto the casting with lettering of equal size and in close proximity to the name of the organization the casting is produced for. This lettering shall be cast so that the producing foundry and the organization the casting is produced for can be easily identified from the same side of the casting. The casting shall also include all markings listed in Section 17.1.

18. PREPARATION FOR DELIVERY

18.1. Unless otherwise stated in the contract or order, the cleaning, preservation, and packing of castings for shipment shall be in accordance with the manufacturer's commercial practice. Packaging and marking shall also be adequate to identify the contents and to ensure acceptance and safe delivery by the carrier for the mode of transportation employed.

18.2. *U.S. Government Procurement*—When specified in the contract or purchase order, marking for shipment shall be in accordance with the requirements of Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military activities.

19. KEYWORDS

19.1. Gray iron castings.

APPENDIX

(Nonmandatory Information)

X1. MECHANICAL PROPERTIES OF CASTINGS

X1.1. The mechanical properties of iron castings are influenced by the cooling rate during and after solidification, by chemical composition (particularly carbon equivalent), by the design of the casting, by the design and nature of the mold, by the location and effectiveness of gates and risers, and by certain other factors.

X1.2. The cooling rate in the mold, and, hence, the properties developed in any particular section are influenced by the presence of cores; chills and chaplets; changes in section thickness; and the existence of bosses, projections, and intersections, such as junctions of ribs and bosses. Because of the complexity of the interactions of these factors, no precise quantitative relationship can be stated between the properties of the iron in various locations of the same casting or between the properties of a casting and those of a test specimen cast from the same iron. When such a relationship is important and must be known for a specification application, it may be determined by appropriate experimentation.

X1.3. Gray iron castings in Classes 20, 25, 30, and 35 are characterized by excellent machinability, high damping capacity, low modulus of elasticity, and comparative ease of manufacture.

X1.3.1. Castings in Classes 40, 45, 50, 55, and 60 are usually more difficult to machine, have lower damping capacity, a higher modulus of elasticity, and are more difficult to manufacture.

X1.4. When reliable information is unavailable on the relationship between properties in a casting and those in a separately cast test specimen, and where experimentation would be unfeasible, the size of the test casting should be selected so as to approximate the thickness of the main or controlling section of the casting.

X1.5. If iron castings are welded (Section 9.2), the microstructure of the iron is usually altered, particularly in the vicinity of the weldment. Therefore, the properties of the casting may be adversely affected by welding. Where practical, appropriate post weld heat-treatment may reduce this effect of welding.

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[1] Available from Standardization Documents Order Desk, Bldg. 4 Section D, Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

Standard Specification for

Bronze Castings for Bridges and Turntables

AASHTO Designation: M 107-09
ASTM Designation: B 22-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Bronze Castings for Bridges and Turntables

AASHTO Designation: M 107-09
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AASHTO M 107-09 is identical to ASTM B 22-08.

Standard Specification for

Wrought Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Use

AASHTO Designation: M 108-09
ASTM Designation: B 100-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Wrought Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Use

AASHTO Designation: M 108-09
ASTM Designation: B 100-08

AASHTO M 108-09 is identical to ASTM B 100-08.

Standard Specification for

Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products

AASHTO Designation: M 111M/M 111-09
ASTM Designation: A 123/A 123M-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Specification for

Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products

AASHTO Designation: M 111M/M 111-09
ASTM Designation: A 123/A 123M-08

1. SCOPE

1.1. This specification covers the requirements for zinc coating (galvanizing) by the hot-dip process on iron and steel products made from rolled, pressed and forged shapes, castings, plates, bars, and strips.

1.2. This specification covers both unfabricated products and fabricated products, for example, assembled steel products, structural steel fabrications, large tubes already bent or welded before galvanizing, and wire work fabricated from uncoated steel wire. This specification also covers steel forgings and iron castings incorporated into pieces fabricated before galvanizing or which are too large to be centrifuged (or otherwise handled to remove excess galvanizing bath metal).

Note 1—This specification covers those products previously addressed in M 111-80, ASTM A 123-78, and ASTM A 386-78.

1.3. This specification does not apply to wire, pipe, tube, or steel sheet which is galvanized on specialized or continuous lines, or to steel less than 0.76 mm [22 gauge (0.0299 in.)] thick.

1.4. The galvanizing of hardware items that are to be centrifuged or otherwise handled to remove excess zinc (such as bolts and similar threaded fasteners; castings; and rolled, pressed, and forged items) shall be in accordance with M 232M/M 232.

1.5. Fabricated reinforcing steel bar assemblies are covered by the present specification. The galvanizing of separate reinforcing steel bars shall be in accordance with ASTM A 767/A 767M.

1.6. This specification is applicable to orders in either SI units (as M 111M) or inch-pound units (as M 111). SI units and inch-pound units are not necessarily exact equivalents. Within the text of this specification and where appropriate, inch-pound units are shown in brackets. Each system shall be used independently of the other without combining values in any way. In the case of orders in SI units, all testing and inspection shall be done using the metric equivalent of the test or inspection method as appropriate. In the case of orders in SI units, such shall be stated to the galvanizer when the order is placed.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 120, Zinc
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *ASTM Standards*:

- A 47/A 47M, Standard Specification for Ferritic Malleable Iron Castings
- A 143/A 143M, Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
- A 384/A 384M, Standard Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies
- A 385, Standard Practice for Providing High-Quality Zinc Coatings (Hot-Dip)
- A 767/A 767M, Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement [4]
- A 780, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- A 902, Standard Terminology Relating to Metallic Coated Steel Products
- B 487, Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section
- B 602, Standard Test Method for Attribute Sampling of Metallic and Inorganic Coatings
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. The following terms and definitions are specific to this specification. ASTM A 902 contains other terms and definitions relating to metallic-coated steel products.

3.2. *Definitions of Terms Specific to This Standard*:

3.2.1. *average coating thickness, n*—the average of three specimen coating thicknesses.

3.2.2. *black, adj*—denotes the condition of not galvanized or otherwise coated. For purposes of this specification, the word “black” does not refer to the color or condition of surface, or to a surface deposit or contamination.

3.2.3. *coating thickness grade, n*—the numerical value from Table 1 at the intersection of a material category and a thickness range.

Table 1—Minimum Average Coating Thickness Grade by Material Category

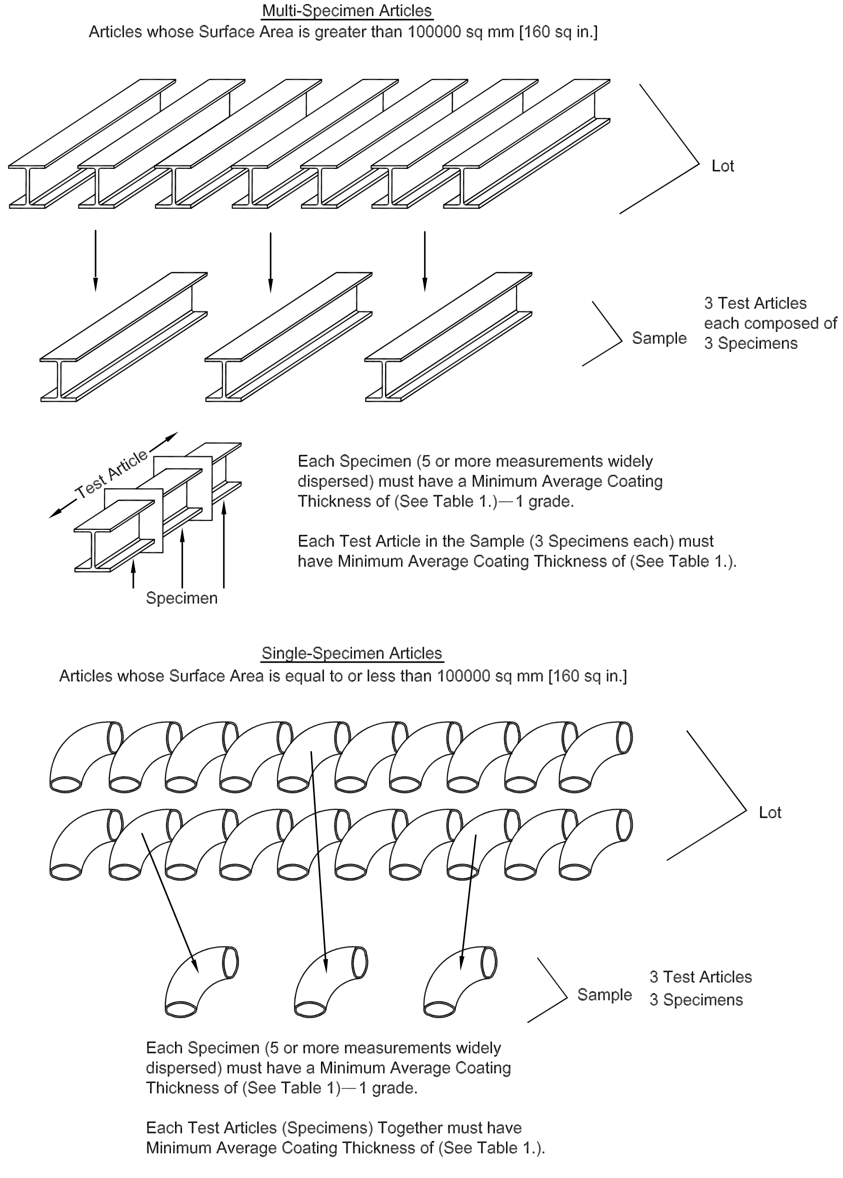
Material Category	All Specimens Tested, Steel Thickness Range (Measured), mm [in.]				
	<1.6 [<$^1/_{16}$]	1.6 to <3.2 [$^1/_{16}$ to <$^1/_8$]	3.2 to 4.8 [$^1/_8$ to $^3/_{16}$]	>4.8 to <6.4 [>$^3/_{16}$ to <$^1/_4$]	≥6.4 [≥$^1/_4$]
Structural Shapes and Plate	45	65	75	85	100
Strip and Bar	45	65	75	85	100
Pipe and Tubing	45	45	75	75	75
Wire	35	50	60	65	80
Reinforcing Bar	—	—	—	—	100

3.2.4. *gross dross inclusions*, *n*—the iron/zinc intermetallics present in a galvanized coating in a form other than finely dispersed pimples.

3.2.4.1. D*iscussion*—These inclusions would create an exposed steel spot if they were removed from the coating. These inclusions are raised surfaces and are easily knocked off through contact with lifting straps or chains, tools, fixtures, or other galvanized parts.

3.2.5. *material category, n*—the general class or type of material or process of manufacture, or both, that nominally describes a unit of product, or from which a unit of product is made. For example, bar grating belongs to the category "strip," handrail belongs to category "pipe," etc.

3.2.6. *multi-specimen article, n*—a unit of product the surface area of which is greater than 100,000 mm^2 [160 in.^{2}]. For thickness testing purposes, articles with surface area greater than 100,000 mm^2 [160 in.^{2}] are subdivided into three continuous local sections, nominally equal in surface area, each of which constitutes a specimen. In the case of any such local section containing more than one material category or steel thickness range as delineated in Table 1, that section will contain more than one specimen. (See Figure 1.)



Each Specimen (5 or more measurements widely dispersed) must have a Minimum Average Coating Thickness of (See Table 1.)—1 grade.

Each Test Article in the Sample (3 Specimens each) must have Minimum Average Coating Thickness of (See Table 1.).

Each Specimen (5 or more measurements widely dispersed) must have a Minimum Average Coating Thickness of (See Table 1)—1 grade.

Each Test Articles (Specimens) Together must have Minimum Average Coating Thickness of (See Table 1.).

Figure 1—Single- and Multi-Specimen Articles

3.2.7. *sample, n*—a collection of individual units of product from a single lot selected in accordance with Section 7, and intended to represent that lot for acceptance. If a sample is taken as representing the lot for acceptance, the sample shall be taken at random from the lot without regard to the perceived quality or appearance of any individual unit in the lot being sampled. The sample consists of one or more test articles.

3.2.8. *single-specimen article, n*—a unit of product the surface area of which is equal to or less than 100,000 mm^2 [160 in.^{2}] or that is centrifuged or otherwise similarly handled in the galvanizing process to remove excess galvanizing bath metal (free zinc). For thickness testing purposes, the entire surface area of each unit of product constitutes a specimen. In the case of any such article containing more than one material category or steel thickness range as delineated in Table 1, that article will contain more than one specimen. (See Figure 1.)

3.2.9. *specimen, n*—the surface of an individual test article or a portion of a test article upon which thickness measurements are to be performed, which is a member of a lot or a member of a sample representing that lot. For magnetic thickness measurements, specimen excludes any area of the surface which is subject to processes (such as, flame cutting, machining, threading, etc.) that can be expected to result in surface conditions not representative of the general surface condition of the test article, or is disqualified by the measurement method. The minimum average coating thickness grade for any specimen shall be one coating grade below that required for the appropriate material category and thickness in Table 1. For a unit of product with surface area equal to or less than 100,000 mm^2 [160 $in.^2$], the entire surface area of each test article constitutes a specimen. In the case of an article containing more than one material category or steel thickness range as delineated in Table 1, that article will contain more than one specimen, as appropriate. (See Figure 1.)

3.2.10. *specimen coating thickness, n*—the average thickness from no fewer than five test measurements on a specimen, when each measurement location is selected to provide the widest dispersion (in all applicable directions) of locations for the steel category of the test article within the confines of the specimen volume.

3.2.11. *test article, n*—an individual unit of product that is a member of the sample and that is examined for conformance to a part of this specification.

4. ORDERING INFORMATION

4.1. Orders for coatings provided under this specification shall include the following:

4.1.1. Quantity (number of pieces to be galvanized) and total mass;

4.1.2. Description (type and size of products) and mass;

4.1.3. AASHTO specification designation and year of issue;

4.1.4. Material identification (Section 5.1) and surface condition or contamination;

4.1.5. Sampling plan, if different from Section 7.3;

4.1.6. Special test requirements (Section 8.1);

4.1.7. Special requirements (special stacking, heavier coating mass, etc.); and

4.1.8. Tagging or piece identification method.

5. MATERIALS AND MANUFACTURE

5.1. *Steel or Iron*—The specification, grade, or designation and type and degree of surface contamination of the iron or steel in articles to be galvanized shall be supplied by the purchaser to the hot-dip galvanizer prior to galvanizing.

Note 2—The presence in steels and weld metal, in certain percentages, of some elements such as silicon, carbon, and phosphorus tends to accelerate the growth of the zinc-iron alloy layer so that the coating may have a matte finish with little or no outer zinc layer. The galvanizer has only limited control over this condition. The mass, shape, and amount of cold working of the product being galvanized may also affect this condition. ASTM A 385 provides guidance on steel selection and discusses the effects of various elements in steel compositions (for example, silicon) that influence coating mass and appearance.

5.2. *Fabrication*—The design and fabrication of the product to be galvanized are the responsibilities of the designer and the fabricator. ASTM A 143, ASTM A 384, and ASTM A 385 provide guidance for steel fabrication for optimum hot-dip galvanizing and shall be complied with in both design and fabrication. Consultation among the designer, fabricator, and galvanizer at appropriate stages in the design and fabrication process will reduce future problems.

5.3. *Castings*—The composition and heat treatment of iron and steel castings shall conform to specifications designated by the purchaser. Some types of castings have been known to show potential problems with predisposition to being embrittled during the normal thermal cycle of hot-dip galvanizing. It is the responsibility of the purchaser to heat-treat or otherwise allow for the possibility of such embrittling phenomena. The requirements for malleable iron castings to be galvanized shall be as stated in ASTM A 47.

5.4. *Zinc*—The zinc used in the galvanizing bath shall conform to M 120. If a zinc alloy is used as the primary feed to the galvanizing bath, then the base material used to make that alloy shall conform to M 120.

5.5. *Bath Composition*—The molten metal in the working volume of the galvanizing bath shall contain not less than an average value of 98.0 percent zinc by mass.

Note 3—The galvanizer may choose to add trace amounts of certain elements (for example, aluminum, nickel, and tin) to the zinc bath to help in the processing of certain reactive steels or to enhance the cosmetic appearance of the finished product. The use of these trace elements is permitted provided that the bulk chemistry of the galvanizing bath is at least 98.0 percent zinc by mass. The elements can be added to the galvanizing bath as part of a prealloyed zinc feed, or they can be added to the bath by the galvanizer using a master feed alloy.

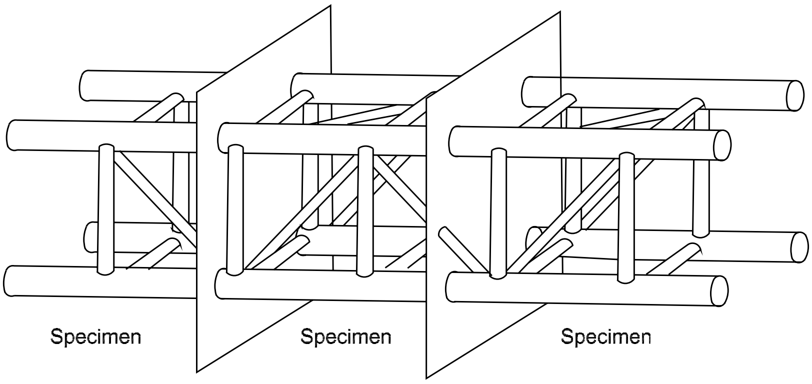
6. COATING PROPERTIES

6.1. *Coating Thickness*—The average thickness of coating for all specimens tested shall conform to the requirements of Table 1 for the categories and thicknesses of the material being galvanized. Minimum average thickness of coating for any individual specimen is one coating grade less that that required in Table 1. Where products consisting of various material thicknesses or categories are galvanized, the coating thickness grades for each thickness range and material category of material shall be as shown in Table 1. In the case of orders in SI units, the values in Table 1 shall be applicable as metric units in micrometers. In the case of orders in inch-pound units, the measured value shall be converted to coating grade units by the use of Table 2. The specification of coating thicknesses heavier than those required by Table 1 shall be subject to mutual agreement between the galvanizer and purchaser. (Figure 2 is a graphic representation of the sampling and specimen delineation steps, and Figure 3 is a graphic representation of the coating thickness inspection steps.)

Table 2—Coating Thickness Grade[a]

Coating Grade	µm	g/m^2	mils	oz/ft^2
35	35	245	1.4	0.8
45	45	320	1.8	1.0
50	50	355	2.0	1.2
55	55	390	2.2	1.3
60	60	425	2.4	1.4
65	65	460	2.6	1.5
75	75	530	3.0	1.7
80	80	565	3.1	1.9
85	85	600	3.3	2.0
100	100	705	3.9	2.3

[a] The values in micrometers (µm) are based on the Coating Grade. The other values are based on conversions using the following formulas: mils = µm × 0.03937; oz/ft^2 = µm × 0.02316; g/m^2 = µm × 7.067.



Note: Each specimen comprises nominally one-third of the total surface area of the article. A minimum of five measurements should be made within the volume of each specimen, as widely dispersed within that volume as is practical so as to represent, as much as possible, the general coating thickness within that specimen volume.

Figure 2—Articles Made of Many Components

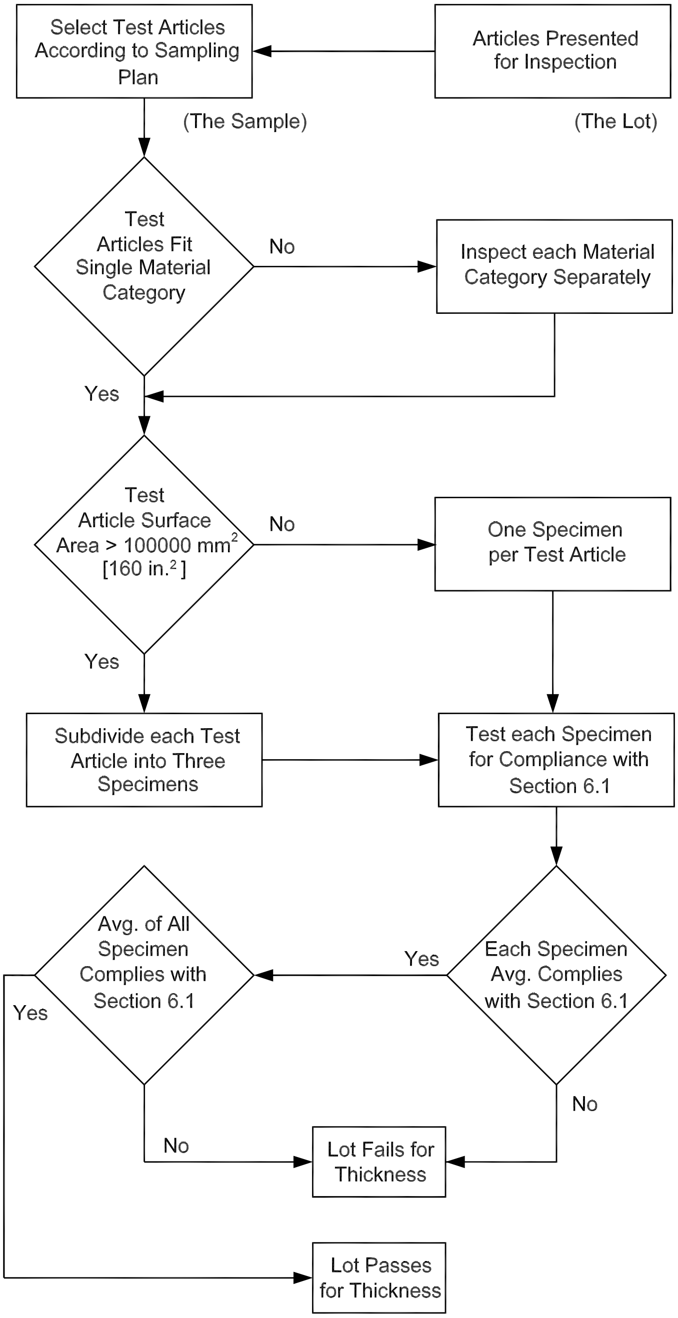


Figure 3—Coating Thickness Inspection Steps

6.1.1. For articles with surface area greater than 100,000 mm^2 [160 $in.^2$] (multi-specimen articles), each test article in the sample must meet the appropriate minimum average coating thickness grade requirements of Table 1, and each specimen coating thickness grade comprising that overall average for each test article shall average not less than one coating grade below that required in Table 1.

6.1.2. For articles with surface area equal to or less than 100,000 mm^2 [160 $in.^2$] (single-specimen articles), the average of all test articles in the sample must meet the appropriate minimum average coating thickness grade requirements of Table 1, and for each test article, its specimen coating thickness shall be not less than one coating grade below that required in Table 1.

6.1.3. No individual measurement, or cluster of measurements at the same general location, on a test specimen shall be cause for rejection under the coating thickness requirements of this specification provided that when those measurements are averaged with the other dispersed measurements to determine the specimen coating thickness grade for that specimen, the requirements of Sections 6.1.1 or 6.1.2, as appropriate, are met.

Note 4—The coating thickness grades in Table 1 represent the minimum value obtainable with a high level of confidence for the ranges typically found in each material category. While most coating thicknesses will be in excess of those values, some materials in each category may be less reactive (for example, because of chemistry or surface condition) than other materials of the steel category spectrum. Therefore, some articles may have a coating grade at or close to the minimum requirement shown in Table 1. In such cases, the precision and accuracy of the coating thickness measuring technique should be taken into consideration when rejecting such articles for coating thickness below that required by this specification. Purchasers desiring a guarantee of heavier coatings than the minimum thicknesses shown herein should use the special requirements (Section 4.1.6) to specify coating thickness grades higher than those shown in Table 1. In addition, the purchaser should anticipate the need for test batches or extra preparation steps or both, such as blasting before galvanizing or other methods, to attempt to reach the higher requirements with consistency. Some higher-than-standard thicknesses may be impractical or unattainable.

6.2. *Finish*—The coating shall be continuous (except as provided below), and as reasonably smooth and uniform in thickness as the mass, size, shape of the item, and necessary handling of the item during the dipping and draining operations as the galvanizing kettle will permit. Except for local excess coating thickness which would interfere with the use of the product or make it dangerous to handle (edge tears or spikes), rejection for nonuniform coating shall be made only for plainly visible excess coating not related to design factors such as holes, joints, or special drainage problems. (See Note 6.) Since surface smoothness is a relative term, minor roughness that does not interfere with the intended use of the product, or roughness that is related to the as-received (ungalvanized) surface condition, steel chemistry, or steel reactivity to zinc shall not be grounds for rejection. (See Note 7.) Surface conditions related to deficiencies related to design, detailing, or fabrication as addressed by ASTM A 385 shall not be grounds for rejection. The zinc coating on threaded components of articles galvanized under this specification shall conform to that required in M 232M/M 232. Surfaces that remain uncoated after galvanizing shall be renovated in accordance with the methods in ASTM A 780, unless directed by the purchaser to leave the uncoated areas untreated for subsequent renovation by the purchaser.

6.2.1. Each area subject to renovation shall be 25 mm [1 in.] or less in its narrowest dimension.

6.2.2. The total area subject to renovation on each article shall be no more than one-half of 1 percent of the accessible surface area to be coated on that article or 26 mm^2 per kg [36 $in.^2$ per ton] of piece mass, whichever is less.

Note 5—Inaccessible surface areas are those that cannot be reached for appropriate surface preparation and application of repair materials as described in ASTM A 780. Such inaccessible areas, for example, would be the internal surfaces of certain tanks, poles, pipes, tubes, and so forth.

6.2.3. The thickness of renovation shall be that required by the thickness grade for the appropriate material category and thickness range in Table 1 in accordance with the requirements of

Section 6.1, except that for renovation using zinc paints, the thickness of renovation shall be 50 percent higher than that required by Table 1, but not greater than 100 μm [4.0 mils].

6.2.4. When areas requiring renovation exceed the criteria previously provided or are inaccessible for repair, the coating shall be rejected.

Note 6—The requirements for the finish of a galvanized product address themselves to a visual type of inspection. They do not address the matter of measured coating thickness variations that can be encountered because of different steels or different thicknesses of a given steel being used in an assembly.

Note 7—Items that are prepared for galvanizing by abrasive cleaning will generally develop a thicker coating with a moderately rougher surface.

6.3. *Threaded Components in Assemblies*—The zinc coating on external threads shall not be subjected to a cutting, rolling, or finishing tool operation, unless specifically authorized by the purchaser. Internal threads are not prohibited from being tapped or retapped after galvanizing. Coatings shall conform to the requirements of M 232M/M 232.

6.4. *Appearance*—Upon shipment from the galvanizing facility, galvanized articles shall be free from uncoated areas, blisters, flux deposits, and gross dross inclusions. Lumps, projections, globules, or heavy deposits of zinc which will interfere with the intended use of the material will not be permitted. Plain holes of 12.5-mm [$^1/_2$-in.] diameter or more shall be clean and reasonably free from excess zinc. Marks in the zinc coating caused by tongs or other items used in handling the article during the galvanizing operation shall not be cause for rejection unless such marks have exposed the base metal and the bare metal areas have exceeded allowable maximums from Sections 6.2.1 and 6.2.2. The pieces shall be handled so that after galvanizing they will not freeze together on cooling.

Note 8—Depending upon product design or material thickness or both, filming or excess zinc buildup in plain holes of less than 12.5-mm [$^1/_2$-in.] diameter may occur that requires additional work to make the holes usable as intended.

6.5. *Adherence*—The zinc coating shall withstand handling consistent with the nature and thickness of the coating and the normal use of the article without peeling or flaking.

Note 9—Although some material may be formed after galvanizing, in general the zinc coating on the articles covered by this specification is too heavy to permit severe bending without damaging the coating.

7. SAMPLING

7.1. Sampling of each lot shall be performed for conformance with the requirements of this specification.

7.2. A lot is a unit of production or shipment from which a sample is taken for testing. Unless otherwise agreed upon between the galvanizer and the purchaser, or established within this specification, the lot shall be as follows: for testing at a galvanizer’s facility, a lot is one or more articles of the same type and size comprising a single order or a single delivery load, whichever is the smaller, or any number of articles identified as a lot by the galvanizer, when these have been galvanized within a single production shift and in the same bath. For test by purchaser after delivery, the lot consists of the single order or the single delivery load, whichever is the smaller, unless the lot identity, established in accordance with the above, is maintained and clearly indicated in the shipment by the galvanizer.

7.3. The method of selection and number of test specimens shall be agreed upon between the galvanizer and the purchaser. Otherwise, the test specimens shall be selected at random from each lot. In this case, the minimum number of specimens from each lot shall be as follows:

Number of Pieces in Lot	Number of Specimens
3 or less	all
4 to 500	3
501 to 1200	5
1201 to 3200	8
3201 to 10000	13
10001 and over	20

Note 10—Where a number of identical items are to be galvanized, a statistical sampling plan may be desired. Such a plan is contained in ASTM B 602, which addresses sampling procedures for the inspection of electrodeposited metallic coatings and related finishes. If ASTM B 602 is used, the level of sampling shall be agreed upon between the galvanizer and the purchaser at the time the coating order is placed.

7.4. A test specimen which fails to conform to a requirement of this specification shall not be used to determine the conformance to other requirements.

8. TEST METHODS

8.1. *Test Requirements*—The following tests shall be conducted to ensure that the zinc coating is being furnished in accordance with this specification. The specifying of tests for adhesion and embrittlement shall be subject to mutual agreement between the galvanizer and purchaser. Visual inspection of the coating shall be made for compliance with the requirements.

8.2. *Thickness of Coating Test*—The thickness of coating is determined by one or more of the three methods described as follows:

8.2.1. *Magnetic Thickness Measurements*—The thickness of the coating shall be determined by magnetic thickness gauge measurements in accordance with ASTM E 376 unless the methods described in Sections 8.2.2, 8.2.3, or 8.2.4 are used. For each specimen (as described in Section 3.2.9), five or more measurements shall be made at points widely dispersed throughout the volume occupied by the specimen so as to represent, as much as practical, the entire surface area of the test specimen. The average of five or more measurements thus made for each specimen is the specimen coating thickness.

8.2.1.1. For articles with surface area greater than 100,000 mm^2 [160 $in.^2$] (multi-specimen articles as described in Section 3.2.6), the average of the three specimen coating thickness grades comprising each test article is the average coating thickness for that test article. A specimen must be evaluated for each steel category and material thickness within the requirements for each specimen of the test article.

8.2.1.2. For articles with surface area equal to or less than 100,000 mm^2 [160 $in.^2$] (single-specimen articles as described in Section 3.2.8), the average of all specimen coating thickness grades is the average coating thickness for the sample.

8.2.1.3. In the case of threaded components, the thickness of coating shall be made on a portion of the article that does not include any threads.

8.2.1.4. The use of magnetic measurement methods is appropriate for larger articles and is appropriate for smaller articles when there is sufficient flat surface area for the probe tip to sit flat on the surface using ASTM E 376.

8.2.2. *Stripping Method*—The average mass of coating shall be determined by stripping a test article, a specimen removed from a test article, or a group of test articles in the case of very small items such as nails, etc., in accordance with T 65M/T 65 unless the methods described in Sections 8.2.1, 8.2.3, or 8.2.4 are used. The mass of coating per unit area thus determined is converted to equivalent coating thickness values in accordance with Table 2 (rounding up or down as appropriate). The thickness of coating thus obtained is the test article coating thickness, or in the case of a specimen removed from a test article, is the specimen average coating thickness.

8.2.2.1. The "stripping method" is a destructive test and is appropriate for single-specimen articles, but is not practical for multi-specimen articles.

8.2.3. *Determining the Mass Before and After Galvanizing*—The average mass of coating shall be determined by using the mass of the articles before and after galvanizing, subtracting the first mass from the second and dividing the result by the surface area unless the methods described in Sections 8.2.1, 8.2.2, or 8.2.4 are used. The first mass shall be determined after pickling and drying and the second after cooling to ambient temperature. The mass of coating per unit area thus determined is converted to equivalent coating thickness values according to Table 2 (rounding up or down as appropriate). The thickness of coating thus obtained is the test article coating thickness.

8.2.3.1. The "determining the mass before and after" method is appropriate for single-specimen articles, but is not practical for multi-specimen articles.

Note 11—Neither the "stripping method" nor the "determining the mass before and after" method takes into account the mass of iron reacted from the article that is incorporated into the coating. Thus, the methods may underestimate coating mass (and therefore the calculated thickness) by up to 10 percent. The accuracy of both methods will be influenced by the accuracy with which the surface area of the articles tested can be determined.

8.2.4. *Microscopy*—The thickness of coating shall be determined by cross-sectional and optical measurement in accordance with ASTM B 487 unless the methods described in Sections 8.2.1, 8.2.2, or 8.2.3 are used. The thickness thus determined is a point value. No fewer than five such measurements shall be made at locations on the test article and shall be as widely dispersed as practical, so as to be representative of the whole surface of the test article. The average of no fewer than five such measurements is the specimen coating thickness.

8.2.4.1. The microscopy method is a destructive test and is appropriate for single-specimen articles, but is not practical for multi-specimen articles.

8.2.5. *Referee Method*—In the event of a dispute over thickness of coating measurements, the dispute shall be resolved as follows:

8.2.5.1. For multi-specimen articles, a new sample shall be taken randomly from the lot of material, which has twice the number of test articles as the sample which failed to conform to this specification. If the lot size is such that the sample size cannot be doubled, then the sample size shall be as previous, but the number of widely dispersed sites at which measurements were made shall be doubled, and these sites will constitute the new sample. This new sample shall be measured using magnetic thickness gauges which have been calibrated for accuracy against reference material thickness standards. If the lot is found to be nonconforming by the new sample, the galvanizer has the right to sort the lot for conforming articles by individual test, to regalvanize nonconforming articles, or to renovate the nonconforming articles in accordance with Section 6.2.

8.2.5.2. For single-specimen articles, a new sample shall be taken randomly from the lot of material, which has twice the number of test articles as the sample which failed to conform to this specification. The test method for the new sample shall be selected by mutual agreement between the purchaser and galvanizer. If the lot is found to be nonconforming by the new sample, the galvanizer has the right to sort the lot for conforming articles by individual test, to regalvanize nonconforming articles, or to renovate the nonconforming articles in accordance with Section 6.2.

8.3. *Adhesion*—Determine adhesion of the zinc coating to the surface of the base metal by cutting or prying with the point of a stout knife applied with considerable pressure in a manner tending to remove a portion of the coating. The adhesion shall be considered inadequate if the coating flakes off in the form of a layer of the coating so as to expose the base metal in advance of the knife point. Do not use testing carried out at edges or corners (points of lowest coating adhesion) to determine adhesion of the coating. Likewise, do not use removal of small particles of the coating by paring or whittling to determine failure.

8.4. *Embrittlement*—Test for embrittlement shall be made in accordance with ASTM A 143. These tests shall not be required unless strong evidence of embrittlement is present.

9. INSPECTION, REJECTION, AND RETEST

9.1. *Inspection by the Galvanizer*—It is the responsibility of the galvanizer to ensure compliance with this specification. This shall be achieved by an in-plant inspection program designed to maintain the coating thickness, finish, and appearance within the requirements of this specification unless the inspection is performed in accordance with Section 9.2.

9.2. *Inspection by the Purchaser*—The purchaser shall accept or reject material by inspection either through the galvanizer’s inspector, the purchaser’s inspector, or an independent inspector. The inspector representing the purchaser shall have access at all times to those areas of the galvanizer’s facility which concern the application of the zinc coating to the material ordered while work on the contract of the purchaser is being performed. The galvanizer shall afford the inspector all reasonable facilities to satisfy him that the zinc coating is being furnished in accordance with this specification.

9.3. *Location*—The material shall be inspected at the galvanizer’s plant prior to shipment. However, by agreement, the purchaser is not prohibited from making tests that govern the acceptance or rejection of the materials in his own laboratory or elsewhere.

9.4. *Reinspection*—When inspection of materials to determine conformity with visual requirements of Section 6.2 warrants rejection of a lot, the galvanizer is not prohibited from sorting the lot and submitting it once again for acceptance after he has removed any nonconforming articles and replaced them with conforming articles.

9.5. The sampling plan that was used when the lot was first inspected shall be used for resampling of a sorted lot. By mutual agreement, the galvanizer is not prohibited from submitting the lot remaining after sorting and removing nonconforming articles without replacement of the nonconforming articles. In such case the now-smaller lot shall be treated as a new lot for purposes of inspection and acceptance.

9.6. Materials that have been rejected for reasons other than embrittlement are not prohibited from being stripped and regalvanized and again submitted for inspection and test at which time they shall conform to the requirements of this specification.

10. CERTIFICATION

10.1. When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each lot have been either tested or inspected as directed by this specification and the requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished.

11. KEYWORDS

11.1. Coatings, zinc; galvanized coatings; steel products, metallic coated; zinc coatings, steel products.

Standard Specification for

Zinc

AASHTO Designation: M 120-08
ASTM Designation: B 6-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Zinc

AASHTO Designation: M 120-08
ASTM Designation: B 6-07

AASHTO M 120-08 is identical to ASTM B 6-07.

Standard Specification for

Copper Sheet, Strip, Plate, and Rolled Bar

AASHTO Designation: M 138M/M 138-08
ASTM Designation: B 152/B 152M-06a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Copper Sheet, Strip, Plate, and Rolled Bar

AASHTO Designation: M 138M/M 138-08
ASTM Designation: B 152/B 152M-06a

AASHTO M 138M/M 138-08 is identical to ASTM B 152/B 152M-06a.

Standard Specification for

General Requirements for Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use

AASHTO Designation: M 160M/M 160-08
ASTM Designation: A 6/A 6M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

General Requirements for Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use

AASHTO Designation: M 160M/M 160-08
ASTM Designation: A 6/A 6M-07

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM A 6/A 6M-07 for the information formerly contained in this standard.

Standard Specification for

Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application

AASHTO Designation: M 163M/M 163-07[1]
ASTM Designation: A 743/A 743M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application

AASHTO Designation: M 163M/M 163-07[1]
ASTM Designation: A 743/A 743M-06

1. SCOPE

1.1. This specification covers iron-chromium and iron-chromium-nickel alloy castings for general corrosion-resistant application. The grades covered by this specification represent types of alloy castings suitable for broad ranges of application, which are intended for a wide variety of corrosion environments.

Note 1—For alloy castings for severe corrosion-resistant service, reference should be made to M 285M/M 285. For general heat-resistant alloy castings, reference should be made to ASTM A 297/A 297M. For nickel alloy castings for corrosion-resistant service, reference should be made to ASTM A 494/A 494M.

1.2. The values stated either in SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification. SI units are applicable for material ordered to M 163M and inch-pound units are applicable for material ordered to M 163.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 285M/M 285, Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 262, Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
- A 297/A 297M, Standard Specification for Steel Castings, Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application
- A 447/A 447M, Standard Specification for Steel Castings, Chromium-Nickel-Iron Alloy (25-12 Class), for High-Temperature Service
- A 494/A 494M, Standard Specification for Castings, Nickel and Nickel Alloy

- A 781/A 781M, Standard Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use
- A 890/A 890M, Standard Specification for Castings, Iron-Chromium-Nickel-Molybdenum Corrosion-Resistant, Duplex (Austenitic/Ferritic) for General Application
- A 957, Standard Specification for Investment Castings, Steel and Alloy, Common Requirements, for General Industrial Use
- E 527, Standard Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

3. GENERAL CONDITIONS FOR DELIVERY

3.1. Except for investment castings, castings furnished to this specification shall conform to the requirements of ASTM A 781/A 781M including any supplementary requirements that are indicated on the purchase order. Failure to comply with the general requirements of ASTM A 781/A 781M constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and ASTM A 781/A 781M, this specification shall prevail.

3.2. Steel investment castings furnished to this specification shall conform to the requirements of ASTM A 957, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of ASTM A 957 constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and ASTM A 957, this specification shall prevail.

4. ORDERING INFORMATION

4.1. Orders for material to this specification should include the following, as required, to describe the material adequately:

4.1.1. Description of the casting by pattern number or drawing,

4.1.2. Grade,

4.1.3. Heat-treatment,

4.1.4. Options in the specification,

4.1.5. Whether castings are to be produced using the investment casting process, and

4.1.6. Supplementary requirements desired, including the standards of acceptance.

5. PROCESS

5.1. The steel shall be made by the electric furnace process with or without separate refining such as argon-oxygen decarburization (AOD).

6. HEAT-TREATMENT

6.1. Castings shall be heat-treated in accordance with the requirements in Table 1.

Note 2—Proper heat-treatment of these alloys is usually necessary to enhance corrosion resistance and, in some cases, to meet mechanical properties. Minimum heat-treat temperatures are specified; however, it is sometimes necessary to heat-treat at higher temperatures, hold for some minimum time at temperature, and then rapidly cool the castings in order to enhance the corrosion resistance and meet mechanical properties.

Table 1—Heat-Treatment Requirements

Grade	Heat-Treatment
CF8, CG3M, CG8M, CG12, CF20, CF8M, CF8C, CF16F, CF16Fa	Heat to 1040˚C [1900˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CH10, CH20, CE30, CK20	Heat to 1093˚C [2000˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CA15, CA15M, CA40, CA40F	(1) Heat to 955˚C [1750˚F] minimum, air cool and temper at 595˚C [1100˚F] minimum, or (2) Anneal at 790˚C [1450˚F] minimum.
CB30, CC50	(1) Heat to 790˚C [1450˚F] minimum, and air cool, or (2) Heat to 790˚C [1450˚F] minimum, and furnace cool.
CF3, CF3M, CF3MN	(1) Heat to 1040˚C [1900˚F] minimum, hold for sufficient time to heat casting to temperature, and cool rapidly. (2) As cast if corrosion resistance is acceptable.
CN3M	Heat to 1175˚C [2150˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CN3MN	Heat to 1150˚C [2100˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CN7M, CG6MMN	Heat to 1120˚C [2050˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CN7MS	Heat to 1150˚C [2100˚F] minimum, 1180˚C [2150˚F] maximum, hold for sufficient time (two-hour minimum) to heat casting to temperature and quench in water.
CA6NM	Heat to 1010˚C [1850˚F] minimum, air cool to 95˚C [200˚F] or lower prior to any optional intermediate temper and prior to the final temper. The final temper shall be between 565˚C [1050˚F] and 620˚C [1150˚F].
CA6N	Heat to 1040˚C [1900˚F], air cool, reheat to 815˚C [1500˚F], air cool, and age at 425˚C [800˚F], holding at each temperature sufficient time to heat casting uniformly to temperature.
CF10SMnN	Heat to 1065˚C [1950˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CA28MWV	(1) Heat to 1025–1050˚C [1875–1925˚F], quench in air or oil and temper at 620˚C [1150˚F] minimum, or (2) Anneal at 760˚C [1400˚F] minimum.
CK3MCuN	Heat to 1150˚C [2100˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CK35MN	Heat to 1150–1200˚C [2100–2190˚F], hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CB6	Heat between 980˚C [1800˚F] and 1050˚C [1920˚F], forced air, cool to 50˚C [120˚F] maximum, and temper between 595˚C and 625˚C [1100˚F and 1160˚F].

7. CHEMICAL REQUIREMENTS

7.1. The chemical requirements are shown in Table 2.

Table 2—Chemical Requirements

		Composition, percent													
Grade (UNS)	Type	Carbon, Max	Manganese, Max	Silicon, Max	Phosphorus, Max	Sulfur, Max	Chromium	Nickel	Molybdenum	Columbium	Selenium	Copper	Tungsten, Max	Vanadium, Max	Nitrogen
CF8 (J92600)	19 Chromium, 9 Nickel	0.08	1.50	2.00	0.04	0.04	18.0–21.0	8.0–11.0	—	—	—	—	—	—	—
CG12 (J93001)	22 Chromium, 12 Nickel	0.12	1.50	2.00	0.04	0.04	20.0–23.0	10.0–13.0	—	—	—	—	—	—	—
CF20 (J92602)	19 Chromium, 9 Nickel	0.20	1.50	2.00	0.04	0.04	18.0–21.0	8.0–11.0	—	—	—	—	—	—	—
CF8M (J92900)	19 Chromium, 10 Nickel with Molybdenum	0.08	1.50	2.00	0.04	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	—	—	—	—	—
CF8C (J92710)	19 Chromium, 10 Nickel with Columbium	0.08	1.50	2.00	0.04	0.04	18.0–21.0	9.0–12.0	—	[a]	—	—	—	—	—
CF16F (J92701)	19 Chromium, 9 Nickel, Free Machining	0.16	1.50	2.00	0.17	0.04	18.0–21.0	9.0–12.0	1.50 max	—	0.20–0.35	—	—	—	—
CF16Fa	19 Chromium, 9 Nickel, Free Machining	0.16	1.50	2.00	0.04	0.20–0.40	18.0–21.0	9.0–12.0	0.40–0.80	—	—	—	—	—	—
CH10 (J93401)	25 Chromium, 12 Nickel	0.10	1.50	2.00	0.04	0.04	22.0–26.0	12.0–15.0	—	—	—	—	—	—	—
CH20 (J93402)	25 Chromium, 12 Nickel	0.20	1.50	2.00	0.04	0.04	22.0–26.0	12.0–15.0	—	—	—	—	—	—	—
CK20 (J94202)	25 Chromium, 20 Nickel	0.20	2.00	2.00	0.04	0.04	23.0–27.0	19.0–22.0	—	—	—	—	—	—	—
CE30 (J93423)	29 Chromium, 9 Nickel	0.30	1.50	2.00	0.04	0.04	26.0–30.0	8.0–11.0	—	—	—	—	—	—	—
CA15 (J91150)	12 Chromium	0.15	1.00	1.50	0.04	0.04	11.5–14.0	1.00 max	0.50 max	—	—	—	—	—	—
CA15M (J91151)	12 Chromium	0.15	1.00	0.65	0.040	0.040	11.5–14.0	1.0 max	0.15–1.0	—	—	—	—	—	—
CB30 (J91803)	20 Chromium	0.30	1.00	1.50	0.04	0.04	18.0–21.0	2.00 max	—	—	—	[b]	—	—	—
CC50 (J92615)	28 Chromium	0.50	1.00	1.50	0.04	0.04	26.0–30.0	4.00 max	—	—	—	—	—	—	—
CA40 (J91153)	12 Chromium	0.20–0.40	1.00	1.50	0.04	0.04	11.5–14.0	1.0 max	0.50 max	—	—	—	—	—	—
CA40F (J91154)	12 Chromium, Free Machining	0.20–0.40	1.00	1.50	0.04	0.20–0.40	11.5–14.0	1.0 max	0.50 max	—	—	—	—	—	—
CF3 (J92500)	19 Chromium, 9 Nickel	0.03	1.50	2.00	0.04	0.04	17.0–21.0	8.0–12.0	—	—	—	—	—	—	—

Table 2—*Continued*

Grade (UNS)	Type	Composition, percent													
		Carbon, Max	Manganese, Max	Silicon, Max	Phosphorus, Max	Sulfur, Max	Chromium	Nickel	Molybdenum	Columbium	Selenium	Copper	Tungsten, Max	Vanadium, Max	Nitrogen
CF10SMnN (J92972)	17 Chromium, 8.5 Nickel with Nitrogen	0.10	7.00–9.00	3.50–4.50	0.060	0.030	16.0–18.0	8.0–9.0	—	—	—	—	—	—	0.08–0.18
CF3M (J92800)	19 Chromium, 10 Nickel with Molybdenum	0.03	1.50	1.50	0.04	0.04	17.0–21.0	9.0–13.0	2.0–3.0	—	—	—	—	—	—
CF3MN (J92804)	19 Chromium, 10 Nickel with Molybdenum and Nitrogen	0.03	1.50	1.50	0.040	0.040	17.0–22.0	9.0–13.0	2.0–3.0	—	—	—	—	—	0.10–0.20
CG6MMN (J93790)		0.06	4.00–6.00	1.00	0.04	0.03	20.5–23.5	11.5–13.5	1.50–3.00	0.10–0.30	—	—	—	0.10–0.30	0.20–0.40
CG3M (J92999)	19 Chromium, 11 Nickel with Molybdenum	0.03	1.50	1.50	0.04	0.04	18.0–21.0	9.0–13.0	3.0–4.0	—	—	—	—	—	—
CG8M (J93000)	19 Chromium, 11 Nickel with Molybdenum	0.08	1.50	1.50	0.04	0.04	18.0–21.0	9.0–13.0	3.0–4.0	—	—	—	—	—	—
CN3M (J94652)		0.03	2.0	1.0	0.03	0.03	20.0–22.0	23.0–27.0	4.5–5.5	—	—	—	—	—	—
CN3MN (J94651)	21 Chromium, 24 Nickel with Molybdenum and Nitrogen	0.03	2.00	1.00	0.040	0.010	20.0–22.0	23.5–25.5	6.0–7.0	—	—	0.75 max	—	—	0.18–0.26
CN7M (N08007)	20 Chromium, 29 Nickel with Copper and Molybdenum	0.07	1.50	1.50	0.04	0.04	19.0–22.0	27.5–30.5	2.0–3.0	—	—	3.0–4.0	—	—	—
CN7MS (J94650)	19 Chromium, 24 Nickel with Copper and Molybdenum	0.07	1.00	2.50–3.50	0.04	0.03	18.0–20.0	22.0–25.0	2.5–3.0	—	—	1.5–2.0	—	—	—
CA6NM (J91540)	12 Chromium, 4 Nickel	0.06	1.00	1.00	0.04	0.03	11.5–14.0	3.5–4.5	0.40–1.0	—	—	—	—	—	—
CA6N (J91541)	11 Chromium, 7 Nickel	0.06	0.50	1.00	0.02	0.02	10.5–12.5	6.0–8.0	—	—	—	—	—	—	—
CA28MWV (J91422)	12 Chromium with Molybdenum, Tungsten and Vanadium	0.20–0.28	0.50–1.00	1.0	0.030	0.030	11.0–12.5	0.50–1.00	0.90–1.25	—	—	—	0.90–1.25	0.20–0.30	—
CK3MCuN J93254)	20 Chromium, 18 Nickel with Copper and Molybdenum	0.025	1.20	1.00	0.045	0.010	19.5–20.5	17.5–19.5	6.0–7.0	—	—	0.50–1.0	—	—	0.180–0.240

Table 2—*Continued*

Grade (UNS)	Type	Composition, percent													
		Carbon, Max	Manganese, Max	Silicon, Max	Phosphorus, Max	Sulfur, Max	Chromium	Nickel	Molybdenum	Columbium	Selenium	Copper	Tungsten, Max	Vanadium, Max	Nitrogen
CK35MN	23 Chromium, 21 Nickel with Molybdenum and Nitrogen	0.035	2.00	1.00	0.035	0.020	22.0–24.0	20.0–22.0	6.0–6.8	—	—	0.40	—	—	0.21–0.32
CB6 (J91804)	16 Chromium, 4 Nickel	0.06	1.00	1.00	0.04	0.03	15.5–17.5	3.5–5.5	0.5 max	—	—	—	—	—	—

[a] Grade CF8C shall have a columbium content of not less than eight times the carbon content and not more than 1.0 percent. If a columbium-plus tantalum alloy in the approximate Cb: Ta ratio of 3:1 is used for stabilizing this grade, the total columbium plus tantalum content shall not be less than nine times the carbon content and shall not exceed 1.1 percent.

[b] For grade CB30, a copper content of 0.90 to 1.20 percent is optional.

Note: CD4MCu has been deleted from M 163M/M 163 and added to ASTM A 890/A 890M. CD4MCu may now be supplied and purchased in compliance with ASTM A 890/A 890M. The chemical and mechanical property requirements of CD4MCu were identical in M 163M/M 163 and ASTM A 890/A 890M at the time of removal from M 163M/M 163.

8. REPAIR BY WELDING

8.1. Repair welding of Grade CA28MWV is not permitted unless by agreement between the manufacturer and the purchaser.

8.2. When methods involving high temperature are used in the removal of discontinuities, castings shall be preheated in accordance with Table 3. Weld repairs shall be subject to the same quality standards as are used to inspect the castings.

Table 3—Minimum Preheat Temperatures

Grade	Minimum Preheat Temperature ˚C	Minimum Preheat Temperature ˚F
CA15, CA15M	205	[400]
CA40, CA28MWV	205	[400]
Others	10	[50]

8.3. Postweld heat-treatment, if required, shall be in accordance with Table 1.

8.3.1. The martensitic grades CA6NM, CA15, CA15M, CB6, and CA40 shall be retempered after weld repairing except that local tempering will be permitted if, in the opinion of the manufacturer, furnace heat-treating will be damaging to the finished surface of a machined casting. Heat-treatment, other than tempering, of grades CA6NM, CA15, CA15M, CB6, and CA40 after weld repairing shall be performed only when agreed upon between the manufacturer and the purchaser. Weld repair on Grade CA40F is not recommended because of the risk of local hardening and possible cracking in the heat-affected zone.

8.3.2. Postweld heat-treatment is not required on the other grades of this specification. When postweld heat-treatment is believed necessary for adequate corrosion resistance in the service environment, castings should be ordered in accordance with M 285M/M 285.

9. PRODUCT MARKING

9.1. Castings shall be marked for material identification with the AASHTO specification number (M 163M/M 163) and grade symbol; that is, CF8, CA15, CB30, etc. In addition, the manufacturer's name or identification mark and the pattern number shall be cast or stamped using the low-stress stamps on all castings. Small-size castings may be such that marking must be limited consistent with the available area. The marking of heat numbers on individual castings shall be agreed upon between the manufacturer and the purchaser. Marking shall be in such position as not to injure the usefulness of the casting.

10. KEYWORDS

10.1. Corrosion resistant; iron-chromium; iron-chromium-nickel; steel castings.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall not apply unless specified in the purchase order. A list of standardized supplementary requirements for use at the option of the purchaser is included in ASTM A 781/A 781M. Those that are ordinarily considered suitable for use with this specification are given below. Others enumerated in ASTM A 781/A 781M may be used with this specification upon agreement between the manufacturer and purchaser.

S1. MAGNETIC PARTICLE EXAMINATION

S2. RADIOGRAPHIC EXAMINATION

S3. LIQUID PENETRANT EXAMINATION

S4. ULTRASONIC EXAMINATION

S5. EXAMINATION OF WELD PREPARATION

S6. CERTIFICATION

S7. PRIOR APPROVAL OF MAJOR WELD REPAIRS

S11. INTERGRANULAR CORROSION TEST

S11.1. An intergranular corrosion test shall be performed in accordance with the appropriate practice for the particular grade involved, as listed in ASTM A 262, or as agreed upon with the purchaser. Intergranular corrosion tests on stabilized or 0.03 percent carbon maximum grades (CF3, CF3M, CF8C, and CG3M) shall be made on sensitized specimens. On all other grades of chromium-nickel steels, intergranular corrosion tests shall be made on specimens representative of the as-shipped condition.

S12. TENSION TEST

S12.1. Tensile properties shall be determined from material representing each heat. The bar from which the test specimen is taken shall be heat-treated in production furnaces to the same procedure as the castings it represents. The results shall conform to the requirements specified in Table 4.

Table 4—Tensile Requirements

Grade	Type	Tensile Strength, Min		Yield Strength, Min		Elongation in 50 mm [2 in.], Min, percent[a]	Reduction of Area, Min, percent
		MPa	[ksi]	MPa	[ksi]		
CF8	19 Chromium, 9 Nickel	485[b]	[70][b]	205[b]	[30][b]	35	—
CG12	22 Chromium, 12 Nickel	485	[70]	195	[28]	35	—
CF20	19 Chromium, 9 Nickel	485	[70]	205	[30]	30	—
CF8M	19 Chromium, 10 Nickel with Molybdenum	485	[70]	205	[30]	30	—
CF8C	19 Chromium, 10 Nickel with Columbium	485	[70]	205	[30]	30	—
CF16F and CF16Fa	19 Chromium, 9 Nickel, Free Machining	485	[70]	205	[30]	25	—
CH20 and CH10	25 Chromium, 12 Nickel	485	[70]	205	[30]	30	—
CK20	25 Chromium, 20 Nickel	450	[65]	195	[28]	30	—
CE30	29 Chromium, 9 Nickel	550	[80]	275	[40]	10	—
CA15 and CA15M	12 Chromium	620	[90]	450	[65]	18	30
CB30	20 Chromium	450	[65]	205	[30]	—	—
CC50	28 Chromium	380	[55]	—	—	—	—
CA40	12 Chromium	690	[100]	485	[70]	15	25
CA40F	12 Chromium, Free Machining	690	[100]	485	[70]	12	—
CF3	19 Chromium, 9 Nickel	485	[70]	205	[30]	35	—
CF10SMnN	17 Chromium, 8.5 Nickel with Nitrogen 9 Nickel	585	[85]	290	[42]	30	—
CF3M	19 Chromium, 10 Nickel with Molybdenum	485	[70]	205	[30]	30	—
CF3MN	19 Chromium, 10 Nickel with Molybdenum, and Nitrogen	515	[75]	255	[37]	35	—
CG6MMN	Chromium-Nickel-Manganese-Molybdenum	585	[85]	290	[42]	30	—
CG3M	19 Chromium, 11 Nickel with Molybdenum	515	[75]	240	[35]	25	—
CG8M	19 Chromium, 11 Nickel with Molybdenum	520	[75]	240	[35]	25	—
CN3M		435	[63]	170	[25]	30	—
CN3MN	21 Chromium 24 Nickel with Molybdenum and Nitrogen	550	[80]	260	[38]	35	—
CN7M	20 Chromium, 29 Nickel with Copper and Molybdenum	425	[62]	170	[25]	35	—
CN7MS	19 Chromium, 24 Nickel with Copper and Molybdenum	485	[70]	205	[30]	35	—
CA6NM	12 Chromium, 4 Nickel	755	[110]	550	[80]	15	35
CA6N	11 Chromium, 7 Nickel	965	[140]	930	[135]	15	50
CA28MWV[c]	12 Chromium with Molybdenum, Tungsten, and Vanadium	965	[140]	760	[110]	10	24
CK3MCuN	20 Chromium, 18 Nickel with Copper and Molybdenum	550	[80]	260	[38]	35	—
CK35MN	23 Chromium, 21 Nickel with Molybdenum and Nitrogen	570	[83]	280	[41]	35	—
CB6	16 Chromium, 4 Nickel	790	[115]	580	[85]	16	35

[a] When ICI test bars are used in tensile testing as provided for in this specification, the gauge length to reduced section diameter ratio shall be 4:1.

[b] For low-ferrite or nonmagnetic castings of this grade, the following values shall apply: tensile strength, min, 450 MPa [65 ksi]; yield point, min, 195 MPa [28 ksi].

[c] These mechanical properties apply only when heat-treatment (1) has been used.

S12.2. Test bars shall be poured in separately cast keel blocks similar to Figure 1, Figure 2, or Figure 3 of ASTM A 781/A 781M.

S12.3. Tension test specimens may be cut from heat-treated castings or from as-cast castings if no heat-treatment is specified for the castings, instead of from test bars, when agreed upon between the manufacturer and the purchaser.

S12.4. Test specimens shall be machined to the form and dimensions of the standard round 50-mm [2-in.] gauge length specimen shown in Figure 4 or Figure 5 of T 244 and shall be tested in accordance with T 244.

S12.5. If the results of the mechanical tests for any heat, lot, or casting do not conform to the requirements specified, retests are permitted as outlined in T 244. At the manufacturer's option, castings may be reheat-treated and retested. When castings are reheat-treated, they may not be reaustenitized more than three times without the approval of the purchaser. Testing after reheat-treatment shall consist of the full number of specimens taken from locations complying with the specification or order.

S12.6. If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted from the same heat.

S13. POST WELD HEAT-TREATMENT

S13.1. Weld repairs shall be considered major in the case of a casting which has leaked on hydrostatic test or when the depth of the cavity after preparation for repair exceeds 20 percent of the actual wall thickness or 25 mm [1 in.], whichever is smaller, or when the extent of the cavity exceeds approximately 65 cm^2 [10 in.^2]. All other weld repairs shall be considered minor.

S13.2. The manufacturer shall inform the purchaser of the extent of defects present in the castings as ordered. Before any casting repairs are undertaken, the purchaser shall consider whether removal of the surface defects will compromise the integrity of the casting, and whether sufficient wall thickness is available to prevent hydrostatic leakage or degrade its life cycle. Weld repairs shall be considered major if the size or depth of defects or flaws could result in leakage or rupture when brought to anticipated ranges of pressure or stress, taking into account the fracture toughness of the material at operating temperatures. Whether the defects shall be weld-repaired or not shall be determined by agreement between the purchaser and the manufacturer.

S13.3. Grades CF8, CG3M, CG8M, CG12, CF20, CF8M, CF8C, CF16F, CF16Fa, CH10, CH20, CE30, CK20, CF3, CF3M, CF3MN, CN7M, CN7MS, CN3MN, CB30, CC50, CA6N, and CK3MCuN shall be heat-treated after major weld repairs, but it is not required after minor repairs except by agreement between the manufacturer and the purchaser.

S14. HARDNESS TESTS

S14.1. Brinell tests on non-austenitic grades shall be conducted. Grades CA15, CA15M, CB30, and CC50 shall have a Brinell hardness of 241 HB maximum. Grade CA6NM shall have a Brinell hardness of 285 HB maximum; Grade CA40 and CA40F, 269 HB maximum; and Grade CA28MWV, 302-352 HB, except for the annealed condition, when the Brinell hardness of this grade shall not exceed 269 HB.

S14.2. The location where the Brinell hardness reading is to be taken and the frequency of such Brinell hardness inspection of the castings shall be established by agreement between the manufacturer and the purchaser.

S15. LOW FERRITE IN CF8

S15.1. When low ferrite or nonmagnetic properties are required, the mechanical property requirements and volume fraction of ferrite as determined by S31, ASTM A 890/A 890M, shall be by agreement between the manufacturer and the purchaser.

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[1] Agrees with ASTM A 743/A 743M-06 except for the addition of Section S13.2 to the Supplementary Requirements.

Standard Specification for

High-Strength Bolts for Structural Steel Joints

AASHTO Designation: M 164-05 (2008)
ASTM Designation: A 325-04b

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

High-Strength Bolts for Structural Steel Joints

AASHTO Designation: M 164-05 (2008)
ASTM Designation: A 325-04b

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM A 325-04b for the information formerly contained in this standard.

Standard Specification for

High-Strength Bolts for Structural Steel Joints [Metric]

AASHTO Designation: M 164M-06
ASTM Designation: A 325M-04b

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

High-Strength Bolts for Structural Steel Joints [Metric]

AASHTO Designation: M 164M-06
ASTM Designation: A 325M-04b

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM A 325M-04b for the information formerly contained in this standard.

Standard Specification for

Steel Bars, Carbon and Alloy, Cold-Finished

AASHTO Designation: M 169-09
ASTM Designation: A 108-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Bars, Carbon and Alloy, Cold-Finished

AASHTO Designation: M 169-09
ASTM Designation: A 108-07

1. SCOPE

1.1. This specification covers cold-finished carbon and alloy steel bars produced in straight length and coil to chemical compositions. Cold-finished bars are suitable for heat-treatment, for machining into components, or for use in the as-finished condition as shafting, or in constructional applications, or for other similar purposes (Note 1). Grades of steel are identified by grade numbers or by chemical composition.

Note 1—A guide for the selection of steel bars is contained in ASTM A 400.

1.2. Some end uses may require one or more of the available designations shown under Supplementary Requirements. Supplementary requirements shall apply only when specified individually by the purchaser.

1.3. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 29/A 29M, Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for
- A 304, Standard Specification for Carbon and Alloy Steel Bars Subject to End-Quench Hardenability Requirements
- A 322, Standard Specification for Steel Bars, Alloy, Standard Grades
- A 400, Standard Practice for Steel Bars, Selection Guide, Composition, and Mechanical Properties
- A 510, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel
- A 576, Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality

2.3. *Other Documents*:

- SAE J1086, "Numbering Metals and Alloys" (UNS)[1]
- *SAE Handbook*[1]
- *ISS Bar Steel: Steel Bar Product Guidelines*[2]

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *product tolerance levels*—cold-finished steel bars produced with up to four increasingly tight tolerance levels for the individual product characteristics, dependent on the method of manufacture necessary to meet purchaser-ordered specifications requirements. (Select Product Tolerance Level 1 unless otherwise specified by the purchaser.)

4. ORDERING INFORMATION

4.1. Orders for cold-finished steel bars to this specification should include the following items to adequately describe the material:

4.1.1. Name of material;

4.1.2. AASHTO specification number and date of issue;

4.1.3. Chemical composition grade designation or limits;

4.1.4. Silicon level, if required;

4.1.5. Additional machinability-enhancing elements (see Footnote F to Table 1 of ASTM A 29/A 29M);

4.1.6. Condition (Surface Roughness tolerances listed in Table 7);

4.1.7. Tolerance levels (refer to tolerance levels listed in Tables 1 through 9);

4.1.8. Shape (round, hexagon, square, flat, etc.), size, and length;

4.1.9. Report of heat analysis, if required;

4.1.10. End use;

4.1.11. Additions to the specification and special or supplementary requirements, if required; and

4.1.12. For coiled product, the coil mass, inside diameter, outside diameter, and coil height limitations, when required.

Note 2—A typical ordering description is as follows: Steel Bar, M 169-___; SAE 1117; Coarse Grain; Cold Drawn; 38.10-mm (1.5-in.) diameter round by 3657.61 mm (12.0 feet) long; Heat Analysis Required; Precision Machine Parts.

5. GENERAL REQUIREMENTS

5.1. Material furnished under this specification shall conform to the applicable requirements of the current edition of ASTM A 29/A 29M.

6. MATERIALS AND MANUFACTURE

6.1. *Feedstock*—Cold-finished bars shall be produced from hot-wrought carbon or alloy steel bars (ASTM A 29/A 29M) or from hot-wrought rod designed for cold-finished bars (ASTM A 510).

6.2. *Condition*—The product bars shall be furnished in one of the following conditions as specified by the purchaser:

6.2.1. *Rounds*:

6.2.1.1. Cold drawn;

6.2.1.2. Cold drawn, turned, and polished;

6.2.1.3. Cold drawn, ground, and polished;

6.2.1.4. Cold drawn, turned, ground, and polished;

6.2.1.5. Cold drawn, turned, and ground;

6.2.1.6. Hot wrought, turned, and polished;

6.2.1.7. Hot wrought, turned, ground, and polished;

6.2.1.8. Hot wrought, turned, and ground; or

6.2.1.9. Hot wrought, rough turned.

6.2.2. *Squares, Hexagons:*

6.2.2.1. Cold drawn, or

6.2.2.2. Cold rolled.

6.2.3. *Flats*:

6.2.3.1. Cold drawn; or

6.2.3.2. Cold rolled.

6.2.4. *Special Bars Sections*:

6.2.4.1. Cold drawn, or

6.2.4.2. Cold rolled.

6.3. *Heat-Treatment*:

6.3.1. Unless otherwise specified, the bars shall be furnished as cold finished. Plain carbon steels with a maximum carbon greater than 0.55 percent and alloy steels with a maximum carbon greater than 0.38 percent shall be annealed prior to cold finishing.

6.3.2. The following heat-treatment processes may be performed singularly or in combination:

6.3.2.1. Annealed,

6.3.2.2. Normalized,

6.3.2.3. Stress relieved, or

6.3.2.4. Quenched and tempered.

7. CHEMICAL COMPOSITION

7.1. *Chemical Composition*:

7.1.1. The chemical analysis of the steel shall conform to that specified in ASTM A 29/A 29M for the steel grade ordered or to other limits as may be specified using the standard ranges in ASTM A 29/A 29M.

7.1.2. Steels may be selected from ASTM A 29/A 29M, A 304, A 322, A 576, and A 510; the *SAE Handbook*; or the ISS steel bar products guideline for bar steel.

7.1.3. When a steel cannot be identified by a standard grade number in accordance with Sections 7.1.1 and 7.1.2, the limits for each required element may be specified using the chemical ranges shown in the table “Heat Analysis Chemical Ranges and Limits of Carbon Steel Bars” of ASTM A 29/A 29M.

8. TOLERANCE LEVELS

8.1. *Cold-Finished Bars*—The permissible dimensional variations for cold-finished carbon and alloy steel bars shall not exceed the applicable tolerance levels for limits stated in Tables 1 through 9.

Table 1—Size Tolerances for Level 1 Cold-Finished Carbon Steel Bars, Cold Drawn or Turned and Polished

Size, mm (in.)[a]	Maximum of Carbon Range 0.28% or less	Maximum of Carbon Range over 0.28% to 0.55% incl	Maximum of Carbon Range to 0.55% incl, Stress Relieved or Annealed After Cold Finishing	Maximum of Carbon Range over 0.55% or All Grades Quenched and Tempered or Normalized and Tempered Before Cold Finishing
All tolerances are in millimeters (inches) and are minus.[b]				
Rounds—Cold Drawn[c] to 152.4 mm (6 in.) or Turned and Polished				
To 38.1 ($1^{1}/_{2}$) incl, in coils, or cut lengths	0.051 (0.002)	0.076 (0.003)	0.102 (0.004)	0.127 (0.005)
Over 38.1 ($1^{1}/_{2}$) to 63.50 ($2^{1}/_{2}$) incl	0.076 (0.003)	0.102 (0.004)	0.127 (0.005)	0.152 (0.006)
Over 63.50 ($2^{1}/_{2}$) to 101.60 (4) incl	0.102 (0.004)	0.127 (0.005)	0.152 (0.006)	0.178 (0.007)
Over 101.60 (4) to 152.40 (6) incl	0.127 (0.005)	0.152 (0.006)	0.178 (0.007)	0.203 (0.008)
Over 152.40 (6) to 203.20 (8) incl	0.152 (0.006)	0.178 (0.007)	0.203 (0.008)	0.229 (0.009)
Over 203.20 (8) to 228.60 (9) incl	0.178 (0.007)	0.203 (0.008)	0.229 (0.009)	0.254 (0.010)
Hexagons				
To 19.05 ($^{3}/_{4}$) incl	0.051 (0.002)	0.076 (0.003)	0.102 (0.004)	0.152 (0.006)
Over 19.05 ($^{3}/_{4}$) to 38.10 ($1^{1}/_{2}$) incl	0.076 (0.003)	0.102 (0.004)	0.127 (0.005)	0.178 (0.007)
Over 38.10 ($1^{1}/_{2}$) to 63.50 ($2^{1}/_{2}$) incl	0.102 (0.004)	0.127 (0.005)	0.152 (0.006)	0.203 (0.008)
Over 63.50 ($2^{1}/_{2}$) to 79.38 ($3^{1}/_{8}$) incl	0.127 (0.005)	0.152 (0.006)	0.178 (0.007)	0.229 (0.009)
Over 79.38 ($3^{1}/_{8}$) to 101.60 (4) incl	0.127 (0.005)	0.152 (0.006)	—	—
Squares				
To 19.05 ($^{3}/_{4}$) incl	0.051 (0.002)	0.102 (0.004)	0.127 (0.005)	0.178 (0.007)
Over 19.05 ($^{3}/_{4}$) to 38.10 ($1^{1}/_{2}$) incl	0.076 (0.003)	0.127 (0.005)	0.152 (0.006)	0.203 (0.008)
Over 38.10 ($1^{1}/_{2}$) to 63.50 ($2^{1}/_{2}$) incl	0.102 (0.004)	0.152 (0.006)	0.178 (0.007)	0.229 (0.009)
Over 63.50 ($2^{1}/_{2}$) to 101.60 (4) incl	0.152 (0.006)	0.203 (0.008)	0.229 (0.009)	0.279 (0.011)
Over 101.60 (4) to 127.00 (5) incl	0.254 (0.010)	—	—	—
Over 127.00 (5) to 152.40 (6) incl	0.356 (0.014)	—	—	—
Flats[d]				
Width:				
To 19.05 ($^{3}/_{4}$) incl	0.076 (0.003)	0.102 (0.004)	0.152 (0.006)	0.203 (0.008)
Over 19.05 ($^{3}/_{4}$) to 38.10 ($1^{1}/_{2}$) incl	0.102 (0.004)	0.127 (0.005)	0.203 (0.008)	0.254 (0.010)
Over 38.10 ($1^{1}/_{2}$) to 76.2 (3) incl	0.127 (0.005)	0.152 (0.006)	0.254 (0.010)	0.305 (0.012)
Over 76.2 (3) to 101.60 (4) incl	0.152 (0.006)	0.203 (0.008)	0.279 (0.011)	0.410 (0.016)
Over 101.60 (4) to 152.40 (6) incl	0.203 (0.008)	0.254 (0.010)	0.305 (0.012)	0.508 (0.020)
Over 152.40 (6)	0.330 (0.013)	0.381 (0.015)	—	—

[a] Standard manufacturing practice is shear cut for cold-drawn bars (size limits vary by producer) which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is undesirable, a saw cut end to remove end distortion should be considered.

[b] While size tolerances are usually specified as minus, tolerances may be ordered all plus, or distributed plus and minus, with the sum being equivalent to the tolerances listed.

[c] Maximum allowable deviation in roundness around the circumference of the same cross section of a round cold-drawn bar is $^{1}/_{2}$ the size tolerance range.

[d] Width governs the tolerances for both width and thickness of flats. For example, when the maximum of carbon range is 0.28 percent or less for a flat 50.80 mm (2 in.) wide and 25.40 mm (1 in.) thick, the width tolerance is 0.127 mm (0.005 in.) and the thickness tolerance is the same, namely, 0.127 mm (0.005 in.).

Table 2—Size Tolerances for Level 1 Cold-Finished Alloy Steel Bars, Cold Drawn or Turned and Polished

Size, mm (in.)[a]	Maximum of Carbon Range 0.28% of less	Maximum of Carbon Range over 0.28% to 0.55% incl	Maximum of Carbon Range to 0.55% incl, Stress Relieved or Annealed After Cold Finishing	Maximum of Carbon Range over 0.55% with or without Stress Relieving or Annealing after Cold Finishing. Also, All Carbons, Quenched and Tempered (Heat Treated), or Normalized and Tempered, before Cold Finishing
All tolerances are in millimeters (inches) and are minus.[b]				
Rounds—Cold Drawn[c] to 152.4 mm (6 in.) or Turned and Polished				
To 25.4 (1) incl, in coils	0.051 (0.002)	0.076 (0.003)	0.102 (0.004)	0.127 (0.005)
Cut Lengths:				
To 38.10 ($1^1/_2$) incl	0.076 (0.003)	0.102 (0.004)	0.127 (0.005)	0.152 (0.006)
Over 38.10 ($1^1/_2$) to 63.50 ($2^1/_2$) incl	0.102 (0.004)	0.127 (0.005)	0.152 (0.006)	0.178 (0.007)
Over 63.50 ($2^1/_2$) to 101.60 (4) incl	0.127 (0.005)	0.152 (0.006)	0.178 (0.007)	0.203 (0.008)
Over 101.60 (4) to 152.40 (6) incl	0.152 (0.006)	0.178 (0.007)	0.203 (0.008)	0.229 (0.009)
Over 152.40 (6) to 203.20 (8) incl	0.178 (0.007)	0.203 (0.008)	0.229 (0.009)	0.254 (0.010)
Over 203.20 (8) to 228.60 (9) incl	0.203 (0.008)	0.229 (0.009)	0.254 (0.010)	0.279 (0.011)
Hexagons				
To 19.05 ($^3/_4$) incl	0.076 (0.003)	0.102 (0.004)	0.127 (0.005)	0.178 (0.007)
Over 19.05 ($^3/_4$) to 38.10 ($1^1/_2$) incl	0.102 (0.004)	0.127 (0.005)	0.152 (0.006)	0.203 (0.008)
Over 38.10 ($1^1/_2$) to 63.50 ($2^1/_2$) incl	0.127 (0.005)	0.152 (0.006)	0.178 (0.007)	0.229 (0.009)
Over 63.50 ($2^1/_2$) to 79.38 ($3^1/_8$) incl	0.152 (0.006)	0.178 (0.007)	0.203 (0.008)	0.254 (0.010)
Over 79.38 ($3^1/_8$) to 101.60 (4) incl	0.152 (0.006)	—	—	—
Squares				
To 19.05 ($^3/_4$) incl	0.076 (0.003)	0.127 (0.005)	0.152 (0.006)	0.203(0.008)
Over 19.05 ($^3/_4$) to 38.10 ($1^1/_2$) incl	0.102 (0.004)	0.152 (0.006)	0.178 (0.007)	0.229 (0.009)
Over 38.10 ($1^1/_2$) to 63.50 ($2^1/_2$) incl	0.127 (0.005)	0.178 (0.007)	0.203 (0.008)	0.254 (0.010)
Over 63.50 ($2^1/_2$) to 101.60 (4) incl	0.178 (0.007)	0.229 (0.009)	0.254 (0.010)	0.305 (0.012)
Over 101.60 (4) to 127.00 (5) incl	0.279 (0.011)	—	—	—
Flats[d]				
To 19.05 ($^3/_4$) incl	0.102 (0.004)	0.127 (0.005)	0.178 (0.007)	0.229 (0.009)
Over 19.05 ($^3/_4$) to 38.10 ($1^1/_2$) incl	0.127 (0.005)	0.152 (0.006)	0.229 (0.009)	0.279 (0.011)
Over 38.10 ($1^1/_2$) to 76.20 (3) incl	0.152 (0.006)	0.178 (0.007)	0.279 (0.011)	0.330 (0.013)
Over 76.20 (3) to 101.60 (4) incl	0.178 (0.007)	0.229 (0.009)	0.305 (0.012)	0.432 (0.017)
Over 101.60 (4) to 152.40 (6) incl	0.229 (0.009)	0.279 (0.011)	0.330 (0.013)	0.533 (0.021)
Over 152.40 (6)	0.356 (0.014)	—	—	—

[a] Standard manufacturing practice is shear cut for cold-drawn bars (size limits vary by producer) which can cause end distortion resulting in those portions of the bar being outside the applicable size tolerance. When this end condition is undesirable, a saw cut end to remove end distortion should be considered.

[b] While size tolerances are usually specified as minus, tolerances may be ordered all plus, or distributed plus and minus, with the sum being equivalent to the tolerances listed.

[c] Maximum allowable deviation in roundness around the circumference of the same cross section of a round cold-drawn bar is $^1/_2$ the size tolerance range.

[d] Width governs the tolerances for both width and thickness of flats. For example, when the maximum of carbon range is 0.28 percent or less for a flat 50.80 mm (2 in.) wide and 25.40 mm (1 in.) thick, the width tolerance is 0.127 mm (0.005 in.) and the thickness tolerance is the same, namely, 0.127 mm (0.005 in.).

Table 3—Size Tolerances for Levels 2 and 3 Cold-Finished Round Bars, Cold-Drawn, Ground and Polished, or Turned, Ground, and Polished

Size, mm (in.) Cold Drawn, Ground and Polished[a]	Size, mm (in.) Turned, Ground, and Polished[a]	Tolerances from Specified Size, Minus Only, mm (in.)	
		Level 2	Level 3
To 38.10 ($1^1/_2$) incl	To 38.10 ($1^1/_2$) incl	0.0254 (0.001)	0.0203 (0.0008)
Over 38.10 ($1^1/_2$) to 63.50 ($2^1/_2$) excl	Over 38.10 ($1^1/_2$) to 63.50 ($2^1/_2$) excl	0.0381 (0.0015)	0.033 (0.0013)
63.50 ($2^1/_2$) to 76.20 (3) incl	63.50 ($2^1/_2$) to 76.20 (3) incl	0.0508 (0.002)	0.0381 (0.0015)
Over 76.20 (3) to 101.60 (4) incl	Over 76.20 (3) to 101.60 (4) incl	0.0762 (0.003)	0.0635 (0.0025)
—	Over 101.60 (4) to 152.40 (6) incl	0.1016 (0.004)[b]	0.0762 (0.003)[b]
—	Over 152.40 (6)	0.127 (0.005)[b]	0.1016 (0.004)[b]

[a] Maximum allowable deviation of roundness or ovality tolerances are agreed upon between purchaser and supplier.

[b] For nonresulfurized steels (steels specified to maximum sulfur limits under 0.08 percent) or for steels thermally treated, the tolerance is increased by 0.025 mm (0.001 in.).

Table 4—Straightness Tolerances for Level 1 Cold-Finished Bars[a,b]

Note 3—All grades quenched-and-tempered or normalized and tempered to Brinell 302 maximum before cold finishing; and all grades stress relieved or annealed after cold finishing. Straightness tolerances are not applicable to bars having Brinell hardness exceeding 302.

		Straightness Tolerances, mm (in.) Maximum Deviation from Straightness in Any 3048-mm (10-ft) Portion of the Bar			
		Maximum of Carbon Range, 0.28% or Less		Maximum of Carbon Range, over 0.28% and All Grades Thermally Treated	
Size, mm (in.)	Length, mm (ft)	Rounds	Squares, Hexagons, and Octagons	Rounds	Squares, Hexagons, and Octagons
Less than 15.88 ($^5/_8$)	Less than 4572 (15)	3.17 ($^1/_8$)	4.76 ($^3/_{16}$)	4.76 ($^3/_{16}$)	6.35 ($^1/_4$)
Less than 15.88 ($^5/_8$)	4572 (15) and over	3.17 ($^1/_8$)	7.94 ($^5/_{16}$)	7.94 ($^5/_{16}$)	9.53 ($^3/_8$)
15.88 ($^5/_8$) and over	Less than 4572 (15)	1.59 ($^1/_{16}$)	3.17 ($^1/_8$)	3.17 ($^1/_8$)	4.76 ($^3/_{16}$)
15.88 ($^5/_8$) and over	4572 (15) and over	3.17 ($^1/_8$)	4.76 ($^3/_{16}$)	4.76 ($^3/_{16}$)	6.35 ($^1/_4$)

[a] The foregoing tolerances are based on the following method of measuring straightness: Departure from straightness is measured by placing the bar on a level table so that the arc or departure from straightness is horizontal, and the depth of the arc is measured with a feeler gauge and a straightedge.

[b] It should be recognized that straightness is a perishable quality and may be altered by mishandling. The preservation of straightness in cold-finished bars requires the utmost care in subsequent handling. Specific straightness tolerances are sometimes required for carbon and alloy steels in which case the purchaser should inform the manufacturer of the straightness tolerances and the methods to be used in checking the straightness.

Table 5—Length Tolerances for Cold-Finished Steel Bars

Product Tolerance Level	Tolerances, mm (in.) Plus Allowances Deviation above Specified Uniform Length		
	Cutting Process	Minimum	Maximum
Level 1	Shear Cut	0.000	50.80 (2.000)
Level 2	In-Line Saw Cut	0.000	25.40 (1.000)
Level 3	Off-Line Saw Cut	0.000	12.70 (0.500)

Table 6—Across-Corner Tolerances for Hexagon and Square Cold-Finished Steel Bars[a]

Product Tolerance Level	Tolerance Range Applied to Across-Corner Calculations	
	Hexagon, mm (in.), minus	Square, mm (in.), minus
Level 1	0.64 (0.025)	0.76 (0.030)
Level 2	0.51 (0.020)	0.64 (0.025)
Level 3	0.38 (0.015)	0.51 (0.020)
	Sharp Corner Hexagon Calculation = $(1.1547 \times D)$	Sharp Corner Square Calculation = $(1.4142 \times D)$
	Round Corner Hexagon Calculation = $[1.1547 \times (D - 2r)] + 2r$	Round Corner Square Calculation = $[1.4142 \times (D - 2r)] + 2r$

[a] When required, type of corner must be specified at time of order inquiry.

Table 7—Surface Roughness Average (R_a) Tolerances for Cold-Finished Steel Bars[a]

Product Tolerance Level	Allowance Maximum Deviation of Surface Roughness Average (R_a) Measurement	
	Turned and Polished Maximum, µm (µin.) (R_a)	Ground and Polished Maximum, µm (µin.) (R_a)
Level 1	Not Required	1.0 (40)
Level 2[b]	1.5 (60)	0.8 (30)
Level 3[b]	1.0 (40)	0.5 (20)

[a] RMS (root mean square calculation) is no longer applied to measure surface roughness. Roughness average (R_a) is current technology measurement output data.

[b] Special surface R_a restrictions must be agreed upon at the time of order inquiry, between purchaser and supplier. Lower R_a values are available with additional bar passes and/or special processing conditions.

Table 8—Surface Discontinuity Tolerances for Cold-Finished Steel Bars[a]

Product Tolerance Level	Maximum Allowable Surface Discontinuity Depth					
	Carbon and Alloy Non-resulfurized		Carbon and Alloy Resulfurized (0.08–0.19% Sulfur)		Carbon and Alloy Resulfurized (0.20–0.35% Sulfur)	
	Maximum Depth 6.35 mm ($^{1}/_{4}$ in.)—15.88 mm ($^{5}/_{8}$ in.) max. mm (in.)	Maximum Depth (% of Size) over 15.88 mm ($^{5}/_{8}$ in.)–152.40 mm (6 in.) (max. percentage)	Maximum Depth 6.35 mm ($^{1}/_{4}$ in.)–15.88 mm ($^{5}/_{8}$ in.) max. mm (in.)	Maximum Depth (% of Size) over 15.88 mm ($^{5}/_{8}$ in.)–152.40 mm (6 in.) (max. percentage)	Maximum Depth 6.35 mm ($^{1}/_{4}$ in.)–15.88 ($^{5}/_{8}$ in.) max. mm (in.)	Maximum Depth (% of Size) 15.88 mm ($^{5}/_{8}$ in.)–152.40 mm (6 in.) (max. percentage)
Level 1	0.20 (0.008)	1.6	0.25 (0.010)	2.0	0.30 (0.012)	2.4
Level 2	0.15 (0.006)	1.0	0.20 (0.008)	1.3	0.25 (0.010)	1.6
Level 3	0.15 (0.006)	0.075	0.15 (0.006)	1.0	0.20 (0.008)	1.3
Level 4[b]	Nil	Nil	Nil	Nil	Nil	Nil

[a] The information in the chart is the expected maximum surface discontinuity depth within the limits of good manufacturing practice. Occasional bars in a shipment may have surface discontinuity that exceed these limits. For critical applications, the purchaser may require the cold-finish steel bar supplier to eddy current test the bars prior to shipment.

[b] Level 4 requires metal removal by turning or multiple grinding passes for small bars.

Table 9—Surface Decarburization Tolerances for Cold-Finished Steel Bars

	Tolerances, mm (in.) Plus Allowances Deviation above Specified Uniform Length	
Product Tolerance Level	Maximum Millimeters of Decarburization per Side of Bar, 6.35 mm ($^{1}/_{4}$-in.)–15.88 mm ($^{5}/_{8}$-in.) Sizes, All Shapes, max. mm (in.)	Maximum Percentage of Decarburization per Side, Based on Percentage of Size over 15.88 mm ($^{5}/_{8}$-in.)–152.40 mm (6-in.) Sizes, All Shapes, (max., %)
Level 1	0.25 mm (0.010)	1.6
Level 2	0.15 mm (0.006)	1.0
Level 3 [a]	Nil	Nil

[a] Level 3 requires metal removal by turning or multiple grinding for small bars.

9. WORKMANSHIP, FINISH, AND APPEARANCE

9.1. *Workmanship:*

9.1.1. Within the limits of good manufacturing and inspection practices, the bars shall be free of injurious imperfections which, due to their nature, degree, or extent, will interfere with the use of the material in machining or fabrication of suitable parts. (See Table 8.)

9.1.2. Table 8 contains the recommended minimum stock removal to ensure removal of surface discontinuities in cold finished bars.

9.2. *Finish:*

9.2.1. Unless otherwise specified, the bars shall have a commercial bright smooth surface finish obtained by conventional cold-finishing operations such as cold drawing or cold rolling.

9.2.2. When a superior bar surface finish is required, bars may be obtained as turned and polished; ground and polished; or turned, ground, and polished. (See Table 7.)

9.2.3. Bars that are thermally treated after cold finishing may exhibit a discolored or oxidized surface.

9.3. *Product Presentation/Appearance*:

9.3.1. The bars shall be given a surface coating of oil or other rust inhibitor to protect against corrosion during shipment.

9.3.2. The bar bundles shall be identified, packaged, and loaded to preserve the physical appearance, product tolerance, and identity of the cold-finished product, as agreed upon between the purchaser and supplier.

10. CERTIFICATION

10.1. Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the test results shall be furnished at the time of shipment.

11. KEYWORDS

11.1. Alloy steel; carbon steel bars; cold-finished; steel bars.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirement of the specification itself.

S1. HOT-ROLLING REDUCTION RATIO

S1.1. When required, purchaser may require the supplier to report the reduction ratio of the initial Bloom/Billet cross-sectional area to the finished hot-rolled cross-sectional area.

S2. STEEL MELTING PROCESS

S2.1. When required, purchaser may require the supplier to report the steel melting process (basic oxygen furnace, electric arc furnace, etc.) for each initial heat/lot number supplied to the purchaser.

S3. STEEL REFINEMENT PROCESS

S3.1. When require, purchaser may require the supplier to report the steel refinement processes performed after melting and before casting (vacuum degassed, etc.) on the heat/lot number supplied to the purchaser.

S4. CONTINUOUS CASTING PROCESS

S4.1. When required, purchaser may require the supplier to report the casting process (bloom, billet, etc.) for each heat/lot number supplied to the purchaser.

S5. COUNTRY OR COUNTRIES OF ORIGIN

S5.1. When required, purchaser may require the supplier to report the country of origin where the steel was melted for each heat/lot number supplied to the purchaser.

S5.2. When required, purchaser may require the supplier to report the country of origin where the steel was hot rolled for each heat/lot number supplied to the purchaser.

S5.3. When required, purchaser may require the supplier to report the country of origin where the steel was cold finished for each heat/lot number supplied to the purchaser.

S6. MECHANICAL PROPERTIES

S6.1. When required, purchaser may require the supplier to report the cold-finished steel bars' mechanical properties for each heat/lot number supplied to the purchaser. Mechanical properties shall be evaluated in accordance with T 244.

S7. SURFACE INSPECTION

S7.1. When required, purchaser may require the supplier to inspect the cold-finished steel bars' surface with an electromagnetic surface inspection process to detect and sort surface discontinuities that exceed the maximum allowed depth tolerances listed in Table 8 or other tolerances agreed upon between the purchaser and supplier.

S8. BAR MARKING

S8.1. When required, bar marking specification requirements shall be agreed upon between the purchaser and supplier.

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[1] Available from Society of Automotive Engineers, 400 Commonwealth Ave., Warrendale, PA 15096.
[2] Available from ISS Customer Service, 410 Commonwealth Drive, Warrendale, PA 15086.

Standard Specification for

Steel Sheet Piling

AASHTO Designation: M 202M/M 202-08
ASTM Designation: A 328/A 328M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Sheet Piling

AASHTO Designation: M 202M/M 202-08
ASTM Designation: A 328/A 328M-07

1. SCOPE

1.1. This specification covers carbon steel sheet piling of structural quality for use in the construction of dock walls, sea walls, cofferdams, excavations, and like applications. When the steel is to be welded, it is presupposed that a welding procedure suitable for the grade of steel and intended use or service will be utilized.

1.2. This specification is applicable to orders in either SI units (as M 202M) or inch-pound units (as M 202). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 202.

1.3. For structural products cut from coiled product and furnished without heat-treatment or with stress relieving only, the additional requirements of M 160M/M 160, including additional testing requirements and reporting of additional tests, apply.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 160M/M 160, General Requirements for Steel, Plates, Shapes, Sheet Piling, and Bars for Structural Use (Discontinued)
- M 164, High-Strength Bolts for Structural Steel Joints (Discontinued)
- M 164M, High-Strength Bolts for Structural Steel Joints [Metric] (Discontinued)
- M 291, Carbon and Alloy Steel Nuts
- M 291M, Carbon and Alloy Steel Nuts [Metric] (Discontinued)

2.2. *ASTM Standards*:

- A 6/A 6M, Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
- A 572/A 572M, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel

3. GENERAL REQUIREMENT FOR DELIVERY

3.1. Sheet piling furnished under this specification shall conform to the requirements of the current edition of M 160M/M 160, for the specific sheet piling ordered, unless a conflict exists, in which case this specification shall prevail.

3.2. Coils are excluded from qualification to this specification until they are processed into finished sheet piling. Sheet piling produced from coil means sheet piling that has been cut to individual lengths from a coil. The processor directly controls, or is responsible for, the operations involved in the processing of a coil into finished sheet piling. Such operations include decoiling, leveling, hot forming or cold forming (if applicable), cutting to length, testing, inspection, conditioning, heat-treatment (if applicable), packaging, marking, loading for shipment, and certification. (See Note 1.)

Note 1—For sheet piling produced from coil and furnished without heat-treatment or with stress relieving only, two test results are to be reported for each qualifying coil. Additional requirements regarding sheet piling produced from coil are described in M 160M/M 160.

4. PROCESS

4.1. The steel may be made by any process that produces material meeting the requirements set forth in this specification.

5. CHEMICAL REQUIREMENTS

5.1. The heat analysis shall conform to the requirements prescribed in Table 2.

Table 1—Chemical Requirements

Element	Composition, Percent, Heat Analysis
Phosphorus, max	0.035
Sulfur, max	0.04
Copper (when specified), min	0.20

5.2. The steel shall conform on product analysis to the requirements prescribed in Table 2, subject to the product analysis tolerances in M 160M/M 160.

6. MECHANICAL REQUIREMENTS

6.1. The material, as represented by the test specimens, shall conform to the requirements as to tensile properties prescribed in Table 2.

Table 2—Tensile Requirements

Tensile strength, min, MPa [ksi]	450 [65][a]
Yield point, min, MPa [ksi]	270 [39]
Elongation in 200 mm [8 in.], min, percent	17[b]
Elongation in 50 mm [2 in.], min, percent	20

[a] Prior to M 202M/M 202–05, the minimum tensile strength was 485 MPa [70 ksi].

[b] See Elongation Requirement Adjustment in the Tension Tests section of M 160M/M 160. See Specimen Orientation in the Tension Tests section of M 160M/M 160.

6.2. A minimum tensile strength of 415 MPa [60 ksi] and a minimum yield point of 250 MPa [36 ksi] shall be permitted for piling sections used in the fabrication of cold-formed connections.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified in the purchase order.

S1. INTERLOCK STRENGTH

S1.1. The minimum strength of the interlocked joint required for certain services may be specified for certain sheet-piling sections subject to specific agreement between the material purchaser and the manufacturer.

Standard Specification for

Steel Bars, Carbon, Merchant Quality, Mechanical Properties

AASHTO Designation: M 227M/M 227-97 (2005)
ASTM Designation: A 663/A 663M-89 (2000)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Bars, Carbon, Merchant Quality, Mechanical Properties

AASHTO Designation: M 227M/M 227-97 (2005)
ASTM Designation: A 663/A 663M-89 (2000)

1. SCOPE

1.1. This specification covers hot-wrought merchant quality carbon steel bars and bar size shapes produced to mechanical property requirements and intended for noncritical constructional applications. (See Section 3.2.)

1.2. Merchant quality hot-wrought steel bar is available in the following ranges of size and section:

1.2.1. Rounds, squares, and hexagons with diameters or distance across flats less than 75 mm [3 in.].

1.2.2. Bar size shapes with maximum dimensions less than 75 mm [3 in.].

1.2.3. Other bar sections with weight per foot less than 60.78 kg/m [40.84 lb/ft].

1.2.4. Flats 150 mm [6 in.] or less in width, more than 5.156 mm [0.203 in.] in thickness, and less than 60.78 kg/m or 77 cm^2 [40.84 lb/ft or 12 in.^{2}] in cross-sectional area.

1.2.5. Flats over 50 to 200 mm [6 to 8 in.] inclusive in width, 6 mm [0.230 in.] in thickness, and under 60.78 kg/m or 77 cm^2 [40.84 lb/ft or 12 in.^{2}] in cross-sectional area.

1.2.6. Hot-wrought merchant quality carbon steel bars subject to mechanical property requirements are hot-wrought in straight lengths only.

1.3. Some applications may require one or more of the available designations shown under supplementary requirements.

Note 1—Special quality hot-wrought carbon steel bars subject to mechanical property requirements are covered in M 255M/ M 255.

1.4. This specification is applicable to orders in either SI units (as M 227M) or inch-pound units (as M 227). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 227.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 255M/M 255, Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 29/A 29M, Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for
- E 290, Standard Test Methods for Bend Testing of Material for Ductility

3. ORDERING INFORMATION

3.1. Orders for material under this specification should include the following information:

3.1.1. Quantity (mass or number of pieces);

3.1.2. Dimensions (cross-sectional shape, size, and length);

3.1.3. Name of material (merchant quality carbon steel bars);

3.1.4. Specification number and date of issue;

3.1.5. Grade designation;

3.1.6. Copper-bearing steel (if required);

3.1.7. Heat analysis or test report (request, if required);

3.1.8. Application and processing; and

3.1.9. Supplementary requirements (if required).

4. GENERAL REQUIREMENTS

4.1. Material furnished under this specification shall conform to the requirements of the current edition of ASTM A 29/A 29M, except as stated in Sections 1.2 and 4.2.

4.2. Merchant quality bars shall be free from visible pipe; however, they may contain pronounced chemical segregation. Internal porosity, surface seams, and other surface irregularities may be present in this quality. Deoxidation practice and grain size are at the manufacturer's option.

4.3. Unless otherwise specified, the bars shall be furnished as rolled and not pickled, blast cleaned, nor oiled.

5. MANUFACTURE

5.1. The steel shall be made by the open-hearth, basic oxygen, or electric furnace process.

6. CHEMICAL COMPOSITION

6.1. The steel shall conform on heat analysis to the following chemical requirements:

Phosphorus, max, percent	0.04
Sulfur, max, percent	0.05
Copper, when copper steel is specified, min, percent	0.20

6.2. When tension tests are waived in accordance with Section 7.1.6, chemistry consistent with the mechanical properties desired shall be applied.

7. MECHANICAL PROPERTIES

7.1. *Tensile Requirements*:

7.1.1. The material as represented by the test specimen shall conform to the applicable requirements in Table 1.

Table 1—Tensile Requirements

Grade Designation	Tensile Strength, MPa [ksi]	Yield Point,[a] Min, MPa [ksi][b]	Elongation, Min, %	
			200-mm [8-in.] Gauge Length	50-mm [2-in.] Gauge Length
310 [45]	310–380 [45–55]	175 [25.0]	27	33
345 [50]	345–415 [50–60]	195 [28.0]	25	30
380 [55]	380–450 [55–65]	210 [30.0]	23	26
415 [60]	415–495 [60–72]	230 [33.0]	21	22
450 [65]	450–530 [65–77]	250 [36.0]	17	20
485 [70]	485–585 [70–85]	270 [39.0]	14	18
515 [75]	515–620 [75–90]	285 [41.0]	14	18
550 [80]	550 min [80 min]	305 [44.0]	13	17

[a] When the tension test does not show a yield point (drop of the beam, halt of the pointer, or sharp-kneed stress-strain diagram), yield strength shall be determined by either 0.5 percent extension-under load or 0.2 percent offset. The minimum MPa [ksi] requirement does not change. The test report, if required, shall show yield strength.

[b] Rounded value.

7.1.2. Test specimens shall be prepared for testing from the material in its as-rolled condition. The tension specimen may be aged as described in T 244.

7.1.3. Test specimens shall be taken longitudinally and may be tested in full thickness or section, or they may be machined to the dimensions shown in Figures 4 or 5 of T 244. If test specimens are selected conforming to the dimensions of Figure 5, they shall be machined from a position midway between the center and the surface of the bar.

7.1.4. Test specimens for shapes and flats may be machined to the form and dimensions shown in Figure 4 of T 244 or with both edges parallel. Test specimens for material more than 40 mm [$1^1/_2$ in.] in thickness or diameter may be machined to a thickness or diameter of at least 20 mm [$^3/_4$ in.] for a length of at least 230 mm [9 in.], or they may conform to the dimensions shown in Figure 5 of T 244.

7.1.5. Tensile requirements shall be determined in accordance with T 244.

7.1.6. Shapes less than 645 mm^2 [1 in.^{2}] in cross section and bars (other than flats) less than 12.5 mm [$^1/_2$ in.] in thickness or diameter need not be subject to tension tests by the manufacturer.

7.1.7. For material more than 20 mm [$^3/_4$ in.] in thickness or diameter, a deduction from the percentage of elongation in 200 mm [8 in.] specified in Table 1 of 0.25 percent shall be made for each increase of 0.8 mm [$^1/_{32}$ in.] in the specified thickness or diameter above 20 mm [$^3/_4$ in.].

7.1.8. For material under 8 mm [$^5/_{16}$ in.] in thickness or diameter, a deduction from the percentage of elongation in 200 mm [8 in.] specified in Table 1 of 2.00 percent shall be made for each decrease of 0.8 mm [$^1/_{32}$ in.] in the specified thickness or diameter below 8 mm [$^5/_{16}$ in.].

7.1.9. For material more than 50 mm [2 in.] in thickness or diameter, a deduction from the percentage of elongation in 50 mm [2 in.] specified in Table 1 of 1.00 percent shall be made for each 25 mm [1 in.] of specified thickness or diameter or fraction thereof over 50 mm [2 in.] in thickness or diameter.

7.2. *Number of Tests*:

7.2.1. Two tension tests shall be made from each heat, unless the finished material from a heat is less than 45 Mg [50 tons], when one tension test will be sufficient. However, for material 50 mm [2 in.] and under in thickness, when the material from one heat differs 9.5 mm [$^3/_8$ in.] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled (larger than the sizes enumerated in Section 7.1.6), regardless of mass represented. For material more than 50 mm [2 in.] thick, when the material from one heat differs 25 mm [1 in.] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled that is more than 50 mm [2 in.] thick regardless of the mass represented.

7.3. *Test Reports*:

7.3.1. When test reports are required by the purchase order, the report shall show the results of each test required by Section 7.2, except that only one test need be reported when the amount of material from a heat in a shipment is less than 9 Mg [10 tons] and when the thickness variations described in Section 7.2 are not exceeded.

7.3.2. The thickness of the product tested may not necessarily be the same as an individual ordered thickness since it is the heat that is tested rather than each ordered item.

7.3.3. When Supplementary Requirements are specified, the report shall include a statement of compliance with the requirement or the results of tests when the requirement involves measured test values.

8. KEYWORDS

8.1. Carbon steel bars; merchant quality steel bars; steel bars.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply when specified by the purchaser.

S1. SPECIAL STRAIGHTNESS

S1.1. Bars may be specified to special straightness tolerance. (Refer to ASTM A 29/A 29M.)

S2. CLEANING

S2.1. The purchaser may specify that the surface of bars be descaled by pickling or blast cleaning.

S3. COATING

S3.1. The purchaser may specify oil on bars that have been descaled.

S4. BEND TESTS

S4.1. *Requirements*:

S4.1.1. The bend-test specimen shall stand being bent at room temperature through 180 degrees without cracking on the outside of the bent portion, to an inside diameter that shall have the relation to the thickness or diameter of the specimen as given in Table 2.

Table 2—Bend Requirements

	Ratio of Bend Diameter to Thickness of Specimen for Thickness or Diameter of Bar, mm [in.]				
Grade Designation	20 [$^3/_4$] and Under	Over 20 [$^3/_4$] to 25 [1] incl	Over 25 [1] to 40 [$1^1/_2$] incl	Over 40 [$1^1/_2$] to 50 [2] incl	Over 50 [2] to Under 75 [3]
310 [45]	Flat	Flat	$^1/_2$	1	1
345 [50]	Flat	$^1/_2$	1	$1^1/_2$	$2^1/_2$
380 [55]	$^1/_2$	1	$1^1/_2$	2	$2^1/_2$
415 [60]	$^1/_2$	1	$1^1/_2$	$2^1/_2$	3
450 [65]	1	$1^1/_2$	2	3	$3^1/_2$
485 [70]	$1^1/_2$	2	$2^1/_2$	3	$3^1/_2$
515 [75]	2	2	3	$3^1/_2$	4
550 [80]	2	$2^1/_2$	3	$3^1/_2$	4

S4.2. *Test Specimens*:

S4.2.1. Bend-test specimens for material 40 mm [$1^1/_2$ in.] and under in diameter or thickness may be the full thickness of the section. For flat bars more than 50 mm [2 in.] in width, the width may be reduced by milling to 40 mm [$1^1/_2$ in.].

S4.2.2. Bend-test specimens for material greater than 40 mm [$1^1/_2$ in.] in diameter or thickness may be machined to a thickness or diameter of at least 20 mm [$^3/_4$ in.] or to 25 by 12.5 mm [1 to $^1/_2$ in.] in section. Machined sides of bend-test specimens may have the corners rounded to a radius of not over 1.6 mm [$^1/_{16}$ in.] for material 50 mm [2 in.] and under in thickness, and not over 3.2 mm [$^1/_8$ in.] in radius for material over 50 mm [2 in.] in thickness.

S4.3. *Number of Tests*:

S4.3.1. Two bend tests shall be made from each heat unless the finished material from a heat is less than 45 Mg [50 tons], when one bend test will be sufficient. However, for material 50 mm [2 in.] and under in thickness, when the material from one heat differs 9.5 mm [$^3/_8$ in.] or more in thickness, one bend test shall be made from the thickest and the thinnest material rolled, regardless of mass represented. For material more than 50 mm [2 in.] thick, when the material from one heat differs 25 mm [1 in.] or more in thickness, one bend test shall be made from both the thickest and the thinnest material rolled that is more than 50 mm [2 in.] thick regardless of the mass represented.

S4.4. *Test Methods*:

S4.4.1. Bend tests shall be made in accordance with ASTM E 290.

Standard Specification for

Zinc Coating (Hot-Dip) on Iron and Steel Hardware

AASHTO Designation: M 232M/M 232-10[1]
ASTM Designation: A 153/A 153M-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Zinc Coating (Hot-Dip) on Iron and Steel Hardware

AASHTO Designation: M 232M/M 232-10[1]
ASTM Designation: A 153/A 153M-09

1. SCOPE

1.1. This specification covers zinc coatings applied by the hot-dip process on iron and steel hardware. The hot-dip galvanizing process consists of parts being immersed in molten zinc for a time sufficient to allow a metallurgical reaction between iron from the steel surface and the molten zinc, resulting in the formation of Zn/Fe alloy layers bonding the coating to the steel surface.

1.2. This specification is intended to be applicable to hardware items that are centrifuged or otherwise handled to remove excess galvanizing bath metal (free zinc). Coating thickness grade requirements reflect this.

1.3. The values stated in SI units are to be regarded as the standard. The equivalent inch-pound units may only be approximate.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 120, Zinc
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *ASTM Standards*:
- A 143/A 143M, Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
- A 780/A 780M, Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings
- A 902, Standard Terminology Relating to Metallic Coated Steel Products
- B 487, Standard Test Method for Measurement of Metal and Oxide Coating Thickness by Microscopical Examination of Cross Section
- B 690, Standard Specification for Prime Western Grade-Recycled (PWG-R) Zinc
- E 376, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Examination Methods

- F 1470, Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection
- F 1789 Standard Terminology for F16 Mechanical Fasteners

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. The following terms and definitions are specific to this specification. ASTM A 902 contains other terms and definitions relating to metallic coated steel products. ASTM F 1789 contains other terms and definitions relating to mechanical fasteners.

3.2. *Definitions of Terms Specific to This Standard*:

3.2.1. *average coating thickness, n*—the average of the specimen coating thickness values for the samples in an inspection lot.

3.2.2. *bare spots, n*—uncoated areas on the surface of the steel part that contain no measurable zinc coating.

3.2.3. *dross inclusions, n*—the iron/zinc intermetallics, oxides, and flux remnants present in a galvanized coating in a form other than the layer growth of the coating.

3.2.4. *individual measurement, n*—the reading from a magnetic thickness gauge of a single coating spot thickness, or the microscopic reading of a coating thickness as seen in an optical microscope at one spot.

3.2.5. *inspection lot, n*—the quantity of identical parts cleaned, fluxed, and galvanized together at one time in an appropriate container that is being submitted for acceptance as a group.

3.2.6. *malleable casting, n*—a steel article that has been subjected to a prolonged anneal to decarburize or graphitize the part to remove as much of the carbon as possible or to convert the carbon to graphite, which permits plastic deformation in compression without rupture.

3.2.7. *sample, n*—a collection of individual units of product from a single inspection lot selected in accordance with Section 6 and intended to represent that inspection lot for acceptance.

3.2.8. *specimen, n*—an individual test article upon which thickness measurements or mass [weight] determinations are performed.

3.2.9. *specimen coating thickness, n*—the average thickness from no fewer than five test measurements on a specimen, when each measurement location is selected to provide the widest dispersion (in all applicable directions) of locations within the specimen volume.

3.2.10. *threaded areas, n*—the sections of a steel part that have threads formed before hot-dip galvanizing.

4. MATERIALS AND MANUFACTURE

4.1. *Steel or Iron*—Ferrous articles to be hot-dip zinc coated shall conform to specifications designated by the purchaser.

4.2. *Zinc*—The zinc used for the coating shall conform to M 120 or ASTM B 690, or both, and shall be at least equal to the grade designated as "Prime Western."

4.2.1. If a zinc alloy is used as the primary feed for the galvanizing bath, then the base material used to make that alloy shall conform to M 120 or ASTM B 690, or both.

4.2.2. The molten metal in the working volume of the galvanizing bath shall contain not less than an average value of 98.0 percent zinc by mass [weight].

Note 1—The galvanizer may choose to add trace amounts of certain elements (for example, aluminum, nickel, bismuth, or tin) to the zinc bath to help in the processing of certain reactive steels or to enhance the cosmetic appearance of the finished product. The elements can be added to the galvanizing bath as a master feed alloy, or they can be added to the bath by the galvanizer as individual feeds.

4.2.3. If high-grade or special high-grade zinc is used, the molten metal in the working volume of the galvanizing bath shall contain not less than an average value of 99.8 percent zinc by mass [weight].

4.3. *Minimum Coating Mass [Weight] or Minimum Coating Thickness*—The minimum coating mass [weight] or the minimum coating thickness shall conform to the requirements prescribed in Table 1 for the material category and thickness of material in which the article belongs.

Table 1—Thickness or Mass [Weight] of Zinc Coating for Various Classes of Material

	Mass [Weight] of Zinc Coating, g/m^2 [oz/ft^2] of Surface, Min		Coating Thickness, microns [mils], Min	
Class of Material	Average of Specimens Tested	Any Individual Specimen	Average of Specimens Tested	Any Individual Specimen
Class A—Casings—Malleable iron, steel	610 [2.00]	550 [1.80]	86 [3.4]	79 [3.1]
Class B—Rolled, pressed, and forged articles (except those which would be included under Classes C and D):				
B-1—4.75 mm [3/16 in.] and over in thickness and more than 380 mm [15 in.] in length	610 [2.00]	550 [1.80]	86 [3.4]	79 [3.1]
B-2—less than 4.75 mm [3/16 in.] in thickness and more than 380 mm [15 in.] in length	458 [1.50]	381 [1.25]	66 [2.6]	53 [2.1]
B-3—any thickness and 380 mm [15 in.] and under in length	397 [1.30]	336 [1.10]	56 [2.2]	48 [1.9]
Class C—Fasteners more than 9.5 mm [$^3/_8$ in.] in diameter and similar articles. Washers 4.75 mm and 6.35 mm [$^3/_{16}$ in. and $^1/_4$ in.] in thickness	381 [1.25]	305 [1.00]	53 [2.1]	43 [1.7]
Class D—Fasteners 9.5 mm [$^3/_8$ in.] and under in diameter, rivets, nails, and similar articles. Washers less than 4.75 mm [$^3/_{16}$ in.] in thickness	305 [1.00]	259 [0.85]	43 [1.7]	36 [1.4]

Note: Length of the piece, stated in Classes B-1, B-2, and B-3, refers to the finished dimension of the piece after fabrication.

4.4. *Threaded Articles*—The zinc coating on threads shall not be subjected to a cutting, rolling, or finishing-tool operation unless specifically authorized by the purchaser. In order to meet overtapping allowances, tapping the threads of nuts or tapped holes after galvanizing is not prohibited.

4.5. *Touch-up and Repair*—Bare spots that are found on parts after galvanizing shall be renovated by use of the methods found in ASTM A 780 if the following criteria are met. The bare spots shall have an area totaling not more than 1 percent of the surface area to be coated excluding threaded areas of the piece, and the bare spots shall not include any threaded areas of the piece. The thickness of the repair shall be equal to the surrounding galvanized coating except for repairs made by paints containing zinc dust, in which case the thickness of the repair shall be 50 percent greater than the thickness of the galvanized coating required for the class of material but shall not be greater than 100 μm (4.0 mils). Repair thickness measurements shall be made in accordance with ASTM A 780. The galvanizer shall make repairs unless directed by the purchaser to deliver items unrepaired for subsequent renovation by the purchaser.

5. WORKMANSHIP, FINISH, AND APPEARANCE

5.1. The zinc-coated articles shall be free from uncoated areas, blisters, flux deposits, dross inclusions, and other types of projections that would interfere with the intended use of the articles, or other defects not consistent with good galvanizing practice.

5.2. The zinc coating shall be smooth and reasonably uniform in thickness.

Note 2—Smoothness of surface is a relative term. Minor roughness that does not interfere with the intended use of the part or roughness that is related to the as-received (ungalvanized) surface condition of the part shall not be grounds for rejection.

Note 3—Since this specification is applicable to items that are centrifuged or otherwise handled to remove excess bath metal (Section 1.2), irregular coating distribution is not normally encountered. Drainage problems, which manifest themselves as local excess coating thickness that would interfere with function or as edge tears or spikes that present a safety hazard because of their sharpness, are grounds for rejection under the terms of Section 5.1.

5.3. Embrittlement is a potential condition of steel that is cold-worked, depending on factors such as the steel type (strength level, aging characteristics), thickness, degree of cold work, and galvanizing process. The galvanizer, the designer, and the fabricator shall take precautions against embrittlement. The precautions to fabricate properly and prepare the material for galvanizing to prevent embrittlement are described in ASTM A 143/A 143M.

Note 4—Low service temperatures increase the risk of brittle failure of all plain carbon steels including those that have been galvanized. This temperature embrittling effect varies with type of steel. The expected service temperature should thus be taken into account when selecting steels for galvanizing.

Note 5—Tin is often added to hot-dip zinc baths to control spangle in the galvanized finish. However, the presence of tin, antimony, or arsenic in the zinc bath can contribute to embrittlement in structural steels, particularly if the steels contain more than 0.10 percent copper. The concentrations of tin, antimony, or arsenic should be individually restricted for each element to 0.01 percent maximum. Use of high-grade or special high-grade zinc restricts the presence of these deleterious elements.

5.4. Malleable castings shall be of such composition as will preclude the possibility that they become embrittled by the galvanizing process or they shall be either cooled from the anneal or subsequently heat-treated so as to immunize them against embrittlement.

5.5. The zinc coating shall adhere tenaciously to the surface of the base metal.

5.6. If the galvanized material covered by this specification is bent or otherwise fabricated to the degree that causes the zinc coatings to stretch or compress beyond the limit of elasticity, any cracking or flaking of the coating resulting from bending or fabricating shall not be cause for rejection.

6. SAMPLING

6.1. Test specimens shall be selected at random from each inspection lot.

6.2. The method of selection and sample size shall be agreed upon between the galvanizer and the purchaser. Otherwise, the sample size selected from each lot shall be as follows:

Number of Pieces in Lot	Sample Size
3 or fewer	all
4 to 500	3
501 to 1200	5
1201 to 3200	8
3201 to 10000	13
10001 and over	20

6.3. A specimen that fails to conform to a requirement of this specification shall not be used to determine the conformance to other requirements.

6.4. The method of sampling for fasteners that are required to meet the standards of the Fastener Quality Act is described in ASTM F 1470. Sample quantities and definitions of terminology are included in the referenced specification.

7. TEST METHODS

7.1. Tests shall be made to ensure that the zinc coating is being furnished in accordance with this specification and as specified for the following:

7.1.1. Minimum coating mass [weight] or minimum coating thickness in Section 4.3.

7.1.2. Finish and appearance in Sections 5.1 and 5.2.

7.1.3. Embrittlement in Sections 5.3 and 5.4.

7.1.4. Adherence in Section 5.5.

7.2. *Average Mass [Weight] of Coating*:

7.2.1. The average mass [weight] of the zinc coating shall be determined by weighing specimens after pickling and drying and again after galvanizing, unless the method described in Section 7.2.2 is used. The number of specimens that are used to determine the average of an inspection lot shall be derived from Section 6.

Note 6—This method does not take into account the mass [weight] of iron reacted from the article that is incorporated into the coating. It will thus underestimate coating mass [weight] by up to approximately 10 percent. Base metal reactivity will affect the extent of underestimation.

7.2.2. In the case of materials inspected after galvanizing, the average mass [weight] of coating shall be determined by stripping the number of specimens derived in Section 6 in accordance with T 65M/T 65, and averaging the results of the individual specimens, unless the method described in Section 7.2.1 is used.

7.3. *Average Thickness of Coating:*

7.3.1. In the case of fasteners such as bolts, nuts, and screws, the determination of the thickness of coating shall be made on a portion of the article that does not include any threads.

7.3.2. The average thickness of coating shall be determined by magnetic thickness gauge in accordance with ASTM E 376 unless the method described in Section 7.3.3 is used. The thickness shall be measured on at least five widely separated spots on a specimen. No individual spot measurement shall be cause for rejection. If an individual spot does not provide a coating thickness reading, this spot must be repaired in accordance with Section 4.5. The five or more individual coating thickness measurements on a specimen must be averaged to determine the specimen average coating thickness. The average coating thickness for the inspection lot is determined by averaging the specimen average coating thickness values for the number of specimens derived from Section 6.

7.3.3. The thickness of coating shall be determined by cross section and optical measurement in accordance with ASTM B 487, unless the method described in Section 7.3.2 is used. The thickness thus determined is a point value. No less than five such measurements shall be made at locations on the specimen, which are as widely dispersed as practical, so as to be representative of the whole surface of the specimen. The average of no less than five such measurements is the specimen average coating thickness. The average coating thickness for the inspection lot is determined by averaging the specimen average coating thickness values for the number of specimens derived from Section 6.

7.4. *Finish and Appearance*—The test for finish and appearance shall be conducted through visual inspection without additional magnification.

7.5. *Embrittlement*—Hardware that is susceptible to embrittlement shall be tested in accordance with ASTM A 143/A 143M. The tests shall be performed through agreement between the galvanizer and the purchaser.

7.6. *Adherence*—Determine adherence of the zinc coating to the surface of the base metal by cutting or prying with the point of a stout knife, applied with considerable pressure in a manner tending to remove a portion of the coating. The adherence shall be considered inadequate if the coating delaminates in the form of a layer of skin so as to expose the base metal in advance of the knife point. Do not use testing carried out at edges or corners (points of lowest coating adherence) to determine adherence of coating. Likewise, do not use removal of small particles of the coating by paring or whittling to determine failure.

8. INSPECTION

8.1. The inspector representing the purchaser shall have access at all times, while work on the contract of the purchaser is being performed, to those areas of the manufacturer’s work space that concern the application of the zinc coating to the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the zinc coating is being furnished in accordance with this specification. All inspection and tests shall be made at the place of manufacture prior to shipments, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

9. REJECTION AND RETEST

9.1. For all galvanized articles except those fasteners that must meet the requirements of the Fastener Quality Act, the following sections are used to determine rejection and retesting.

9.2. When partial inspection of materials to determine conformity with visual requirements of Section 5 warrants rejection of a lot, the galvanizer is not prohibited from sorting the lot and submitting it once again for inspection.

9.3. The number of specimens in a sample of a lot permitted to fail the conformance tests shall be agreed upon between the galvanizer and the purchaser.

9.4. If a set of test specimens fails to conform to the requirements of this specification, two additional sets shall be tested, both of which shall conform to the requirements in every respect, or the lot of material represented by the specimens shall be rejected.

9.5. Materials that have been rejected for reasons other than embrittlement are not prohibited from being stripped, regalvanized, and resubmitted for test and inspection. They shall then conform to the requirements of this specification.

10. PACKAGING

10.1. The supplier shall employ such methods of packaging zinc-coated articles as shall be required to ensure their receipt by the purchaser in satisfactory condition, with the use to be made of the article being taken into consideration.

11. CERTIFICATION

11.1. When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each inspection lot have been either tested or inspected as directed by this specification and the requirements have been met. When specified in the purchase order or contract, a report of the test results shall be furnished.

12. KEYWORDS

12.1. Coatings, zinc; galvanized coatings; steel hardware, zinc coated; steel products, metallic coated; zinc coatings, steel products.

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[1] Agrees with ASTM A 153/A 153M-09 except for the addition of Section 4.2.3, and Note 5 in Section 5.3.

Standard Specification for

Structural Bolts, Alloy Steel, Heat-Treated, 150 ksi Minimum Tensile Strength

AASHTO Designation: M 253-05 (2008)
ASTM Designation: A 490-04a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Structural Bolts, Alloy Steel, Heat-Treated, 150 ksi Minimum Tensile Strength

AASHTO Designation: M 253-05 (2008)
ASTM Designation: A 490-04a

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM A 490-04a for the information formerly contained in this standard.

Standard Specification for

High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints [Metric]

AASHTO Designation: M 253M-05
ASTM Designation: A 490M-04a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints [Metric]

AASHTO Designation: M 253M-05
ASTM Designation: A 490M-04a

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM A 490M-04a for the information formerly contained in this standard.

Standard Specification for

Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties

AASHTO Designation: M 255M/M 255-05 (2008)
ASTM Designation: A 675/A 675M-03$^{\epsilon 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties

AASHTO Designation: M 255M/M 255-05 (2008)

ASTM Designation: A 675/A 675M-03$^{\epsilon 1}$

1. SCOPE

1.1. This specification covers hot-wrought, special quality, carbon steel bars and bar size shapes produced to mechanical property requirements and intended for general constructional applications.

1.2. The bars are available in nine strength grades designated 310, 345, 380, 415, 450, 485, 515, 550, and 620 [45, 50, 55, 60, 65, 70, 75, 80, and 90] corresponding to the minimum ultimate tensile strength in MPa [ksi]. The chemical composition is selected by the manufacturer to develop the required mechanical properties.

1.3. Hot-wrought, special quality, carbon steel bars subject to mechanical property requirements are hot wrought in straight lengths only. Sections and sizes available are covered in ASTM A 29/A 29M.

1.4. Some applications may require one or more of the available designations shown under Supplementary Requirements.

Note 1—Merchant-quality hot-wrought carbon steel bars subject to mechanical property requirements are covered in M 227M/M 227.

1.5. This specification is applicable to orders in either SI units (as M 255M) or inch-pound units (as M 255). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 255.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 227M/M 227, Steel Bars, Carbon, Merchant Quality, Mechanical Properties
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 29/A 29M, Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for
- E 290, Standard Test Methods for Bend Testing of Material for Ductility

3. TERMINOLOGY

3.1. *Description of Terms*:

3.1.1. *special quality*—special quality bars are used when end use, method of fabrication, or subsequent processing treatment requires quality characteristics not available in merchant quality. Typical applications involve bending or machining for general constructional uses. Some end uses or fabricating procedures can necessitate one or more requirements, which are described in the Supplementary Requirements.

4. ORDERING INFORMATION

4.1. Orders for material under this specification should include the following information:

4.1.1. Quantity (mass or number of pieces);

4.1.2. Name of material (hot-wrought special quality bars);

4.1.3. Dimensions, including length;

4.1.4. Cross section (round, square, hexagon, equal leg angle, etc.);

4.1.5. AASHTO designation and date of issue;

4.1.6. Grade designation (Table 2);

4.1.7. Leaded steel, if required (Section 7.2);

4.1.8. Copper bearing steel, if required (Section 7.3);

4.1.9. Test report, if required (Section 10);

4.1.10. Supplementary Requirements or special requirements, if required; and

4.1.11. Application and processing.

Note 2—A typical ordering description is as follows: 5000 kg [10000 lb] Hot-Wrought Special Quality Carbon Steel Bars, 25-mm diameter × 3 m [1 in. × 10 ft] Round, M 255M/M 255, Grade 345 [50], Copper Bearing, Test Report Required, S3 Special Straightness, Boiler Supports.

5. GENERAL REQUIREMENTS

5.1. Material furnished under this specification shall conform to the applicable requirements for the current edition of ASTM A 29/A 29M.

6. MATERIALS AND MANUFACTURE

6.1. *Melting Practice*—The steel shall be made by one or more of the following primary processes: open-hearth, basic oxygen, or electric furnace. The primary melting may incorporate separate degassing or refining and may be followed by secondary melting using electroslag remelting or vacuum-arc remelting. Where secondary melting is employed, the heat shall be defined as all of the ingots remelted from a single primary heat.

6.2. *Deoxidation*:

6.2.1. Unless otherwise specified, the steel shall be rimmed, capped, semi-killed, or killed at the producer's option.

6.2.2. When required, the purchaser may specify the required deoxidation practice, dependent upon strength grade specified, purchaser's methods of fabrication, and end use requirements. Killed steels can be produced to coarse or fine austenitic grain size (see Supplementary Requirement S1).

6.3. *Condition*—Unless otherwise specified, the bars shall be furnished as-rolled and not pickled, blast cleaned, or oiled. At the producer's option, bars may be cleaned for inspection.

7. CHEMICAL COMPOSITION

7.1. The steel shall conform to the chemical requirements specified in Table 1.

7.2. *Leaded Steel*—When required, lead may be specified as an added element. When lead is specified as an added element, a range from 0.15 to 0.35 percent inclusive shall be furnished. Such a steel is identified by adding the letter L after the grade designation, for example 415L [60L].

7.3. *Copper-Bearing Steel*—When required, copper may be specified as an added element. Copper-bearing steel is identified by stating "copper-bearing" on the purchase order.

7.4. When tension tests are waived in accordance with Section 8.1.1.2, chemistry consistent with the mechanical properties desired shall be applied.

8. MECHANICAL PROPERTIES

8.1. *Tension Tests*:

Table 1—Chemical Requirements (Heat Analysis)

Element	Composition, Percent
Phosphorus, max	0.040
Sulfur, max	0.050
Copper, when copper steel is specified, min	0.20
Lead	[a]

[a] When required, lead may be specified as an added element. See Section 7.2.

8.1.1. *Requirements*:

8.1.1.1. The material as represented by the test specimen shall conform to the applicable requirements in Table 2.

Table 2—Tensile Requirements

Grade Designation[c]	Tensile Strength		Yield Point, Min[a]		Elongation, Min %[b]	
	MPa	ksi	MPa	ksi	200-mm [8-in.] Gauge Length	50-mm [2-in.] Gauge Length
310 [45]	310 to 380	[45 to 55]	155	22.5	27	33
345 [50]	345 to 415	[50 to 60]	170	25	25	30
380 [55]	380 to 450	[55 to 65]	190	27.5	23	26
415 [60]	415 to 495	[60 to 72]	205	30	21	22
450 [65]	450 to 530	[65 to 77]	225	32.5	17	20
485 [70]	485 to 585	[70 to 85]	240	35	14	18
515 [75]	515 to 620	[75 to 90]	260	37.5	14	18
550 [80]	550 min	[80 min]	275	40	13	17
620 [90]	620 min	[90 min]	380	55	10	14

[a] When the tension test does not show a yield point (drop of the beam, halt of the pointer, or sharp-kneed stress-strain diagram), yield strength shall be determined by either 0.5% extension under load or 0.2% offset. The minimum MPa [ksi] requirement does not change. The test report, if required, shall show yield strength.

[b] See Sections 8.1.1.3 through 8.1.1.6 for deduction in elongation due to section size.

[c] When lead is required, add the letter "L" after the grade designation; for example, 310L [45L].

8.1.1.2. Shapes less than 645 mm^2 [1 in.^{2}] in cross section and bars (other than flats) less than 12.5 mm [$^1/_2$ in.] in thickness or diameter need not be subject to tension tests by the manufacturer.

8.1.1.3. For material greater than 20 mm [$^3/_4$ in.] in thickness or diameter, a deduction of 0.25 percent from the percentage of elongation in 200 mm [8 in.] specified in Table 2 shall be made for each increase of 0.8 mm [$^1/_{32}$ in.] in the specified thickness or diameter above 20 mm [$^3/_4$ in.].

8.1.1.4. For material under 8 mm [$^5/_{16}$ in.] in thickness or diameter, a deduction of 2.00 percent from the percentage of elongation in 200 mm [8 in.] specified in Table 2 shall be made for each decrease of 0.8 mm [$^1/_{32}$ in.] in the specified thickness or diameter below 8 mm [$^5/_{16}$ in.].

8.1.1.5. For grades 310, 345, 380, and 415 [45, 50, 55, 60, and 65] for material over 50 mm [2 in.] in thickness or diameter, a deduction of 1.00 percent from the percentage of elongation in 50 mm [2 in.] specified in Table 2 shall be made for each 25 mm [1 in.] of specified thickness or diameter or fraction thereof over 50 mm [2 in.] in thickness in diameter.

8.1.1.6. For grades 485, 515, 550, and 620 [70, 75, 80, and 90] for material over 50 mm [2 in.] in thickness or diameter, a deduction of 1.00 percent from the percentage of elongation in 50 mm [2 in.] specified in Table 2 shall be made for each 25 mm [1 in.] of specified thickness or diameter, or fraction thereof, over 50 mm [2 in.] in diameter or thickness, to a maximum deduction of 3 percent.

8.1.2. *Test Specimens*:

8.1.2.1. Test specimens shall be prepared for testing from the material in its as-rolled condition unless otherwise specified (see Supplementary Requirements). The tension specimen may be aged as described in T 244.

8.1.2.2. Test specimens shall be taken longitudinally and may be tested in full thickness or section, or they may be machined to the dimensions shown in Figures 4 or 5 of T 244. If test specimens are selected conforming to the dimensions of Figure 5, they shall be machined from a position midway between the center and the surface of the bar.

8.1.2.3. Test specimens for shapes and flats may be machined to the form and dimensions shown in Figure 4 of T 244 or with both edges parallel. Test specimens for material greater than 40 mm [$1^{1}/_{2}$ in.] in thickness or diameter may be machined to a thickness or diameter of at least 20 mm [$^{3}/_{4}$ in.] for a length of at least 230 mm [9 in.], or they may conform to the dimensions shown in Figure 5 of T 244.

8.1.3. *Number of Tests*—Two tension tests shall be made from each heat, unless the finished material from a heat is less than 45 Mg [50 tons], when one tension test will be sufficient. However, for material 50 mm [2 in.] and under in thickness, when the material from one heat differs 9.5 mm [$^{3}/_{8}$ in.] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled (larger than the sizes in Section 8.1.1.2) regardless of the mass represented. For material more than 50 mm [2 in.] thick, when the material from heat differs 25 mm [1 in.] or more in thickness, one tension test shall be made from both the thickest and the thinnest material rolled that is more than 50 mm [2 in.] thick regardless of the mass represented.

8.1.4. *Test Method*—Tension tests shall be made in accordance with T 244 using the applicable method for determining yield point.

8.2. *Bend Tests*:

8.2.1. *Requirements*:

8.2.1.1. Bend requirements apply only to flat bars (all sizes), bars other than flats less than 12.5 mm [$^{1}/_{2}$ in.] in thickness or diameter, and shapes less than 645 mm^{2} [1 in.^{2}] in cross section. When bend tests are required for other sizes, Supplementary Requirement S6 must be specified.

8.2.1.2. The bend test specimen shall stand being bent at room temperature through 180 degrees without cracking on the outside of the bent portion, to an inside diameter which shall have the relation to the thickness or diameter of the specimen as given in Table 3.

Table 3—Bend Requirements

	Ratio of Bend Diameter to Thickness of Specimen for Thickness or Diameter of Bar, mm [in.]						
Grade Designation	20 [$^{3}/_{4}$] and Under	Over 20 [$^{3}/_{4}$] to 25 [1], incl	Over 25 [1] to 40 [$1^{1}/_{2}$], incl	Over 40 [$1^{1}/_{2}$] to 50 [2], incl	Over 50 [2] to 75 [3], incl	Over 75 [3] to 125 [5], incl	Over 5 [125]
310 [45]	Flat	Flat	$^{1}/_{2}$	1	1	2	3
345 [50]	Flat	$^{1}/_{2}$	1	$1^{1}/_{2}$	$2^{1}/_{2}$	3	$3^{1}/_{2}$
380 [55]	$^{1}/_{2}$	1	$1^{1}/_{2}$	2	$2^{1}/_{2}$	3	$3^{1}/_{2}$
415 [60]	$^{1}/_{2}$	1	$1^{1}/_{2}$	$2^{1}/_{2}$	3	$3^{1}/_{2}$	4
450 [65]	1	$1^{1}/_{2}$	2	3	$3^{1}/_{2}$	4	5
485 [70]	$1^{1}/_{2}$	2	$2^{1}/_{2}$	3	$3^{1}/_{2}$	4	5
515 [75]	2	2	3	$3^{1}/_{2}$	4	$4^{1}/_{2}$	6
550 [80]	2	$2^{1}/_{2}$	3	$3^{1}/_{2}$	4	$4^{1}/_{2}$	6
620 [90][a]							

[a] Bend requirements are not required for Grade 620 [90], but may be specified by agreement between purchaser and manufacturer. (See Supplementary Requirement S6.)

8.2.2. *Test Specimens*:

8.2.2.1. Bend-test specimens for material 40 mm [$1^{1}/_{2}$ in.] and under in diameter or thickness may be the full thickness of the section. For flat bars more than 50 mm [2 in.] in width, the width may be reduced by milling to 40 mm [$1^{1}/_{2}$ in.].

8.2.2.2. Bend-test specimens for material greater than 40 mm [$1^1/_2$ in.] in diameter or thickness may be machined to a thickness or diameter of at least 20 mm [$^3/_4$ in.] or to 25 × 12.5 mm [1 × $^1/_2$ in.] in section. Machined sides of bend-test specimens may have the corners rounded to a radius of not more than 1.6 mm [$^1/_{16}$ in.] for material 50 mm [2 in.] and under in thickness, and not more than 3.2 mm [$^1/_8$ in.] in radius for material greater than 50 mm [2 in.] in thickness.

8.2.3. *Number of Tests*—When subject to bend test, two bend tests shall be made from each heat, unless the finished material from a heat is less than 45 Mg [50 tons], when one bend test will be sufficient. However, for material 50 mm [2 in.] and under in thickness, when the material from one heat differs 9.5 mm [$^3/_8$ in.] or more in thickness, one bend test shall be made from both the thickest and the thinnest material rolled regardless of the mass represented. For material more than 50 mm [2 in.] thick, when the material from one heat differs 25 mm [1 in.] or more in thickness, one bend test shall be made from both the thickest and the thinnest material rolled that is more than 50 mm [2 in.] thick regardless of the mass represented.

8.2.4. *Test Methods*—Bend tests shall be made in accordance with ASTM E 290.

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9. WORKMANSHIP, FINISH, AND APPEARANCE

9.1. Bars shall be free of visible pipe, undue segregation, and injurious surface imperfections.

9.2. *Surface Finish*—The bars shall have a commercial hot-wrought finish obtained by conventional hot rolling. See Section 6.3 for producer's descaling option.

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10. CERTIFICATION

10.1. When specified by the purchaser, a manufacturer's certification that the material was manufactured and tested in accordance with this specification together with a report of the heat analysis, tensile requirements, and bend-test (if applicable) results shall be furnished. Only one test need be reported when the amount of material from a heat in a shipment is less than 9 Mg [10 tons] and when the thickness variations described in Sections 8.1.3 and 8.2.3 are not exceeded. The report shall include the name of the manufacturer, AASHTO designation number and date of issue, grade, heat number, and size.

10.2. The thickness of the product tested may not necessarily be the same as an individual ordered thickness since it is the heat that is tested rather than each ordered item.

10.3. When Supplementary Requirements are specified, the report shall include a statement of compliance with the requirement or the results of tests when the requirement involves measured test values.

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11. KEYWORDS

11.1. Carbon steel bars; hot-wrought steel bars; steel bars.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirements of the specification itself.

S1. GRAIN SIZE

S1.1. The steel shall conform to the coarse austenitic grain size requirement or the fine grain size requirement of ASTM A 29/A 29M.

S2. THERMAL TREATMENT

S2.1. When required, the purchaser may specify that the material be stress relieved.

S3. SPECIAL STRAIGHTNESS

S3.1. Bars may be specified to special straightness tolerance (refer to ASTM A 29/A 29M).

S4. CLEANING

S4.1. The purchaser may specify that the surface of bars be descaled by pickling or blast cleaning.

S5. COATING

S5.1. The purchaser may specify oil on bars that have been descaled.

S6. BEND REQUIREMENT

S6.1. Bend requirements for Grade 620 [90] may be specified. The bend ratio shall be as agreed upon. Bend requirements for all other grades, when specified, shall be as specified in Table 3.

S7. CARBON RESTRICTION

S7.1. On grades 310 [45], 345 [50], 380 [55], and 415 [60], carbon shall be 0.35 percent max.

Standard Specification for

Structural Steel for Bridges

AASHTO Designation: M 270M/M 270-10
ASTM Designation: A 709/A 709M-09a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Structural Steel for Bridges

AASHTO Designation: M 270M/M 270-10
ASTM Designation: A 709/A 709M-09a

1. SCOPE

1.1. This specification covers carbon and high-strength low-alloy steel structural shapes, plates, and bars and quenched and tempered alloy steel for structural plates intended for use in bridges. Nine grades are available in four yield strength levels as follows:

Table 1—Yield Strength Levels

Grade SI [U.S.]	Yield Strength, MPa [ksi]
250 [36]	250 [36]
345 [50]	345 [50]
345S [50S]	345 [50]
345W [50W]	345 [50]
HPS 345W [HPS 50W]	345 [50]
HPS 485W [HPS 70W]	485 [70]
HPS 690W [HPS 100W]	690 [100]

1.1.1. Grades 250 [36], 345 [50], 345S [50S], and 345W [50W] are also included in ASTM A 36/A 36M, A 572/A 572M, A 992/A 992M, A 588/A 588M, and A 514/A 514M, respectively. When the supplementary requirements of this specification are specified, they exceed the requirements of A 36/A 36M, A 572/A 572M, A 992/A 992M, A 588/A 588M, and A 514/A 514M.

1.1.2. Grades 345W [50W], HPS 345W [HPS 50W], HPS 485W [HPS 70W] and HPS 690W [HPS 100W] have enhanced atmospheric corrosion resistance (Section 13.1.2). Product availability is shown in Table 2.

1.2. Grade HPS 485W [HPS 70W] or HPS 690W [HPS 100W] shall not be substituted for Grade 250 [36], 345 [50], 345S [50S], 345W [50W], or HPS 345W [HPS 50W]. Grade 345W [50W] or HPS 345W [HPS 50W] shall not be substituted for Grade 250 [36], 345 [50], or 345S [50S] without agreement between the purchaser and supplier.

1.3. When the steel is to be welded, it is presupposed that a welding procedure suitable for the grade of steel and intended use or service will be utilized. See Appendix X3 of ASTM A 6/A 6M for information on weldability.

Table 2—Tensile and Hardness Requirements[a]

					Minimum Elongation, Percent				
					Plates and Bars [c,e]		Shapes[e]		
Grade	Plate Thickness, mm [in.]	Structural Shape Flange or Leg Thickness, mm [in.]	Yield Point or Yield Strength,[b] MPa [ksi]	Tensile Strength, MPa [ksi]	200 mm or 8 in.	50 mm or 2 in.	200 mm or 8 in.	50 mm or 2 in.	Reduction of Area[c,d] Min, percent
250 [36]	To 100 [4], incl	to 75 [3], incl.	250 [36] min	400–550 [58–80]	20	23	20	21	—
		over 75 [3.]	250 [36] min	400 [58] min	—	—	20	19	—
345 [50]	To 100 [4], incl	all	345 [50] min	450 [65] min	18	21	18	21[f]	—
345S [50S]	[g]	all	345–450 [50–65][h,i]	450 [65]h	—	—	18	21	—
345W [50W] and HPS 345W [HPS 50W]	To 100 [4], incl	all	345 [50] min	485 [70] min	18	21	18	21[j]	—
HPS 485W [HPS 70W]	To 100 [4], incl	[g]	485 [70][b] min	585–760 [85–110]	—	19k	—	—	—
HPS 690W [HPS 100W]	To 65 [$2^{1}/_{2}$], incl	[g]	690 [100][b] min	760–895 [110–130]	—	18[k]	—	—	[l]

[a] See “Orientation” and “Preparation” under “Tension Tests” in M 160M/M 160.

[b] Measure at 0.2 percent offset or 0.5 percent extension under load as described in Section 13 of T 244.

[c] Elongation and reduction of area not required to be determined for floor plates.

[d] For plates wider than 600 mm [24 in.], the reduction of area requirement, where applicable, is reduced five percentage points.

[e] For plates wider than 600 mm [24 in.], the elongation requirement is reduced two percentage points. See elongation requirement adjustments under the Tension Tests section of M 160M/M 160.

[f] Elongation in 50 mm [2 in.], 19 percent minimum for shapes over 75 mm [3 in.].

[g] Not applicable.

[h] The yield-to-tensile ratio shall be 0.87 or less for shapes that are tested from the web location; for all other shapes, the requirement is 0.85.

[i] A maximum yield strength of 70 ksi [480 MPa] is permitted for structural shapes that are required to be tested from the web location.

[j] For wide flange shapes with flange thickness greater than 75 mm [3 in.], elongation in 50 mm [2 in.] of 18 percent minimum applies.

[k] If measured on the Figure 3 (T 244) 40-mm [$1^{1}/_{2}$-in.] wide specimen, the elongation is determined in a 50-mm [2-in.] gauge length that includes the fracture and shows the greatest elongation.

[l] 40 percent minimum applies if measured on the Figure 3 (T 244) 40-mm [$1^{1}/_{2}$-in.] wide specimen, 50 percent minimum applies if measured on the Figure 4 (T 244) 12.5-mm [$^{1}/_{2}$-in.] round specimen.

[m] Not applicable to fracture critical Tension Components. (See Table 10.)

Note: Where “—” appears in this table, there is no requirement.

1.4. For structural products to be used as tension components requiring notch toughness testing, standardized requirements are provided in this standard, and they are based upon American Association of State Highway and Transportation Officials (AASHTO) requirements for both fracture-critical and non-fracture-critical members.

1.5. Supplementary requirements are available but shall apply only if specified in the purchase order.

1.6. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system is to be used independently of the other, without combining values in any way.

1.7. For structural products cut from coiled product and furnished without heat-treatment or with stress relieving only, the additional requirements of ASTM A 6/A 6M, including additional testing requirements and the reporting of additional tests, apply.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 243M/T 243, Sampling Procedure for Impact Testing of Structural Steel
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 6/A 6M, Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
- A 36/A 36M, Standard Specification for Carbon Structural Steel
- A 435/A 435M, Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates
- A 514/A 514M, Standard Specification for High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Welding
- A 572/A 572M, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
- A 588/A 588M, Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance
- A 992/A 992M, Standard Specification for Structural Steel Shapes
- E 112, Standard Test Methods for Determining Average Grain Size
- G 101, Standard Guide for Estimating the Atmospheric Corrosion Resistance of Low-Alloy Steels

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *main load-carrying member*—a steel member designed to carry primary design loads, including dead, live, impact, and other loads.

3.1.2. *secondary member*—a steel member used for aligning and bracing of main load-carrying members, or for attaching utilities, signs or other items to them, but not to directly support primary design loads.

3.1.3. *non-fracture-critical member*—a main load-carrying member the failure of which would not be expected to cause collapse of a structure or bridge with multiple, redundant load paths.

3.1.4. *fracture-critical member*—a main load-carrying member or tension component of a bending member the failure of which would be expected to cause collapse of a structure or bridge without multiple, redundant load paths.

3.1.5. *tension component*—a part or element of a fracture-critical or non-fracture-critical member that is in tension under various design loadings.

3.1.6. *non-tension component*—a steel member that is not in tension under any design loading.

4. ORDERING REQUIREMENTS

4.1. In addition to the items listed in the ordering information section of ASTM A 6/A 6M, the following items should be considered if applicable:

4.1.1. Type of component (tension or nontension, fracture-critical or non-fracture-critical) (see Section 10).

4.1.2. Impact testing temperature zone (see Table 3).

Table 3—Relationship between Impact Testing Temperature Zones and Minimum Service Temperatures

Zone	Minimum Service Temperature, °C [°F]
1	–18 [0]
2	Below –18 to –34 [0 to –30]
3	Below –34 to –51 [–30 to –60]

5. GENERAL REQUIREMENTS FOR DELIVERY

5.1. Material furnished under this specification shall conform to the requirements of the current edition of ASTM A 6/A 6M for the specific structural product unless a conflict exists, in which case this specification shall prevail.

5.2. Coils are excluded from qualification to this specification until they are processed into a finished structural product. “Structural products produced from coil” means structural products that have been cut to individual lengths from a coil. The processor controls, or is responsible for, the operations involved in the processing of a coil into a finished structural product. Such operations include decoiling, leveling or straightening, hot forming or cold forming (if applicable), cutting to length, testing, inspection, conditioning, heat-treatment (if applicable), packaging, marking, loading for shipment, and certification. (See Note 1.)

Note 1—For structural products produced from coil and finished without heat-treatment or with stress relieving only, two test results are to be reported for each qualifying coil. Additional requirements regarding structural products from coil are described in ASTM A 6/A 6M.

6. MATERIALS AND MANUFACTURE

6.1. For Grades 250 [36] and 345 [50], the steel shall be semi-killed or killed.

6.2. For Grades 345W [50W], HPS 345W [HPS 50W], and HPS 485W [HPS 70W], the steel shall be made to fine grain practice.

6.3. For Grade 345S [50S], the steel shall be killed. Killed steel is confirmed on the test report by a statement of killed steel, a value of 0.10 percent or more for the silicon content, or a value of 0.015 percent or more for the total aluminum content.

6.4. For Grade 345S [50S], the steelmaking practice used shall be one that produces steel having a nitrogen content not greater than 0.015 percent and includes the addition of one or more nitrogen-binding elements, or one that produces steel having a nitrogen content of not greater than 0.012 percent (with or without the addition of nitrogen-binding elements). The nitrogen content need not be reported, regardless of which steelmaking practice was used.

6.5. For Grades HPS 345W [HPS 50W], HPS 485W [HPS 70W], and HPS 690W [HPS 100W], the steel shall be made using a low-hydrogen practice, such as vacuum degassing during steel making; controlled soaking of the ingots or slabs; controlled slow cooling of the ingots, slabs, or plates; or a combination thereof.

6.6. For Grade HPS 690W [HPS 100W] the requirements fine austenitic grain size in ASTM A 6/A 6M shall be met.

6.7. Grades HPS 345W [HPS 50W] and HPS 485W [HPS 70W] shall be furnished in one of the following conditions: as-rolled, control-rolled, thermo-mechanical control processed (TMCP) with or without accelerated cooling, or quenched and tempered.

7. HEAT-TREATMENT

7.1. For quenched and tempered Grades HPS 345W [HPS 50W] and HPS 485W [HPS 70W], the heat-treatment shall be performed by the manufacturer and shall consist of heating the steel to not less than 900ºC [1650ºF], quenching it in water or oil, and tempering it at not less than 590ºC [1100ºF]. The heat-treating temperatures shall be reported on the test certificates.

7.2. For Grade HPS 690W [HPS 100W], the heat-treatment shall be performed by the manufacturer and shall consist of heating the steel to a temperature in the range from 870 to 925ºC [1600 to 1700ºF], quenching it in water, and tempering it at not less than 565ºC [1050ºF] for a time to be determined by the manufacturer. The heat-treating temperatures shall be reported on the test certificates.

8. CHEMICAL REQUIREMENTS

8.1. The heat analysis shall conform to the requirements of the specified grade, as given in Tables 4 through Table 9.

8.2. For Grade 345S [50S], in addition to the elements listed in Table 6, test reports shall include, for information, the chemical analysis for tin. Where the amount of tin is less than 0.02 percent, it shall be permissible for the analysis to be reported as <0.02 percent.

8.3. The maximum permissible carbon equivalent value shall be 0.47 percent for structural shapes with flange thickness over 50 mm [2 in.], and 0.45 percent for other structural shapes. The carbon equivalent shall be based on heat analysis. The required chemical analysis as well as the carbon equivalent shall be reported. The carbon equivalent shall be calculated using the following formula:

$$CE = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

Table 4—Grade 250 [36] Chemical Requirements (Heat Analysis)

		Plates[a]				Bars		
Product Thickness, mm [in.]	Shapes,[b] all	To 20 [$^{3}/_{4}$], incl	Over 20 to 40 [$^{3}/_{4}$ to 1$^{1}/_{2}$], incl	Over 40 to 65 [1$^{1}/_{2}$ to 2$^{1}/_{2}$], incl	Over 65 to 100 [2$^{1}/_{2}$ to 4], incl	To 20 [$^{3}/_{4}$] incl	Over 20 to 40 [$^{3}/_{4}$ to 1$^{1}/_{2}$], incl	Over 40 to 100 [1$^{1}/_{2}$ to 4], incl
Carbon max percent	0.26	0.25	0.25	0.26	0.27	0.26	0.27	0.28
Manganese percent	—	—	0.80–1.20	0.80–1.20	0.85–1.20	—	0.60–0.90	0.60–0.90
Phosphorus max percent	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sulfur max percent	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Silicon max percent	0.40	0.40	0.40	0.15–0.40	0.015–0.40	0.40	0.40	0.40
Copper min percent when copper steel is specified	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[a] For each reduction of 0.01 percentage point below the specified carbon maximum, an increase of 0.06 percentage point manganese above the specified maximum will be permitted up to the maximum of 1.35 percent.

[b] Manganese content of 0.85 to 1.35 percent and silicon content of 0.15 to 0.40 percent is required for shapes over 634 kg/m [426 lb/ft].

Note: Where "—" appears in this table, there is no requirement. The heat analysis for manganese shall be determined and reported as described in the Heat Analysis section of M 160M/M 160.

Table 5—Grade 345 [50] Chemical Requirements (Heat Analysis)[a]

					Silicon[b]		
Max Diameter, Thickness, or Distance Between Parallel Faces, mm [in.]	Carbon, Max percent	Manganese,[c] Max percent	Phosphorus, Max percent	Sulfur, Max percent	Plates to 40-mm [$1^{1}/_{2}$-in.] Thick, Shapes to 634 kg/m [426 lb/ft], Bars, Zees, and Rolled Tees, Max percent[d]	Plates over 40-mm [$1^{1}/_{2}$-in.] Thick and Shapes over 634 kg/m [426 lb/ft], percent	Columbium, Vanadium, and Nitrogen
100 [4]	0.23	1.35	0.04	0.05	0.40	0.15–0.40	See Footnote.[e]

[a] Copper, when specified, shall have a minimum content of 0.20 percent by heat analysis (0.18 percent product analysis).

[b] Silicon content in excess of 0.40 percent by heat analysis must be negotiated.

[c] Manganese, minimum by heat analysis of 0.80 percent (0.75 percent product analysis) shall be required for all plates more than 10 mm [$^{3}/_{8}$ in.] in thickness; a minimum of 0.50 percent (0.45 percent product analysis) shall be required for plates 10 mm [$^{3}/_{8}$ in.] and less in thickness and for all other products. The manganese-to-carbon ratio shall not be less 2-to-1. For each reduction of 0.01 percent point below the specified carbon maximum, an increase of 0.06 percent point manganese above the specified maximum is permitted, up to a maximum of 1.60 percent.

[d] Bars greater than 40 mm [$1^{1}/_{2}$ in.] in diameter, thickness, or distance between parallel faces, shall be made by a killed steel practice.

[e] Alloy content shall be in accordance with one of the following types, and the contents of the applicable elements shall be reported:

Type	Elements	Heat Analysis, Percent
1	Columbium[f]	0.005–0.05[g]
2	Vanadium	0.01–0.15
3	Columbium[f]	0.005–0.05[h]
	Vanadium	0.01–0.15
	Columbium plus vanadium	0.02–0.15[h]
5	Titanium	0.006–0.04
	Nitrogen	0.003–0.015
	Vanadium	0.06 max

[f] Columbium shall be restricted to Grade 345 [50] plate, bar, zee, and rolled tee thickness of 20 mm [$^{3}/_{4}$ in.], max, and to shapes with flange or leg thickness to 40 mm [$1^{1}/_{2}$ in.] inclusive unless killed steel is furnished. Killed steel shall be confirmed by a statement of killed steel on the test report, or by a report of the presence of a sufficient quantity of a strong deoxidizing element, such as silicon at 0.10 percent or higher, or aluminum at 0.015 percent or higher.

[g] Product analysis limits = 0.004 to 0.06 percent.

[h] Product analysis limits = 0.01 to 0.16 percent.

Table 6—Grade 345S [50S] Chemical Requirements (Heat Analysis)

Element	Composition, percent
Carbon, max	0.23
Manganese	0.50 to 1.60[a]
Silicon, max	0.40
Vanadium, max	0.15[b]
Columbium,max	0.05[b]
Phosphorus, max	0.035
Sulfur, max	0.045
Copper, max	0.60
Nickel, max	0.45
Chromium, max	0.35
Molybdenum, max	0.15

[a] Provided that the ratio of manganese to sulfur is not less than 20 to 1, the minimum limit for manganese for shapes with flange or leg thickness not exceeding 25 mm [1 in.] shall be 0.30 percent.

[b] The sum of columbium and vanadium shall not exceed 0.15 percent.

Table 7—Grade 345W [50W] Chemical Requirements (Heat Analysis)

Element	Composition, percent[a]		
	Type A	Type B	Type C
Carbon[b]	0.19 max	0.20 max	0.15 max
Manganese[b]	0.80–1.25	0.75–1.35	0.80–1.35
Phosphorus	0.04 max	0.04 max	0.04 max
Sulfur	0.05 max	0.05 max	0.05 max
Silicon	0.30–0.65	0.15–0.50	0.15–0.40
Nickel	0.40 max	0.50 max	0.25–0.50
Chromium	0.40–0.65	0.40–0.70	0.30–0.50
Copper	0.25–0.40	0.20–0.40	0.20–0.50
Vanadium	0.02–0.10	0.01–0.10	0.01–0.10

[a] Weldability data for these types have been qualified by FHWA for use in bridge construction.

[b] For each reduction of 0.01 percentage point below the specified maximum for carbon, an increase of 0.06 percentage point above the specified maximum for manganese is permitted, up to a maximum of 1.50 percent.

Note: Types A, B, and C are equivalent to ASTM A 588/A 588M Grade A, B, and C, respectively.

Table 8—Grades HPS 345W [HPS 50W], HPS 485W [HPS 70W], and HPS 690W [HPS 100W] Chemical Requirements (Heat Analysis)

Element	Composition, percent	
	Grades HPS 345W [HPS 50W] and HPS 485W [HPS 70W]	Grade HPS 690W [HPS 100W]
Carbon	0.11 max	0.08 max
Manganese		
65 mm [2.5 in.] and under	1.10–1.35	0.95–1.50
Over 65 mm [2.5 in.]	1.10–1.50	0.95–1.50
Phosphorus	0.020 max	0.015 max
Sulfur[a]	0.006 max	0.006 max
Silicon	0.30–0.50	0.15–0.35
Copper	0.25–0.40	0.90–1.20
Nickel	0.25–0.40	0.65–0.90
Chromium	0.45–0.70	0.40–0.65
Molybdenum	0.02–0.08	0.40–0.65
Vanadium	0.04–0.08	0.04–0.08
Columbium (Niobium)	—	0.01–0.03
Aluminum	0.010–0.040	0.020–0.050
Nitrogen	0.015 max	0.015 max

[a] The steel shall be calcium treated for sulfate shape control.

Note: Where "—" appears in this table, there is no requirement.

9. TENSILE REQUIREMENTS

9.1. The material as represented by test specimens, except as specified in Section 7.2, shall conform to the requirements for tensile properties prescribed in Table 2.

9.2. For Grade 250 [36], shapes less than 645 mm^2 [1 $in.^2$] in cross section and bars, other than flats, less than 12.5 mm [$^1/_2$ in.] in thickness or diameter need not be subjected to tension tests by the manufacturer.

10. IMPACT TESTING REQUIREMENTS

10.1. *Non-Fracture-Critical, T, Tension Components*—Structural products ordered for use as tension components of non-fracture-critical members shall be impact tested in accordance with T 243M/T 243 and as given in Table 10. The test results shall meet the requirements given in Table 10.

10.2. *Fracture-Critical, F, Tension Components*—Structural products ordered for use as tension components of fracture-critical members shall be impact tested in accordance with T 243M/T 243 and as given in Table 10. The test results shall meet the requirements given in Table 10.

10.3. Steel grades ordered for use without suffix T or F as listed in 10.1 and 10.2 do not require impact testing and shall be used as non-tension components or secondary members only.

Table 9—Non-Fracture-Critical Tension Component Impact Test Requirements

Grade	Thickness, mm [in.]	Min Average Energy, J [ft-lbf]		
		Zone 1	Zone 2	Zone 3
250T [36T][a]	To 100 [4] incl	20 [15] at 21°C [70°F]	20 [15] at 4°C [40°F]	20 [15] at –12°C [10°F]
345T [50T],[a,b] 345ST [50ST],[a] 345WT [50WT][a,b]	To 50 [2] incl	20 [15] at 21°C [70°F]	20 [15] at 4°C [40°F]	20 [15] at –12°C [10°F]
	Over 50 to 100 [2 to 4] incl	27 [20] at 21°C [70°F]	27 [20] at 4°C [40°F]	27 [20] at –12°C [10°F]
HPS 345WT [HPS 50WT][a,b]	To 100 [4] incl	27 [20] at –12°C [10°F]	27 [20] at –12°C [10°F]	27 [20] at –12°C [10°F]
HPS 485WT [HPS 70WT][c,d]	To 100 [4] incl	34 [25] at –23°C [–10°F]	34 [25] at –23°C [–10°F]	34 [25] at –23°C [–10°F]
HPS 690WT [HPS 100WT][c]	To 65 [$2^{1}/_{2}$] incl	34 [25] at –34°C [–30°F]	34 [25] at –34°C [–30°F]	34 [25] at –34°C [–30°F]
	Over 65 to 100 [$2^{1}/_{2}$ to 4] incl	48 [35] at –34°C [–30°F]	48 [35] at –34°C [-30°F]	48 [35] at –34°C [-30°F]

[a] The Charpy V-notch (CVN) impact testing shall be at "H" frequency in accordance with T 243 M/T 243.

[b] If the yield point of the structural product exceeds 450 MPa [65 ksi], the testing temperature for the minimum average energy required shall be reduced by 8°C [15°F] for each increment of 70 MPa [10 ksi] above 450 MPa [65 ksi]. The yield point is the value given in the test report.

[c] The CVN-impact testing shall be at "P" frequency in accordance with T 243M/T 243.

[d] If the yield strength of the structural product exceeds 585 MPa [85 ksi], the testing temperature for the minimum average energy required shall be reduced by 8°C [15°F] for each increment of 70 MPa [10 ksi] above 585 MPa [85 ksi]. The yield strength is the value given in the test report.

Table 10—Fracture-Critical Tension Component Impact Test Requirements

Grade	Thickness, mm [in.]	Min Test Value Energy,[a] *J* [ft-lbf]	Minimum Average Energy,[a] *J* [ft-lbf]		
			Zone 1	Zone 2	Zone 3
250F [36F]	To 100 [4] incl	27 [20]	34 [25] at 21°C [70°F]	34 [25] at 4°C [40°F]	34 [25] at –12°C [10°F]
345F [50F][b], 345SF [50SF], 345WF [50WF][b]	To 50 [2] incl	27 [20]	34 [25] at 21°C [70°F]	34 [25] at 4°C [40°F]	34 [25] at –12°C [10°F]
	Over 50 to 100 [2 to 4] incl	33 [24]	41 [30] at 21°C [70°F]	41 [30] at 4°C [40°F]	41 [30] at –12°C [10°F]
HPS 345WF [HPS 50WF][b]	To 100 [4] incl	33 [24]	41 [30] at –12°C [10°F]	41 [30] at –12°C [10°F]	41 [30] at –12°C [10°F]
HPS 485WF [HPS 70WF][c]	To 100 [4] incl,	38 [28]	48 [35] at –23°C [–10°F]	48 [35] at –23°C [–10°F]	48 [35] at –23°C [–10°F]
HPS 690WF [HPS 100WF]	To 65 [$2^{1}/_{2}$] incl	38 [28]	48 [35] at –34°C [–30°F]	48 [35] at –34°C [–30°F]	48 [35] at –34°C [-30°F]
	Over 65 to 100 [2 ½ to 4] incl	*d*	Not permitted	Not permitted	Not permitted

[a] The Charpy V-notch (CVN) impact testing shall be at "P" frequency in accordance with T 243M/T 243 except for plates of Grades 250F [36F], 345F [50F], 345WF [50WF], HPS 345WF [HPS 50WF], and HPS 485WF [HPS 70WF], for which the sampling shall be as follows:

1. As-rolled (including control-rolled and TMCP) plates shall be sampled at each end of each plate as rolled.
2. Normalized plates shall be sampled at one end of each plate as heat-treated.
3. Quenched and tempered plates shall be sampled at each end of each plate as heat-treated.

[b] If the yield point of the structural product exceeds 450 MPa [65 ksi], the testing temperature for the minimum average energy and minimum test value energy required shall be reduced by 8°C [15°F] for each increment of 70 MPa [10 ksi] above 450 MPa [65 ksi]. The yield point is the value given in the test report.

[c] If the yield strength of the structural product exceeds 585 MPa [85 ksi], the testing temperature for the minimum average energy and minimum test value energy required shall be reduced by 8°C [15°F] for each movement of 70 MPa [10 ksi] above 585 MPa [85 ksi]. The yield point is the value given in the test report.

[d] Not applicable.

11. TEST SPECIMENS AND NUMBER OF TENSION TESTS

11.1. For Grades 250 [36], 345 [50], and 345W [50W], and non-quenched and tempered Grades HPS 345W [HPS 50W] and HPS 485W [HPS 70W], location and condition, number of tests, and preparation of test specimens shall meet the requirements of ASTM A 6/A 6M.

11.2. The following requirements, which are in addition to those of ASTM A 6/A 6M, shall apply only to HPS 690W [HSP 100W] and quenched and tempered Grades HPS 345W [HPS 50W] and HPS 485W [HPS 70W].

11.2.1. When possible, all test specimens shall be cut from the plate in its heat-treated condition. If it is necessary to prepare test specimens from separate pieces, all of these pieces shall be full thickness, and shall be similarly and simultaneously heat-treated with the material. All such separate pieces shall be of such size that the prepared test specimens are free of any variation in properties due to edge effects.

11.2.2. After final heat-treatment of the plates, one tension test specimen shall be taken from a corner of each plate as heat-treated (except as specified in Section 11.1).

Note 2—The term “plate” identifies the “plate as heat-treated.”

12. RETESTS

12.1. Grades 250 [36], 345 [50], 345S [50S], and 345W [50W], and non-quenched and tempered Grades HPS 345W [HPS 50W] and HPS 485W [HPS 70W] shall be retested in accordance with ASTM A 6/A 6M.

12.2. The manufacturer may reheat treat quenched and tempered plates that fail to meet the mechanical property requirements of this specification. All mechanical property tests shall be repeated when the material is resubmitted for inspection.

13. ATMOSPHERIC CORROSION RESISTANCE

13.1. Steels meeting this specification provide two levels of atmospheric corrosion resistance:

13.1.1. Steel grades without suffix provide a level of atmospheric corrosion resistance typical of carbon steel without copper.

13.1.2. The steel for Grades 345W [50W], HPS 345W [HPS 50W], and HPS 485W [HPS 70W] shall have an atmospheric corrosion resistance index of 6.0 or higher, calculated from the heat analysis in accordance with ASTM G 101. (See Note 3.) When properly exposed to the atmosphere, these steels can be used bare (unpainted) for many applications. The steel for HPS 690W [HPS 100W] provides an improved level of atmospheric corrosion resistance over alloy steel without copper.

Note 3—For methods of estimating the atmospheric corrosion resistance of low-alloy steels, see ASTM G 101. The user is cautioned that the ASTM G 101 predictive equation (Predictive Method Based on the Data of Larabee and Coburn) for calculation of an atmospheric corrosion resistance index has only been verified for the composition limits stated in that guide.

14. MARKING

14.1. In addition to the marking requirements of ASTM A 6/A 6M, the structural product shall be marked as follows:

14.1.1. For Grades 50W [345W] the composition type shall be included.

14.1.2. For structural products that conform to the requirements of Section 10.1, the letter *T* and the applicable zone number (1, 2, or 3) shall follow the grade designation.

14.1.3. For structural products that conform to the requirements of Section 10.2, the letter *F* and the applicable zone number (1, 2, or 3) shall follow the grade designation.

15. KEYWORDS

15.1. Alloy; atmospheric corrosion resistance; bars; bridges; carbon; fracture-critical; high-strength; low-alloy; non-fracture-critical; plates; quenched; shapes; steel; structural steel; tempered.

SUPPLEMENTARY REQUIREMENTS

Requirements other than those shown in this section may be specified subject to agreement between the supplier and the purchaser. In addition, the following supplementary requirements are also suitable for use with this specification.

S1. FREQUENCY OF TENSION TESTS

S1.1. Tension testing that is additional to the tension testing required by ASTM A 6/A 6M shall be made as follows:

S1.1.1 *Plate*—One tension test shall be made using a test specimen taken from each as rolled or as heat-treated plate.

S1.1.2 *Structural Shapes*—One tension test shall be made using a test specimen taken from each 5 Mg [5 tons] of material produced on the same mill of the same nominal size, excluding length, from each heat of steel. Each single piece exceeding 5 Mg [5 tons] in mass [weight] shall be tested. If shapes are heat-treated, one test shall be made on specimens taken from each heat of the same nominal size, excluding length, in each furnace lot.

S1.1.3 *Bars*—One tension test shall be made using a test specimen taken from each 5 Mg [5 tons] of the same heat and same diameter or thickness if the material is furnished as rolled or is heat-treated in a continuous-type furnace. For material heat-treated in a noncontinuous furnace, one test shall be taken from each heat of the same bar diameter or thickness for each furnace charge.

S2. ULTRASONIC EXAMINATION

S2.1. Refer to S8 of ASTM A 6/A 6M.

S3. MAXIMUM TENSILE STRENGTH (GRADES 345 [50], 345W [50W]), AND 345S [50S]

S3.1. Refer to S18 of ASTM A 6/A 6M.

S4. FINE AUSTENITIC GRAIN SIZE

S4.1. The steel shall be killed and have a fine austenitic grain size.

S5. ATMOSPHERIC CORROSION RESISTANCE

S5.1. When specified, the material manufacturer shall supply to the purchaser evidence of atmospheric corrosion resistance satisfactory to the purchaser.

S5.2. Refer to S23 of ASTM A 6/A 6M (applicable to Grades 250 [36] and 345 [50]).

S6. LIMITATION ON WELD REPAIR (FRACTURE-CRITICAL MATERIAL ONLY)

S6.1. Weld repair of the base metal by the material manufacturer or supplier is not permitted.

Standardized supplementary requirements for use at the option of the purchaser are listed in ASTM A 6/A 6M.

S7. SINGLE-HEAT BUNDLES

S7.1. Bundles containing shapes or bars shall be from a single heat of steel.

Standard Specification for

Wire Rope and Sockets for Movable Bridges

AASHTO Designation: M 277-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Wire Rope and Sockets for Movable Bridges

AASHTO Designation: M 277-06

1. SCOPE

1.1. This specification covers steel wire rope for use in movable bridges. Both operating and counterweight ropes are included in nominal 6 × 19 rope construction. Suitable sockets are also included.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 102M/M 102, Steel Forgings, Carbon and Alloy, for General Industrial Use
- M 120, Zinc
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

2.2. *ASTM Standards*:

- A 29/A 29M, Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for
- A 148, Standard Specification for Steel Castings, High Strength, for Structural Purposes
- A 603, Standard Specification for Zinc-Coated Steel Structural Wire Rope
- A 709, Standard Specification for Structural Steel for Bridges

2.3. *ANSI Standard*:

- B4.1, American National Standards Institute—Sockets, Pinholes, Pins

2.4. *Military Standard*:

- MIL-P-24216, Military Specifications—Fiber Polypropylene Cores for Wire Rope

3. TERMINOLOGY

3.1. *acceptance breaking strength*—the minimum ultimate strength value on which conformance to the specification shall be based.

3.2. *bright wires*—wires in ropes that are uncoated.

3.3. *center*—the inner or foundation member (wire or twisted fibrous material) in a strand around which the wires are laid.

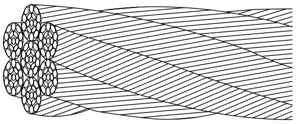
3.4. *circumference*—the measured perimeter of a circle circumscribing the wires of a strand or the strands of a wire rope.

3.5. *core*—the foundation member (a twisted fibrous material) of a wire rope around which strands are laid.

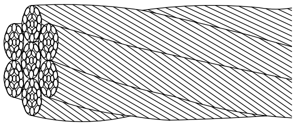
3.6. *fibers*—the material of which the centers or cores are made.

3.7. *filler wires*—small diameter auxiliary wires for supporting and positioning main wires. Filler wires are included in the actual wire count and identification of the rope construction.

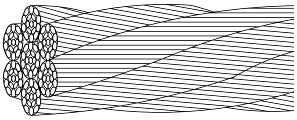
3.8. *lang lay (See Figure 1.)*—the direction of lay of the wires in the strand and of the strand in the rope is the same. As a result, the rope has an appearance that the wires are diagonal to the axis of the rope. The wires and the strands may run to the right, “right lang lay” (commonly called “lang lay”) or to the left, “left lang lay” (on specific orders only).



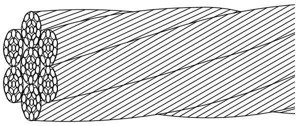
Right Regular Lay



Right Lang Lay



Left Regular Lay



Left Lang Lay

Figure 1—Lays in Wire Rope

3.9. *lay*—used by the wire rope industry in two different ways as follows:

3.9.1. The lay is the manner in which the wires in a strand or the strands in a wire rope lay (twisted). (See Figure 1.)

3.9.2. The lay is the distance parallel to the longitudinal axis in which a wire makes a complete turn (spiral or helix) about the axis of the rope. It is also called the lay length or the pitch. (See Figure 2.)

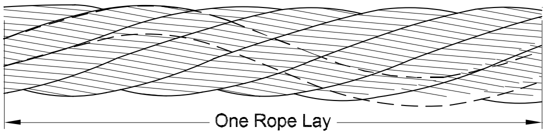
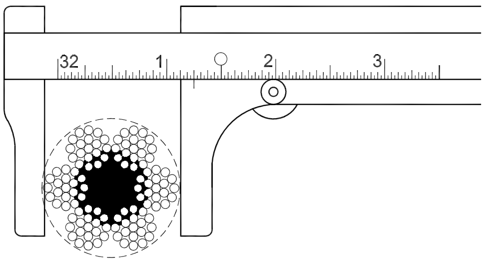


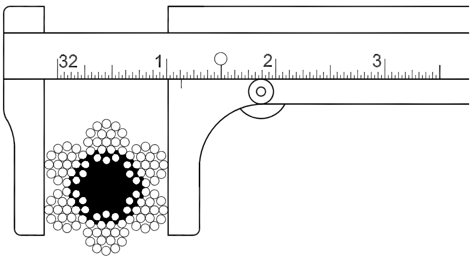
Figure 2—Lay as a Unit of Measure

3.10. *nominal breaking strength*—the value on which designs should be based.

3.11. *ordered diameter*—the nominal diameter of the circumscribing circle of a wire rope of strand. (See Figure 3.)



Correct Way
This gives correct diameter.



Incorrect Way
This does not give correct diameter.

Figure 3—Determination of the Wire Rope Diameter

3.12. *pitch (lay length)*—the distance parallel to the longitudinal axis in which a wire makes a complete turn about the axis of the rope.

3.13. *preformed strand*—a strand in which the wires are permanently shaped to the spiral form they assume in the strand.

3.14. *preformed wire rope*—a wire rope in which the strands are permanently shaped to the spiral form they assume in the wire rope.

3.15. *prestretching*—stretching is the result of two components: the structural stretch, caused by the lengthening of the rope lay, compression of the core, and adjustment of the wires and strands to the load; and the elastic stretch caused by elongation of the wires. Prestretching is the application of a prescribed tensile force prior to delivery (see Section 5.2.4) intended to permanently adjust the rope for most of the structural stretch component, so that when it is placed in service the elastic stretch will be the only significant cause of additional elongation.

3.16. *regular lay*—designates that the wires in the rope strand lay in one direction while the strand itself rotates in the rope in an opposite direction. The rope has, therefore, an outward appearance that all wires in the rope are roughly parallel to the longitudinal axis of the rope. There are two regular lays, as follows:

3.16.1. *right regular lay (commonly called "regular lay")*—the strands run in the rope downwards to the right (clockwise) while the wires in the strands rotate to the left (counterclockwise). This is the most used lay.

3.16.2. *left regular lay*—the strands in the rope run downwards to the left (counterclockwise) while the wires in the strand run to the right (clockwise). (See Figure 1.) The left regular lay is not a commonly used lay and must be specifically ordered.

3.17. *reels, manufacturing*—reels on which the strands and the wire ropes are wound in one continuous length as they are formed on the rope closing machine.

3.18. *reels, shipping*—reels on which wire strands or wire ropes, cut to the ordered lengths, are wound from the manufacturing reel for shipment.

3.19. *rope*—a symmetrically arranged and helically twisted assembly of strands.

3.20. *sockets*— type of wire fitting, including bridge sockets, which are steel castings with baskets for securing rope ends and equipped with adjustable bolts. Closed type as "U-bolt" with or without a bearing block in the U of the bolt. Open type has two eyebolts and pin.

3.21. *strand*—a symmetrically arranged and helically twisted assembly of wires.

3.22. *6 × 19 wire rope*—a common type of construction composed of six strands, each strand containing an equal number of wires, ranging between 15 and 26. The six strands are helically twisted around a core of polypropylene, natural hard fiber, an independent wire rope, or a strand.

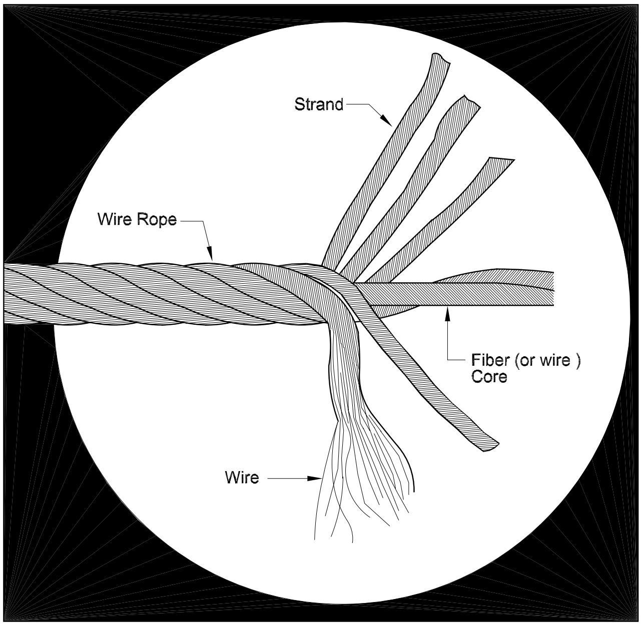


Figure 4—Components of Wire Rope

4. ORDERING INFORMATION

4.1. Orders for material under this specification shall include the following information:

4.1.1. Total length and individual lengths,

4.1.2. Nominal diameter,

4.1.3. Prestretched or non-prestretched,

4.1.4. Construction (type of core, lay, etc.),

4.1.5. Galvanizing class and type, or bright,

4.1.6. Grade of rope,

4.1.7. Details on socket requirements,

4.1.8. AASHTO designation and date of issue, and

4.1.9. Special requirements: Mechanical tests, inspection, packaging requirements.

Note 1—A typical ordering description is as follows: 2926 m (9600 ft), 38.1 mm (1.5 in.), improved plow steel, regular lay, in 732 m (2400 ft) spoolless packs to M 277, bright.

Note 2—Manufacturer should be advised to include sufficient materials to provide for the samples described in Section 7.

5. MATERIALS AND MANUFACTURE

5.1. *Base Metal*—Wire rope and strand shall be made of improved plow steel. The steel for wires shall be made by the basic oxygen or electric furnace processes.

5.2. *Construction of Wire Rope*:

5.2.1. The actual diameter of wire rope (the diameter of a circumscribed circle) shall be measured when the rope is unstressed. The measurement shall be made as required in Section 10.1.2.

The tolerance from nominal diameter of bright wire rope shall be –0 percent to +5 percent.

5.2.2. All ropes shall be preformed wire rope of 6 × 19 filler wire construction with a hard fiber or polypropylene core.

5.2.3. Ropes shall be laid in accordance with the best practice. Every effort shall be made to obtain ropes of uniform physical properties. The ropes shall be fabricated in the greatest lengths practicable, and all similar ropes for any one bridge shall be cut from ropes manufactured with one setting on one closing machine.

5.2.4. Prestretched rope shall meet the minimum modulus of elasticity shown in Table 1.

5.2.4.1. If specified, a test for modulus of elasticity shall be made on each manufactured length of wire rope. The modulus of elasticity shall be determined from a gauge length of not less than 50 diameters and shall be computed on the sum of the gross metallic cross-sectional areas of the wire making up the wire rope. Throughout the range from 10 percent of the strength listed in Table 6 to 90 percent of the prestretching tension, this modulus of elasticity shall not be less than the specified minimum shown in Table 1.

Table 1—Minimum Modulus of Elasticity of Prestretched Structural Wire Rope

Nominal Diameter Wire Rope, mm (in.)	Minimum Modulus, GPa (psi)
12.7–63.5 (0.5–2.5)	138 (20000000)

5.2.4.2. *Prestretching*—Each rope shall be prestretched using the following procedure: (1) Tension the rope to 40 percent of its ultimate tensile strength as determined in Section 7.5 and hold that load for 300 seconds. (2) Reduce the load to 5 percent of the ultimate tensile strength. (3) Repeat this load–unload cycle two more times. (4) Release the load completely.

5.2.5. All wire ropes, unless otherwise specified, shall be right regular lay, and the maximum length of rope lay shall be as follows:

- *Operating Ropes*—6.75 times nominal rope diameter
- *Counterweight Ropes*—7.5 times nominal rope diameter

The lay of the wires in the strands shall be such as to make the wires approximately parallel to the axis of the rope where they would come in contact with a circular cylinder circumscribed on the rope.

5.2.6. Fiber core for wire rope shall be one of the hard fibers or polypropylene fiber. The hard fibers are manila (abaca) and sisal (African, Java, Mauritius, Mexican, and Yucatan). A mixture of two or more species of hard fibers may be used. Polypropylene fibers shall meet the requirements of MIL-P-24216. Fiber core shall be of commercial quality and shall be thoroughly cleaned, free of waste, evenly twisted, of uniform plies and of good workmanship.

5.2.6.1. Fiber cores and centers shall be thoroughly impregnated during fabrication with a lubricant that shall contain copper compounds or other preservation material to allay deterioration of fiber parts due to rot or mildew and shall not be injurious to steel wires. This requirement is not applicable to polypropylene cores or centers.

5.2.7. The wires of uncoated (not galvanized) steel wire ropes shall be thoroughly coated with a suitable lubricant during the process of manufacture. The lubricant shall have a mineral base compounded with additives designed to provide corrosion protection and lubricating qualities during shipping, storage, handling, and the initial period of service and suitable base for subsequent field re-lubrications. The lubricant shall be free from substances injurious to steel wires and fiber cores.

5.2.8. Coated (galvanized) steel wire ropes may be lightly lubricated during fabrication at the option of the manufacturer.

5.2.9. No splicing or joining of strands shall be permitted in the manufactured length of rope. Welds made prior to wire drawing are permitted. Joining of wires by welding during stranding operation is permissible and such joints shall be dispersed sufficiently so as to maintain the minimum tensile or breaking strength as listed in Table 2.

Table 2—Tensile Properties of Wire

Diameters of Wire, mm (in.)	Minimum Tensile Strength Uncoated,[a] GPa (psi)	Minimum Elongation, percent
0.89–1.53 (0.038–0.060)	1.65 (238000)	1.50
1.54–2.54 (0.061–0.100)	1.58 (230000)	1.75
2.55–3.56 (0.101–0.140)	1.55 (225000)	2.00
3.57–4.83 (0.141–0.190)	1.50 (218000)	2.25

[a] For galvanized wire deduct 10 percent of strength.

6. ZINC COATING

6.1. When specified to be zinc coated, the wire rope is normally furnished with Class A zinc-coated wire throughout. It may be furnished with Class B or Class C mass zinc-coated outer wires and Class A inner wires or Class B mass or Class C zinc-coated wires throughout where additional corrosion protection is required by the purchaser. The purchaser must specify such increase.

6.1.1. The slab zinc, when used, shall conform to M 120 for Zinc, High Grade or better.

6.2. The weight of the zinc coating on the individual wires prior to the fabrication of the wire rope shall be not less than that specified in Table 3 for the class designated when tested in accordance with the stripping test of T 65M/T 65.

Table 3—Minimum Weight of Coating

Nominal Diameters of Coated Wire	Mass of Zinc Coating, Minimum kg/m^2 (oz/ft^2) of Uncoated Wire Surface		
mm. (in.)	Class A Coating	Class B Coating	Class C Coating
1.02–1.55, incl (0.040–0.061)	0.12 (0.40)	0.24 (0.80)	0.37 (1.20)
1.56–2.01, incl (0.062–0.079)	0.15 (0.50)	0.30 (1.00)	0.46 (1.50)
2.02–2.34, incl (0.080–0.092)	0.18 (0.60)	0.37 (1.20)	0.55 (1.80)
2.35–2.62, incl (0.093–0.103)	0.21 (0.70)	0.43 (1.40)	0.64 (2.10)
2.63–3.03, incl (0.104–0.119)	0.24 (0.80)	0.49 (1.60)	0.73 (2.40)
3.04–3.61, incl (0.120–0.142)	0.26 (0.85)	0.52 (1.70)	0.78 (2.55)
3.62–4.76, incl (0.143–0.187)	0.27 (0.90)	0.55 (1.80)	0.82 (2.70)
4.77 and larger[a] (0.188)	0.30 (1.00)	0.61 (2.00)	0.92 (3.00)

[a] This is not to imply that larger wire will be manufactured to any unlimited diameter. It only implies that the wire sizes chosen by the wire rope manufacturer must meet the requirements of this specification.

6.3. The zinc-coated wire, prior to fabrication into wire rope, shall be capable of being wrapped two turns in a close helix at a rate exceeding 15 turns per minute in around a cylindrical steel mandrel equal to five times the nominal diameter of the wire under test without cracking or flaking the zinc coating to such an extent that any zinc can be removed by rubbing with the bare fingers.

Note 3—Loosening or detachment during the adherence test of superficial small particles of zinc formed by mechanical polishing of the surface of the coated wire shall not be considered cause for rejection.

6.4. Zinc coating shall be applied by either the electrolytic-plating process or by hot dipping in molten zinc as specified by the purchaser.

6.5. Zinc coating shall be free from uncoated spots, lumps, pits, blisters, gritty areas, dross, and flux.

7. PHYSICAL REQUIREMENTS

7.1. The tensile strength of individual wires shall conform to the requirements of Table 2.

7.2. The total ultimate elongation of the wires measured on a 250-mm (10-in.) gauge length, at the breaking strength of the wire, shall be not less than shown in Table 2.

7.3. *Dimension, Permissible Variation*—The diameter variation of like-positioned wires in the strands of the wire rope shall not exceed the tolerances listed in Table 4.

Table 4—Diameter Tolerance for Like-Positioned Wires

Diameters of Wire, mm (in.)	Total Variation, mm (in.)
0.96–1.53 (0.038–0.060)	0.051 (0.002)
1.54–2.54 (0.061–0.100)	0.064 (0.0025)
2.55–3.56 (0.101–0.140)	0.076 (0.003)
3.57–4.83 (0.141–0.190)	0.089 (0.0035)

7.4. In lieu of complying with the elongation requirements in Table 2, the torsional test described in Section 7.4.1 may be performed.

7.4.1. The test specimens of the wire shall be subjected to a torsion test in which the distance between the jaws of the testing machine is 200 mm (8 in.). The number of complete successive turns of 360 degrees in one direction through which a 200-mm (8-in.) length of wire can be twisted around its longitudinal axis, without breaking or showing any signs of splitting or other defects, shall not be less than shown in Table 5.

Table 5—Torsion Test Requirements for Individual Wires

Diameter of Wire, mm (in.)	Turns
0.96 (0.038)	57
1.14 (0.045)	48
1.27 (0.050)	43
1.40 (0.055)	39
1.52 (0.060)	35

7.4.2. One end of the wire is to be rotated with respect to the other end of the wire at continuous, uniform speed until breakage occurs. During the test, the applied tension shall be sufficient to straighten the wire. The speed of rotation shall not exceed 60 turns per minute. Such tests shall be carried out by a mechanically driven device in order to secure operation at constant, uniform speed. The machine must be equipped with an automatic counter to record the number of twists causing breakage. One jaw shall be fixed axially and the other jaw moved axially and be arranged for applying tension weights to wire under test. Tests in which breakage occurs within 3 mm ($^1/_8$ in.) of the jaw shall be discarded.

7.5. *Ultimate Strength*—In order to demonstrate the strength of the rope and its fastenings, the length of the test specimen shall not be less than 0.91 m (3 ft) between sockets for wire ropes up through 25.4 mm (1 in.) diameter inclusive and not less than 1.52 m (5 ft) between sockets for wire ropes 25.4 to 63.5 mm (1 to 2.5 in.) diameter. The test shall be valid if failure occurs 50.8 mm (2 in.) or more from the sockets or holding mechanism. The test specimens shall have sockets, selected at random from those used in filling the order, attached to their ends. The number of test pieces shall be not fewer than two from each original length in which the rope is fabricated, and not more than 10 percent of the total number of finished lengths of rope to be made for the order. The test pieces shall be taken from both ends of the original lengths in which the rope is fabricated. A suitable mark shall be placed around the rope near the end of the socket, so that any movement of the latter can readily be detected. These test pieces are to be stressed to destruction in a suitable testing machine. The maximum rate of loading shall not be more than 3.5 MPa/sec (500 psi/sec). The sockets used for these tests shall not be used in the structure. Under this stress, bright (uncoated) wire rope shall develop the minimum nominal strength given in Table 6. When ropes are galvanized, deduct 10 percent from bright rope strengths shown.

Table 6—Ultimate Strength of Improved Plow Steel Rope 6 × 19 Classification Wire Rope, Bright (Uncoated), Fiber Core

Nominal Diameter, mm (in.)	Approx Mass, kg/m (lb/ft)	Nominal Strength Improved Plow Steel, kN (lb)
13 ($^1/_2$)	0.62 (0.42)	95.2 (21400)
14 ($^9/_{16}$)	0.79 (0.53)	120.0 (27000)
16 ($^5/_8$)	0.98 (0.66)	148.6 (33400)
19 ($^3/_4$)	1.41 (0.95)	211.7 (47600)
22 ($^7/_8$)	1.92 (1.29)	286.5 (64400)
25 ((1)	2.50 (1.68)	371.9 (83600)
29 ($1^1/_8$)	3.17 (2.13)	468.0 (105200)
32 ($1^1/_4$)	3.91 (2.63)	574.7 (129200)
35 ($1^3/_8$)	4.73 (3.18)	691.3 (155400)
38 ($1^1/_2$)	5.62 (3.78)	818.5 (184000)
41 ($1^5/_8$)	6.61 (4.44)	951.9 (214000)
44 ($1^3/_4$)	7.66 (5.15)	1103.2 (248000)
48 ($1^7/_8$)	8.80 (5.91)	1254.4 (282000)
51 (2)	10.00 (6.72)	1423.4 (320000)
54 ($2^1/_8$)	11.30 (7.59)	1592.5 (358000)
57 ($2^1/_4$)	12.70 (8.51)	1779.3 (400000)
60 ($2^3/_8$)	14.10 (9.50)	1939.4 (436000)
64 ($2^1/_2$)	15.62 (10.50)	2108.5 (474000)

8. SOCKETS

8.1. All sockets used with wire ropes shall be made from forged solid blanks of normalized M 102M/M 102 Class 2 steel, without the use of welding, or be machined from hot-rolled ASTM A29 alloy steels, such as Grades E4130 or 8620, and subsequently normalized or quenched and tempered to attain a 345 MPa [50 ksi] minimum yield strength and 550 MPa [80 ksi] minimum tensile strength. Sockets for ropes with 64-mm [2.5-in.] diameter may be made of ASTM A148 Grade 80-50 cast steel. All sockets shall have the minimum average energy required by ASTM A709 for Grade 50, as determined by Charpy V-notch impact test. The minimum average energy required is dependent on whether the socket is fracture-critical or nonfracturecritical, and in what temperature zone the bridge is located. The sockets shall be neatly finished to the exact dimensions shown on the plans. All socket pins shall be Class C normalized steel forgings or be machined from hot-rolled ASTM A29 alloy steels, such as Grades E4130 or 8620, and subsequently normalized or quenched and tempered to attain a 345 MPa [50 ksi] minimum yield strength and 550 MPa [80 ksi] minimum tensile strength. In every case, the dimensions of the sockets shall be such that no part under tension shall be stressed higher than 90 percent of yield strength when the rope is stressed to its specified ultimate strength. The sockets shall be attached to the ropes by using zinc of a quality not less than that defined for High Grade in the current specifications for Zinc Metal (Slab Zinc) of M 120. A reliable method of attachment shall be used that will permit the rope, when stressed to 80 percent of its ultimate strength under the test specified in Section 7.5, to slip not more than one-sixth the nominal diameter of the rope. If a greater movement shall occur, the method of attachment shall be changed until a satisfactory one is found.

The zinc used in attaching the sockets must not be too hot or it will anneal the wires. The correct temperature range for zinc for this purpose is from 455 to 565ºC (850 to 1050ºF). Filling of the socket with zinc must be performed in one continuous operation.

8.2. Sockets, pinholes, and pins shall be machined for an RC8 fit in accordance with ANSI B4.1. Sockets shall be painted in the shop as specified by the purchaser.

9. SAMPLING AND TESTING

9.1. *Wire Rope*:

9.1.1. A lot shall consist of all the wire rope of one type, class, construction, size, and material presented for delivery at one time on the same contract or order.

9.1.2. When wire rope or strand can be identified by its manufacturing reel, one sample 3.7 m (12 ft) long shall be taken from one shipping reel in the lot.

9.1.3. When wire rope or strand cannot be identified by its manufacturing reel, one sample 3.7 m (12 ft) long shall be cut from each reel or coil submitted for inspection.

9.1.4. *Resample and Retest*—If the original sample fails, two more samples will be cut and tested from the same reel or coil. Both re-samples must pass, or the cable may be rejected.

9.2. *Sockets*:

9.2.1. A lot of sockets shall consist of all the sockets of one type, class, construction, size, and material presented for delivery at one time on the same contract or order.

9.2.2. The sockets shall be stronger than the rope with which they are used. If a socket should break during the test specified in Section 7.5, two others shall be selected and attached to another piece of rope and the test repeated. This process shall be continued until the inspector is satisfied of their reliability, in which case the lot shall be accepted. If, however, 10 percent or more of all sockets tested break at a load less than the specified minimum strength, the entire lot shall be rejected, and new ones made of stronger material or to a heavier design shall be furnished.

10. INSPECTION

10.1. All tests and inspection shall be made at the place of manufacture unless otherwise specified and shall be so conducted as not to interfere unnecessarily with the operation of the works. The manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. When specified, inspection may be waived, and certified copies of test reports furnished.

10.1.1. Each reel (or coil) in the lot shall be visually examined for workmanship and measured for dimensional requirements.

10.1.2. The examination of the wire rope diameter shall be made of the free end of the rope in the shipping reel. Beginning not less than 1.5 m (5 ft) from the end of the rope, the diameter shall be measured at three places not less than 1.5 m (5 ft) apart with a slide caliper as shown in Figure 1. The average of the measured diameters shall be the diameter of the rope.

10.1.3. The examination of pitch or the lay length shall be made at the free end of the wire rope or strand on the shipping reel. Beginning not less than 3 m (10 ft) from the end of the rope, the length of five or more pitches shall be measured. The distance measured shall be divided by the number of pitches, in order to arrive at the pitch or the length of a single lay.

10.1.4. Sockets shall be visually inspected for dimensions, workmanship, and manufacturing flaws.

11. PACKAGING AND MARKING

11.1. Wire rope shall be packaged in coils or reels at the discretion of the manufacturer unless otherwise specified. Wire rope shall be packaged in such a manner so that no permanent deformation of wires in the strand or strands in the wire rope will occur. It shall be protected against damage by weather or handling. Each reel or coil shall have a strong tag securely fastened to it showing the length, size, grade, AASHTO designation, and the name or mark of the manufacturer.

11.2. Sockets shall be placed in suitable containers so as to protect them from damage until time of use. Each container shall be marked with the quantity, type of socket, size, grade, AASHTO designation, and name or mark of the manufacturer.

Standard Specification for

Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service

AASHTO Designation: M 285M/M 285-07
ASTM Designation: A 744/A 744M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service

AASHTO Designation: M 285M/M 285-07
ASTM Designation: A 744/A 744M-06

1. SCOPE

1.1. This specification covers iron-chromium-nickel alloy, stainless steel castings intended for particularly severe corrosive applications.

1.2. This specification requires postweld heat-treatment of all weld repairs affecting surfaces intended to be wetted by the corrosive medium. For applications for which postweld heat-treatment is not considered mandatory for retention of acceptable corrosion resistance, refer to M 163M/M 163.

Note 1—For general corrosion-resistant alloy castings, reference should be made to M 163M/M 163. For general heat-resistant alloy castings, reference should be made to ASTM A 297/A 297M. For nickel-base alloy castings, refer to ASTM A 494/A 494M.

1.3. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification. SI units are applicable for material ordered to M 285M and inch-pound units for material ordered to M 285.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 163M/M 163, Castings, Iron-Chromium, Iron-Chromium-Nickel, Corrosion Resistant, for General Application
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 262, Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
- A 297/A 297M, Standard Specification for Steel Castings, Iron-Chromium and Iron-Chromium-Nickel, Heat Resistant, for General Application
- A 494/A 494M, Standard Specification for Castings, Nickel, and Nickel Alloy
- A 732/A 732M, Standard Specification for Castings, Investment, Carbon and Low Alloy Steel, for General Application and Cobalt Alloy for High Strength at Elevated Temperatures
- A 781/A 781M, Standard Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use
- A 957/A 957M, Standard Specification for Investment Castings, Steel and Alloy, Common Requirements, for General Industrial Use

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 527, Standard Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

2.3. *American Welding Society Standards*:

- AWS A5.11, Specification for Nickel and Nickel Alloy Covered Welding Electrodes[1]
- AWS A5.14, Specification for Nickel and Nickel Alloy Bare Welding Rods and Electrodes[1]

3. TERMINOLOGY

3.1. *Definition of Term Specific to This Standard*:

3.1.1. *wetted surface, n*—one that contacts a corrosive environment.

4. GENERAL CONDITIONS FOR DELIVERY

4.1. Except for investment castings, castings furnished to this specification shall conform to the requirements of ASTM A 781/A 781M including any supplementary requirements that are indicated on the purchase order. Failure to comply with the general requirements of ASTM A 781/A 781M constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and ASTM A 781/A 781M, this specification shall prevail.

4.2. Steel investment castings furnished to this specification shall conform to the requirements of ASTM A 957, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of ASTM A 957 constitutes nonconformance with this specification. In case of conflict between the requirements of this specification and ASTM A 957, this specification shall prevail.

5. ORDERING INFORMATION

5.1. Orders for material to this specification should include the following, as required, to describe the material adequately:

5.1.1. Description of the casting by pattern number or drawing (dimensional tolerances shall be included on the casting drawing),

5.1.2. Grade,

5.1.3. Heat-treatment,

5.1.4. Identify wetted surface(s),

5.1.5. Options in the specification,

5.1.6. Whether castings are to be produced using the investment casting process, and

5.1.7. Supplementary requirements desired, including the standards of acceptance.

6. PROCESS

6.1. Alloys shall be melted by the electric furnace process with or without separate refining, such as argon-oxygen-decarburization (AOD).

7. HEAT-TREATMENT

7.1. Castings shall be heat-treated in accordance with the requirements in Table 1.

Note 2—Proper heat-treatment of these alloys is usually necessary to enhance corrosion resistance and, in some cases, to meet mechanical properties. Minimum heat-treat temperatures are specified; however, it is sometimes necessary to heat-treat at higher temperatures, hold for some minimum time at temperature, and then rapidly cool the castings in order to enhance the corrosion resistance and meet mechanical properties.

Table 1—Heat-treatment Requirements

Grade (UNS)	Heat-treatment
CF8 (J92600), CG8M (J93000), CF8M (J92900), CF8C (J92710), CF3 (J92500), CF3M (J92800), CG3M (J92999)[a]	Heat to 1040˚C [1900˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CN7M (N08007)	Heat to 1120˚C [2050˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.
CN7MS (J94650)	Heat to 1150˚C [2100˚F] minimum, 1180˚C [2150˚F] maximum, hold for sufficient time (2 h minimum) to heat casting to temperature and quench in water.
CN3MN (J94651)	Heat to 1150˚C [2100˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or cool rapidly by other means.
CK3MCuN (J93254)	Heat to 1150˚C [2100˚F] minimum, hold for sufficient time to heat casting to temperature, quench in water or rapid cool by other means.

[a] For optimum tensile strength, ductility, and corrosion resistance, the solution annealing temperatures for Grades CF8M, CG8M and CF3M should be in excess of 1040˚C [1900˚F].

8. CHEMICAL REQUIREMENTS

8.1. The materials shall conform with the chemical requirements prescribed in Table 2.

9. WORKMANSHIP, FINISH, AND APPEARANCE

9.1. Machined welding ends shall be suitably protected against damage during shipping.

10. REPAIR BY WELDING

10.1. The composition of the deposited weld metal shall be similar to that of the casting except in grade CK3MCuN. In the case of grade CK3MCuN, the composition of the deposited metal shall be similar to that of AWS A5.14ER NiCrMo-3 (UNS NO6625) or AWS A5.11 E NiCrMo-3 (UNS W86112) when postweld heat-treatment is not required, and the composition of the deposited metal shall be either similar to that of the base metal or similar to that of AWS A5.14 ER NiCrMo-3 or AWS A5.11 E NiCrMo-3 when postweld heat-treatment is required.

10.1.1. The composition of the deposited weld metal shall be similar to that of the casting except in grade CN3MN. In the case of grade CN3MN, the composition of the deposited weld metal shall be similar to that of AWS A5.14 ER NiCrMo-3 or ER NiCrMo-4 or ER NiCrMo-10 or the composition of the deposited weld metal shall be similar to that of AWS A5.11 E NiCrMo-3 or E NiCrMo-4 or E NiCrMo-10 when postweld heat-treatment is or is not required.

10.2. Weld repairs shall be considered major in the case of a casting that has leaked on hydrostatic test or when the depth of the cavity after preparation for repair exceeds 20 percent of the actual wall thickness, or 25 mm [1 in.], whichever is smaller, or when the extent of the cavity exceeds approximately 65 cm^2 [10 $\mathrm{in.}^2$]. All other weld repairs shall be considered minor. Major and minor weld repairs shall be subject to the same quality standards as are used to inspect the castings. When methods involving high temperatures are used in the removal of discontinuities, castings shall be preheated to 10°C [50°F] minimum.

Table 2—Chemical Requirements

Grade (UNS)	Type	Carbon, Max	Manganese, Max	Silicon, Max	Phosphorus, Max	Sulfur, Max	Chromium	Nickel	Molybdenum	Columbium	Copper	Selenium	Tungsten, Max	Vanadium, Max	Iron, Max	Nitrogen
		Composition, percent														
CF8 (J92600)	19 Chromium, 9 Nickel	0.08	1.50	2.0	0.04	0.04	18.0–21.0	8.0–11.0	—	—	—	—	—	—	—	—
CF8M (J92900)	19 Chromium, 10 Nickel with Molybdenum	0.08	1.50	2.0	0.04	0.04	18.0–21.0	9.0–12.0	2.0–3.0	—	—	—	—	—	—	—
CF8C (J92710)	19 Chromium, 10 Nickel with Columbium	0.08	1.50	2.0	0.04	0.04	18.0–21.0	9.0–12.0	—	[a]	—	—	—	—	—	—
CF3 (J92500)	19 Chromium, 9 Nickel	0.03[b]	1.50	2.0	0.04	0.04	17.0–21.0	8.0–12.0	—	—	—	—	—	—	—	—
CF3M (J92800)	19 Chromium, 10 Nickel with Molybdenum	0.03[b]	1.50	1.50	0.04	0.04	17.0–21.0	9.0–13.0	2.0–3.0	—	—	—	—	—	—	—
CG3M (J92999)	19 Chromium, 11 Nickel with Molybdenum	0.03	1.50	1.50	0.04	0.04	18.0–21.0	9.0–13.0	3.0–4.0	—	—	—	—	—	—	—
CG8M (J93000)	19 Chromium, 11 Nickel with Molybdenum	0.08	1.50	1.50	0.04	0.04	18.0–21.0	9.0–13.0	3.0–4.0	—	—	—	—	—	—	—
CN7M (N08007)	20 Chromium, 29 Nickel with Copper and Molybdenum	0.07	1.50	1.50	0.04	0.04	19.0–22.0	27.5–30.5	2.0–3.0	—	3.0–4.0	—	—	—	—	—
CN7MS (J94650)	19 Chromium, 24 Nickel with Copper and Molybdenum	0.07	1.0	2.50–3.50	0.04	0.03	18.0–20.0	22.0–25.0	2.5–3.0	—	1.5–2.0	—	—	—	—	—
CN3MN (J94651)	21 Chromium, 24 Nickel with Molybdenum and Nitrogen	0.03	2.00	1.00	0.040	0.010	20.0–22.0	23.5–25.5	6.00–7.00	—	0.75 max	—	—	—	—	0.18–0.26
CK3MCuN (J93254)	20 Chromium, 18 Nickel with Molybdenum and copper	0.025	1.20	1.00	0.045	0.010	19.5–20.5	17.5–19.5	6.0–7.0	—	0.05–1.00	—	—	—	—	0.180–0.240

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[a] Grade CF8C shall have a columbium content of not less than eight times the carbon content and not more than 1.0 percent. If a columbian-plus-tantalum alloy in the approximate Cb:Ta ratio of 3:1 is used for stabilizing this grade, the total columbium-plus-tantalum content shall not be less than nine times the carbon content and shall not exceed 1.1 percent.

[b] For purposes of determining conformance with this specification, the observed or calculated value for carbon content shall be rounded to the nearest 0.01 percent in accordance with the rounding method of ASTM E 29.

10.3. Castings shall be postweld heat-treated in accordance with Table 1 after all major weld repairs and after those minor weld repairs involving either of the following conditions: (1) welding on a wetted surface, or (2) welding that heats a wetted surface to or above 425°C [800°F].

Note 3—The maximum wetted surface temperature of 425°C [800°F] permitted on minor weld repairs without subsequent heat-treatment for the austenitic grades is necessary to avoid sensitization to intergranular corrosion. Minor repairs of this type can be made by using a low heat input (example, 2000 J/mm [50 000 J/in.]) welding process or by cooling wetted surfaces with water during welding, or both. Wetted surface temperature measurement can be accomplished with temperature-indicating crayon or contact pyrometer.

11. REJECTION AND REHEARING

11.1. Samples that represent rejected material shall be preserved for two weeks from the date of transmission of the rejection report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

12. PRODUCT MARKING

12.1. Castings shall be marked for material identification with the AASHTO M 285M/M 285 or ASTM A 744/A 744M specification number and grade symbol; that is, CF8, CN7M, etc. In addition, the manufacturer’s name or identification mark and the pattern number shall be cast or stamped using low-stress stamps on all castings. Small-size castings may be such that marking must be limited consistent with the available area. The marking of heat numbers on individual castings shall be agreed upon by the manufacturer and the purchaser. Marking shall be in such position as not to injure the usefulness of the casting.

13. KEYWORDS

13.1. Austenitic stainless steel; corrosion; stainless steel; steel castings.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall not apply unless specified in the purchase order. A list of standard supplementary requirements for use at the option of the purchaser is included in ASTM A 781/A 781M. Those that are ordinarily considered for use with this specification are given below. Others enumerated in ASTM A 781/A 781M may be used with this specification upon agreement between the manufacturer and the purchaser.

S2. RADIOGRAPHIC EXAMINATION

S3. LIQUID PENETRANT EXAMINATION

S5. EXAMINATION OF WELD PREPARATION

S6. CERTIFICATION

S7. PRIOR APPROVAL OF MAJOR WELD REPAIRS

S21. INTERGRANULAR CORROSION TEST

S21.1 An intergranular corrosion test shall be performed in accordance with the appropriate practice for the grade involved, as listed in ASTM A 262, or as agreed upon with the purchaser. Intergranular corrosion tests on stabilized or 0.03 percent carbon maximum grades (CF3, CF3M, CF8C, CG3M, CK3MCuN, and CN3MN) shall be made on sensitized specimens. On all other grades of chromium-nickel steels, intergranular corrosion tests shall be made on specimens representative of the as-shipped condition.

S22. TENSION TEST

S22.1 Tensile properties shall be determined from material representing each heat. The bar from which the test specimen is taken shall be heat-treated in production furnaces to the same procedure as the casting it represents. The results shall conform to the requirements specified in Table 3.

Table 3—Tensile Requirements

Grade (UNS)	Type	Tensile Strength, Min MPa	Tensile Strength, Min [ksi]	Yield Strength, Min MPa	Yield Strength, Min [ksi]	Elongation in 50 mm [2 in.], Min, percent[a]
CF8 (J92600)	19 Chromium, 9 Nickel	485[b]	[70][b]	205[b]	[30][b]	35[b]
CF8M (J92900)	19 Chromium, 10 Nickel with Molybdenum	485	[70]	205	[30]	30
CF8C (J92710)	19 Chromium, 10 Nickel with Columbium	485	[70]	205	[30]	30
CF3 (J92500)	19 Chromium, 9 Nickel	485	[70]	205	[30]	35
CF3M (J92800)	19 Chromium, 10 Nickel with Molybdenum	485	[70]	205	[30]	30
CG3M (J92999)	19 Chromium, 11 Nickel with Molybdenum	515	[75]	240	[35]	25
CG8M (J93000)	19 Chromium, 11 Nickel with Molybdenum	520	[75]	240	[35]	25
CN7M (N08007)	20 Chromium, 29 Nickel with Copper and Molybdenum	425	[62]	170	[25]	35
CN7MS (J94650)	19 Chromium, 24 Nickel with Copper and Molybdenum	485	[70]	205	[30]	35
CN3MN (J94651)	21 Chromium, 24 Nickel with Molybdenum and Nitrogen	550	[80]	260	[38]	35
CK3MCuN (J93254)	20 Chromium, 18 Nickel with Molybdenum and Copper	550	[80]	260	[38]	35

[a] When ICI test bars are used in tensile testing as provided for in this specification, the gauge length to reduced section diameter ratio shall be 4:1.

[b] For low-ferrite or nonmagnetic castings of this grade, the following values shall apply: tensile strength, min 450 MPa [65 ksi]; yield point, min 195 MPa [28 ksi].

S22.2 Test bars shall be poured in separately cast keel blocks similar to Figures 1 or 2 of ASTM A 781/A 781M.

S22.3 Tension test specimens may be cut from heat-treated castings, or from as-cast castings if no heat-treatment is specified for the castings, instead of from test bars, when agreed upon by the manufacturer and the purchaser.

S22.4 Test specimens shall be machined to the form and dimensions of the standard round 50-mm [2-in.] gauge length specimen shown in Figure 6 of T 244, unless the purchase order is for investment castings, in which case the specimens shall be prepared in accordance with S3.2 of ASTM A 732/A 732M. Testing shall be in accordance with T 244.

S22.5 If the results of the mechanical tests for any heat, lot, or casting do not conform to the requirements specified, retests are permitted as outlined in T 244. At the manufacturer's option, castings may be reheat-treated and retested. When castings are reheat-treated, they may not be reaustenitized more than three times without the approval of the purchaser. Testing after reheat-treatment shall consist of the full number of specimens taken from locations complying with the specification or order.

S23. SURFACE CARBON ANALYSIS

S23.1 An analysis for carbon shall be made from a casting representative of each heat. The sample for the analysis shall be within 0.25 mm [0.010 in.] of the surface and taken after removal of scale and other contaminants at a location to be agreed upon between the manufacturer and purchaser. The carbon content shall meet the carbon requirement of the pertinent grade as shown in Table 2. Other sampling depths and surface carbon requirements may be agreed upon between the purchaser and manufacturer.

APPENDIX

(Nonmandatory Information)

X1. RECOMMENDED FILLER METALS FOR CAST STAINLESS STEELS

X1.1. Listed in Table X1.1, for information, are the filler metals most commonly recommended for welding cast stainless steels. Only those materials having AWS designations are included. The standard prefixes designating covered electrodes, bare rod, etc., and the usability suffixes have been intentionally omitted. Special applications, or supplier or customer preference, may dictate the use of alternate or overmatched filler materials.

Table X1.1—Recommended Filler Materials for Cast Stainless Steel

Casting ACI Designation (UNS)	Recommended Filler Material (AWS Designation)
CF8 (J92600)	308
CF8M (J92900)	316, 308Mo
CF8C (J92710)	309Cb, 347
CF3 (J92500)	308L
CF3M (J92800)	308MoL 316L
CG3M (J92999)	317L
CG8M (J93000)	317
CN3MN (J94651)	NiCrMo-3, NiCrMo-12
CN7M (N08007)	320, 320LR
CN7MS (J94650)	320, 320LR
CK3MCuN (J93254)	NiCrMo-3, NiCrMo-12

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[1] Available from American Welding Society, P.O. Box 351040, 550 N.W. LeJeune Road, Miami, FL 33135.

Standard Specification for

Carbon and Alloy Steel Nuts

AASHTO Designation: M 291-09
ASTM Designation: A 563-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Carbon and Alloy Steel Nuts

AASHTO Designation: M 291-09
ASTM Designation: A 563-07

AASHTO M 291-09 is identical to ASTM A 563-07 except for the following provisions:

1. All references to the ASTM standards contained in ASTM A 563-07, listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standards

ASTM	AASHTO
A 194/A 194M	M 292M/M 292
A 325	M 164
A 490M	M 253
A 709/A 709M	M 270M/M 270
B 695	M 298
F 2329	M 232M/M 232

2. Replace Section 3.1.7 of ASTM A 563-07 with the following:

   3.1.7 AASHTO designation and year of issue, and

3. Replace Note 3 of ASTM A 563-07 with the following:

Note 3—An example of an ordering description follows: 1000 $^{7}/_{8}$–9 heavy hex nuts, Grade C, hot-dip zinc-coated, AASHTO M 291-____.

4. Sections 5.4 and 5.5 of ASTM A 563-07 are not included in AASHTO M 291-09.
5. Replace the last row in Table 3 of ASTM A 563-07 with the following:

DH[D]	$^{1}/_{4}$ to $1^{1}/_{2}$	hex thick	175	150	248	352	C24	C38

6. Add a last sentence to Footnote A in Table 3 of ASTM A 563-07 as follows:

   "When M 292 zinc-coated inch series nuts are supplied, the zinc coating, overtapping, lubrication, and rotational capacity testing shall be in accordance with M 291."

7. Add a last sentence to Footnote B in Table 3 of ASTM A 563-07 as follows:

   "When M 292 zinc-coated inch series nuts are supplied, the zinc coating, overtapping, lubrication, and rotational capacity testing shall be in accordance with M 291."

8. Add the following subsection to Section 10 of ASTM A 563-07.

   10.2 The proof load should be determined at a free running cross head speed not exceeding 1.0 in./min and shall be maintained for 10 seconds before releasing the load.

9. Replace Section 15.2.1.1 of ASTM A 563-07 with the following:

   15.2.1.1 AASHTO designation and grade,

10. Replace Section 16.1 of ASTM A 563-07 with the following:

    16.1 The party responsible for the fastener shall be the organization that supplies the fastener to the purchaser. The responsible party shall supply test reports, certified by the manufacturer, that indicate the fasteners were manufactured, sampled, tested, and inspected in accordance with this specification and meet all of its requirements.

11. Add the following Subsection S1.2 to ASTM A 563-07:

S1.2 Zinc-coated bolts and zinc-coated lubricated nuts shall be capable of conforming to the test requirement in Section S1.2.1. After this tightening test, the assembly shall show no signs of failure.

S1.2.1 A zinc-coated bolt shall be placed in a steel joint and assembled with a zinc-coated washer and a zinc-coated nut. The joint shall be one or more flat structural steel plates with a total thickness, including the washer, such that three to five full threads of the bolt are located between the bearing surfaces of the bolt head and nut. The hole in the joint shall have the same nominal diameter as the hole in the washer. The initial tightening of the nut shall produce a load in the bolt not less than 10 percent of the specified proof load. After this initial tightening, the nut position shall be marked relative to the bolt and the rotation shown in Table 1 shall be applied. During rotation, the bolt head shall be restrained from turning.

12. Add Table S1.1 to immediately follow Section S1 of ASTM A 563-07.

Table S1.1—Rational Capacity Test for Zinc-Coated Nuts

Bolt Length, in.	Nominal Nut Rotation, Deg (Turn)
Up to and including 4 × dia	300 ($^{5}/_{6}$)
Over 4 × dia but exceeding 8 × dia	360 (1)
Over 8 × dia	420 ($1^{1}/_{6}$)

13. Replace top row (A 563 Grade and ANSI Nut Style), row 3 (Grade of Bolt: A 325 Type 1) and row 4 (Grade of Bolt: A 325 Type 3) in Table X1.1 of ASTM A 563-07 with the following:

Table X1.1—Nut and Bolt Suitability Guide

			M 291 Grade and ANSI Nut Style[a]					
			Recommended[b]		Suitable[c]			
Grade of Bolt[d]	Surface Finish[e]	Nominal Size, in.	Hex	Heavy Hex	Square	Hex	Heavy Hex	Hex Thick
M 164 Types 1 and 2	Non-zinc coated	$^{1}/_{2}$ to $1^{1}/_{2}$	—	C	—	—	C3, D, DH, DH3	—
	Zinc-coated	$^{1}/_{2}$ to $1^{1}/_{2}$	—	DH	—	—	—	—
M 164 Type 3	Non-zinc coated	$^{1}/_{2}$ to $1^{1}/_{2}$	—	C3	—	—	DH3	—

14. Replace row 11 (Grade of Bolt: A 490 Types 1 and 2) and row 12 (Grade of Bolt: A 490 Type 3) in Table X1.1 of ASTM A 563-07 with the following:

Table X1.1—Nut and Bolt Suitability Guide

			M 291 Grade and ANSI Nut Style[a]					
			Recommended[b]		Suitable[c]			
Grade of Bolt[d]	Surface Finish[e]	Nominal Size, in.	Hex	Heavy Hex	Square	Hex	Heavy Hex	Hex Thick
M 253 Type 1	Non-zinc coated	$^{1}/_{2}$ to $1^{1}/_{2}$	—	DH	—	—	DH3	—
M 253 Type 3	Non-zinc coated	$^{1}/_{2}$ to $1^{1}/_{2}$	—	DH3	—	—	—	—

Standard Specification for

Carbon and Alloy Steel Nuts [Metric]

AASHTO Designation: M 291M-07
ASTM Designation: A 563M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Carbon and Alloy Steel Nuts [Metric]

AASHTO Designation: M 291M-07
ASTM Designation: A 563M-06

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM A 563M-06 for the information formerly contained in this standard.

Standard Specification for

Carbon and Alloy Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both

AASHTO Designation: M 292M/M 292-10
ASTM Designation: A 194/A 194M-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Carbon and Alloy Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both

AASHTO Designation: M 292M/M 292-10
ASTM Designation: A 194/A 194M-09

1. SCOPE

1.1. This specification covers a variety of carbon, alloy, and martensitic stainless steel nuts in the size range M6 through M100 [$^1/_4$ through 4 in.] nominal. It also covers austenitic stainless steel nuts in the size range M6 [$^1/_4$ in.] nominal and above. These nuts are intended for high-pressure or high-temperature service or both. Grade substitutions without the purchaser's permission are not allowed.

1.2. Bars from which the nuts are made shall be hot-wrought. The material may be further processed by centerless grinding or by cold drawing. Austenitic stainless steel may be solution annealed or annealed and strain-hardened. When annealed and strain-hardened austenitic stainless steel is ordered in accordance with Supplementary Requirement S1, the purchaser should take special care to ensure that Section 8.2.2, Supplementary Requirement S1, and Appendix X1 are thoroughly understood.

1.3. Supplementary requirements (Sections S1 through S8) of an optional nature are provided. These shall apply only when specified in the inquiry, contract, and order.

1.4. This specification is applicable to orders in either SI units (as M 292M) or inch-pound units (as M 292). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text. Material shall be furnished to SI units when the order specifies the applicable "M" designation.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- M 299, Coatings of Cadmium Mechanically Deposited
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 276, Standard Specification for Stainless Steel Bars and Shapes
- A 320/A 320M, Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service
- A 370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products

- A 962/A 962M, Standard Specification for Common Requirements for Steel Fasteners or Fastener Materials, or Both, Intended for Use at Any Temperature from Cryogenic to the Creep Range
- B 633, Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
- B 766, Standard Specification for Electrodeposited Coating of Cadmium
- E 18, Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
- E 112, Standard Test Methods for Determining the Average Grain Size
- F 1940, Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners
- F 1941, Standard Specification for Electrodeposited Coatings on Threaded Fasteners (Unified Inch Screw Threads (UN/UNR))
- F 2329, Standard Specification for Zinc Coating, Hot Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners

2.3. *ANSI Standards*: [1]

- B1.1, Unified Screw Threads
- B1.13M, Metric Screw Threads
- B18.2.2, Square and Hex Nuts
- B18.2.4.6M, Metric Heavy Hex Nuts

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *austenitic grades*—all grades with a prefix of “8” or “9.”

3.1.2. *ferritic grades*—Grades 1, 2, 2H, 2HM, 3, 4, 6, 6F, 7, 7M, and 16.

3.1.3. *Lot*:

3.1.3.1. Unless otherwise specified (Section 3.1.3.2), a lot is the quantity of nuts of a single nominal size and grade produced by the same manufacturing process.

3.1.3.2. When Supplementary Requirement S5 is invoked on the purchase order, the following definitions of a lot shall apply:

for Grade 8 nuts—the quantity of all the nuts of a single nominal diameter and grade made from the same heat of steel and made by the same manufacturing process.

for all other grade nuts (Sections 8.2 and 8.1.2.1)—all the nuts of a single nominal diameter and grade made from the same heat number and heat-treated in the same batch if batch-type heat-treating equipment is used or heat-treated in the same continuous run of not more than 8 hours under the same conditions if continuous-type heat treating equipment is used.

3.1.4. *Type*:

3.1.4.1. *for Grade 8 nuts*—variations within the grade designated by a letter and differentiated by chemistry and by manufacturing process.

3.1.4.2. *for Grade 6 nuts*—variations within the grade designated by the letter F and differentiated by chemical additions made for machinablility.

3.1.5. *series*—the dimensional relationship and geometry of the nuts as described in ANSI B18.2.2 or B18.2.4.6M.

4. ORDERING INFORMATION

4.1. The inquiry and order for material under this specification shall include the following as required to describe the material adequately:

4.1.1. Specification designation, year date, grade, issue date, and revision letter;

4.1.2. Quantity, number of pieces;

4.1.3. Dimensions (Section 9);

4.1.4. Options in accordance with Sections 8.2.2.1, 9.1, 9.2, 10.3, and 12; and

4.1.5. Supplementary Requirements, if any.

4.2. *Coatings*—Coatings are prohibited unless specified by the purchaser (see Supplementary Requirements S7 and S8). When coated nuts are ordered, the purchaser should take special care to ensure that Appendix X2 is thoroughly understood.

4.3. See Supplementary Requirement S3 for nuts to be used in low-temperature applications (Specification ASTM A 320/A 320M).

4.4. See Supplementary Requirement S9 for proof-load testing of nuts manufactured to dimensions and configurations other than those covered in Tables 3 or 4.

5. COMMON REQUIREMENTS

5.1. Material and fasteners supplied to this specification shall conform to the requirements of ASTM A 962/A 962M. These requirements include test methods, finish, thread dimensions, marking, certification, optional supplementary requirement, and others. Failure to comply with the requirements of specification ASTM A 962/A 962M constitutes nonconformance with this specification. In case of conflicts between the requirements of this specification and specification ASTM A 962/A 962M, this specification shall prevail.

6. MANUFACTURE (PROCESS)

6.1. Stainless steels for all types of Grade 6 and 8 nuts shall be made by one of the following processes:

6.1.1. Electric-furnace (with separate degassing and refining optional),

6.1.2. Vacuum induction furnace, or

6.1.3. Either of the above followed by electroslag remelting or consumable-arc remelting.

6.2. The steel producer shall exercise adequate control to eliminate excessive inhomogeneity, nonmetallics, pipe, porosity, and other defects.

6.3. Grades 1 and 2 nuts shall be hot or cold forged, or shall be machined from hot-forged, hot-rolled, or cold-drawn bars.

6.3.1. All Grade 1 and 2 nuts made by cold forging or by machining from cold-drawn bars shall be stress-relief annealed at a temperature of at least 538°C [1000°F].

6.3.2. Grade 1 and 2 nuts made by hot forging or by machining from hot-forged or hot-rolled bars need not be given any stress relief annealing treatment.

6.4. Grades 2H, 2HM, 3, 4, 6, 6F, 7, 7M, and 16 nuts shall be hot or cold forged or shall be machined from hot-forged, hot-rolled, or cold-drawn bars and shall be heat-treated to meet the required mechanical properties. Nuts machined from bars heat-treated in accordance with this specification need not be reheat treated. For Grade 2HM and 7M nuts, a final stress relief shall be done at or above the minimum tempering temperature after all forming, machining, and tapping operations. This final stress relief may be the tempering operation. These grades of nuts shall be reheated above the critical range of the steel, quenched in a suitable medium, and then tempered at a temperature not less than the following:

Grade and Type	Minimum Tempering Temperature, °C [°F]
2H	455 [850]
2HM	620 [1150]
3	565 [1050]
4	595 [1100]
6 and 6F	595 [1100]
7	595 [1100]
7M	620 [1150]
16	650 [1200]

6.4.1. Grade 6 and 6F nuts shall be tempered for a minimum of 1 hour at the temperature.

6.5. Grades 8, 8C, 8M, 8T, 8F, 8P, 8N, 8MN, 8R, 8S, 8LN, 8MLN, 8MLCuN, and 9C nuts shall be hot or cold forged, or shall be machined from hot-forged, hot-rolled, or cold-drawn bars.

6.6. Grades 8A, 8CA, 8MA, 8TA, 8FA, 8PA, 8NA, 8MNA, 8RA, 8SA, 8LNA, 8MLNA, 8MLCuNA, and 9CA nuts shall be hot or cold forged or shall be machined from hot-forged, hot-rolled, or cold-drawn bars and the nuts shall subsequently be carbide-solution treated by heating them for a sufficient time at a temperature to dissolve chromium carbides followed by cooling at a rate sufficient to prevent reprecipitation of the carbides.

Table 1—Chemical Requirements[a,b,c]

Grade Symbol	Material	UNS Number	Carbon, percent	Manganese, percent	Phospho–rus, percent	Sulfur,[d] percent	Silicon, percent	Chromium, percent	Nickel, percent	Molybde–num, percent	Titanium, percent	Columbium and Tan-talum, percent	Selenium, percent	Other Elements, percent
1	carbon		0.15 min	1.00 max	0.040 max	0.050 max	0.40 max	—	—	—	—	—	—	—
2,2 HM, and 2H	carbon		0.040 min	1.00 max	0.040 max	0.050 max	0.040 max	—	—	—	—	—	—	—
4	carbon molybdenum		0.40–0.50	0.70–0.90	0.035 max	0.040 max	0.15–0.35	—	—	0.20–0.30	—	—	—	—
3	AISI 501		0.10 min	1.00 max	0.040 max	0.030 max	1.00 max	4.00–6.00	—	0.40–0.65	—	—	—	—
6	AISI 410	S41000	0.15 max	1.00 max	0.040 max	0.030 max	1.00 max	11.50–13.50	—	—	—	—	—	—
6F	AISI 416 with sulfur	S41600	0.15 max	1.25 max	0.060 max	0.15 min	1.00 max	12.00–14.00	—	—	—	—	—	—
6F	AISI 416 with selenium	S41623	0.15 max	1.25 max	0.060 max	0.060 max	1.00 max	12.00–14.00	—	—	—	—	0.15 min	—
7, 7M	AISI 4140/ 4142/4145/ 4140H 4142H 4145H		0.37–0.49	0.65–1.10	0.035 max	0.04 max	0.15–0.35	0.75–1.20	—	0.15–0.25	—	—	—	—
8, 8A	AISI 304	S30400	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	18.00–20.00	8.00–11.0	—	—	—	—	—
8C, 8CA	AISI 347	S34700	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	17.00–19.00	9.00–12.0	—	—	10 × carbon content, min	—	—
8M, 8MA	AISI 316	S31600	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	16.00–18.00	10.00–14.00	2.00–3.00	—	—	—	—
8T, 8TA	AISI 321	S32100	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	17.00–19.00	9.00–12.00	—	5 × (C+N), min– 0.70 max.	—	—	Nitrogen, 0.10
8F, 8FA	AISI 303 with sulfur	S30300	0.15 max	2.00 max	0.20 max	0.15 min	1.00 max	17.00–19.00	8.00–10.00	—	—	—	—	—
8F, 8FA	AISI 303 with selenium	S30323	0.15 max	2.00 max	0.20 max	0.06 max	1.00 max	17.00–19.00	8.00–10.00	—	—	—	0.15 min	—
8P, 8PA	AISI 305 with restricted carbon	S30500	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	17.00–19.00	11.00–13.00	—	—	—	—	—
8N, 8NA	AISI 304N	S30451	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	18.00–20.00	8.00–11.0	—	—	—	—	Nitrogen, 0.10–0.16

Continued on next page.

Table 1—Chemical Requirements[a,b,c] *(Continued)*

Grade Symbol	Material	UNS Number	Carbon, percent	Manganese, percent	Phosphorus, percent	Sulfur,[d] percent	Silicon, percent	Chromium, percent	Nickel, percent	Molybdenum, percent	Titanium, percent	Columbium and Tantalum, percent	Selenium, percent	Other Elements, percent
8LN, 8LNA	AISI 304LN with restricted carbon	S30453	0.030 max	2.00 max	0.045 max	0.030 max	1.00 max	18.00–20.00	8.00–11.0	—	—	—	—	Nitrogen, 0.10–0.16
8MN, 8MNA	AISI 316N	S31651	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	16.00–18.00	10.00–13.00	2.00–3.00	—	—	—	Nitrogen, 0.10–0.16
8MLN, 8MLNA	AISI 316LN with restricted carbon	S31653	0.030 max	2.00 max	0.045 max	0.030 max	1.00 max	16.00–18.00	10.00–13.00	2.00–3.00	—	—	—	Nitrogen, 0.10–0.16
8R, 8RA[e]	XM19	S20910	0.06 max	4.00–6.00	0.045 max	0.030 max	1.00 max	20.5–23.5	11.5–13.5	1.5–3.0	—	0.10–0.30	—	Nitrogen, 0.20–0.40 Vanadium, 0.10–0.30
8S, 8SA		S21800	0.10 max	7.0–9.0	0.060 max	0.030 max	3.5–4.5	16.0–18.0	8.0–9.0	—	—	—	—	Nitrogen, 0.08–0.18
8MLCuN, 8MLCuNA	S 31254	S31254	0.020 max	1.00 max	0.030 max	0.010 max	0.80 max	19.5–20.5	17.5–18.5	6.0–6.5	—	—	—	Nitrogen, 0.18–0.22 Copper, 0.50–1.00
9C, 9CA	N08367	N08367	0.030 max	2.00 max	0.040 max	0.030 max	1.0	20.0–22.0	23.5–25.5	6.0–7.0—	—	—	—	Nitrogen, 0.18–0.25 Copper, 0.75
16	Chromium Molybdenum Vanadium		0.36–0.47	0.45–0.70	0.035 max	0.040 max	0.15–0.35	0.80–1.15	—	0.50–0.65	—	—	—	Vanadium, 0.25–0.35 Aluminum 0.015 max

[a] The intentional addition of Bi, Se, Te, and Pb is not permitted except for Grades 6F, 8F, and 8FA, in which Se is specified and required.

[b] Total aluminum, soluble, and insoluble.

[c] Maximum, unless minimum or range is indicated.

[d] Because of the degree to which sulfur segregates, product analysis for sulfur over 0.060 percent max is not technologically appropriate.

[e] As described in Specification ASTM A 276.

7. CHEMICAL COMPOSITION

7.1. Each alloy shall conform to the chemical composition requirements prescribed in Table 1.

8. MECHANICAL REQUIREMENTS

8.1. *Hardness Test*:

8.1.1. Requirements:

8.1.1.1. All nuts shall be capable of meeting the hardness requirements specified in Table 2.

8.1.1.2. Sample nuts of Grades 1, 2, 2H, 2HM, 3, 4, 7, 7M, and 16 that have been given the treatment described in Section 8.1.5 shall meet the minimum hardness specified in Table 2.

Table 2—Hardness Requirements

		Completed Nuts		Sample Nut After Treatment as in Section 8.1.5	
		Rockwell Hardness			
Grade and Type	Brinell Hardness	C Scale	B Scale	Brinell Hardness, Min	Rockwell Hardness B Scale, Min
1	121 min	—	70 min	121	70
2	159–352	—	84 min	159	84
2H to M36 [1½ in.], incl.	248–327	24–35	—	179	89
2H over M36 [1½ in.]	212–327	35 max	95 min	147	79
2HM and 7M	159–235		84–99	159	84
3, 4, 7, and 16	248–327	24–35	—	201	94
6 and 6F	228–271	20–28	—	—	—
8, 8C, 8M, 8T, 8F, 8P, 8N, 8MN, 8LN, 8MLN, 8MLCuN, and 9C	126–300	32 max	60 min	—	—
8A, 8CA, 8MA, 8TA, 8FA, 8PA, 8NA, 8MNA, 8LNA, 8MLNA, 8MLCuNA, and 9CA	126–192	—	60–90	—	—
8R, 8RA, 8S, and 8SA	183–271	25 max	88 min	—	—

8.1.2. Number of Tests (Grades 1, 2, 2H, 3, 4, 7, and 16 and all types of Grade 6):

8.1.2.1. Tests on the number of sample nuts in accordance with the following table shall be performed by the manufacturer following all production heat treatments:

Lot Size	Samples
Up to 800	1
801 to 8000	2
8001 to 22000	3
>22000	5

8.1.2.2. In addition, a hardness test shall be performed by the manufacturer in accordance with Section 8.1.5 on one sample nut selected from each nominal diameter and series from each grade and heat number following completion of all production heat treatments.

8.1.3. *Number of Tests, Grades 2HM and 7M*:

8.1.3.1. Each nut shall be tested by Brinell or Rockwell methods to ensure product conformance.[2]

8.1.3.2. In addition, Section 8.1.2.2 shall be met.

8.1.4. *Number of Tests, All Types of Grade 8*—Tests on the number of sample nuts in accordance with Section 8.1.2.1 shall be performed by the manufacturer.

8.1.5. *Test 2*—In addition to the testing required by Section 8.1.2.1, the manufacturer shall also perform hardness tests on sample nuts after the following test heat treatment. After completion of all production heat treatments, heat the specimen nuts to the temperatures indicated below for 24 hours, then slow cool. Test at room temperature.

Grade[a]	Temperature, °C [°F]
1	455 [850]
2, 2H, 2HM	540 [1000]
3, 4, 7, 7M	590 [1100]
16	650 [1200]

[a] Nuts intended to be coated with zinc or cadmium (marked in accordance with the requirements of Supplementary Requirements S8) are not subjected to the requirements of 8.1.5 (see Appendix X2).

8.1.5.1. *Special Requirement, Grades 2HM and 7M*—Preparation of Grades 2HM and 7M nuts for hardness test and the hardness test itself shall be performed with consideration to (1) protect legibility of markings; (2) minimize exterior dimensional changes; and (3) maintain thread fit.

8.2. *Proof Load Test*:

8.2.1. *Requirements*—All nuts listed in Tables 3 or 4 shall be capable of withstanding the proof loads specified therein. Proof-load testing of nuts manufactured to dimensions and configurations other than those covered in Table 3 or 4 is required only when S9 is specified in the order or inquiry.

Table 3—Proof Load Using Threaded Mandrel [Metric]

Nominal Size, mm	Thread pitch	Stress Area, mm^2	Proof Load, kN[a]					
			Grade 1		Grades 2, 2HM, 6, 6F, 7M		Grades 2H, 3, 4, 7, 16	
			Heavy Hex[b]	Hex[c]	Heavy Hex[d]	Hex[e]	Heavy Hex[f]	Hex[g]
M6	1.0	20.1	18.0	16.6	20.8	18.7	29.2	20.8
M8	1.25	38.6	32.8	30.2	37.9	34.0	44.1	37.9
M10	1.50	58.0	51.9	47.9	60.0	53.9	69.9	60.0
M12	2.0	84.3	75.5	69.5	87.3	78.4	101.6	87.3
M14	2.0	115.0	102.9	94.9	119.0	107.0	138.6	119.0
M16	2.0	157.0	140.5	129.5	162.5	146.0	189.2	162.5
M20	2.5	245.0	219.3	202.1	253.6	227.8	295.2	253.6
M22	2.5	303.0	271.2	249.9	313.6	281.8	365.1	313.6
M24	3.0	353.0	315.9	291.2	365.4	328.3	425.4	365.4
M27	3.0	459.0	411.0	3787	475.1	426.9	553.4	475.1
M30	3.5	561.0	502.1	462.8	580.6	521.7	676.0	580.6
M36	4.0	817.0	731.2	674.0	845.6	759.8	984.5	845.6

			All Types of Grade 8, and Grades 9C and 9CA	
			Heavy Hex[h]	Hex[i]
M6	1.0	20.1	11.1	10.4
M8	1.25	38.6	20.1	18.8
M10	1.50	58.0	31.9	29.9
M12	2.0	84.3	46.4	43.4
M14	2.0	115.0	63.3	59.2
M16	2.0	157.0	86.4	80.9
M20	2.5	245.0	134.8	126.2
M22	2.5	303.0	166.7	156.0
M24	3.0	353.0	194.2	181.8
M27	3.0	459.0	252.5	236.4
M30	3.5	561.0	308.6	288.9
M36	4.0	817.0	449.4	420.8

[a] See limit for proof-load test in Section 8.2.2.1. The proof load for jam nuts shall be 46 percent of the tabulated load.

[b] Based on proof stress of 895 MPa.

[c] Based on proof stress of 825 MPa.

[d] Based on proof stress of 1035 MPa.

[e] Based on proof stress of 930 MPa.

[f] Based on proof stress of 1205 MPa.

[g] Based on proof stress of 1035 MPa.

[h] Based on proof stress of 550 MPa.

[i] Based on proof stress of 515 MPa.

Note: Proof loads are not design loads.

Table 4—Proof-Load Using Threaded Mandrel [Inch Series]

Nominal Size, in.	Threads per inch	Stress Area, mm^2, [in.^{2}]	Proof Load, kN [lbf][a]					
			Grade 1		Grades 2, 2HM, 6, 6F, 7M		Grades 2H, 3, 4, 7, 16	
			Heavy Hex[b]	Hex[c]	Heavy Hex[d]	Hex[e]	Heavy Hex[f]	Hex[g]
$^1/_4$	20	0.0316	4130	3820	4770	4300	5570	4770
$^5/_{16}$	18	0.0524	6810	6290	7860	7070	9170	7860
$^3/_8$	16	0.0774	10080	9300	11620	10460	13560	11620
$^7/_{16}$	14	0.1063	13820	12760	15940	14350	18600	15940
$^1/_2$	13	0.1419	18450	17030	21280	19160	24830	21280
$^9/_{16}$	12	0.182	23660	21840	27300	24570	31850	27300
$^5/_8$	11	0.226	29380	27120	33900	30510	39550	33900
$^3/_4$	10	0.334	43420	40080	50100	45090	58450	50100
$^7/_8$	9	0.462	60060	55440	69300	62370	80850	69300
1	8	0.606	78780	72720	9090	81810	106000	90900
1$^1/_8$	8	0.790	102700	94800	118500	106700	138200	118500
1$^1/_4$	8	1.000	130000	120000	150000	135000	175000	150000
1$^3/_8$	8	1.233	160200	148000	185000	166500	215800	185000
1$^1/_2$	8	1.492	194000	170040	223800	201400	261100	223800

			All Types of Grade 8, and Grades 9C and 9CA	
			Heavy Hex[h]	Hex[i]
$^1/_4$	20	0.0316	2540	2380
$^5/_{16}$	18	0.0524	4190	3930
$^3/_8$	16	0.0774	6200	5810
$^7/_{16}$	14	0.1063	8500	7970
$^1/_2$	13	0.1419	11350	10640
$^9/_{16}$	12	0.182	14560	13650
$^5/_8$	11	0.226	18080	16950
$^3/_4$	10	0.334	26720	25050
$^7/_8$	9	0.462	36960	34650
1	8	0.606	48480	45450
1$^1/_8$	8	0.790	63200	59250
1$^1/_4$	8	1.000	80000	75000
1$^3/_8$	8	1.233	98640	92450
1$^1/_2$	8	1.492	119360	111900

See limit for proof-load test in Section 8.2.2.1. The proof load for jam nuts shall be 46 percent of the tabulated load.

[b] Based on proof stress of 130000 psi.

[c] Based on proof stress of 120000 psi.

[d] Based on proof stress of 150000 psi.

[e] Based on proof stress of 9135000 psi.

[f] Based on proof stress of 1175000 psi.

[g] Based on proof stress of 150000 psi.

[h] Based on proof stress of 80000 psi.

[i] Based on proof stress of 75000 psi.

Note: Proof loads are not design loads.

8.2.2. *Number of Tests*:

8.2.2.1. The manufacturer shall test the number of nuts specified in 8.1.2.1 following all production heat treatments. Nuts that would require a proof load in excess of 705 kN [160 000 lbf] may be furnished on the basis of minimum hardness requirements. Testing of nuts requiring a proof load in excess of 705 kN [160 000 lbf] is covered in Supplementary Requirements S1 and S4.

8.2.3. *Test Method*—The test shall be in accordance with Appendix A3, Paragraph A3.5.1 of T 244.

8.3. *Cone Proof Load*:

8.3.1. *Requirements*—This test shall be performed only when visible surface discontinuities become a matter of issue between the manufacturer and the purchaser. The requirements specified in Table 5 and Table 6 shall be met for the size range M6 to M36 [$^1/_4$ to $1^1/_2$ in.]. Nuts in the size range $^1/_4$ to $1^1/_2$ in. inclusive and M6 to M36 inclusive shall be proof-load tested. Nuts not in this size range and all types of Grade 8 nuts are not subject to this test. Also, nuts manufactured to dimensions and configurations other than those covered by ASTM A 962/A 962M, ANSI B1.1, B1.13M, B18.2.2, and B18.2.4.6M are not subject to the cone proof load test. The cone proof load applied shall be determined in accordance with the Cone Proof Load requirements in ASTM A 962/A 962M (tables, or formulae, or both) based upon the proof stresses shown in Tables 5 and 6 of M 292M/M 292.

Table 5—Proof Load Using 120° Hardened Steel Cone[a] [Metric]

Nominal Size, mm	Thread pitch	Stress Area, mm^2	Proof Load, kN [lbf][a]					
			Grade 1		Grades 2, 2HM, 6, 6F, 7M			Grades 2H, 3, 4, 7, 16
			Heavy Hex[b]	Hex[c]	Heavy Hex[d]	Hex[e]	Heavy Hex[f]	Hex[d]
M6	1.0	20.1	16.9	15.4	19.3	17.3	22.5	19.3
M8	1.25	38.6	29.6	27.3	34.2	30.8	39.9	34.2
M10	1.50	58.0	45.7	42.1	52.8	47.5	61.5	52.8
M12	2.0	84.3	64.6	59.5	74.7	67.1	86.9	74.7
M14	2.0	115.0	85.6	78.9	99.0	88.9	115.3	99.0
M16	2.0	157.0	113.5	104.7	131.2	118.0	152.9	131.2
M20	2.5	245.0	166.6	153.6	192.7	173.2	224.4	192.7
M22	2.5	303.0	199.6	183.9	230.8	207.4	268.7	230.8
M24	3.0	353.0	224.9	207.4	260.1	233.7	302.9	260.1
M27	3.0	459.0	277.7	256.0	321.1	288.6	373.9	321.1
M30	3.5	561.0	321.3	296.2	371.6	334.0	432.6	371.6
M36	4.0	817.0	415.3	382.8	480.3	431.6	559.2	480.3

[a] Based upon the following equation (this equation cannot be used for extrapolating values beyond the size ranges listed in this table):

$CPL = (1 - 0.012D) \times f \times A_s \times 0.001$

where:

CPL = cone stripping proof load kN;

D = nominal diameter of nut, mm;

f = minimum proof stress of nut, MPa (See footnotes *b, c, d, e,* and *f*.);

A_s = tensile stress area of nut, in.^{2} = $0.7854\ [D - 0.9382P]^2$;

P = thread pitch, mm .

[b] Based on proof stress of 895 MPa.

[c] Based on proof stress of 825 MPa.

[d] Based on proof stress of 1035 MPa.

[e] Based on proof stress of 930 MPa.

[f] Based on proof stress of 1205 MPa.

Table 6—Proof Load Using 120° Hardened Steel Cone[a] [Inch Series]

Nominal Size, in.	Threads per inch	Stress Area, in.^{2}	Proof Load, lbf[a]					
			Grade 1		Grades 2, 2HM, 6, 6F, 7M			Grades 2H, 3, 4, 7, 16
			Heavy Hex[b]	Hex[c]	Heavy Hex[d]	Hex[e]	Heavy Hex[f]	Hex[d]
$^1/_4$	20	0.0316	3800	3550	4400	4000	5150	4400
$^5/_{16}$	18	0.0524	6150	5700	7100	6400	8300	7100
$^3/_8$	16	0.0774	8950	8250	10300	9300	12000	10300
$^7/_{16}$	14	0.1063	12000	11100	13850	12450	16150	13850
$^1/_2$	13	0.1419	15700	14500	18100	16300	21100	18100
$^9/_{16}$	12	0.182	19650	18150	22700	20400	26500	22700
$^5/_8$	11	0.226	23900	22050	27550	24800	32150	27550
$^3/_4$	10	0.334	33650	31050	38850	34950	45300	38850
$^7/_8$	9	0.462	44300	40900	51100	46600	59650	51100
1	8	0.606	55150	50900	63650	57300	74250	63650
$1^1/_8$	8	0.790	68000	62800	78500	70650	91600	78500
$1^1/_4$	8	1.000	81250	75000	93750	84400	109350	93750
$1^3/_8$	8	1.233	94250	86950	108750	97800	126850	108750
$1^1/_2$	8	1.492	106700	98500	123100	110800	143600	123100

[a] Based upon the following equation (this equation cannot be used for extrapolating values beyond the size ranges listed in this table):

$CPL = (1 - 0.30D) \times f \times A_s$

where:

CPL = cone stripping proof load lbf;
D = nominal diameter of nut, in.;
f = minimum proof stress of nut, psi (See footnotes *b, c, d, e,* and *f*.);
A_s = tensile stress area of nut, in.^{2} = $0.7854\,[D - 0.9743/n]^2$;
n = threads per inch.

[b] Based on proof stress of 130000 psi.

[c] Based on proof stress of 120000 psi.

[d] Based on proof stress of 150000 psi.

[e] Based on proof stress of 135000 psi.

[f] Based on proof stress of 175000 psi.

8.3.2. *Number of Tests*—Sample nuts in accordance with Section 8.1.2.1 shall be tested by the manufacturer. The manufacturer shall sample and test the number of nuts specified in Section 8.1.2.1. The lots shall be considered acceptable if the sample nut(s) withstand(s) application of the cone proof load without failure.

9. DIMENSIONS

9.1. Nuts shall be hexagonal in shape, and in accordance with the dimensions for the hex or heavy hex series, as required, by ANSI B18.2.2 and B18.2.4.6M. Unless otherwise specified, the American National Standard Heavy Hex Series shall be used and nuts shall be either double chamfered or have a machined or forged washer face, at the option of the manufacturer, and conform to the angularity requirements of ANSI B18.2.2 and B18.2.4.6M.

9.2. Unless otherwise specified, threads shall be in accordance with ANSI B1.1 or B1.13M, and shall be gauged in accordance with ANSI B1.2 and B1.13M as described in Sections 9.2.1 and 9.2.2.

9.2.1. Inch series nuts up to and including 1 in. nominal size shall be UNC Series Class 2B fit. Metric nuts up to and including M24 nominal size shall be coarse thread series tolerance 6H.

9.2.2. Inch series nuts greater than 1 in. nominal size shall be either UNC Series Class 2B fit or 8 UN Series Class 2B fit. Unless otherwise specified, the 8 UN series shall be furnished. Metric nuts over M24 nominal size shall be coarse thread series tolerance 6H.

10. WORKMANSHIP, FINISH, AND APPEARANCE

10.1. Nuts shall be free of defects and shall be of good commercial finish.

10.2. If visible surface imperfections in size M6 through M36 [$^1/_4$ through $1^1/_2$ in.] and in any grade other than Grade 8 become a matter of issue between the manufacturer and the purchaser, the cone proof load test described in Section 8.3 shall be employed.

10.3. If a scale-free bright finish is required, this shall be specified on the purchase order.

11. RETESTS

11.1. Provisions for retests by the purchaser and the purchaser's representative are specified in Supplementary Requirement S2.

12. CERTIFICATION

12.1. The producer of nuts shall furnish a certification to the purchaser or his representative showing the results of the chemical analysis, macroetch examination (carbon and alloy steels only), mechanical tests, and the minimum tempering temperature for nuts of Grade 2H, 2HM, 3, 4, 6, 6F, 7, and 7M.

12.2. Certification shall also include at least the following:

12.2.1. A statement that the fasteners were manufactured, sampled, tested, and inspected in accordance with the specification and any supplementary requirements or other requirements designated in the purchase order or contract and were found to meet those requirements;

12.2.2. The specification number, year, date, and identification symbol.

13. PRODUCT MARKING

13.1. All nuts shall bear the manufacturer's identification mark.

13.2. Nuts shall be legibly marked to indicate the grade and the process of the manufacturer, as presented in Table 7. Marking of wrench flats or bearing surfaces is not permitted unless agreed upon between manufacturer and purchaser.

Table 7—Marking of Nuts

Grade and Type	Nuts Hot Forged or Cold Punched	Nuts Machined from Bar Stock	Nuts Manufactured in Accordance with Section 6.6
1	1	1B	—
2	2	2B	—
2H[a]	2H	2HB	—
2HM[a]	2HM	2HMB	—
3	3	3B	—
4	4	4B	—
4L[b]	4L	4BL	—
6	6	6B	—
6F	6F	6FB	—
7	7	7B	—
7L[b]	7L	7BL	—
7M[a]	7M	7MB	—
8	8	8B	8A
8C	8C	8CB	8CA
8M	8M	8MB	8MA
8T	8T	8TB	8TA
8F	8F	8FB	8FA
8P	8P	8PB	8PA
8N	8N	8NB	8NA
8MN	8MN	8MNB	8MNA
8R	8R	8RB	8RA
8S	8S	8SB	8SA
8LN	8LN	8LNB	8LNA
8MLN	8MLN	8MLNB	8MLNA
8MLCuN	8MLCuN	8MLCuNB	8MLCuNA
9C	9C	9CB	9CA
16	16	16B	—

[a] The letters H and M indicate heat-treated nuts. (See Section 6.)

[b] See Supplementary Requirement S3.

13.3. For purposes of identification marking, the manufacturer is considered the organization that certifies the fastener was manufactured, sampled, tested, and inspected in accordance with the specification and the results have been determined to meet the requirements of this specification.

14. KEYWORDS

14.1. Bolting; chemical analysis; coated; marking on fasteners; plated.

SUPPLEMENTARY REQUIREMENTS

One or more of the following supplementary requirements shall be applied only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon in writing by the manufacturer and purchaser. Supplementary requirements shall in no way negate any requirement of the specification itself.

S1. STRAIN-HARDENED AUSTENITIC STEEL NUTS

S1.1. Strain-hardened Grades 8, 8C, 8T, 8M, 8F, 8P, 8N, or 8MN nuts may be specified. When Supplementary Requirement S1 is invoked in the order, nuts shall be machined from cold-drawn bars or shall be cold forged to shape. No subsequent heat-treatment shall be performed on the nuts. Nuts made in accordance with this requirement shall be proof-load tested in accordance with Section 8.2.2.1 and shall withstand the proof load specified in Table S1.1 and Table S1.2. Testing nuts requiring proof loads greater than 705 kN [160000 lbf] is required only when Supplementary Requirement S4 is invoked. The hardness limits of Table 2 do not apply to strain-hardened nuts. Nuts made in accordance with this requirement shall be marked with the Grade symbol underlined.

Table S1.1—Proof-Load Testing of Strain-Hardened Nuts Using Threaded Mandrel [Metric]

Proof Load, kN[a]						
Nominal Size, mm	Thread pitch	Stress Area, mm^2	Grade 8M (Strain Hardened)	Grade 8M (Strain Hardened)	All Other Types of Grade 8 (Strain Hardened)	All Other Types of Grade 8 (Strain Hardened)
			Heavy Hex[b]	Hex[c]	Heavy Hex[d]	Hex[b]
M6	1.0	20.1	15.3	13.9	17.3	15.3
M8	1.25	38.6	27.8	25.3	31.3	27.8
M10	1.50	58.0	44.1	40.0	49.9	44.1
M12	2.0	84.3	64.1	58.2	72.5	64.1
M14	2.0	115.0	87.4	79.4	98.9	87.4
M16	2.0	157.0	119.3	108.3	135.0	119.3
M20	2.5	245.0	186.2	169.0	210.9	186.2
M22	2.5	303.0	209.0	187.9	240.9	209.0
M24	3.0	353.0	243.5	218.9	280.6	243.5
M27	3.0	459.0	300.6	268.5	332.7	300.6
M30	3.5	561.0	367.5	328.2	406.7	367.5
M36	4.0	817.0	506.5	449.4	563.7	506.5

[a] The proof load for jam nuts shall be 46 percent of the tabulated value.

[b] Based on proof stress of 760 MPa up to M20; 690 MPa M22 to M24; 655 MPa M27 to M30; 620 MPa for M36.

[c] Based on proof stress of 690 MPa up to M20; 620 MPa M22 to M24; 585 MPa M27 to M30; 550 MPa for M36.

[d] Based on proof stress of 860 MPa up to M20; 795 MPa M22 to M24; 725 MPa M27 to M30; 690 MPa for M36.

Note: Proof loads are not design loads.

Table S1.2—Proof-Load Testing of Strain-Hardened Nuts Using Threaded Mandrel [Inch Series]

			Proof Load, lbf[a]			
Nominal Size, in.	Threads per inch	Stress Area, in.^{2}	Grade 8M (Strain Hardened)	Grade 8M (Strain Hardened)	All Other Types of Grade 8 (Strain Hardened)	All Other Types of Grade 8 (Strain Hardened)
			Heavy Hex[b]	Hex[c]	Heavy Hex[d]	Hex[b]
$^{1}/_{4}$	20	0.0316	3480	3160	3950	3480
$^{5}/_{16}$	18	0.0524	5760	5240	6550	5760
$^{3}/_{8}$	16	0.0774	8510	7740	9675	8510
$^{7}/_{16}$	14	0.1063	11690	10630	13290	11690
$^{1}/_{2}$	13	0.1419	15610	14190	17740	15610
$^{9}/_{16}$	12	0.182	20020	18200	22750	20020
$^{5}/_{8}$	11	0.226	24860	22600	28250	24860
$^{3}/_{4}$	10	0.334	36740	33400	41750	36740
$^{7}/_{8}$	9	0.462	46200	41580	53130	46200
1	8	0.606	60600	54540	69690	60600
$1^{1}/_{8}$	8	0.790	75050	67150	82950	75050
$1^{1}/_{4}$	8	1.000	95000	85000	105000	95000
$1^{3}/_{8}$	8	1.233	110970	98640	123300	110970
$1^{1}/_{2}$	8	1.492	134280	119360	149200	134280

[a] The proof load for jam nuts shall be 46 percent of the tabulated value.

[b] Based on proof stress of 110000 psi up to $^{3}/_{4}$ in.; 100000 psi 7/8 to 1 in.; 95000 psi 11/8 to $1^{1}/_{4}$ in.; 90000 psi 13/8 to $1^{1}/_{2}$ in.

[c] Based on proof stress of 100000 psi up to $^{3}/_{4}$ in.; 90000 psi 7/8 to 1 in.; 85000 psi 11/8 to $1^{1}/_{4}$ in.; 80000 psi 13/8 to $1^{1}/_{2}$ in.

[d] Based on proof stress of 125000 psi up to $^{3}/_{4}$ in.; 115000 psi 7/8 to 1 in.; 105000 psi 11/8 to $1^{1}/_{4}$ in.; 100000 psi 13/8 to $1^{1}/_{2}$ in.

Note: Proof loads are not design loads.

S2. RETESTS BY PURCHASER’S REPRESENTATIVE

S2.1. The purchaser’s representative may select two nuts per keg (90-kg [200-lb] unit) for sizes M16 [$^{5}/_{8}$ in.] and smaller, one nut per keg for sizes over M16 [$^{5}/_{8}$ in.] up to and including M36 [$1^{1}/_{2}$ in.], and one nut per every two kegs for sizes larger than M36 [$1^{1}/_{2}$ in.] which shall be subjected to the tests specified in Section 8.

S3. LOW-TEMPERATURE REQUIREMENTS FOR GRADE 4, GRADE 7, OR GRADE 7M NUTS

S3.1. When low-temperature requirements are specified for Grade 4 or Grade 7 nuts, the Charpy test procedures and requirements as defined in ASTM A 320/A 320M for Grade L7 shall apply. When low-temperature requirements are specified for Grade 7M nuts, the Charpy test procedures and requirements as defined in ASTM A 320/A 320M for Grade L7M shall apply. Depending on the size of nuts, separate test samples of the same heat may be required and shall be processed through heat-treatment with the nuts for which the test is to apply. Impact testing is not required when the bar stock or nut is smaller than 16 mm [$^{5}/_{8}$ in.] in diameter.

S3.2. An “L” shall be added to the marking, as shown in Table 7, for nuts so tested.

S4. PROOF LOAD TESTS OF LARGE NUTS

S4.1. Proof-load testing of nuts requiring proof loads of over 705 kN [160000 lbf] is required. Testing shall be performed in accordance with Section 8.2 to the loads required in Table S4.1 and Table S4.2. The maximum load will be based entirely on the equipment available.

Table S4.1—Proof Load for Large Heavy Hex Nuts[a] [Metric]

			Proof Load, kN [b]		
Nominal Size, mm	Thread pitch	Stress Area, mm^2	Grade 1 Heavy Hex	Grade 2, 2HM, 6, 6F, 7M Heavy Hex	Grade 2H, 3, 4, 7, 16 Heavy Hex
M42	4.5	1120	1002.4	1159.2	1349.6
M48	5	1470	1315.7	1521.4	1771.4
M56	5.5	2030	1816.9	2101.0	2446.2
M64	6	2680	2398.6	2773.8	3229.4
M72	6	3460	3096.7	3581.1	4169.3

[a] ANSI B18.2.4.6.M in the size range over M36 provides dimensions only for heavy hex nuts. Refer to Section 8.3.1.

[b] Proof loads for nuts of larger dimensions or other thread series may be calculated by multiplying the thread stress area times the proof stress in the notes to Table 3 or Table 8. The proof load for jam nuts shall be 46 percent of the tabulated load.

Table S4.2—Proof Load for Large Heavy Hex Nuts[a] [Inch Series]

			Proof Load, lbf[b]		
Nominal Size, in.	Threads per inch	Stress Area, in.^{2}	Grade 1 Heavy Hex	Grade 2, 2HM, 6, 6F, 7M Heavy Hex	Grade 2H, 3, 4, 7, 16 Heavy Hex
1$^5/_8$	8	1.78	231400	267000	311500
1$^3/_4$	8	2.08	270400	312000	364000
1$^7/_8$	8	2.41	313300	361500	421800
2	8	2.77	360100	415500	484800
2$^1/_4$	8	3.56	462800	534000	623000
2$^1/_2$	8	4.44	577200	666000	777000
2$^3/_4$	8	5.43	705900	814500	950250

[a] ANSI B18.2.2 in the size range over 1$^1/_2$ in. provides dimensions only for heavy hex nuts. Refer to Section 8.3.1.

[b] Proof loads for nuts of larger dimensions or other thread series may be calculated by multiplying the thread stress area times the proof stress in the notes to Table 4 or Table 9. The proof load for jam nuts shall be 46 percent of the tabulated load.

S5. CONTROL OF PRODUCT BY HEAT NUMBER

S5.1. When control of nuts by actual heat analysis is required and this supplementary requirement is specified, the manufacturer shall identify the completed nuts in each shipment by the actual heat number. When this supplementary requirement is specified, a certificate including the results of the actual production tests of each test lot together with the heat chemical analysis shall be furnished by the manufacturer.

S6. GRAIN SIZE REQUIREMENTS FOR NON H GRADE AUSTENITIC STEELS USED ABOVE 540°C [1000°]

S6.1. For design metal temperatures above 540°C [1000°F], the material shall have a grain size of No. 7 or coarser as determined in accordance with ASTM E 112. The grain size, so determined, shall be reported on the Certificate of Test.

S7. COATING ON NUTS

S7.1. It is the purchaser's responsibility to specify in the purchase order all information required by the coating facility. Examples of such information may include but are not limited to the following:

S7.1.1. Reference to the appropriate coating specification and type, thickness, location, modification to dimensions, and hydrogen embrittlement relief.

Note S1—Modifications of thread dimensions may result in loss of load carrying capability.

S7.1.2. Reference to Specifications A 153/A 153M, B 633, B 695, B 696, B 766, F 1940, F 1941, F 2329 or other specifications.

S8. MARKING COATED NUTS

S8.1. Nuts coated with zinc shall have ZN marked after the grade symbol. Nuts coated with cadmium shall have CD marked after the grade symbol.

Note S2—As an example, the marking for zinc-coated 2H fasteners will now be 2HZN rather than 2H*.

S9. PROOF-LOAD TESTING

S9.1. Proof-load tests of nuts made to dimensions, thread pitch, and configurations other than those covered in Table 3 or Table 4 shall be made using loads agreed upon between the manufacturer and the purchaser.

APPENDIXES

(Nonmandatory Information)

X1. STRAIN HARDENING OF AUSTENITIC STEELS

X1.1. Strain hardening is the increase in strength and hardness that results from plastic deformation below the recrystallization temperature (cold work). This effect is produced in austenitic stainless steels by reducing oversized bars to the desired final size by cold drawing or other process. The degree of strain hardening achievable in any alloy is limited by its strain-hardening characteristics. In addition, the amount of strain hardening that can be produced is further limited by the variables of the process, such as the total amount of cross-section reduction, die, angle, and bar size. In large diameter bars, for example, plastic deformation will occur principally in the outer regions of the bar so that the increased strength and hardness due to strain hardening is achieved predominantly near the surface of the bar. That is, the smaller the bar, the greater the penetration of strain hardening. Thus, the mechanical properties of a given strain-hardened fastener are dependent not just on the alloy, but also on the size of bar from which it is machined.

X2. COATINGS AND APPLICATION LIMITS

X2.1. Use of coated fasteners at temperatures above approximately one-half the melting point (Celsius or Fahrenheit) of the coating is not recommended unless consideration is given to the potential for liquid or solid metal embrittlement, or both. The melting point of elemental zinc is approximately 415°C [780°F]. Therefore, application of zinc-coated fasteners should be limited to temperatures less than 210°C [390°F]. The melting point of cadmium is approximately 320°C [600°F]. Therefore, application of cadmium-coated fasteners should be limited to temperatures less than 160°C [300°F].

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[1] Available from American National Standards Institute, 11 West 42nd St., 13th Floor, New York, NY 10036.

[2] An underline as a marking requirement for grades 2HM and 7M has been removed but is permitted.

Standard Specification for

Hardened Steel Washers

AASHTO Designation: M 293-10
ASTM Designation: F 436-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Hardened Steel Washers

AASHTO Designation: M 293-10
ASTM Designation: F 436-09

AASHTO M 293-10 is identical to ASTM F 436-09 except for the following provisions:

1. All references to the ASTM standards contained in ASTM F 436-09, listed in the following table, shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO
A 709/A 709M	M 270M/M 270
B 695	M 298
F 2329	M 232M/M 232

2. Add Sections 10.3 and 10.4 to Section 10 of ASTM F 436-09 as follows:

   10.3 If zinc-coated washers are supplied, hardness testing shall be performed after zinc coating. The zinc coating shall be removed prior to taking hardness measurements.

   10.4 If zinc-coated washers are supplied, the thickness of the zinc coating shall be measured.

3. Replace Section 14.1 of ASTM F 436-09 with the following:

   14.1 The party responsible for the washers shall be the organization that supplies the washers to the purchaser. The responsible party shall supply test reports, certified by the manufacturer, that indicate the washers were manufactured, sampled, tested, and inspected in accordance with this specification and all of its requirements.

Standard Specification for

Hardened Steel Washers [Metric]

AASHTO Designation: M 293M-06
ASTM Designation: F 436M-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Hardened Steel Washers [Metric]

AASHTO Designation: M 293M-06
ASTM Designation: F 436M-04

The AASHTO equivalent of this specification has been discontinued. Please refer to ASTM F 436M-04 for the information formerly contained in this standard.

Standard Specification for

Coatings of Zinc Mechanically Deposited on Iron and Steel

AASHTO Designation: M 298-10
ASTM Designation: B 695-04 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Coatings of Zinc Mechanically Deposited on Iron and Steel

AASHTO Designation: M 298-10
ASTM Designation: B 695-04 (2009)

AASHTO M 298-10 is identical to ASTM B 695-04 (2009) except that all references to the ASTM standards contained in ASTM B 695-04 (2009), listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standards	
ASTM	AASHTO
A 153	M 232M/M 232
A 194	M 292M/M 292

Standard Specification for

Coatings of Cadmium Mechanically Deposited

AASHTO Designation: M 299-10
ASTM Designation: B 696-00 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Coatings of Cadmium Mechanically Deposited

AASHTO Designation: M 299-10
ASTM Designation: B 696-00 (2009)

AASHTO M 299-10 is identical to ASTM B 696-00 (2009).

Standard Specification for

Steel Anchor Bolts

AASHTO Designation: M 314-90 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Anchor Bolts

AASHTO Designation: M 314-90 (2008)

1. SCOPE

1.1. This specification covers externally threaded steel anchor bolts intended for anchoring structural supports to concrete foundations. Such structural supports include building columns; column supports for highway signs, street lighting, and traffic signals; steel bearing plates; and other similar applications.

1.2. The anchor bolts are subject to tensile property requirements and are available in three grades (yield strength levels). Special chemical restrictions apply when weldable steel is required.

1.3. Zinc coating (galvanizing) requirements are included for bolts requiring corrosion protection.

1.4. The recommended grade and style of nuts for each grade of anchor bolt are included.

1.5. This specification does not cover the requirements of mechanical expansion anchors or powder activated nails or studs for concrete.

1.6. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 160M/M 160, General Requirements for Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use (Discontinued)
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- M 291, Carbon and Alloy Steel Nuts
- M 293, Hardened Steel Washers
- M 298, Coatings of Zinc Mechanically Deposited on Iron and Steel
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standard*:

- A 751, Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

2.3. *ANSI Standards*:

- ANSI B1.1, Unified Screw Threads
- ANSI B18.2.2, Square and Hex Nuts

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *anchor bolt*—a steel bar or rod, one end of which is intended to be cast in concrete, while the opposite end is threaded and projects from the concrete, for anchoring other material to the concrete.

3.1.1.1. *discussion*—the end of the bar or rod cast in concrete may be either straight or provided with an anchor such as a hook or welded or bolted attachment to resist forces imposed on the bolt, as required.

3.1.2. *fabricator*—the manufacturer of the bolt.

3.1.3. *producer*—the manufacturer of the steel rods or bars.

3.1.4. *purchaser*—the purchaser of the finished anchor bolt or the purchaser's designated agent.

3.1.5. *supplier*—the agent who furnishes the finished bolts and nuts to the purchaser; may be the fabricator.

4. CLASSIFICATION

4.1. Anchor bolts covered by this specification are classified as follows:

4.1.1. *Grade*—The anchor bolts shall be furnished in one of three grades (Grade 36, Grade 55, or Grade 105) corresponding to the minimum yield strength of the steel (Section 8.1).

4.1.2. Weldable steel shall meet the requirements of Supplementary Requirement S1, when specifically ordered.

5. ORDERING INFORMATION

5.1. Orders for anchor bolts under this specification shall include the following information as necessary to adequately describe the desired product:

5.1.1. Quantity (number of pieces);

Note 1—If the purchaser intends to perform destructive tests on fabricated bolts, the fabricator should be advised so that an adequate number are produced, especially for sizes and grades not readily available from stock.

5.1.2. Name of material (steel anchor bolts);

5.1.3. AASHTO designation including year of issue;

5.1.4. Grade of steel (Section 4.1.1);

5.1.5. Weldable steel to meet Supplementary Requirement S1, when required;

5.1.6. *Dimensions*—diameter (based on nominal thread diameter), bolt length, thread length, length of hook (if hook is required);

5.1.7. Zinc coating or other protective coating (when required) (Section 6.4);

5.1.7.1. Specify the zinc-coating process, whether hot-dip, mechanically deposited, or no preference;

5.1.7.2. Specify length from exposed end to be coated, or entire length;

5.1.8. Number of nuts, either total number or number per bolt;

5.1.9. Number of washers, either total number or number per bolt, and dimensions if other than standard washers;

5.1.10. Specify if inspection at place of manufacture is required (Section 12.1);

5.1.11. Specify if certified test report is required (Section 14.1); and

5.1.12. Any special requirements.

6. MATERIALS AND MANUFACTURE

6.1. *Bolts*:

6.1.1. Steel for anchor bolts shall be made by the open hearth, basic oxygen, or electric furnace process.

6.1.2. Threads of anchor bolts may be rolled or cut, and shall conform to the requirements in Section 9.2.

6.1.3. Hooks on anchor bolts, when required, may be made by cold bending or hot bending, provided no cracks develop in the bend length. When hot bending is elected, at no time shall any portion of the anchor bolt reach a temperature in excess of 595ºC (1100ºF). The bending shall not significantly reduce the cross-sectional area of the bolt (Section 9.3).

6.2. *Nuts*:

6.2.1. Nuts shall conform to M 291 for inch-series threads for the grade and style indicated for each grade and size of anchor bolt, and whether plain or zinc coated, as shown in Table 1.

6.2.2. The requirements for the recommended grade and style of nut may be fulfilled by furnishing a nut of one of the grades or styles specified in M 291 that has equal or higher proof load stress.

Table 1—Nuts

Anchor Bolts			Nuts	
Grade	Size, mm (in.)	Condition	Grade	Style
36	6 to 38 ($^1/_4$ to $1^1/_2$)	Plain or Zinc Coated	A	Hex
36	Over 38 to 102 (over $1^1/_2$ to 4)	Plain or Zinc Coated	A	Heavy Hex
55	6 to 38 ($^1/_4$ to $1^1/_2$)	Plain	A	Hex
55	6 to 38 ($^1/_4$ to $1^1/_2$)	Zinc Coated	A	Heavy Hex
55	Over 38 to 102 (over $1^1/_2$ to 4)	Plain or Zinc Coated	A	Heavy Hex
105	6 to 38 ($^1/_4$ to $1^1/_2$)	Plain	D	Hex
105	6 to 38 ($^1/_4$ to $1^1/_2$)	Zinc Coated	DH	Heavy Hex
105	Over 38 to 76 (over $1^1/_2$ to 3)	Plain or Zinc Coated	DH	Heavy Hex

6.2.3. Nuts to be used on coated anchor bolts may be tapped oversize. The diametral amounts for oversize tapping indicated in M 291 as minimums are the maximum limits for oversize tapping for this anchor bolt specification.

Note 2—Steel to steel thread engagement is reduced between bolt and nut threads when the nut is tapped oversize. The purchaser should therefore be aware that nuts zinc coated and tapped oversize will have a lower tensile capacity than nuts that have not been tapped oversize. (See Table 3, M 291).

6.3. *Washers*:

6.3.1. Washers, when required, shall conform to M 293 unless otherwise specified in the order.

6.4. *Coatings for Enhanced Corrosion Resistance*:

6.4.1. *Zinc Coatings, Hot-Dip, and Mechanically Deposited*:

6.4.1.1. When zinc-coated anchor bolts, nuts, and washers are required, the purchaser shall specify the zinc coating process, for example hot-dip, mechanically deposited, or no preference.

6.4.1.2. When hot-dip is specified, the fasteners shall be zinc coated by the hot-dip process in accordance with the requirements of Class C of M 232M/M 232.

6.4.1.3. When mechanically deposited is specified, the fasteners shall be zinc coated by the mechanical deposition process in accordance with the requirements of Class 50 of M 298.

6.4.1.4. When no preference is specified, the supplier may furnish either a hot-dip zinc coating in accordance with M 232M/M 232, Class C, or a mechanically deposited zinc coating in accordance with M 298, Class 50.

6.4.2. Coatings other than hot-dip and mechanically deposited zinc coatings, when required, shall be specified in the order and the complete specification for the coating shall be included as a part of the order.

6.4.3. Threads for coated anchor bolts shall meet the requirements of Section 9.2 before the coating is applied.

7. CHEMICAL COMPOSITION

7.1. Steel shall conform to the following chemical limitations:

	Heat Analysis	Product Analysis
Phosphorus, max, percent	0.040	0.048
Sulfur, max, percent	0.050	0.058
Copper, min, percent when Cu is specified	0.20	0.18

7.2. The additional chemical limitations in Section S1.5 apply when bolts are ordered as weldable.

8. TENSILE PROPERTIES

8.1. Steel bars from which anchor bolts are made, as well as the finished anchor bolts, shall conform to the tensile requirements shown in Table 2.

Table 2—Tensile Properties

Grade	Yield Strength, Min, MPa (ksi)	Tensile Strength, Min, MPa (ksi)	Elongation,[a] Min, Percent		Reduction of Area, Min, Percent
			In 200 mm (8 in.)	In 50 mm (2 in.)	
36	248 (36)	400 to 552 (58 to 80)	20	23	40
55	379 (55)	517 to 655 (75 to 95)	18	21	30
105	724 (105)	862 to 1034 (125 to 150)	12	15	45[b]

[a] The requirement for elongation in 200 mm (8 in.) applies to bars and bolts tested full size. The requirement for elongation in 50 mm (2 in.) applies to test on machined specimens.

[b] Bolts over 50 to 63 mm (2 to 2$^1/_2$ in.), 22 percent min; over 63 to 75 mm (2$^1/_2$ to 3 in.), 20 percent min; over 76 to 102 mm (3 to 4 in.), 18 percent min.

9. DIMENSIONS

9.1. *Nominal Size*—The nominal anchor bolt diameter shall be the same as the nominal diameter of the threads.

9.2. *Thread Dimensions*—Threads on anchor bolts shall be Unified National Coarse Series, as specified in ANSI B1.1, and shall have Class 2A tolerances.

9.2.1. Bolts to be used with nuts that have been tapped oversize, in accordance with M 291, shall have Class 2A threads before coating. After coating, the maximum limit of pitch and major diameter may exceed the Class 2A limit by the following amount:

Diameter, mm (in.)	Oversize Limit, mm (in.)[a]
Up to 11.1 ($^7/_{16}$), incl	0.41 (0.016)
Over 11.1 to 25.4 ($^7/_{16}$ to 1), incl	0.53 (0.021)
Over 25.4 (1)	0.79 (0.031)

[a] These values are the same as the minimum oversize tapping required for zinc-coated nuts in M 291.

9.2.2. The gauging limits for bolts shall be verified during manufacture or use by assembly of a nut tapped as nearly as practical to the amount oversize shown above. In case of dispute, a calibrated thread ring gauge of that same size (Class × tolerance, gauge tolerance plus) shall be used.

Assembly of the gauge or the nut described above must be possible with hand effort following application of light machine oil to prevent galling and damage to the gauge. Length of threads shall be the specified length, plus 25 mm (1 in.), minus zero.

9.3. *Bar Diameter*:

9.3.1. When threads are rolled, the diameter of the bar before threading shall not be less than the minimum pitch diameter specified for Class 2A threads in ANSI B1.1.

9.3.2. When the threads are cut, the diameter of the bar before threading shall not be less than the specified diameter less the tolerance in M 160M/M 160 for round bars.

9.3.3. The bend section of bent bars shall have a cross-sectional area not less than 90 percent of the area of straight portions of the bar. The area in the bend shall be calculated by the formula:

$$A_b = 0.25\,\pi D \cdot d \qquad (1)$$

where:

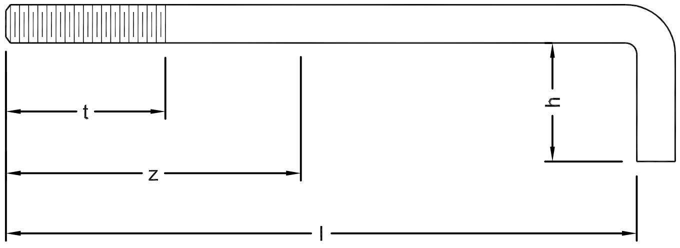
A_b = cross-sectional area in the bend;

d = minor (or minimum) diameter at any point, generally in the plane of the bend; and

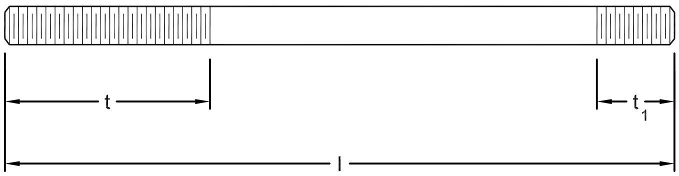
D = major diameter, at the same cross section as and at 90 degrees to the minor diameter.

9.4. *Bolt Dimensions*:

9.4.1. The overall length of straight anchor bolts, or length to the inside of the hook, shall be the specified length plus or minus 13 mm ($^1/_2$ in.) for bolt lengths of 600 mm (24 in.) or less, and plus or minus 25 mm (1 in.) for longer bolts (Figure 1).



Anchor Bolt with Hook



Straight Anchor Bolt

Note: h = length of hook;
l = length of bolt;
t = length of threads (exposed end);
t_1 = length of threads (encased end), when required;
z = length of zinc coating, min, when partial zinc coating is required.

Figure 1—Anchor Bolt Dimensions

9.4.2. The length of hooks shall be the specified length, plus or minus 10 percent of the specified hook length, or ±13 mm ($^1/_2$ in.), whichever is greater (Figure 1).

9.4.3. The bend angle of hooks shall be the specified angle plus or minus five degrees.

9.5. *Coated Length*:

9.5.1. When only the exposed end of the anchor bolt is required to be zinc coated, the length of zinc coating shall be at least equal to the length specified in the order. There is no limit on extra length of zinc coating.

10. NUMBER OF TESTS AND RETESTS

10.1. The steel producer shall conduct tests for tensile properties and chemical analysis and shall certify the results to the fabricator of the anchor bolts. The fabricator shall be responsible for tests for zinc coating and dimensional requirements.

10.2. The purchaser shall have the right to perform any of the inspections and tests set forth in this specification. Tests may be made on either the bar stock or on the completed anchor bolts.

10.3. One test for chemical composition shall be made from each heat. One test for tensile properties shall be made for each diameter of each heat, and if the bars are heat-treated, for each furnace lot. The number of tests for zinc coating shall be as specified in M 232M/M 232.

10.3.1. Where identity to a specific heat number (and furnace lot number for heat-treated bars) has not been maintained, the number of tests shall be based on the quantity of bolts of a given description, as shown in Table 3.

Table 3—Number of Tests

	Number of Specimens	
Number of Bolts in Order of Each Description	25.4-mm (1-in.) Diameter and Smaller	Over 25.4-mm (1-in.) Diameter
100 and fewer	1	1
101 to 250	1	2
251 to 500	2	3
501 to 1000	3	5
1001 and more (additional per 1000 bolts)	1	2

10.4. If a sample fails to meet any tensile property requirement and the results are within 14 MPa (2 ksi) of the required tensile strength, within 7 MPa (1 ksi) of the required yield strength, or within two percentage points of the required elongation, a retest shall be permitted on two randomly selected specimens for each original tensile specimen failure from the lot. If all results of these retest specimens meet the specified requirements, the lot shall be accepted.

10.4.1. If any test specimen shows defective machining, it may be discarded and another specimen substituted.

10.5. If a sample fails to meet any requirement, other than a tensile property requirement, and the results are within 10 percent of the limit, a retest will be permitted on two randomly selected specimens for each original nonconforming specimen from the lot. If the results of tests on these retest specimens, for the requirement that was originally nonconforming, meet the specified requirement, the lot shall be accepted.

10.6. If a sample is determined to have threads not conforming to the requirements, where the determination was made using other than standard thread gauges, and the fabricator contests the rejection of the anchor bolts or nuts, the final determination of acceptability shall be as follows. The fabricator shall have full size tension tests made on the anchor bolt and nut assembly in the presence of the purchaser's representative. The assembly must develop a tensile load at least equal to the stress area of the bolt multiplied by the minimum tensile strength for the grade of anchor bolt specified. The stress area is calculated from the equation:

$$A_s = 0.7854\,[D-(0.9743/n)]^2 \qquad (2)$$

where:

A_s = stress area, mm^2 (in.^{2});

D = nominal diameter of bolt, mm (in.); and

n = threads per mm (in.).

11. TEST METHODS

11.1. Chemical analyses shall be performed in accordance with ASTM A 751.

11.2. Tensile property tests shall be conducted according to T 244, with the following exceptions:

11.2.1. Tension test specimens shall be the full section of the bar as rolled, except that bars greater than 38-mm ($1^1/_2$-in.) diameter in Grade 36 or Grade 55, or greater than 32-mm ($1^1/_4$-in.) diameter in Grade 105, may be machined to provide standard 12.5-mm (0.500-in.) specimens as described in Table 5 of T 244 when equipment of sufficient capacity for full-size testing is not available. In the event that bolts are tested by both full size and by machined specimen methods, the full size test shall govern if a controversy between the two methods exists.

11.3. Determine the quantity of zinc coating by the methods of M 232M/M 232.

12. INSPECTION

12.1. If the inspection described in Section 12.2 is required by the purchaser, it shall be specified in the inquiry and contract or order.

12.2. The inspector representing the purchaser shall have free entry to all parts of the fabricator's works that concern the manufacture of the material ordered. The fabricator shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections required by the specification that are requested by the purchaser's representative shall be made, if possible, before shipment, and shall be conducted so as not to interfere unnecessarily with the operation of the works.

13. REJECTION AND REHEARING

13.1. Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the fabricator promptly and in writing. In case of dissatisfaction with the results of the test, the fabricator may make claim for a rehearing.

14. CERTIFICATION AND REPORTS OF TESTING

14.1. When specified by the purchaser, a certification that the material was manufactured and tested in accordance with this specification shall be furnished and shall include a report of the tensile test results and chemical analysis (including carbon equivalent for weldable bolts). The report shall include the name of the steel producer, AASHTO designation number, grade, heat number, size, and authorized signature.

15. PRODUCT MARKING

15.1. Bars from which the anchor bolts are made shall be identified as specified in M 160M/M 160.

15.1.1. The end of each fabricated anchor bolt intended to project from the concrete shall be painted to identify the grade as follows:

Grade	Paint Color
36	Blue
55	Yellow
105	Red

SUPPLEMENTARY REQUIREMENT

The following supplementary requirement shall apply only when specified in the purchase order or contract:

S1. BOLTS SUITABLE FOR WELDING

S1.1. The material described in this section is intended for welding. This supplemental section, by chemical composition restrictions and by a carbon equivalent formula, provides assurance of weldability.

S1.2. Welding technique is of fundamental importance when bolts produced to this supplementary section are welded. It is assumed that suitable welding procedures for the steel being welded and the intended service will be selected.

S1.3. The requirements of this supplementary requirement supersede conflicting provisions of the general specification.

S1.4. Because of the embrittling effects of welding temperatures on cold-forged steel, this supplemental section is limited to hot-forged bolts, or, if not forged, to the thread bars, studs, or bolts produced from hot-rolled bars without forging. Cold-forged bolts or cold-drawn threaded bars are suitable if they are given a thermal treatment by heating to a temperature of not less than 815ºC [1500ºF] and air-cooled.

S1.5. *Chemical Composition*:

S1.5.1 Steel shall conform to the following limitations:

	Heat Analysis	Product Analysis
Carbon, max, percent	0.30	0.33
Manganese, max, percent	1.35	1.41
Phosphorus, max, percent	0.040	0.048
Sulfur, max, percent	0.050	0.058
Silicon, max, percent	0.50	0.55

S1.5.2 *Carbon Equivalent*—In addition to the requirements in Section S1.5.1, the analysis shall be such as to provide a carbon equivalent (CE) meeting the following requirements:

S1.5.2.1. For alloy or low-alloy steel, the carbon equivalent shall not exceed 0.45 percent when calculated as follows:

$$\mathrm{CE} = \%\mathrm{C} + \frac{\%\mathrm{Mn}}{6} + \frac{\%\mathrm{Cu}}{40} + \frac{\%\mathrm{Ni}}{20} + \frac{\%\mathrm{Cr}}{10} - \frac{\%\mathrm{Mo}}{50} - \frac{\%\mathrm{V}}{10} \qquad \textit{(S1.1)}$$

S1.5.2.2. For carbon steel, the carbon equivalent shall not exceed 0.40 percent when calculated as follows:

$$\mathrm{CE} = \%\mathrm{C} + \frac{\%\mathrm{Mn}}{4} \qquad \textit{(S1.2)}$$

S1.6. *Marking*—Each fabricated anchor bolt conforming to this Supplementary Requirement S1 shall be designated by a white paint mark on the side of the bar near the end to be encased in concrete.

Standard Practice for

Qualification of Deformed and Plain Reinforcing Steel Bar, Welded Wire, and Wire Producing Mills

AASHTO Designation: R 53-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Qualification of Deformed and Plain Reinforcing Steel Bar, Welded Wire, and Wire Producing Mills

AASHTO Designation: R 53-10[1]

1. SCOPE

1.1. This recommended practice shall apply to all producing mills that supply deformed and plain steel reinforcement bars, welded wire, or wire for use on State Transportation Agency projects.

1.2. The initial qualification and all subsequent qualifications of the producing mill's quality system and compliance testing will be in accordance with the procedure outlined herein.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement
- M 227M/M 227, Steel Bars, Carbon, Merchant Quality, Mechanical Properties
- M 322M/M 322, Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 82/A 82M, Standard Specification for Steel Wire, Plain, for Concrete Reinforcement
- A 185/A 185M, Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete
- A 496/A 496M, Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement
- A 497/A 497M, Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete
- A 615, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- A 706/A 706M, Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

- A 880-95, Standard Practice for Criteria for Use in Evaluation of Testing Laboratories and Organizations for Examination and Inspection of Steel, Stainless Steel, and Related Alloys
- A 996/A 996M, Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

3. TERMINOLOGY

3.1. *compliance testing*—testing performed in accordance with referenced AASHTO and ASTM standards and/or test methods.

3.2. *documented quality system*—the producing mill shall maintain documentation of their quality system by use of a Quality Manual (QM).

3.3. *nonconformance*—not meeting the requirements of this specification.

3.4. *producing mills (deformed and plain reinforcing steel bar, welded wire, or wire)*—locations where steel billets, rail steel, and axle steel are heated and rolled into finished steel bars or rods, or where welded wire, or wire products are produced.

3.5. *test report*—information (test values, chemical analysis, etc.) as required by the referenced specification and contained in a report form generated by the producing mill. Origin of materials (steel billets, rail-steel, axle-steel, and rod) used to roll the bars or wire is also shown on this report.

3.6. *qualification agency*—The entity that performs this qualification procedure at the producing mill. AASHTO's National Transportation Product Evaluation Program's (NTPEP) Project Panel on Reinforcing Steel is responsible for oversight of the program and securing the services of the qualification agency.

4. PURPOSE

4.1. This document establishes a uniform procedure for the qualification of producing mills that supply deformed and plain steel reinforcement bars, welded wire, or wire for use on State Transportation Agency projects.

4.2. This document describes the procedures and conditions for producing mill qualification.

5. QUALIFICATION PROCEDURE

5.1. *General*—Qualification shall be based on satisfactory compliance to an audit of:

5.1.1. The producing mill's Documented Quality System, and

5.1.2. Compliance testing.

Note 1—Subsequent qualifications of producing mills that have demonstrated compliance to a recognized international/national quality program may have the Documented Quality System audit waived. In such cases, compliance testing will be the focus of qualification.

5.2. *Application*:

5.2.1. The producing mill shall submit a request for attaining mill qualification to the Qualification Agency.

5.2.2. Upon receipt of the request, the qualifying agency shall furnish the producing mill a copy of the application form. The completed application form shall be submitted to the Qualification Agency along with a copy of the mill's QM, meeting the requirements of R 18, Section 6. Frequency of calibration shall be on an annual basis. Other formats for the QM may be acceptable after review and acceptance by the Qualification Agency.

5.2.3. After receipt of the application form, the Qualification Agency shall arrange to perform an on-site audit of the applying producing mill's facility.

5.3. *Quality System Audit*:

5.3.1. The Qualification Agency shall use an approved standardized audit checklist and verify compliance with the procedures outlined in the producing mill's Documented Quality System.

5.4. *Compliance Testing*:

5.4.1. Compliance testing will be performed on product manufactured by the producing mill using the producing mill's testing equipment. Calibration of testing equipment shall be current at the time of the audit. The Qualification Agency will designate samples. All testing will be witnessed by the representative(s) of the Qualification Agency. As an option, compliance testing may also be performed on State Agency or Qualification Agency contracted equipment.

5.5. *Sampling and Testing*:

5.5.1. A minimum of ten heats/lot over the range of production sizes and grades will be sampled from material available from stock.

5.5.2. Three samples from different pieces within the same heat/lot will be obtained. Each sample will require enough length to provide for one tensile test, one bend test, one weld shear (for welded wire), and for two retests. Supply enough material to evaluate members in both the primary and secondary directions.

5.5.3. The producing mill shall provide the necessary resources to obtain and test the samples in accordance with the referenced specification.

5.5.4. Test results will be recorded on the worksheet supplied by the Quality Reviewer.

5.6. *Evaluation of Test Results*:

5.6.1. Compliance test results will be compared to the requirements of referenced specification(s). All test results of all samples shall meet the requirements of the applicable specification(s).

5.6.2. In the event that the test results from an individual sample do not meet the requirements of the referenced specification, retesting of material from the nonconforming heat in addition to two additional heats of the same size and grade will be performed during the compliance testing period. All of the retested samples shall meet the requirements of the applicable specification(s).

5.6.3. In the event that the test results from an individual sample do not meet the requirements of the referenced specification, it is the responsibility of the producing mill to submit to the NTPEP Project Panel on Reinforcing Steel objective corrective actions that satisfy the basic cause analysis of the nonconformance and implemented corrective action upon requesting requalification.

5.7. *Audit Results*—Producing mills, having been qualified in accordance with this procedure, will have their audit results posted for review and approval by each State Transportation Agency. The review and approval will be in accordance with the NTPEP Project Panel on Reinforcing Steel's workplan.

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[1] This practice is intended to be used for the national qualification program for reinforcing steel.

Standard Specification for

Sodium Chloride

AASHTO Designation: M 143-03 (2007)
ASTM Designation: D 632-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Sodium Chloride

AASHTO Designation: M 143-03 (2007)
ASTM Designation: D 632-01

AASHTO M 143-03 (2007) is identical to ASTM D 632-01 except that all references to ASTM C 136 contained in AASHTO M 143-03 (2007) shall be replaced with AASHTO T 27.

Standard Specification for

Calcium Chloride

AASHTO Designation: M 144-07
ASTM Designation: D 98-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Calcium Chloride

AASHTO Designation: M 144-07
ASTM Designation: D 98-05

AASHTO M 144-07 is identical to ASTM D 98-05 except for the following provisions:

1. All references to ASTM D 345 contained in ASTM D 98-05 shall be replaced with AASHTO T 143.
2. AASHTO M 144-07 does not reference MIL-STD-105 (Section 7.1, ASTM D 98-05), and does not include Federal Government packaging requirements (Sections 10.3 through 10.6, ASTM D 98-05).

Standard Specification for

Epoxy Protective Coatings

AASHTO Designation: M 200-73 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Epoxy Protective Coatings

AASHTO Designation: M 200-73 (2007)

1. SCOPE

1.1. This specification covers two-component epoxy resin adhesive for use as protective and or skid resistant overlays on portland cement concrete surfaces and bridge decks. Two classes of epoxy resin adhesive are provided.

1.2. *Classes*:

1.2.1. Class I, bitumen modified coating is for use in protective coatings for skid resistant and/or protective overlays for cement concrete bridge decks and surfaces. It includes a recommended practice for the preparation of the concrete surface and for the application of the epoxy prime coat when required, epoxy top coat, glass fabric when required, and cover material. Each system may be used as a wearing course or as a protective coating beneath an asphalt concrete pavement.

1.2.2. Class II, oil modified coating is for use, with suitable aggregate, in mortar overlays 9.5 to 12.7 mm ($^3/_8$ to $^1/_2$ in.) thick as skid resistant and/or protective overlays for cement concrete bridge decks and surfaces. It is also suitable for application in a thin layer under asphaltic concrete as described for Class I material. It is not generally recommended as a wearing course in thin layers.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 55, Water in Petroleum Products and Bituminous Materials by Distillation

2.2. *ASTM Standards*:

- D 154, Standard Guide for Testing Varnishes
- D 412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
- D 482, Standard Test Method for Ash from Petroleum Products
- D 570, Standard Test Method for Water Absorption of Plastics
- D 638, Standard Test Method for Tensile Properties of Plastics
- D 664, Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration
- D 1078, Standard Test Method for Distillation Range of Volatile Organic Liquids

- D 1084, Standard Test Methods for Viscosity of Adhesives
- D 1652, Standard Test Method for Epoxy Content of Epoxy Resins
- D 1668, Standard Specification for Glass Fabrics (Woven and Treated) for Roofing and Waterproofing
- D 2240, Standard Test Method for Rubber Property—Durometer Hardness

2.3. *Other Standard*:

- FSS HH-C-466, Cloth, Glass, Coated (For Membrane Waterproofing and Built-Up Roofing) Also refer to ASTM D 1668 as noted above.

CLASS I—BITUMEN-MODIFIED EPOXY RESIN MIXTURE

3. MATERIALS

3.1. Epoxy Resin Mixture shall be furnished in two components for combining in equal volumes immediately before use in accordance with the written instructions of the manufacturer.

3.2. *Top Coat*:

3.2.1. *Component A (Modified-Epoxy Resin)*—Top coat shall consist of a condensation product of epichlorohydrin with bisphenol A, shall contain no reactive diluents, no insolubles, and shall conform to the requirements of Table 1.

Table 1—Requirements for Component A

Property	Top Coat
Epoxide equivalent[a]	225 to 275
Viscosity, Pa·s (poises), 25˚C (77˚F) (Spindle No. 3, 20 r/min)	0.8 to 1.6 (8 to 16)
Ash, mass, percent, max	0.2
Volatile loss (to 177˚C (350˚F)) cm^3, max	3.00
Specific gravity, 25/25˚C (77/77˚F)	1.10 to 1.25

[a] Grams of material containing one gram equivalent of epoxide.

Note 1—When the slope of the concrete surface exceeds about 3 percent, a thixotropic agent approved by the engineer may be added to Component A by the formulator to either or both coats. If a thixotropic agent is used, the requirement for ash, viscosity, and epoxide equivalent will not apply.

3.2.2. *Component B (Modified-Amine Hardening Agent)*—Top coat shall be the hardening agent for Component A Top Coat and shall be composed of a bitumen which has been especially treated with a modified aliphatic polyamine. It shall contain no contaminants, reactive diluents, or insolubles and shall conform to the requirements of Table 2.

Table 2—Requirements for Component B

Property	Top Coat
Viscosity, Pa·s (poises), 25˚C (77˚F) (Spindle No. 2, 20 r/min)	0.2 to 0.8 (2 to 8)
Ash, mass, percent, max	0.5
Volatile loss (to 177˚C (350˚F)) cm^3, max	3.00
Specific gravity, 25/25˚C (77/77˚F)	1.10 to 1.25
Water, mass, percent, max	2.0
Alkalinity, equivalent/100 g	0.19 to 0.27

3.3. *Prime Coat:*

3.3.1. When a prime coat is ordered, the prime coat shall consist of a mixture of Component A and Component B to which has been added toluene or 2-nitro propane not in excess of 10 percent of the total volume.

3.3.2. Component A Primer shall be composed of Component A Top Coat to which has been added toluene to produce a mixture of flowing consistency. In areas subject to air pollution control regulations forbidding the use of toluene, 2-nitro propane shall be used.

3.3.3. Component B Primer shall be composed of Component B Top Coat to which has been added toluene to produce a mixture of flowing consistency while maintaining a 1:1 ratio with Component A Primer. In areas subject to air pollution control regulations forbidding the use of toluene, 2-nitro propane shall be used.

3.4. *Physical Requirements of Cured Epoxy Resin System*—When Component A Top Coat and Component B Top Coat are combined on an equal basis the mixture shall conform to the requirements of Table 3.

Table 3—Physical Properties of the Cured System

Property	Top Coat
Water absorption, mass, percent, max	0.3
Tensile strength, min Pa (psi)	2758 (400)
Elongation, percent, min	35
Gel time, minutes	25–50
Shore D hardness, 25˚C (77˚F)	35–65
Bond strength, direct tension, min, Pa (psi)	621 (90)
Flexural creep, min:	
24 hours, in. (mm)	0.010 (0.2540)
7 days, in. (mm)	0.015 (0.3810)

3.5. *Thixotropic Agent (Mineral Filler)*:

3.5.1. When mineral fillers are specified or permitted, they shall be inert and nonsettling or readily dispersible. The filler shall have a fineness such that at least 99 percent shall pass the 0.045-mm (No. 325) sieve and 100 percent shall pass the 0.150-mm (No. 100) sieve.

3.6. *Aggregates*:

3.6.1. *Surface Application*—The aggregate for surface application shall be nonfriable, nonpolishing, clean, and free from surface moisture. It shall be durable and sound and shall have a proven record of performance in applications of this type. Known suitable aggregates include aluminum oxide, emery, silica sand, garnet, and blast-furnace slag. The grading of the aggregate shall conform to the requirements given in Table 4.

Table 4—Aggregate Gradation

Sieve Designation		Mass, Percent, Passing	
mm	No.	Grade A	Grade B
4.75	4	—	100
2.36	8	100	0–5
0.600	30	0–3	—
0.075	200	0–1	0–1

3.6.2. Aggregate, which will be exposed to traffic, shall have a minimum Mohs' scale of hardness of 7.

3.7. *Waterproofing Fabric*:

3.7.1. Waterproofing fabric shall be woven glass fabric conforming to FSS HH-C-466 or to ASTM D 1668, except that the requirement for minimum mass of coating shall be waived.

Note 2—Grade A Aggregate is recommended when the Coal-Tar Coating is to be used as a Wearing Course. Grade B aggregate is recommended when the Coal-Tar Epoxy Coating is to be followed by an asphaltic concrete Wearing Course.

4. PACKAGING

4.1. *Packaging*—The two components of the epoxy resin system furnished under this specification shall be supplied in separate containers that are nonreactive with the materials contained therein.

4.2. *Marking*—Each container of the two components shall be labeled with the name of the mixture, the component type, the name of the manufacturer, the lot or batch number, the date of packaging, and the quantity contained therein. The proper component type shall also be placed on each lid and shall show whether it is formulated for use as a primer or as a top coat. Each label shall include essentially the following text for *Directions for Use*:

DIRECTIONS FOR USE

The contents of the separate packages containing Components A and B must be thoroughly stirred before use to redisperse any mineral filler used. ***Do not use the same paddle to stir Component A as is used to stir Component B***. To mix the adhesive, blend one part by volume of Component A with one part by volume of Component B and stir thoroughly. Do not mix more material than can be used before it hardens.

Equipment and tools must be cleaned with toluene before the adhesive has set. Components A and B should be stored at a temperature between 24 and 27ºC (75 and 80ºF) for several hours before use.

Warning—This material will cause severe dermatitis if proper precautions are not followed. ***Do not let it come in contact with the skin or eyes***. Use gloves and protective creams on the hands. If contact with the skin occurs, wash thoroughly with soap and water. If any gets in the eyes, flush for 10 minutes with water and secure immediate medical attention. ***Do not attempt to remove this material from the skin with solvents***.

5. CERTIFICATION

5.1. At the request of the purchaser, the manufacturer of the epoxy resin system shall certify that Components A and B meet the requirements of this specification. Such certification shall consist of either a copy of the manufacturer's test report or a statement by the manufacturer, accompanied by a copy of the test results, that the Components A and B have been sampled and tested. Such certification shall indicate the date of testing and shall be signed by an authorized agent of the formulator or manufacturer.

5.2. At the request of the purchaser, the formulator shall certify that the mineral filler used in either component meets the following:

5.2.1. The filler shall be inert and nonsettling or readily dispersible. It shall have a fineness such that at least 99 percent shall pass the 0.045-mm (No. 325) sieve and 100 percent shall pass the 0.150-mm (No. 100) sieve.

6. METHOD OF TESTING

6.1. Tests shall be conducted in accordance with the following methods:

6.1.1. *Epoxide Equivalent*—ASTM D 1652.

6.1.2. *Viscosity*—ASTM D 1084, Viscosity of Adhesives, Method B. Using Spindle No. 3 at 20 r/min for Component A and Spindle No. 2 at 20 r/min for Component B, except that the temperature shall be 25.0 ± 0.5ºC (77 ± 1ºF).

6.1.3. *Ash*—ASTM D 482.

6.1.4. *Volatile Loss*—ASTM D 1078, except that a 10 mL graduated cylinder with 0.1 mL subdivisions shall be used as a receiver and the distillation shall be discontinued when the temperature reaches 177ºC (350ºF). Record the volume of the distillate in the receiver as volatile loss.

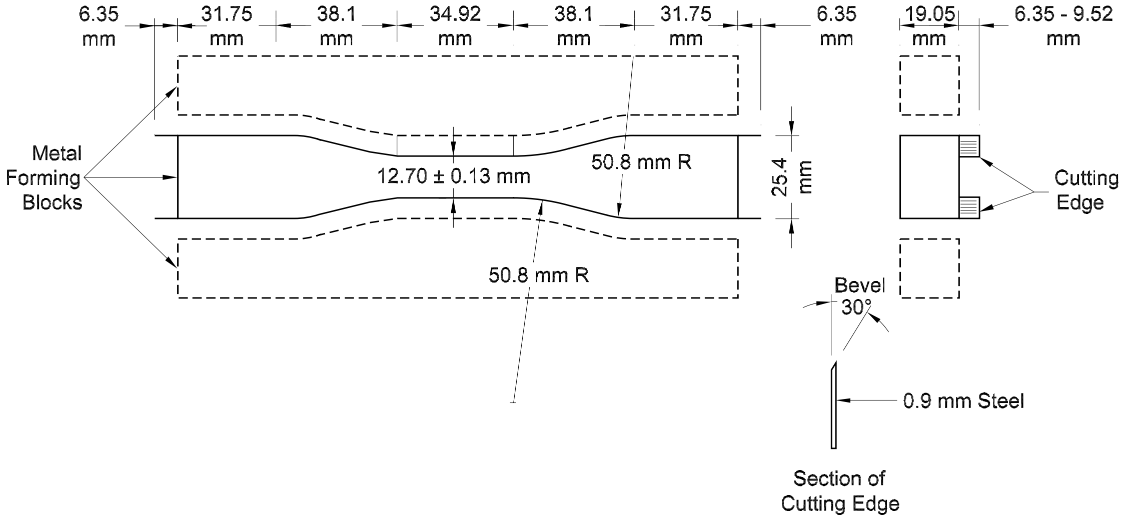
6.1.5. *Specific Gravity*—ASTM D 154.

6.1.6. *Water Content*—AASHTO T 55.

6.1.7. *Alkalinity*—ASTM D 664, titrated to the first end-point, which will occur at a pH of about 6.3.

6.1.8. *Water Absorption*—ASTM D 570, 0.5-hour boiling water immersion after seven-day cure at 25ºC (77ºF).

6.1.9. *Tensile Strength and Elongation*—ASTM D 638. The speed of testing shall be 5.1 mm (0.20 in.) per minute ±25 percent (Speed B) using specimens cut from a laboratory cast sheet 3.2 mm ($^1/_8$ in.) thick. The cast shall be allowed to harden for 18 hours at 25ºC (77ºF) plus 5 hours at 70ºC (158ºF) and allowed to return to room temperature before cutting and testing. The test specimens shall be cut using Die C of ASTM D 412, having a gauge length of 25.4 mm (1 in.) and a width of 12.7 mm (0.500 in.), or by use of a die similar to that shown in Figure 1.



Metric Equivalents

mm	in.
50.8	2
38.1	1 1/2
34.92	1 3/8
31.75	1 1/4
25.40	1
19.05	3/4
12.7	1/2
9.52	3/8
6.35	1/4
0.13	5/1000
0.9	20 gauge

Note: Cutting edge is of 0.9 mm spring steel and is held between three metal blocks machined to conform to the above dimensions.

Figure 1—Cutting Die for Tensile Test

6.1.10. *Gel Time*—The following procedure shall be used to determine gel time. Measure 30 mL (1 oz) of Component A and 30 mL (1 oz) of Component B each at 25ºC (77ºF) into an unwaxed paper cup and record the time. Immediately, the two components shall be mixed by stirring for three minutes with a wooden tongue depressor, periodically scraping the walls and the bottom of the cup. The mixture shall be poured into a 240 mL (8 oz) unwaxed paper cup placed on a wooden bench top. Starting 20 minutes from the time recorded above the mixture shall be probed every two minutes with a small stick, until a small ball forms in the center of the container. The total time, including mixing, required for the ball to form shall be recorded as gel time. The test shall be performed in a room or enclosed area maintained at 25 ± 2ºC (77 ± 3.6ºF) and 50 ± 5 percent relative humidity.

6.1.11. *Shore Hardness*—ASTM D 2240, except that the specimen for testing shall be prepared and cured using the following procedure. Measure 30 mL (1 oz) of Component A and 30 mL (1 oz) of Component B at 25 ± 2ºC (77 ± 3.6ºF) into an unwaxed paper cup. The two components shall be mixed by stirring for 3 minutes with a wooden tongue depressor, periodically scraping the walls and bottom of the cup. The mixture shall be poured into an unwaxed paper container with a diameter not less than 60 mm (2.36 in.) placed on a wooden bench top. The mixture shall be allowed to harden without being disturbed, 24 hours in a room or enclosed area maintained at 25 ± 2ºC (77 ± 3.6ºF) and 50 ± 5 percent relative humidity before testing.

6.1.12. *Bond Strength*—The cured epoxy mixture shall develop a bond strength that is equal to or greater than the cohesive strength of the concrete when tested for adhesion as specified in the report of A.C.I. Committee 403 title No. 59-43. This test comprises bonding a standard 51-mm (2-in.) pipe cap to the concrete surface and measuring the tensile force required to bring about separation.

6.1.13. *Low Temperature Creep*—California Test Method 419A.

7. RECOMMENDED CONSTRUCTION PRACTICE

7.1. *Preparation of Surfaces*—Surfaces of concrete to be treated shall be sandblasted before applying tar-epoxy mixture.

7.1.1. When the mixture is to be applied to old surfaces having heavy local deposits of oil, grease, and other adherent foreign materials, which will interfere with proper cleaning, these deposits shall be completely removed using any suitable means. Possible methods include solvents, such as trichloroethylene or xylene, heavy-duty detergents and/or mechanical means such as scraping. Where the concrete surface has deteriorated, it shall be cleaned down to sound material and patched, if necessary.

7.1.2. New concrete shall be aged at least 14 days before any coating is applied.

7.1.3. Both old and new concrete shall then be cleaned by sandblasting. Sandblasting shall be accomplished in such a manner as to insure the removal of all laitance or any other substance that would prevent good adhesion of the epoxy. Suitable traps shall be installed in sandblasting equipment to prevent water or oil from being deposited on the bridge surface. After sandblasting, the surface shall be swept, vacuumed, hosed, or blown free of all dust and grit. The surface of the concrete shall be dry when the epoxy coating is applied.

7.1.4. Unless specifically permitted, bitumen modified epoxy mixture shall be applied only when the air temperature is above 10ºC (50ºF).

7.2. *Preparation of Mixtures*—Equal parts, by volume, of the two components shall be mixed mechanically batchwise, or continuously in automatic paving equipment which provides continuous metering, mixing, and application at a controlled rate. Caution shall be exercised to make certain that Component A Primer, is mixed with Component B Primer, and that Component A Top Coat, is mixed with Component B Top Coat.

7.2.1. If the components are to be mixed batchwise, mixing shall be performed with a propeller-type stirrer, or other power agitator attached to a 12.7 mm ($^1/_2$ in.) heavy-duty drill. Care must be exercised to incorporate thoroughly mixed material at the sides and bottom of the mixing container. Mixing time shall be not less than 5 minutes at 15 to 27ºC (60 to 80ºF) or 3 minutes at 27 to 38ºC (80 to 100ºF).

7.2.2. The mixed material will set quickly if allowed to remain in a large mass such as in the mixing container. The pot life is approximately as follows:

Air Temperature	Pot Life (Measured from Beginning of Mixing)
15°C–21°C (60°F–70°F)	18 min
21°C–27°C (70°F–80°F)	12 min
27°C–32°C (80°F–90°F)	10 min
32°C–38°C (90°F–100°F)	8 min

7.3. *Application of Primer*—The resinous material for the prime coat shall be distributed evenly over the entire area to be surfaced at a minimum thickness of 0.38 mm (15 mils) 0.4 kg/m^2 (0.75 lb/yd^2 approximately). The prime coat shall be applied uniformly to all areas to be subsequently given a second coat and so that no gray areas remain. Care shall be taken to treat the curbs on each side to a height of at least 50 mm (2 in.). The prime coat shall be spread with rollers or approved mechanical equipment touched up by hand.

7.4. *Application of Top Coat*—After the prime coat has set sufficiently to walk on or to operate equipment over (and in any case within 24 hours), the top coat mixture shall be distributed evenly over the entire area to be surfaced at the rate specified in Section 7.4.1. If binder is mixed batchwise, it shall be leveled with lutes, brooms, paint rollers, or screeds.

7.4.1. The exact rate of application of the top coat mixture shall be determined by the engineer. As a check on the rate of application, measured volumes of the mixture shall be applied to measured areas of the surface. The top coat shall be applied at a rate such that the total application for the two coats will give a thickness of 1.5 mm (60 mil) (0.66 m^2/L (27 sq ft/gal)) or 1.6 kg/m^2 (3 lb/yd^2) approximately. One liter has a mass of approximately 1.15 kg (1 gallon has a mass of approximately 9.6 pounds).

7.5. *Application of Fabric*—When fabric is to be incorporated to form an impervious membrane beneath an asphaltic wearing course, the fabric shall be immediately embedded in the epoxy top coat. To provide a watertight seal at the curb and deck joint, it is recommended that a glass fabric tape approximately 200 mm (8 in.) wide be applied to the deck and 50 mm (2 in.) of the curb before applying the full width of fabric to the flat surface of the deck. All fabric shall be lapped at least 50 mm (2 in.) transversely and longitudinally.

7.6. *Application of Aggregate*—While the epoxy mixture is still liquid, the surfacing aggregate shall be dropped into the epoxy in excess of the rate necessary to cover the surface. The aggregate must be sprinkled or dropped vertically in such a manner that the level of the epoxy mixture is not disturbed. The aggregate shall be applied within 5 minutes after the application of the epoxy, except at temperatures below 21ºC (70ºF) when a maximum of 10 minutes is allowable.

7.7. After the aggregate is spread, all vehicular and foot traffic shall be prohibited in the area until the epoxy cement is hardened and the embedded aggregate cannot be removed. When the epoxy has completely hardened, excess aggregate shall be swept up for recovery or disposal.

CLASS II—OIL-MODIFIED EPOXY RESIN MIXTURE

8. MATERIALS

8.1. The oil modified epoxy resin mixture shall be furnished in two components to be combined in equal volumes immediately prior to use in accordance with the written instructions of the manufacturer.

8.1.1. Component A (Transparent Modified Epoxy Resin) shall be based on a liquid epoxy resin, a condensation product of hisphenol A and epichlorohydrin. The component shall be homogeneous and shall conform to the requirements of Table 5.

Table 5—Requirements for Component A

Property	Specific Value
Epoxide equivalent	275 to 300
Viscosity, Pa·s (Poises) 25˚C (77˚F), spindle No. 3, r/min	2.5 (25) max
Water content, mass, percent	0.2 max
Volatile loss, mL to 121˚C (250˚F), at 1.3 kPa (10 mm) absolute pressure	2.0 max

8.1.2. Component B (Transparent Modified Amine Curing Agent) shall be the curing agent for use with Component A and shall be composed of a polyamine modified with petroleum oils, flexibilizers, and accelerators. It shall contain no contaminants or insolubles and shall conform to the requirements of Table 6.

Table 6—Requirements for Component B

Property	Specific Value
Alkalinity, ep./100 g	0.21 to 0.25
Viscosity, Pa·s (Poises) 25˚C (77˚F), spindle No. 1, 20 r/min	1.5 max
Water content, mass, percent	0.2 max
Volatile loss, mL to 177˚C (350˚F)	1.0 max

8.1.3. When Components A and B are combined on an equal basis by volume, the mixture shall conform to the requirements of Table 7.

Table 7—Physical Properties of the Cured System

Property	Specific Value
Water absorption, mass, percent	0.5 max
Tensile strength, kPa (psi), 25 ± 1˚C (77 ± 2˚F)	6205 (900) min
Elongation at max load, percent 25 ± 1˚C (77 ± 2˚F)	40 min
Gel time, minutes, 25 ± 1˚C (77 ± 2˚F)	30 to 60
Shore hardness, 25 ± 1˚C (77 ± 2˚F)	35 to 65

9. METHODS OF TESTING

9.1. For tests to be performed on cured material, the curing schedule shall be a minimum of 24 hours at 24 to 27ºC (75 to 80ºF) followed by 20 ± 2 hours at 57 ± 3ºC (135 ± 5ºF).

9.1.1. *Epoxide Equivalent*—ASTM D 1652.

9.1.2. *Viscosity*—Brookfield.

9.1.3. *Water Content*—AASHTO T 55.

9.1.4. *Volatile Loss, Component A*—ASTM D 1189, and Component B—ASTM D 1079.

9.1.5. *Alkalinity*—ASTM D 664. Titrated to the first end point which will occur at a pH of about 6.3.

9.1.6. *Water Absorption*—ASTM D 570, 0.5 hour in boiling water.

9.1.7. *Tensile Strength and Elongation, ASTM D 638*—Individual specimens shall be cast to conform to dimensions for Type I. Thickness shall be 33 ± 5 mm (0.13 ± 0.02 in.). Speed of testing shall be 5.1 mm per min (0.20 in. per minute) ± 25 percent (Speed B).

9.1.8. *Gel Time*—The gel time shall be determined by weighing into a 240 mL (8 ounce) unwaxed paper cup sufficient amounts of each component, in the proper ratio for the particular material being tested, to make a total mass of 60.0 ± 0.2 g. The time shall be recorded and the two components mixed together by stirring for three minutes with a wooden tongue depressor or small spatula, periodically scraping the walls and bottom of the cup. The cup shall then be set on a wooden block and probed every two minutes with a small glass rod starting 20 minutes from the initiation of mixing. The time at which a semi-solid gel is formed shall be recorded as the gel time.

9.1.9. *Shore D Hardness*—ASTM D 2240 as modified in Section 7.1.11.

10. PACKAGING

10.1. Components shall be packaged and marked as set forth under "Packaging" in Sections 4.1 and 4.2.

Standard Specification for

Expanded and Extruded Foam Board (Polystyrene)

AASHTO Designation: M 230-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Expanded and Extruded Foam Board (Polystyrene)

AASHTO Designation: M 230-07

1. SCOPE

1.1. This specification covers expanded and extruded polystyrene board used for lightweight fill or highway pavement insulation applications.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- C 177, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus
- C 272, Standard Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions
- C 303, Standard Test Method for Dimensions and Density of Preformed Block and Board-Type Thermal Insulation
- C 518, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
- C 578, Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation
- D 1621, Standard Test Method for Compressive Properties of Rigid Cellular Plastics
- D 1622, Standard Test Method for Apparent Density of Rigid Cellular Plastics
- D 2863, Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)

3. GENERAL REQUIREMENTS

3.1. The expanded polystyrene board shall be formed by the expansion of polystyrene base resin in an extrusion process. The board shall be homogeneous and shall consist of a continuum of closed cells.

4. PHYSICAL PROPERTIES

4.1. The board shall conform to the requirements prescribed in Table 1 when tested by the procedures specified in Section 6.

4.2. Design data should specify both the required compressive strength and thickness. (Normal manufacturing processes and distribution systems allow for 105-kPa, 170-kPa, 275-kPa, 415-kPa, and 690-kPa boards. Boards are manufactured based upon need, with 275-kPa board normally used as insulation for AASHTO's axle loadings of 98 kN.)

Table 1—Physical Property Requirements

Foam Classification Type ASTM C 578	Compressive Strength[a] kPa ASTM D 1621	Thermal Resistance[b] [R-value at 23.9ºC] ASTM C 518 or C 177	Max Water Absorption (% by Vol) ASTM C 272	Oxygen Index (%) ASTM D 2863	Minimum Density[c] (kg/m^3) ASTM C 303 or ASTM D 1622
X	105 min	0.88 min	0.3	24 min	21
IV	170 min	0.88 min	0.3	24 min	26
VI	275 min	0.88 min	0.3	24 min	29
VII	415 min	0.88 min	0.3	24 min	35
V	690 min	0.88 min	0.3	24 min	48
II	105 min	0.70 min	3.0	24 min	22

[a] Compressive strength to be determined at five percent deflection of specimen thickness or yield, whichever occurs first. A minimum of 275 kPa required for AASHTO's normal axle loading of 98 kN.

[b] Units: °C × m^2/W. Tabulated values show required thermal resistance of a 25-mm thickness at a mean temperature of 23.9ºC.

[c] When used for lightweight fill, the maximum density shall not exceed 1.25 × minimum density.

5. DIMENSIONAL TOLERANCES

5.1. Normally, extruded polystyrene foam boards shall be either 610 by 2440 mm or 1220 by 2440 mm with the thickness being specified by the user.

5.2. The permissible variations from the ordered dimensions shall be as follows (ASTM C 578):

5.2.1. Length ±0.8 mm per 305 mm of length,

5.2.2. Width ±1.6 mm per 305 mm of width,

5.2.3. Thickness ±1.6 mm per 25 mm of thickness (Note 1).

Note 1—When used for insulation, the thickness of board used shall be based upon heat flow theory and local conditions.

6. METHODS OF TESTING

6.1. The physical properties enumerated in this specification shall be determined in accordance with the following methods of the American Society for Testing and Materials (ASTM):

6.1.1. *Compressive Strength*—ASTM D 1621, Procedure A, except that the compressive strength shall be determined when the specimen is compressed 5 percent of measured thickness or at the first major load deviation, whichever comes first. A major load deviation shall be that point on the stress-strain curve where the stress load drops significantly below the normal stress fluctuation characteristic of the material under test (Note 2).

Note 2—Construction requirements should specify a smooth surface upon which the board is to be placed to prevent point loadings, wooden skewers or piles of non-frost susceptible sand or gravel used to hold the boards from "separating" or "shoving" during covering, and a minimum of 250 mm of granular material above the insulation for "stress absorption" or prevention of crushing of the insulation by construction traffic. An on-site test with the proposed methods of construction, including layer thickness and construction equipment, is recommended to ensure that there is no separation of the boards nor crushing of the insulation. The potential for differential icing should be taken into consideration when selecting the depth of cover over the extruded foam board.

6.1.2. *Oxygen Index*—ASTM D 2863. This test shall be used to establish the minimum oxygen index.

6.1.3. *Water Absorption*—ASTM C 272.

6.1.4. *Thermal Resistance*—Test in accordance with ASTM C 177 or ASTM C 518. Tests shall be conducted with a temperature differential of 28 ± 1ºC.

6.1.5. *Density*—Test in accordance with ASTM C 303 or ASTM D 1622.

7. HAZARDS

7.1. *Health and Safety*—Each manufacturer has a duty to warn when shipment, storage, installation, use, or ultimate disposal of a product may expose individuals to health or safety hazards. The manufacturer shall provide the user with appropriate information regarding any known hazards associated with the recommended handling and use of the product, and shall recommend the protective measures to be employed in its safe utilization.

Standard Specification for

Epoxy Resin Adhesives

AASHTO Designation: M 235M/M 235-03 (2007)[1]
ASTM Designation: C 881-99

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Epoxy Resin Adhesives

AASHTO Designation: M 235M/M 235-03 (2007)[1]
ASTM Designation: C 881-99

1. SCOPE

1.1. This specification covers two-component, epoxy-resin bonding systems for application to portland cement concrete, which are able to cure under humid conditions and bond to damp surfaces.

1.2. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. For specific hazards statements, see Section 9.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- C 882, Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear[2]
- C 884, Standard Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay[2]
- D 570, Standard Test Method for Water Absorption of Plastics[3]
- D 638, Standard Test Method for Tensile Properties of Plastics[3]
- D 648, Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position[3]
- D 695, Standard Test Method for Compressive Properties of Rigid Plastics[3]
- D 1259, Standard Test Methods for Nonvolatile Content of Resin Solutions[4]
- D 1652, Standard Test Method for Epoxy Content of Epoxy Resins[5]
- D 2393-95, Test Method for Viscosity of Epoxy Resins and Related Components [6]
- D 2566, Test Method for Linear Shrinkage of Cured Thermosetting Casting Resins During Cure (Withdrawn 1993)[6]

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *binder, n*—the cementitious part of a grout, mortar, or concrete that binds the aggregate or filler into a cohesive mass.

3.1.2. *bonding system, n*—the product resulting from the combination of all the components supplied for use as a bonding material.

3.1.3. *component, n*—a constituent that is intended to be combined with one or more other constituents to form a bonding system.

3.1.4. *contact strength, n*—bond strength measured by slant shear after a specified contact and cure time.

3.1.5. *contact time, n*—specified time between when the epoxy system is applied and when the two segments are bonded together and still achieve a specified bond strength after a specified curing time and temperature.

3.1.6. *curing agent, n*—a substance that causes the conversion of a fluid resin system to a solid cured resin by means of a chemical reaction.

3.1.7. *epoxy equivalent, n*—the weight of resin containing one molecular weight of epoxy groups.

3.1.8. *epoxy resin, n*—a resin that contains or did contain epoxy groups principally responsible for its polymerization.

3.1.9. *filler, n*—a finely divided solid, predominantly passing the 75-µm [No. 200] sieve, that is used to improve certain properties of the bonding system or to reduce cost.

3.1.10. *formulator, n*—the agency responsible for preparing the separate components and for recommending the proportions to be used in preparing the final bonding system.

3.1.11. *lot or batch, n*—that quantity of manufactured material which has been subjected to the same unit chemical or physical processes intended to make the final product substantially uniform.

3.1.12. *manufacturer, n*—a producer of a basic constituent part of a component.

3.1.13. *reactive diluent, n*—a relatively free flowing liquid used to reduce the viscosity of the liquid resin or resin mixture, and which contains reactive groups that cause it to become an integral part of the cured resin.

3.1.14. *working (pot) life, n*—the time after mixing during which a bonding system or mixture containing it retains sufficient workability for proper use.

4. CLASSIFICATION

4.1. This specification provides for the classification of epoxy-resin bonding systems by type, grade, class, and color.

4.2. *Types*—Seven types of systems that are distinguished by the requirements of Table 1 are recognized.

Table 1—Physical Requirements of Bonding Systems

	Type						
Property	I	II	III	IV	V	VI	VII
Viscosity Pa·s [P]:							
Grade 1, max	2.0 [20]	2.0 [20]	2.0 [20]	2.0 [20]	2.0 [20]	—	—
Grade 2, min	2.0 [20]	2.0 [20]	2.0 [20]	2.0 [20]	2.0 [20]	—	—
Max	10 [100]	10 [100]	10 [100]	10 [100]	10 [100]		
Consistency, mm [in.]:							
Grade 3, Types I, II, III, IV, V, VI, VII, max	6.0 [$^{1}/_{4}$]	6.0 [$^{1}/_{4}$]	6.0 [$^{1}/_{4}$]	6.0 [$^{1}/_{4}$]	6.0 [$^{1}/_{4}$]	6.0 [$^{1}/_{4}$]	6.0 [$^{1}/_{4}$]
Gel time, minutes, min	30	30	30	30	30	30	30
Bond strength, min MPa [psi]:							
2 days (moist cure)	7.0 [1000]	—	—	7.0 [1000]	—	7.0 [1000]	—
14 days (moist cure)	10.0 [1500]	10.0 [1500]	10.0 [1500]	10.0 [1500]	10.0 [1500]	—	7.0 [1000]
Absorption, 24-h max, %	1	1	1	1	1	—	—
Heat deflection: Temperature, min ˚C [˚F]:							
7 days	—	—	—	50 [120]	50 [120]	—	—
14 days	—	—	—	—	—	50 [120]	50 [120]
Thermal compatibility	—	—	passes test	—	—	—	—
Linear coefficient of shrinkage on cure, max	0.005	0.005	—	0.005	0.005	—	—
Compressive yield strength, min, MPa [psi]:							
24 h	—	—	—	—	—	14.0 [2000]	—
36 h	—	—	—	—	—	—	7.0 [1000]
48 h	—	—	—	—	—	40.0 [6000]	—
72 h	—	—	—	—	—	—	14.0 [2000]
7 days	55.0 [8000]	35.0 [5000]	—	70.0 [10000]	55.0 [8000]	—	—
Compressive modulus, MPa [psi]:							
Min	1000 [150000]	600 [90000]	—	1400 [200000]	1000 [150000]	—	—
Max	—	—	896 [130000]	—	—	—	—
Tensile strength, 7 days min, MPa [psi][a]	35.0 [5000]	14.0 [2000]	—	50.0 [7000]	40.0 [6000]	—	—
Elongation at break, percent, min	1	1	30	1	1	—	—
Contact strength, MPa [psi] min							
2 days	—	—	—	—	—	7.0 [1000]	—
14 days	—	—	—	—	—	—	7.0 [1000]

[a] Not required for Viscosity Grade 3 Systems

4.2.1. *Type I*—For use in non-load-bearing application for bonding hardened concrete to hardened concrete and other materials, and as a binder in epoxy mortars or epoxy concretes.

4.2.2. *Type II*—For use in non-load-bearing applications for bonding freshly mixed concrete to hardened concrete.

4.2.3. *Type III*—For use in bonding skid-resistant materials to hardened concrete, and as a binder in epoxy mortars or epoxy concretes used on traffic-bearing surfaces (or surfaces subject to thermal or mechanical movements).

4.2.4. *Type IV*—For use in load-bearing applications for bonding hardened concrete to hardened concrete and other materials and as a binder for epoxy mortars and concretes.

4.2.5. *Type V*—For use in load-bearing applications for bonding freshly mixed concrete to hardened concrete.

4.2.6. *Type VI*—For bonding and sealing segmental precast elements with internal tendons and for span-by-span erection when temporary post tensioning is applied.

4.2.7. *Type VII*—For use as a non-stress-carrying sealer for segmental precast elements when temporary post tensioning is not applied as in span-by-span erection.

Note 1—Epoxy resin systems will adhere to a wide variety of materials, including wood, metals, masonry, and most plastics. Polyethylene, TFE-fluorocarbon, cellophane, and greased or waxed surfaces are among the few materials to which these systems will not adhere.

4.3. *Grades*—Three grades of systems are defined according to their flow characteristics and are distinguished by the viscosity and consistency requirements of Table 1.

4.3.1. *Grade 1*—Low viscosity.

4.3.2. *Grade 2*—Medium viscosity.

4.3.3. *Grade 3*—Non-sagging consistency.

4.4. *Classes*—Classes A, B, and C are defined for Types I through V, and Classes D, E, and F are defined for Types VI and VII, in accordance with the range of temperatures for which they are suitable (Note 2).

4.4.1. *Class A*—For use below 4.0ºC [40ºF] the lowest allowable temperature to be defined by the manufacturer of the product.

4.4.2. *Class B*—For use between 4.0 and 15.0ºC [40 and 60ºF].

4.4.3. *Class C*—For use above 15.0ºC [60ºF] the highest allowable temperature to be defined by the manufacturer of the product.

4.4.4. *Class D*—For use 4.0 and 18.0ºC [40 and 65ºF].

4.4.5. *Class E*—For use between 15.0 and 30.0ºC [60 and 80ºF].

4.4.6. *Class F*—For use between 25.0 and 30.0ºC [75 and 90ºF].

Note 2—The temperature in question is usually that of the surface of the hardened concrete to which the bonding system is to be applied. This temperature may be considerably different from that of the air. Where unusual curing rates are desired, it is possible to use a class of bonding agent at a temperature other than that for which it is normally intended. For example, a Class A system will cure rapidly at room temperature.

4.5. *Color*—Epoxy resin systems are normally unpigmented, but they can be colored or darkened. If a specific color is desired, it should be so stated by the purchaser.

5. ORDERING INFORMATION

5.1. The purchaser shall specify the type, grade, class, and color of bonding system desired and the size of units in which the components shall be furnished. Special requirements regarding filling of either the components or the final bonding system should be stated. The product furnished under this specification is intended to be resistant to moisture and therefore should be suitable for either indoor or outdoor exposure.

5.2. The purchaser may specify a minimum gel time of 5 minutes for Types I and IV when automatic proportioning, mixing, and dispensing equipment are used.

6. MATERIALS AND MANUFACTURE

6.1. The systems covered by this specification shall be furnished in two components for combining immediately prior to use in accordance with written instructions of the formulator. Component A shall contain an epoxy resin with or without a reactive diluent. Component B shall contain one or more curing agents, which on mixing with Component A shall cause the mixture to harden. A suitable inert filler may be uniformly incorporated in one or both components. The filler shall be either nonsettling or readily dispersible in any component in which it is incorporated. All systems shall cure under humid conditions, and bond to damp surfaces.

7. CHEMICAL COMPOSITION

7.1. The epoxy-resin constituent of Component A shall have an epoxy equivalent of 155 to 275.

8. PHYSICAL PROPERTIES

8.1. A mixture of Components A and B in the proportions recommended by the formulator shall conform to the properties prescribed in Table 1.

9. SAFETY HAZARDS

9.1. **Caution**—Epoxy resins contain irritants, especially to the skin, eyes, and respiratory system. Persons handling these materials shall use appropriate protective clothing, including rubber or plastic gloves. If an epoxy resin should contact the skin, it shall be removed immediately with a dry cloth or paper towel, and the area of contact washed thoroughly with soap and water. Solvents shall ***not*** be used, because they carry the irritant into the skin. Cured epoxy resins are innocuous.

10. SAMPLING

10.1. Take a representative sample of each of the two components from a well-blended lot prior to packaging or by withdrawing samples from no fewer than 5 percent of the containers comprising the lot or shipment. Unless the samples of the same component taken from containers show visual evidence of variability, they may be combined into a single composite sample. In place of the foregoing, packaged materials may be sampled by a random selection of containers of each component from each lot, provided such a procedure is acceptable to the purchaser.

11. TEST METHODS

11.1. *Consistency*—Test Method to Determine the Consistency of an Epoxy Resin System.

11.1.1. *Scope*—This test provides a method for determining the consistency of Grade 3 epoxy resin systems.

11.1.2. *Significance and Use*—This test method is used to determine compliance with the requirements of the specification.

11.1.3. *Apparatus*:

11.1.3.1. *Paper cup*—approximately 0.100-L [3-oz] unwaxed paper cup.

11.1.3.2. *Mixing blade*—Ordinary wooden tongue depressor or stick of similar size.

11.1.3.3. *Glass panel*.

11.1.3.4. *Conditioning*—Condition the individual components and any equipment with which they will come in contact to the following temperatures: Class A, 32 ± 2ºF [0 ± 1ºC]; Class B, 10 ± 1ºC [50 ± 2ºF]; Class C, 23 ± 1º C [73 ± 2ºF]; Class D, 18 ± 1ºC [65 ± 2ºF]; Class E, 27 ± 1ºC [80 ± 2ºF]; Class F, 32 ± 1ºC [90 ± 2ºF] or the temperature at which the material will be used (Note 2).

11.1.4. *Procedure*—Prepare approximately 30 cm^3 of the bonding system. Weigh the necessary amounts of the components to an accuracy of 1 percent into a single approximately 100-cm^3 [3-oz] unwaxed paper cup. Mix immediately with a wooden tongue depressor or stick of similar size. Note the time at which mixing begins. Mix for 3 minutes, taking care to scrape the side and bottom of the cup periodically. Immediately apply about 2 cm^3 of the mixture to a glass panel. Form a semicylindrical bead of the bonding system by drawing the applicator blade through the sample in a straight line with the panel horizontal. Immediately raise the panel to a position inclined no greater than 10º from vertical and with the bead horizontal. Maintain the panel and sample at their original temperature until the bonding system has cured, as determined by an inability to indent it appreciably with a pencil point or fingernail. Determine the consistency by measuring the flow of the lower edge of the bead from its original position at three points along its length.

11.1.5. *Report*—Report the average value to the nearest 1 mm [$^1/_8$ in.].

11.1.6. *Precision and Bias*:

11.1.6.1. *Precision*—The precision of the procedure in this test method for consistency is being determined.

11.1.6.2. *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

11.2. *Gel Time*—Test method to determine the gel time of an epoxy resin system.

11.2.1. *Scope*—This test method determines the time after mixing when an epoxy resin system gels.

11.2.2. *Significance and Use*—This test method is used to determine compliance with the requirements of the specification.

11.2.3. *Apparatus*:

11.2.3.1. *Paper cup*—250-cm^3 [approximately 8-oz] unwaxed paper cup.

11.2.3.2. *Mixing blade*—Ordinary wooden tongue depressor or stick of similar size.

11.2.4. *Conditioning*—Condition the individual components and any equipment with which they will come in contact to the temperatures set forth in Section 11.1, depending on the class of system in question, or to the temperature at which the material will be used, providing that temperature is within the ranges established in Section 4.4 for Types I, II, III, and V. For Types VI and VII use the highest temperature of the specified class (Note 2). Prepare 60 g of the bonding system for Types I through V and 4.0 L [1 gal] for Types VI and VII using the procedures set forth in Section 11.1.

11.2.5. *Procedure*—Transfer as much as possible of the sample into an approximately 250-cm^3 [8-oz] unwaxed paper cup and set it on a wooden surface in a location maintained at the original conditioning temperature and not subject to abnormal room air movement. Determine the time at which a soft, gelatinous mass forms in the center of the sample by probing every 2 minutes with a wooden tongue depressor or similar device, starting 8 minutes after the beginning of mixing.

11.2.6. *Report*—The gel time is the interval between the beginning of mixing and the formation of the gelatinous mass.

11.2.7. *Precision and Bias*:

11.2.7.1. *Precision*—The precision of the procedure in this test method for gel time is being determined.

11.2.7.2. *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

11.3. *Filler Content*—Test Method to Determine the Filler Content of Epoxy Resin Systems.

11.3.1. *Scope*—This test method is a quantitative test to determine the filler content of epoxy resin systems.

11.3.2. *Significance and Use*—The filler content of an epoxy resin system must be known in order to determine the epoxy equivalent.

11.3.3. *Apparatus*:

11.3.3.1. 150-mL beaker.

11.3.3.2. Medium-porosity, fritted-disk filtering crucible.

11.3.3.3. *Mixing blade*—Ordinary wooden tongue depressor or stick of similar size.

11.3.4. *Reagents*:

11.3.4.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[7] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

11.3.4.2. Methyl ethyl ketone (MEK).

11.3.4.3. Benzene.

11.3.5. *Procedure*—Weigh, to the nearest 0.1 mg, approximately 10 g of the epoxy resin component into a 150-mL beaker. Add 50 mL of methyl ethyl ketone (MEK) to the beaker, and stir the contents until all the soluble matter is dissolved. If the sample is black, owing to the presence of bituminous material, the solvent used shall be a mixture of 1 + 1 MEK and benzene, by volume. Dry a medium-porosity, fritted-disk filtering crucible to constant weight at 110 ± 5ºC [230 ± 9ºF]. Wet the filter with MEK, then filter the contents of the beaker through the filtering crucible with the aid of a vacuum. Transfer the contents of the beaker entirely to the crucible, and wash the beaker and the residue on the filter with MEK. The total volume of solvent used to transfer and wash the residue should be about 200 mL. Dry the filter and residue to constant weight at 110 ± 5ºC [230 ± 9ºF].

11.3.6. *Report*—Calculate the percentage of filler in the component, and report the value to the nearest 0.1 percent.

11.3.7. *Precision and Bias:*

11.3.7.1. *Precision*—The precision of the procedure in this test method for filler content is being determined.

11.3.7.2. *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

11.4. *Epoxy Equivalent*—Determine the epoxy equivalent of Component A in accordance with ASTM D 1652. Calculate the epoxy equivalent after correcting for any filler and volatile contents of the component as follows:

$$x = y\,(1 - f - v) \qquad (1)$$

where:

x = corrected weight per epoxy equivalent of the component,

y = weight per epoxy equivalent of the total component as determined by ASTM D 1652,

f = weight fraction of filler in the component, and

v = weight fraction of volatile matter in the component.

11.5. *Viscosity*—Determine the viscosity of the freshly mixed resin system by means of ASTM D 2393-95, except that the determination shall be made at the temperature given in Section 11.1 for the class of material in question.

11.6. *Absorption*—Determine the absorption by means of ASTM D 570. The test specimens shall have the shape and dimensions specified for molded plastics, shall be cured for 14 days at a temperature of 23 ± 1ºC [73 ± 2ºF], shall be tested in accordance with the procedure for 24-hour immersion, and shall be reconditioned, if necessary, as directed in ASTM D 570.

11.7. *Bond Strength*—Determine the bond strength in accordance with ASTM C 882.

11.8. *Thermal Compatibility*—Determine the thermal compatibility in accordance with ASTM C 884.

11.9. *Heat Deflection Temperature*—Determine the heat deflection temperature in accordance with ASTM D 648, except condition, mix, cure, and start testing the resin components at 23 ± 1ºC [73 ± 2ºF].

11.10. *Linear Coefficient of Shrinkage*—Determine the linear coefficient of shrinkage in accordance with ASTM D 2566, except condition, mix, cure, and test the resin components at 23 ± 1ºC [73 ± 2ºF].

11.11. *Compressive Yield Strength and Modulus*—Determine the compressive yield strength and modulus in accordance with ASTM D 695, except condition, mix, and cure the resin components at the lowest application temperature of the specified class. Test at 23 ± 1ºC [73 ± 2ºF] without delay. Use of a 25.4 × 25.4 × 50.8-mm [1 × 1 × 2-in.] specimen is also acceptable.

11.12. *Tensile Strength and Elongation at Break*—Determine the tensile strength and elongation at break in accordance with ASTM D 638, except condition, mix, and cure at the lowest application temperature of the specified class. Test at 23 ± 1ºC [73 ± 2ºF], without delay.

11.13. *Contact Strength*—Determine the contact strength in accordance with ASTM C 882 except condition the material and the specimens at the highest application temperature of the specified class and apply the bonding system at a thickness of 2 mm [$^1/_{16}$ in.] on the slanted surface of each half cylinder. Maintain at the highest application temperature and assemble the two half cylinders after 1 hour for Type VI and 8 hours for Type VII. Cure at the assembly temperature and test at 23 ± 1ºC [73 ± 2ºF]. Contact strength is expressed in terms of pascals [pounds per square inch] obtained after a specified time of cure.

12. REJECTION AND REHEARING

12.1. The purchaser has the right to reject material that fails to conform to the requirements of this specification. Rejection shall be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer or supplier has the right to a rehearing.

12.2. If all requirements of this specification are met, except those pertaining to bond strength, the bond tests shall be repeated. If the sample again fails to meet the bond strength requirements, the entire lot shall be rejected.

12.3. *Retest*—Lots of material that have been rejected may be reworked by the producer to correct the defects and resubmitted for test provided specific approval of the purchaser has been obtained for such resubmission. Before resubmission of the material, full particulars concerning the action taken to correct the defects in the original material shall be made available to the purchaser.

13. PACKAGING AND PACKAGE MARKING

13.1. *Packaging*—The two components furnished under this specification shall be supplied in separate containers that are nonreactive with the contents. They are usually supplied in amounts such that the recommended proportions of the final mixture can be obtained by combining one container of Component A with one container of Component B.

13.2. *Marking*—Containers shall be identified as "Component A—Contains Epoxy Resin" and "Component B—Contains Curing Agent" and shall show the type, grade, class, and color. Each container shall be marked with the name of the formulator, the lot number, the date of packaging, the quantity contained therein, and the recommended mixing ratio, by both weight and volume.

14. KEYWORDS

14.1. Bonding; bonding systems; contact strength; contact time; epoxy resin.

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[1] Similar but not technically equivalent to ASTM C 881-99.

[2] *Annual Book of ASTM Standards*, Volume 04.02.

[3] *Annual Book of ASTM Standards*, Volume 08.01.

[4] *Annual Book of ASTM Standards*, Volume 06.01.

[5] *Annual Book of ASTM Standards*, Volume 06.03.

[6] *Annual Book of ASTM Standards*, Volume 08.02.

[7] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, D.C. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

Standard Practice

Evaluation of Transportation-Related Earthborne Vibrations

AASHTO Designation: R 8-96 (2009)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Evaluation of Transportation-Related Earthborne Vibrations

AASHTO Designation: R 8-96 (2009)[1]

1. SCOPE

1.1 This standard practice is to provide guidance for the assessment of potential or alleged structural damage due to earthborne vibrations related to transportation facility construction, maintenance, or operation.

2. INTRODUCTION

2.1 The construction, maintenance, and operation of transportation facilities generate vibrations, which are transmitted through the air and earth and are subsequently received or "sensed" by structures or inhabitants. Only earthborne vibrations are addressed in this standard practice. (See Section X2.8, Appendix X2.)

2.2 Currently accepted practice in monitoring earthborne vibrations considers two parameters—earth particle velocity and wave frequency—determined at the site of concern (Siskind et al. 1980; see Figure 1). Sensing instruments are usually set out on the ground adjacent to the subject structure. For determination of safe vibration control limits, special concerns may dictate placement of sensors directly on specific parts of a structure such as the foundation, a supporting column, or a wall.

2.3 Much of the data concerning structural damage has been determined from blasting activities. Blasting is a commonly used construction-related procedure that produces vibrations characterized by a wide frequency range and potentially high intensities but of very short duration.

Transportation-related activities, such as vehicular or rail traffic, may be the source of repetitive, cyclical vibrations of much lower intensity than those caused by blasting. There may be concern in this regard because of potential for fatigue of structural components. Documentation of specific damage due to such transportation-related vibrations is scarce (Whiffin and Leonard 1971; Ames et al. 1976).

2.4 People "sense" or respond to a much broader range of vibration frequencies and intensities than do structures. Intrusive vibration levels can annoy humans at much lower intensities than levels considered critical for structures (see Figure 2). Such sensitivity causes concern for structural damage potential even at the extremely low levels of vibration that are a recognized nuisance to people. Various threshold limits have been recommended in standards aimed at minimizing damage to various structures. Recommended safe vibration limits are based upon the appearance of "threshold cracks" or cosmetic cracking. Such cracks appear at lower vibration levels than do architectural or minor damage. The applicability of specific limitations is often the subject of litigation requiring expert witness opinion.

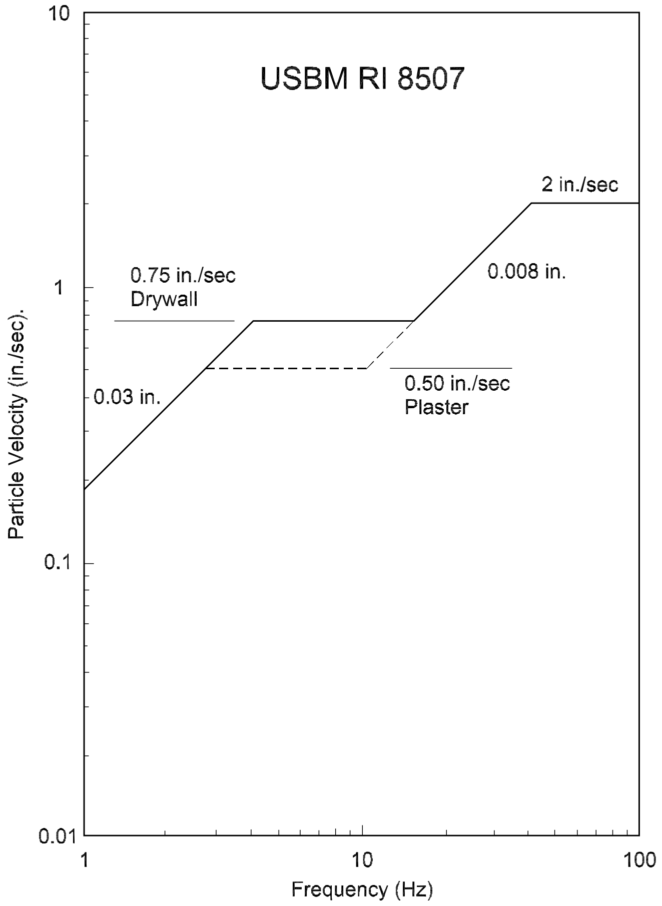

Figure 1—Safe Vibration Limit Recommendations for Residential Structures

2.5 Concerns of anticipated or perceived damage can be related to structures or their contents. Practically all buildings contain fine cracks or imperfections that are not noticed until concern is stimulated by perception of abnormal vibrations. Evaluation of the potential effects of transportation-related earthborne vibrations requires documentation of the background or pre-existing condition of the structure or component of concern. Such an evaluation should also include a determination of the intrusive vibration characteristics (amplitudes and frequencies) at the point of interest. Dowding (1992) reviews the various methods for determining ground vibration frequencies. Analysis of the results may necessitate modification at the vibration source or mitigation of effects at the location of concern.

3. PROCEDURE

3.1 A survey of the site should be made by personnel capable of locating, evaluating, and documenting significant or apparent evidence of distress. Such surveys preferably should be made before the onset of any objectionable vibration-producing activity. The scope of the inspection should be appropriate for both the subject of concern and the intensity of the vibrations. Photographic or video documentation of the inspection is recommended. Any procedures requiring intrusion on property should be specifically permitted by the property owner, preferably in writing. Specialists in vibration monitoring are often contracted for survey services.

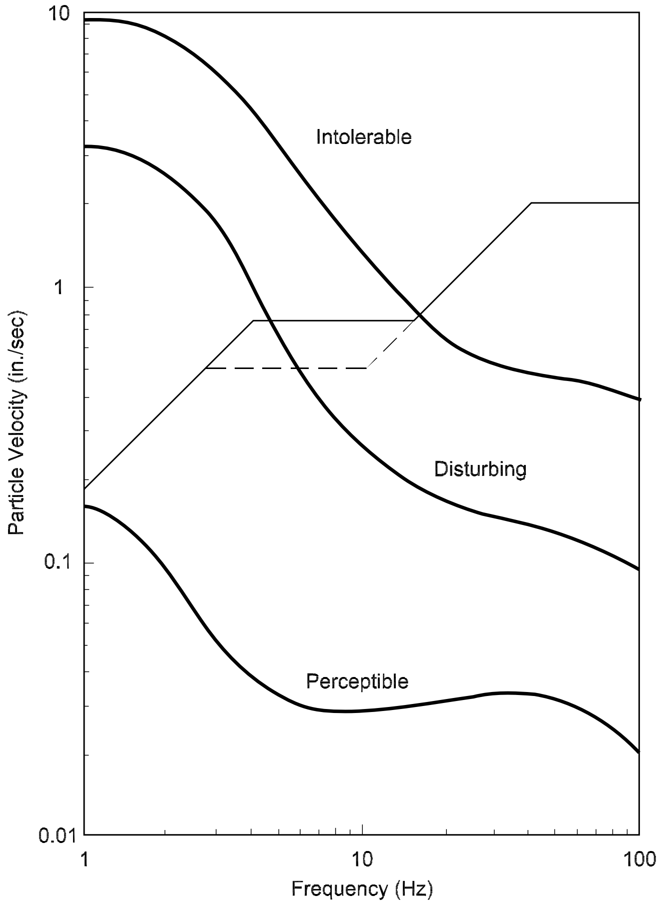

Figure 2—Safe Vibration Limit (USBM RI 8507) and Human Perception (Rathbone)

3.2 All vibrations arriving at the monitoring location within the selected sensitivity range of the seismograph are recorded. For comparison purposes, it is often useful to obtain recordings of the normal or background vibrations at the site when the specific objectionable source is not present. The sensitivity range of the instrument should be selected so that recording is initiated below the intensity of the objectionable vibrations and extends above the highest expected intensity. It may be necessary to estimate or predetermine the expected intensity level to be sensed in order to select the appropriate instrument range setting to be used during monitoring. It is necessary to determine the time when the vibration source is active. Specific activities of the vibration source, such as driving of piles, as opposed to extraction, vibratory compaction, or pavement-breaking activities, should be indexed in time for proper correlation with the arrivals on the vibration records. Since the determination of frequency is important, instruments that provide a time-history or waveform of each velocity component for a vibration event are preferred.

3.3 A field calibration procedure should be conducted before the start of monitoring and recording. The incoming ground vibrations should be measured on the ground at foundation level, as close to the structure as possible to be consistent with studies providing safe vibration limits (Siskind and Stagg 1985). The transducer is positioned with the longitudinal axis (indicated by an arrow) toward the vibration source or parallel to the structure. Transducers must be adequately coupled with the ground or the structural component being monitored. (See Section X1.5, Appendix X1.) Instrument manufacturers provide appropriate instructions and recommendations for special installations. Some published threshold criteria are based on specific monitoring procedures.

Consistent procedures in the placement and location of transducers during monitoring are recommended for comparison of results.

3.4 Records of the incoming vibrations are typically displayed in a waveform plot or strip chart plot. The peak particle velocities in longitudinal, transverse, and vertical planes are shown along with the respective dominant or principal frequencies. The highest recorded particle velocity among the three planes is indexed to its time of occurrence within the recorded interval. This velocity is reported as the peak particle velocity for a particular event.

3.5 The recorded peak particle velocity is compared with criteria appropriate for the subject of concern. Many currently used digital instruments produce a record that displays the particle velocities and associated zero crossing frequencies, or arrivals plotted against a base of the U.S. Bureau of Mines (USBM) RI 8507 curve, which is a commonly accepted criterion for threshold cracking concerns in the United States (see Figure X2.1). Other criteria may be applicable in special circumstances (see Appendix X2).

3.6 In the event of a complaint, a site visit should be made as soon as possible to assess the situation and to compile necessary documentation. A report document should include all relevant data such as the basis for the investigation, time and date of the survey, persons involved, and a description of the property. It should also include a description of the instrumentation, description and log of the monitoring procedure, the monitoring results, and the conclusions reached based on comparison with applicable criteria, standards, or expert recommendation.

3.7 The following information should be obtained when complaints of intrusive vibrations are received:

3.7.1 Time and date of the complaint;

3.7.2 Name, address, and phone number of the complainant;

3.7.3 The alleged damage and/or complaint;

3.7.4 The time and date on which the damage occurred;

3.7.5 The type and location of the alleged damaging or intrusive vibration source;

3.7.6 A photograph or sketch of the physical problem;

3.7.7 Any actions that are demanded; and

3.7.8 Reference to any previous complaints by the complainant or in the vicinity.

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APPENDIXES

X1. GENERAL INFORMATION

X1.1. *Threshold*:

X1.1.1. The point at which a physiological or psychological effect is initiated.

X1.2. *Threshold Cracking*:

X1.2.1. The manifestation of cosmetic damage; the formation of the most superficial interior cracking, which occurs in all homes due to various environmental factors and household activities. Safe vibration limits are set to avoid these types of cracks.

X1.3. *Architectural or Minor Damage*:

X1.3.1. Non-structural damage that does not affect the strength or function of a structure, such as cracked plaster or wallboard, cracked or broken windows, or hairline cracks in masonry walls.

X1.4. *Major Damage*:

X1.4.1. Damage resulting in serious weakening of a structure; for example, substantial settlements or shifting of foundations, distortion or weakening of the superstructure, large cracks in foundation or bearing walls, or walls out of plumb.

X1.5. *Transducers*:

X1.5.1. Velocity-sensing transducers (geophones) with response capability in three mutually perpendicular axes or components: one vertical and two horizontal (radial and transverse). The frequency response of the transducer should be linear from at least 4 Hz to more than 200 Hz. Sensitivity should range from less than 0.02 in./s to more than 5.0 in./s.

X1.5.2. Accelerometers are sometimes used as transducers in specialized applications. Such applications include low-frequency studies, structure response analyses, and high-frequency or close-in work (Oriard 1980; Stagg and Engler 1980). Accelerometers measure acceleration, the rate at which particle velocity changes, in terms of *g*, the acceleration of gravity. The recorded signal can be electronically integrated to produce a record of particle velocity.

X1.5.3. It is extremely important that transducers are adequately coupled to monitoring surfaces (Stagg and Engler 1980; Siskind and Stagg 1985). Sandbags are not always sufficient (Duvall 1961; Robertson 1993). In general, surface placement techniques are adequate only for low-frequency, low-amplitude levels (less than 1.0 in./s at less than 20 Hz) and acceleration levels of less than 0.2 *g* (Stagg and Engler 1980). A study by Blair (1987) suggests a lower acceleration value of 0.1 *g*. The preferred emplacement method of the USBM is to bury transducers in soils and to firmly anchor (such as gluing or bolting) transducers to hard surfaces.

X1.6. *Limiting Velocity*:

X1.6.1. Maximum vibration levels not to be exceeded to prevent threshold cracking or damage.

X1.7. *Peak Particle Velocity (PPV)*:

X1.7.1. The maximum recorded particle velocity from any one of the three axes of movement (vertical [V_v], horizontal [V_h], and transverse [V_t]) for a recorded vibration event.

X1.8. *Resultant or Vector Sum*:

X1.8.1. See Peak True Vector Sum.

X1.9. *True Vector Sum (V)*:

X1.9.1. The resultant of vectorially adding the three components of velocity at the same instant of time.

$$\bar{V} = \sqrt{V_v^2 + V_h^2 + V_t^2} \qquad (X1.1)$$

X1.9.2. *Peak True Vector Sum*:

X1.9.3. The highest true vector sum value of the three components of velocity during the record interval.

X1.10. *Peak Pseudo Vector Sum*:

X1.10.1. The resultant of vectorially adding the maximum velocity from each of the three traces regardless of the time at which they occurred on the record. This practice, although sometimes used, is not appropriate.

X1.11. *Dominant or Principal Frequency*:

X1.11.1. The frequency associated with the peak particle velocity. It may be found by zero crossing, Fourier frequency, or response spectrum techniques as described by Dowding (1992).

X1.12. *Natural or Resonant Frequency*:

X1.12.1. A structure will continue to oscillate when the source of excitation is discontinued. This motion by the structure is called free vibration. The number of times per second a structure vibrates during free vibration is the natural frequency of the structure. The amplitude of vibration will be the greatest when the frequency of the incoming ground vibration is the same as the natural frequency of the structure. Natural frequencies of residential structures were calculated by Dowding et al., 1981. For whole structures, they ranged from 3 to 11 Hz and for individual walls, they ranged from 12 to 20 Hz.

X1.13. *Time-History*:

X1.13.1. The waveform plot, as in velocity versus time (velocity time-history) or acceleration versus time (acceleration time-history), of a vibration event.

X1.14. *Background Vibrations*:

X1.14.1. Vibrations normally present prior to the onset of any activity generating vibrations of special interest.

X1.15. *Site Inspection or Survey*:

X1.15.1. The systematic documentation of the existing condition of a structure or site. The extent or content of the inspection depends on the site. Dowding (1985) gives an example of such an investigation form.

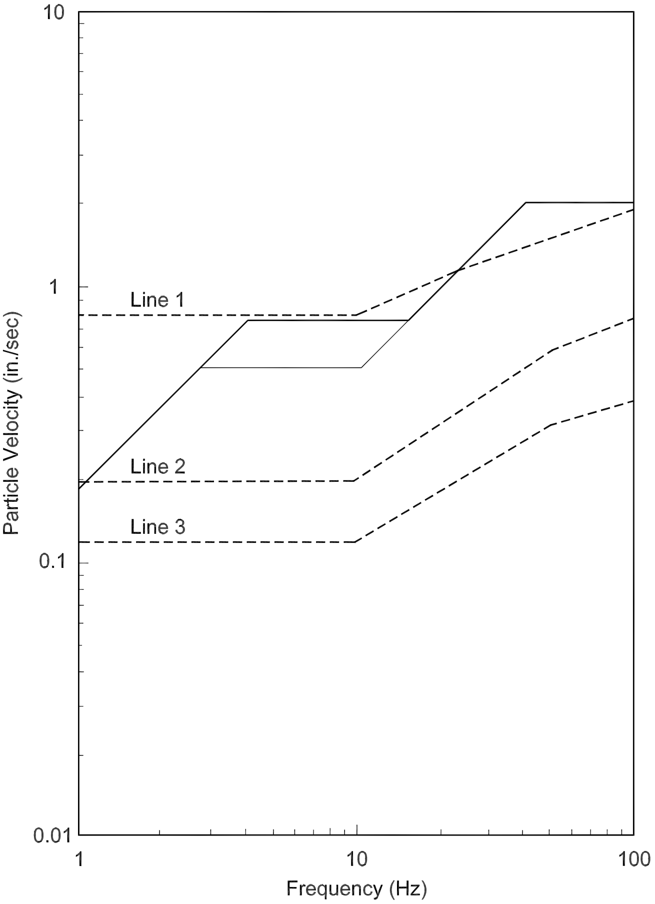
X1.16. *Liquefaction*:

X1.16.1. A condition in which a cohesionless soil will lose its strength and undergo large deformations due to the buildup and maintenance of high pore pressures that are equal or close to the confining pressure in the soil (after Seed 1979). The pore pressure buildup may be due to static stresses, but more commonly it is due to cyclic stress applications. For more information, the reader is referred to, among others, Seed 1979; Seed et al. 1983; Tokimatsu and Seed 1987; Kramer and Seed 1988; Rollins and Seed 1990; Fiegel and Kutter 1994.

X2. CRITERIA FOR LIMITING VIBRATIONS

X2.1. *Threshold for Earthborne Vibrations*:

X2.1.1. At the present, there is no universally accepted standard for limiting earthborne vibrations. Various approaches are being implemented to address specific concerns. In the United States, the USBM RI 8507 threshold recommendations are most commonly referenced. The German guidelines DIN 4150 (see Figure X2.1) and the British Standard BS 7385 (see Figure X2.2) are examples of criteria used in other countries as a basis for evaluation of potential damage. Note the basis for the guideline levels of DIN 4150 are unknown; however, they are considered safe and very conservative (Dowding 1992; Siskind 1994). Special interest groups, such as historical preservation societies as one example, issue threshold guidelines for concerns within their jurisdiction. The basis for the guidelines should be established in any particular application.



(Adapted from DIN 4150)

Line	Type of Structure
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design
2	Dwelling and buildings of similar design and/or use
3	Structures that, because of their particular sensitivity to vibration, do not correspond to those listed in lines 1 and 2, and are of great intrinsic value (e.g., buildings that are under a preservation order)

Figure X2.1—Vibration Guidelines—USBM RI 8507 (Solid Line) Compared to DIN 4150 (Dashed Line)

X2.2. *Peak Particle Velocity and Frequency*:

X2.2.1. The current USBM threshold recommendations and the other aforementioned criteria recognize the relationship of peak particle velocity and frequency. The USBM recommendations are the result of tests on essentially residential structures. Recommendations include a caution that threshold damage may occur at displacements greater than 0.030 in. at frequencies below 4 Hz and 0.008 in. at frequencies between 12 and 40 Hz. (See Figure 1.)

X2.3. *Peak True Vector Sum Particle Velocity*:

X2.3.1. The threshold recommendations of the USBM for assessing damage potential are based on the maximum particle velocity without preference to any of the three components. Some instruments provide a value known as the true vector sum or resultant. This value is sometimes used to express the maximum intensity of a vibration event. The peak true vector sum is a conservative estimate of the peak particle velocity as it is always greater than the maximum particle velocity from any one of the three components.

X2.3.2. There is no frequency associated with the true vector sum. Therefore, the true vector sum or the resultant cannot be used in conjunction with the USBM RI 8507 curve. The use of the true vector sum is limited to a few regulations requiring compliance with a specified peak particle velocity limit without regard to frequency. Most of these regulations are historically linked to two USBM publications: RI 5968, published in 1962 and Bulletin 656, published in 1971 (Siskind 1991). Both publications advocated the use of particle velocity as the best descriptor of ground vibration damage. RI 5968 was the first to recommend a maximum single component amplitude of 2.0 in./s, without regard to frequency, as a safe particle velocity criterion.

X2.4. *Peak Particle Velocity for Underground Structures*:

X2.4.1. Threshold cracking recommendations are developed for specific categories of structures. USBM 8507 is based on residential structures. The application of such criteria to markedly different types of structures such as foundation walls, buried pipelines, and other underground structures is common and inaccurate. Whereas aboveground structures have freedom to respond to ground motion, buried structures are restrained in their response.

X2.4.2. Recent studies have demonstrated that the vibration amplitude at ground level is much greater than that actually measured on a buried pipeline (Linehan et al. 1992; Siskind and Stagg 1993). It can be shown that a ground strain criterion is analytically more appropriate for buried structures than a criterion based on velocity. Hence, the use of strain and resulting stresses to develop criteria for buried structures is advocated (Esparza, Westine, and Wenzel 1981; Dowding and Corser 1981). A buried steel pipeline can sustain allowable strains at vibration levels of 5.0 in./s to 45.0 in./s. (Westine et al. 1978; Linehan et al. 1992; Siskind and Stagg 1993). At least one major utility has established a criterion of a peak particle velocity of 4.0 in./s over their buried optical fiber cables.

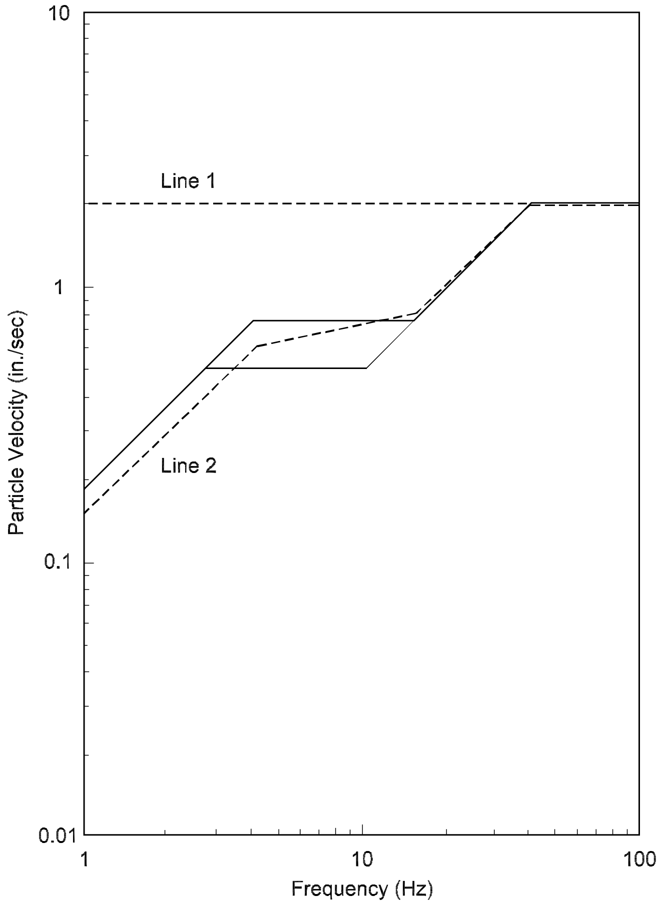
X2.4.3. A tunnel with a shotcrete liner can experience a particle velocity of 36.0 in./s before the appearance of threshold cracking (Hendron 1977). A restrained monolithic concrete block can experience 10.0 in./s before cracking (Crawford and Ward 1965; Oriard 1987). Prediction equations for stresses and strains in buried pipelines are presented in Esparza (1981, 1991) and Dowding (1985).

X2.5. *Cumulative Effect of Repeated Ground Vibration*:

X2.5.1. There is considerable concern about the cumulative effect of repeated ground vibration or fatigue on a structure. Documentation in the literature is limited. For example, most large metropolitan areas have many residential structures in close proximity to subway systems. Over the years such structures have been exposed to numerous cycles of low level vibrations without any apparent attributable damage. Comprehensive studies were conducted by the USBM (Stagg et al. 1984). Tests in a residential structure subjected to repeated, mechanically induced vibration levels equal to 0.5 in./s on the ground outside produced threshold cracking after 56,000 cycles.

X2.6. *Continuous Ground Vibrations*:

X2.6.1. The vibration levels that can be tolerated from a transient or short duration event, such as a blast, are higher than the levels from a steady-state or continuous vibration source, such as a vibratory compactor (Wiss 1981). Guidance on human response to vibrations of various durations is provided by ANSI S3.29-1983 and the British Standard BS 6472:1992. Because of their longer duration, incoming continuous ground vibrations with dominant frequencies close to the natural frequency of a structure are more likely to be amplified due to structural resonance (Crum and Siskind 1993). With regard to threshold cracking, Wiss (1967) stated, common practice for continuous vibrations is to reduce the allowable transient level of 2.0 in./s by as much as 80 percent.



(Adapted from BS 7385)

Line	Type of Building
1	Reinforced or framed structures Industrial and heavy commercial buildings
2	Unreinforced or light framed structures Residential or light commercial type buildings

Figure X2.2—Vibration Guidelines—USBM RI 8507 (Solid Line) Compared to BS 7385 (Dashed Line)

X2.7. *Soil Liquefaction*:

X2.7.1. Building damage due to the potential liquefaction of certain soils or the permanent displacement of the ground as a result of vibrations is another area of concern. Saturated, loose, uniformly, or poorly graded sands and silts are sensitive to cyclic vibrations such as might be produced by vibratory pile driving (Wiss 1981; Clough and Chameau 1980), vibratory compaction (Tynan 1973), or vibrating tampers conducting a seismic reflection survey (Hryciw et al. 1990). In some cases, these materials may liquify as a result of a single impact (Tynan 1973; Tschebotarioff 1973) or densify as due to an explosion (Dowding 1994). These activities can produce noticeable settlement even at low vibration levels (0.1 to 0.7 in./s) which are known not to produce threshold cracking (Dowding 1994; Leathers 1994; Leznicki et al. 1994; Kim et al. 1994). In such cases, the limiting criteria may be dictated by the soil conditions.

X2.8. *Airborne Vibrations*:

X2.8.1. Only earthborne vibrations are addressed in this standard practice. However, airborne vibrations can also produce noticeable structural responses. For information on airborne vibrations, the reader is referred to, among others, Siskind et al. 1980(1); Stachura et al. 1981 and 1984.

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[1] An earlier version of this standard, R 8-81 (1990), was deleted by the Subcommittee on Materials in 1993 and did not appear in the 17th Edition. R 8-96 (2009) is a major revision of this standard practice.

Standard Practice for

Definition of Terms Related to Quality and Statistics As Used in Highway Construction

AASHTO Designation: R 10-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Definition of Terms Related to Quality and Statistics As Used in Highway Construction

AASHTO Designation: R 10-06

1. SCOPE

1.1 This standard practice is to provide standard definitions for terms used in specifications, test methods, and the various quality assurance procedures.

2. GENERAL PROVISIONS

2.1 It is recommended that AASHTO specifications and procedures, including standard practices, incorporate the following accepted terms as defined. These terms and their definitions are directed primarily to the various quality assurance sampling and acceptance plans. Where a definition conflicts with a standard, the standard will govern.

3. DEFINITIONS

3.1 *acceptable quality level (AQL)*—the level of established actual quality for a quality characteristic that is fully acceptable. [For example, when the quality measure used is percent within limits (PWL), the AQL is the established (not estimated) PWL at which the quality characteristic is fully acceptable. Acceptance plans should be designed so that AQL material will receive an expected pay (EP) of 100 percent.]

3.2 *acceptance*—the process whereby all factors used by the agency (i.e., sampling, testing, and inspection) are evaluated to determine the degree of compliance with contract requirements and to determine the corresponding value for a given product.

3.3 *acceptance constant (k)*—the minimum allowable quality index (*Q*). [The acceptance constant *k* is the acceptance limit associated with the quality index quality measure. In other words, for acceptance, *Q* must be greater than or equal to *k*.]

3.4 *acceptance limit*—in variables acceptance plans, the limiting upper or lower value, placed on a quality measure, that will permit acceptance of a lot. [While the test values for material samples are evaluated against specification limits and engineering limits, the computed quality level for a specific quality measure is evaluated against the acceptance limit. For example, the minimum allowable PWL called for in a QA specification might be 65 PWL. This is the acceptance limit.]

3.5 *acceptance number (c)*—in attributes acceptance plans, the maximum number of defective or nonconforming units in the sample that will permit acceptance of the inspected lot or batch.

3.6 *acceptance plan*—also called “acceptance sampling plan” or “statistical acceptance plan. ” An agreed upon process for evaluating the acceptability of a lot of material. It includes: lot size and sample size (i.e., number of samples), quality measure, acceptance limit(s), evaluation of risks, and pay adjustment provisions.

3.7 *acceptance sampling and testing*—sampling and testing performed by the agency, or its designated agent, to evaluate acceptability of the final product. Also called “verification sampling and testing” when specifically used to validate the contractor’s data.

3.8 *acceptance quality characteristic (AQC)*—a quality characteristic that is measured and used to determine acceptability.

3.9 *accepted reference value*—a value that serves as an agreed-upon reference for comparison, and which is derived as: (1) a theoretical or established value, based on scientific principles, (2) an assigned or certified value, based on experimental work of some national or international organization, or (3) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group.

3.10 *accredited laboratories*—laboratories which are recognized by a formal accrediting body as meeting quality system requirements including demonstrated competence to perform standard test procedures.

3.11 *action limits*—see *control chart limits*.

3.12 *accuracy*—the degree to which a measurement, or the mean of a distribution of measurements, tends to coincide with the true population mean. [When the true population mean is not known, the degree of agreement between the observed measurements and an accepted reference value may be used to quantify the accuracy of the measurements.]

3.13 *adjusted pay schedule*—see *pay adjustment schedule*.

3.14 *adjusted pay system*—see *pay adjustment system*.

3.15 *aesthetic value*—the worth of an item of construction in terms of pleasing appearance or gratifying performance.

3.16 *alpha* (α) *error*—see *seller’s risk*.

3.17 *alpha sub PF* (α_{PF})—see *seller’s risk*. For acceptance plans with pay adjustments, the probability that acceptable quality level (AQL) material or construction will be assessed a pay factor less than PF with respect to a single acceptance quality characteristic. For example, α_{100} for a compressive strength pay adjustment acceptance plan is the probability that AQL compressive strength material will be assessed less than 100 percent pay for compressive strength; this probability includes the probability of rejection, α_0, with respect to compressive strength. [The use of α_{PF} addresses the need to quantify, for pay adjustment acceptance plans, the probabilities associated with each possible pay decision regarding AQL material (e.g., payment of 0, 70, 80, 90, 100, or 105 percent for AQL material). A seller (contractor) is usually most interested in α_{100}.]

3.18 *alternative hypothesis* (H_a)—the hypothesis to be accepted if the null hypothesis (H_o) is disproved (i.e., rejected).

3.19 *analysis of variance (ANOVA)*—a mathematical method of isolating causes of variation.

3.20 *assignable cause*—a source of variation, usually due to error or process change, which can be detected by statistical methods and corrected within economic limits. [When assignable causes are identified and removed, the production process is “under control”.]

3.21 *attribute*—a characteristic that, by its presence or absence, classifies a unit or segment as conforming or nonconforming.

3.22 *attributes acceptance plan*—a statistical acceptance procedure where the acceptability of a lot of material or construction is evaluated by (1) noting the presence or absence of some characteristic or attribute in each of the units or samples in the group under consideration, and (2) counting how many units do or do not possess this characteristic.

3.23 *average*—a measure of central value that usually refers to the arithmetic mean $(\bar{X})$. May also refer to the median or mode. [The mean, median, and mode are equal for a normal distribution. As a distribution becomes more skewed, the mean, median, and mode will differ more and more.]

3.24 *average absolute deviation (AAD)*—for a series of test results, the mean of absolute deviations from a target or specified value. [Its use as an acceptance measure is not recommended.]

3.25 *average run length (ARL)*—in a sample sense, the average number of times that a process will have been sampled and evaluated before a shift in process level is signaled. In a unit sense, the average number of units that will have been produced before a shift in level is signaled. [A long ARL is desirable for a process located at its specified level (to minimize calling for unneeded investigation or corrective action) and a short ARL is desirable for a process shifted to some undesirable level (so that corrective action will be called for promptly). ARL curves are used to describe the relative quickness in detecting level shifts of various control chart systems.]

3.26 *batch*—a specified quantity of material produced through a uniform operation or process. [A batch is usually smaller than a lot.]

3.27 *beta (*β*) error*—see *buyer's risk*.

3.28 *beta sub PF (*β_{PF}*)*—see *buyer's risk*. For acceptance plans with pay adjustments, the probability that rejectable quality level (RQL) material will be assessed a pay factor greater than or equal to *PF*. For example, β_{100} for a compressive strength pay adjustment acceptance plan is the probability RQL compressive strength material will be assessed 100 percent pay or more for compressive strength. [The use of β_{PF} addresses the need to quantify, for pay adjustment acceptance plans, the probabilities associated with each possible pay decision regarding RQL material (e.g., payment of 0, 70, 80, 90, 100, or 105 percent for RQL material). A buyer (agency) is usually most interested in β_{100}.]

3.29 *bias*—an error, constant in direction, that causes a measurement, or the mean of a distribution of measurements, to be offset from the true population mean.

3.30 *biased sampling*—a sampling procedure whereby samples obtained from a lot do not have an equal probability of being chosen. [Some examples of conventional biased approaches to sampling which have been utilized by agencies and contractors include representative sampling, uniform interval sampling, quota sampling, and selective sampling.]

3.31 *buyer's risk (*β*)*—also called "agency's risk or risk of a Type II" or "beta (β) error. " It is the risk to the agency of accepting rejectable quality level (RQL) material or workmanship. [For an accept/reject acceptance plan, it is the probability that an acceptance plan will erroneously accept RQL material or workmanship with respect to a single acceptance quality characteristic. For variables acceptance plans using adjusted pay schedules, it is equivalent to β_{PF}, where $PF = 100$. It is the probability that a variable payment acceptance plan will erroneously fully accept RQL material or workmanship at 100 percent pay or greater with respect to a single acceptance quality characteristic.]

3.32 *calibration*—a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or between values represented by a material measure or a reference material, and the corresponding values realized by standards. [The purpose of calibration is to ensure that measurements made by the laboratory are traceable to the International System of Units (SI). Where traceability of measurements to SI units is not possible or relevant, measurements must be traceable to certified reference materials, agreed methods, or consensus standards. Uncertainty estimates obtained during calibration are used to judge if an instrument is suitable for its intended purpose. There is a need to re-establish traceability or recalibrate only when instrument measurements drift out of control (as determined through verification of calibration). See *standardization.*]

3.33 *certified technician*—a technician certified by some agency as proficient in performing certain duties. [A certified technician is considered to be qualified. A qualified technician may or may not be certified. See *qualified technician*.]

3.34 *chance cause*—a source of variation that is inherent in any production process and cannot be eliminated because it is due to random, expected causes.

3.35 *characteristic*—a measurable property of a material, product, or item of construction.

3.36 *class*—a group of data values (measurements, observations, or test values) that all satisfy a given set of conditions associated with a frequency distribution.

3.37 *class frequency*—the number of data values falling into a particular class.

3.38 *classification*—the acts of evaluating if an attribute or variable does or does not conform to requirements, and the documentation of results.

3.39 *class interval*—the difference in value between the lower and the upper limits of a given class.

3.40 *class limits*—the upper and lower values that define a given class.

3.41 *class midpoint*—the central value of a particular class.

3.42 *cluster sampling*—the random selection of clusters (i.e., groups or bundles) from a population. For each cluster selected, random sampling of the contained elements may then be performed. [Examples of cluster sampling are selection of city blocks as primary sampling units; selection of a household as a cluster of people (of which only one may be interviewed); selection of bundles of rods or pipe from a shipment; and selection, from a shipment, of cartons that contain boxes or packages within them.]

3.43 *coefficient of determination* (r^2)—a measure of the relationship between a single dependent random variable or response Y and a known independent variable X. It represents the proportion of the total variation of Y due to X. For instance, if $r^2 = 0.81$ ($r = \pm 0.9$. See *correlation coefficient*.), then 81 percent of the variation in the values of Y may be accounted for by the relationship with the variable X. [The value of r^2 from a regression model cannot be evaluated as “good” or “bad” in singularity; it can only be judged relative to other models that have been estimated on similar phenomena. Thus, an r^2 of 0.30 for one phenomenon might be extremely informative, while for another phenomenon it might be uninformative.]

3.44 *coefficient of variation* (v)—the ratio of the standard deviation to the mean expressed as a percent. It provides a measure of dispersion or spread relative to the mean.

3.45 *combined pay factor*—see *composite pay factor*.

3.46 *component of variance*—a part of the total variance identified with a specified source of variability.

3.47 *composite pay factor*—also called “combined pay factor or overall pay factor.” A multiplication factor, often expressed as a percentage, which considers two or more quality characteristics and is used to determine the contractor’s final payment for a unit of work. [It is usually established using a performance model and life-cycle cost analysis.]

3.48 *computer simulation*—use of a computer to generate conditions approximating actual or operational conditions. [Computer simulation is a powerful and convenient tool to solve certain problems that are intractable by other methods.]

3.49 *confidence interval*—an estimate of an interval in which the estimated parameter will lie with predetermined probability (called the confidence level).

3.50 *confidence level*—if a large number of confidence intervals are constructed, the proportion of time that the estimated parameter will lie within the interval. [A confidence level is usually expressed as a percentage, typically ranging from 90 to 99 percent. *Confidence level* = 1 – α.]

3.51 *confidence limits*—the end points of a confidence interval.

3.52 *conflict resolution*—see *dispute resolution*.

3.53 *conformal index (CI)*—a measure of the dispersion of a series of results around a target or specified value, expressed as the square root of the quantity obtained by summing the squares of the deviations from the target value and dividing by the number of observations. The standard deviation is a measure of precision, but the CI is a measure of exactness (accuracy) or degree of conformance with the target. [Its use as an acceptance measure is not recommended.]

$$CI = \sqrt{\sum\left(X_i - T\right)^2 / n} \qquad (1)$$

3.54 *conformance*—an affirmative indication or judgment that a product or process has met project requirements; also, the state of having met the requirements.

3.55 *control chart*—also called “statistical control chart.” A graphical plot of quality control measurements or test results used to identify variation in a production or placement process due to either chance causes or assignable causes. [Control charts have statistically derived control limits. Plotted values may be for individual measurements or the averages of groups of measurements. The control limits can be established statistically based on sample sizes of $n = 1$ or $n > 1$. Sample sizes of $n > 1$ are preferred, with sample sizes of $n = 3$, 4, or 5 being the most common.]

3.56 *control chart factor*—a factor, varying with sample size, to convert specified statistics or parameters into a central line value or control limit appropriate to the control chart.

3.57 *control chart method*—the method of using control charts to determine whether or not processes are in a stable state.

3.58 *control chart limits*—also called “action limits.” Statistically derived boundaries applied to a control chart in controlling material production or placement. [Control chart limits are expressed as the upper control limit (UCL) and the lower control limit (LCL). When values of the material characteristics fall within these limits, the process is “under control.” When values fall outside the limits, there is an indication that some assignable cause is present causing the process to be “out of control.”]

3.59 *controlled process*—a production process in which the mean and variability of a series of tests on the product remain stable, with the variability due to chance cause only. [A process might be “under control” but produce out-of-specification material if the specification limits are tight. Similarly, a process might be “out of control” in that the mean or variability is outside of control limits, yet the specification limits might be wide enough that the material produced is within specifications.]

3.60 *correlation coefficient (r)*—a measure of the relationship between a single dependent (response) random variable *Y* and a known independent variable *X*. [The correlation coefficient ranges in value from –1 to +1, indicating a perfect negative relationship at –1, absence of relationship at 0, and perfect positive relationship at +1. Thus, when *Y* varies directly with *X*, the correlation coefficient is positive; when *Y* bears an inverse relationship to *X*, the correlation coefficient is negative. See *coefficient of determination.*]

3.61 *criticality*—the classification of contract requirements by the degree to which they affect safety, performance, or life-cycle cost.

3.62 *data*—measurements or test values organized for computation or analysis.

3.63 *defect*—a failure to meet a requirement with respect to a single quality characteristic.

3.64 *defective*—having one or more defects.

3.65 *dependent variable*—see *response variable*.

3.66 *design of experiments*—also called “experimental design.” The arrangement in which an experimental program is to be conducted, and the selection of the levels (versions) of one or more factors or factor combinations to be included in the experiment.

3.67 *deviation*—the difference between an individual value and its stated value or intended level. [In practice, deviation is usually taken to infer the deviation from the mean or deviation from the target value.]

3.68 *disincentive*—a pre-established decrease in payment to the contractor applied to a contract bid item for which the level of materials quality and workmanship, determined by statistical means, does not meet the specified acceptable quality level (AQL). The disincentive is usually expressed as a percentage of the original contract bid price.

3.69 *dispersion*—the extent to which data values are scattered about a target or central value.

3.70 *dispute resolution*—also called “conflict resolution.” The procedure used to resolve conflicts resulting from discrepancies between the agency’s and contractor’s results of sufficient magnitude to impact payment. [The procedure may, as an initial step, include the testing of independent samples and, as a final step, third-party arbitration.]

3.71 *distribution*—an arrangement of data which shows the frequency of occurrence of each successive individual measurement or range of measurements.

3.72 *distribution curve*—the smooth curve describing an arrangement of data that shows the frequency of occurrence.

3.73 *documentation*—proof in the form of detailed records or charts supporting the effectiveness of a quality assurance system.

3.74 *end-result specifications*—specifications that require the contractor to take the entire responsibility for producing and placing a product. The highway agency’s responsibility is to either accept or reject the final product or to apply a pay adjustment that is commensurate with the degree of compliance with the specifications. [End-result specifications have the advantage of allowing the contractor flexibility in exercising options for new materials, techniques, and procedures to improve the quality and/or economy of the end product.]

3.75 *engineering limits*—the absolute limiting value(s) placed on a quality characteristic beyond which the result for an individual sample is considered to be unacceptable. [Engineering limits are established to identify material that does not provide the minimum required engineering properties. They usually have an upper engineering limit (UEL), a lower engineering limit (LEL), or both. The engineering limits may be the same as the specification limits.]

3.76 *estimator*—a statistic used to estimate a parameter to help describe the population. [The estimate may be given as a point estimate or as an interval estimate.]

3.77 *event*—the occurrence, or absence, of an attribute.

3.78 *expected pay (EP) curve*—a graphical representation of an acceptance plan that shows the relationship between the established actual quality of a lot and its expected pay. [The EP is the mathematical pay expectation, or average pay the contractor can expect to receive over the long run for submitted lots of a given quality. The EP should be 100 percent pay for AQL material. Both OC and EP curves should be used to evaluate how well an acceptance plan is theoretically expected to work.]

3.79 *experimental design*—see *design of experiments*.

3.80 *F-test (F-statistic)*—a hypothesis test involving the comparison of the variances of two sets of data. The null hypothesis is the variance of one population equals the variance of another population.

3.81 *frequency*—the number of items or values that occur within a given interval (or class).

3.82 *frequency distribution*—a grouping of data values into intervals (or class intervals) showing the number of values in each interval.

3.83 *frequency histogram*—also called “histogram.” A type of bar chart that depicts the frequency of occurrence of each data value as a rectangle (or bar). The width of each rectangle represents the data interval, while the height represents the number of data values in the interval (or class interval).

3.84 *frequency polygon*—a broken line graph constructed by drawing line segments that join the mid-points of the top of each rectangle (or bar) in a frequency histogram.

3.85 *frequency table*—a tabular presentation of data consisting of a minimum of two columns. One column presents the data intervals (or classes) in some useful order and the other column presents the corresponding frequencies.

3.86 *graduated reduction in contract price*—reductions that are initially small for slight deviations from specified requirements but increase rapidly as the size of deviations increases.

3.87 *grand mean*—the sum of the means of sets or subgroups of data divided by the total number of sets or subgroups.

3.88 *histogram*—see *frequency histogram*.

3.89 *hypothesis*—a tentative theory or supposition provisionally adopted to explain certain facts and to guide in the investigation of others. It is a statement concerning the value of a population parameter which can be tested statistically to determine the validity of the statement.

3.90 *hypothesis test*—a statistical procedure based on probability theory used to determine whether a hypothesis is a reasonable statement and should not be rejected, or is unreasonable and should be rejected. [Reasonableness is determined by testing the hypothesis at a specific level of statistical significance.]

3.91 *incentive/disincentive provision (for quality)*—a pay adjustment schedule which functions to motivate the contractor to provide a high level of quality. [A pay adjustment schedule, even one which provides for pay increases, is not necessarily an incentive/disincentive provision, as individual pay increases/decreases may not be of sufficient magnitude to motivate the contractor toward high quality.]

3.92 *increments*—small quantities of material of equal size that are obtained from a sampling location and combined to form a sample.

3.93 *independent assurance (IA)*—activities that are an unbiased and independent evaluation of all the sampling and testing (or inspection) procedures used in the quality assurance program. [IA provides an independent verification of the reliability of the acceptance (or verification) data obtained by the agency and the data obtained by the contractor. The results of IA testing or inspection are not to be used as a basis of acceptance. IA provides information for quality system management.]

3.94 *independent sample*—a sample taken without regard to any other sample that may also have been taken to represent the material in question. [An independent sample is sometimes taken to verify an acceptance decision. This is possible because the data sets from independent samples, unlike those from split samples, each contain independent information reflecting all sources of variability, i.e., sampling, testing, materials, and construction.]

3.95 *independent t-test*—a hypothesis test involving the comparison of the means of two independently obtained sets of data. The null hypothesis is the mean of one normal population equals the mean of another normal population.

3.96 *inference*—a logical conclusion about a population based on a sample.

3.97 *inherent variability*—also called “inherent variance.” The effect of random or inconsequential causes in a given process. [The four components of inherent variability include sampling variability, testing variability, materials variability, and construction variability.]

3.98 *iteration*—(1) the act or process of repeating something; a replication. [Iteration, as opposed to replication, is the preferred term for use with respect to Monte Carlo simulations.] (2) The method of successive trials, each trial producing a result that successively better approximates the desired result.

3.99 *item*—an object or quantity of material on which a set of observations can be made.

3.100 *kurtosis*—the degree of peakedness in a probability distribution. For the normal distribution, the kurtosis coefficient equals 0. A positive kurtosis coefficient indicates a relatively peaked distribution in comparison with the normal distribution, while a negative coefficient indicates a relatively flat distribution.

Population kurtosis coefficient:

$$\gamma_2 = \left[\sum \left(X_i - \mu \right)^4 / n\sigma^4 \right] - 3 \tag{2}$$

Sample kurtosis coefficient:

$$g_2 = \left[n\left(n+1\right) \sum \left(X_i - \bar{X} \right)^4 \Big/ s^4 \left(n-1\right)\left(n-2\right)\left(n-3\right) \right] - \left[3\left(n-1\right)^2 \Big/ \left(n-2\right)\left(n-3\right) \right] \tag{3}$$

3.101 *linear regression*—see *simple linear regression*.

3.102 *lot*—a specific quantity of material from a single source which is assumed to be produced or placed by the same controlled process.

3.103 *lot acceptance plan*—see *acceptance plan*.

3.104 *lower control limit (LCL)*—see *control chart limits*.

3.105 *lower specification limit (LSL)*—the lower statistically based limiting value associated with a quality characteristic and used to evaluate the acceptability of a lot.

3.106 *materials and construction (M&C) variable*—a characteristic of materials and/or construction that can be directly or indirectly controlled. Thickness is an example of an *M&C* variable that is controlled directly; compressive strength is an example of one controlled indirectly.

3.107 *materials and methods specifications*—see *method specifications.*

3.108 *materials sample*—see *sample.*

3.109 *mean* $(\bar{X})$—the arithmetic average of a set of measurements or test values.

3.110 *median*—a type of average. The midpoint of an array of values after they have been ordered from the smallest to the largest, or the largest to the smallest. There are as many values above the median as below it in the data array.

3.111 *method of least squares*—a technique of estimation of a parameter which minimizes Σe^2, where e is the difference between the observed value and the predicted value derived from the assumed model.

3.112 *method specifications*—also called “materials and methods specifications.” Specifications that require the contractor to produce and place a product using specified materials in definite proportions and specific types of equipment and methods under the direction of the agency. [Experience has shown this tends to obligate the agency to accept the completed work regardless of quality.]

3.113 *mixture design*—also called “mix design.” (1) The process of determining and quantifying the required characteristics of a mixture, including developing, evaluating, and testing trial mixtures to verify that the required characteristics can be met. For portland cement concrete (PCC) mixtures, some examples of required characteristics are workability, durability, and strength; and for hot mix asphalt (HMA), examples are rutting resistance and fatigue cracking resistance. [The mixture design process leads to the development of a mixture specification.] (2) A quantified description (resulting from the mixture design process) of a mixture developed, evaluated, and tested to meet the specifications.

3.114 *mixture proportioning*—the identification of mixture ingredients and the selection of appropriate quantities of these ingredients to fulfill the mixture design. [The mixture proportioning process results in a quantification of the mixture ingredients by weight or by volume.]

3.115 *mode*—a type of average. The value in a distribution that occurs most frequently. For grouped data, it is the midpoint of the class containing the most values.

3.116 *Monte Carlo simulation*—a simulation technique (usually performed by a computer and particularly useful for QA applications) that uses random numbers to sample from probability distributions to produce hundreds or thousands of scenarios (called iterations, trials, or runs). [A complete Monte Carlo simulation thus uses each result from each individual iteration.]

3.117 *multiple deficiencies*—more than one defect in a unit of product with respect to the characteristic(s) under consideration.

3.118 *multiple linear regression*—a means of predicting a dependent (response) random variable *Y*, using more than one known independent variable X_i. [The so-called independent variables are independent of *Y* but not necessarily independent among themselves. $Y = a + bX_1 + cX_2$, where $X_2 = \sin X_1^2$ is an example of a multiple linear regression equation. Note that in all cases X_i may be any function, not necessarily of the first degree. The concept of linear is that used in linear algebra—namely the parameters occur linearly.]

3.119 *music bar chart*—see *run chart*.

3.120 *n*—see *sample size*. The symbol for the number of samples or sample measurements obtained and used in a statistical analysis.

3.121 *non-central t distribution*—also called "noncentral Student t distribution." The noncentral *t* distribution is a generalization of the Student *t* distribution and is used when the population mean and standard deviation are both unknown. If $\overline{x}$ and *s* are the mean and standard deviation of an independent random sample of size *n* from a normal distribution with mean μ and $\sigma^2 = n$, then

$$t(v) = \frac{\overline{x} - \mu}{s} \tag{4}$$

$$v = n - 1 \tag{5}$$

When the mean of the normal distribution is not μ, then the ratio has the noncentral *t* distribution. The noncentrality parameter is the difference between the sample mean and μ. The noncentral *t* distribution allows us to determine the probability that we would detect a difference between $\overline{X}$ and μ in a *t*-test. The formula for the probability that a noncentral *t* variate falls in the range [–*t*, *t*] is:

$$\Pr((-t) < \overline{x} < t \,|\, (v, \delta)) = \sum_{j=0}^{\infty} \left(\frac{\left(\frac{1}{2}\delta^2\right)^j}{j!} e^{\frac{\delta^2}{2}} \right) I\left(\frac{\overline{x}^2}{v + \overline{x}^2} \,\middle|\, \frac{1}{2} + j, \frac{v}{2} \right) \tag{6}$$

where *I*(*x*|*a*,*b*) is the incomplete beta function with parameters *a* and *b*, δ is the noncentrality parameter, and ν is the degrees of freedom.

3.122 *nonlinear regression*—a means of predicting a dependent (response) random variable *Y*, using an equation in which the parameters do not occur linearly. The exponential equation, $Y = ae^{bx+c}$, is an example of a nonlinear regression equation. [However, by taking the logarithm to the base *e*, the equation can be transformed into the form $\log_e Y = \log_e a + bX + c$. Such a model is called intrinsically linear. On the other hand, $Y = e^{-ax} - e^{-bx}$ cannot be transformed; such a model is called intrinsically nonlinear.]

3.123 *normal curve*—see *standard normal distribution*.

3.124 *normal distribution*—see *standard normal distribution*.

3.125 *normality*—the state of being normally distributed or having a normal distribution.

3.126 *null hypothesis* (H_o)—the hypothesis being tested. [Contrary to intuition, the null hypothesis is often a research hypothesis that the analyst would prefer to reject in favor of the alternative hypothesis. The null hypothesis can never be proved true. It can, however, be shown, with specified risks of error, to be untrue. If it is not disproved (i.e., not rejected), one usually acts on the assumption that there is no reason to doubt that it is true.]

3.127 *observation*—(1) the process of obtaining information regarding the presence or absence of an attribute of a test specimen, or of making a reading on a characteristic or dimension of a test specimen, or (2) the attribute or measurement information obtained from the process. [The term "observed value" is preferred for this second usage.]

3.128 *observed value*—the value obtained by carrying out the complete protocol of the test method once, being either a single test determination or an average or other specified combination of a specified number of test determinations.

3.129 *operating characteristic (OC) curve*—a graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either (1) the probability of its acceptance or (2) the probability of its acceptance at various payment levels.

3.130 *overall pay factor*—see *composite pay factor*.

3.131 *paired t-test*—also called "*t*-test for paired measurements (samples)." A statistical test used to compare the test values for multiple pairs of split samples. The test uses the differences between the pairs of test values and determines whether the average difference from 0 is statistically significant.

3.132 *parameter*—a constant or coefficient that describes some characteristic of a population. Some examples of parameters are the population standard deviation, the population mean, and the population regression coefficients. [In most highway QA applications, the true population parameter value is unknown. The parameter value can be estimated by calculating a statistic from the sample data.]

3.133 *pavement condition indicator*—also called "pavement distress indicator." A measure of the condition of an existing pavement section at a particular point in time, such as cracking measured in ft/mi or in mm/km, or wheel path faulting measured in in./mi or mm/km. [When considered collectively, pavement condition indicators provide an estimate of the overall adequacy of a particular roadway.]

3.134 *pavement distress indicator*—see *pavement condition indicator*.

3.135 *pavement performance*—the history of pavement condition indicators over time or with increasing axle load applications.

3.136 *pay adjustment*—the actual amount, either in dollars or in dollars per area/weight/volume, that is to be added or subtracted to the contractor's bid price or unit bid price.

3.137 *pay adjustment schedule (for quality)*—also called "price adjustment schedule" or "adjusted pay schedule." A pre-established schedule, in either tabular or equation form, for assigning pay factors associated with estimated quality levels of a given characteristic. The pay factors are usually expressed as percentages of the contractor's bid price per unit of work but may also be given as direct dollar amounts.

3.138 *pay adjustment system (for quality)*—also called "price adjustment system" or "adjusted pay system." All pay adjustment schedules along with the equation or algorithm that is used to determine the overall pay factor for a submitted lot of material or construction. [A pay adjustment system, and each pay adjustment schedule, should yield sufficiently large pay increases/decreases to provide the contractor sufficient incentive/disincentive for high/low quality.]

3.139 *pay factor (PF)*—a multiplication factor, often expressed as a percentage, that considers a single quality characteristic and is used to determine the contractor's payment for a unit of work.

3.140 *percent conforming*—for attribute acceptance plans, the percentage of units having no departure of an attribute from its intended level. [Percent conforming + percent nonconforming = 100.]

3.141 *percent defective (PD)*—the percentage of the lot falling outside specification limits. $PD = 100 - PWL$. [PD may refer to either the population value or the sample estimate of the population value. The term "percent nonconforming" should not be used as a synonym for PD.]

3.142 *percent nonconforming*—the percentage of units having at least one departure of an attribute from its intended level.

3.143 *percent within limits (PWL)*—the percentage of the lot falling above a lower specification limit, beneath an upper specification limit, or between upper and lower specification limits. $PWL = 100 - PD$. [PWL may refer to either the population value or the sample estimate of the population value. The term "percent conforming" should not be used as a synonym for PWL.]

3.144 *performance specifications*—specifications that describe how the finished product should perform over time. [For highways, performance is typically described in terms of changes in physical condition of the surface and its response to load, or in terms of the cumulative traffic required to bring the pavement to a condition defined as "failure." Specifications containing warranty/guarantee clauses are a form of performance specifications. Other than the warranty/guarantee type, performance specifications have not been used for major highway pavement components (subgrades, bases, riding surfaces) because there have not been suitable nondestructive tests to measure long-term performance immediately after construction. They have been used for some products (e.g., highway lighting, electrical components, and joint sealant materials) for which there are suitable tests of performance.]

3.145 *performance-based specifications*—quality assurance specifications that describe the desired levels of fundamental engineering properties (e.g., resilient modulus, creep properties, and fatigue) that are predictors of performance and appear in primary prediction relationships (i.e., models that can be used to predict stress, distress, or performance from combinations of predictors that represent traffic, environment, supporting materials, and structural conditions).

3.146 *performance-related specifications*—quality assurance specifications describing the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance. These characteristics (e.g., air voids in hot mix asphalt (HMA) pavements and compressive strength of portland cement concrete) are amenable to acceptance testing at the time of construction. [True performance-related specifications not only describe the desired levels of these quality characteristics, but also employ the quantified relationships containing the characteristics to predict as-constructed pavement performance. They thus provide the basis for rational acceptance/pay adjustment decisions.]

3.147 *performance-related variable*—a characteristic of materials and/or construction that has an influence on performance, either by itself or interactively when in combination with other *M&C* variables. [Any variable that is a primary or secondary predictor is a performance-related variable.]

3.148 *polynomial regression*—a means of predicting a dependent (response) random variable Y, using a known independent variable X, through a polynomial equation. $Y = a X^2 + bX + c$ is an example of a curvilinear, polynomial regression equation.

3.149 *pooled sample standard deviation* (S_p)—the square root of the pooled variance. See *pooled sample variance*.

$$S_p = \sqrt{\frac{s_p^2\left(n_1 - 1\right) + s_2^2\left(n_2 - 1\right) + \ldots s_x^2\left(n_x - 1\right)}{n_1 + n_2 + \ldots n_x - N}} \qquad (7)$$

where:

s_x = the sample standard deviation of each data set,

n_x = the number of results in each data set, and

N = the total number of data sets.

3.150 *pooled sample variance* (s_p^2)—a weighted average of sample variances each weighted by the degrees of freedom ($n_x - 1$). [The pooled sample variance is used when an average of several sample variances represented by different sample sizes is desired.]

$$S_p^2 = \frac{s_1^2\left(n_1 - 1\right) + s_2^2\left(n_2 - 1\right) + \ldots s_x^2\left(n_x - 1\right)}{n_1 + n_2 + \ldots n_x - N} \qquad (8)$$

where:

s_x = the sample standard deviation of each data set,

n_x = the number of results in each data set, and

N = the total number of data sets.

3.151 *population*—a collection of all possible individuals, objects, or items that possess some common specified characteristic(s) which can be measured.

3.152 *population standard deviation* (σ)—a measure of the dispersion of a complete series of results around their mean. The population standard deviation is the square root of the population variance.

$$\sigma = \sqrt{\frac{\sum\left(x - \mu\right)^2}{n}} \qquad (9)$$

3.153 *population variance* (σ^2)—a measure of the dispersion of a complete series of results around their mean, expressed as the sum of the squares of the deviations from the mean of the results divided by the number of observations.

$$\sigma^2 = \sqrt{\frac{\sum\left(x - \mu\right)^2}{n}} \qquad (10)$$

3.154 *power curve*—a curve, used in hypothesis testing, to indicate the probability of rejecting a hypothesis. The curve shows the relation between the probability (1–β) of rejecting the hypothesis that a sample belongs to a given population with a given characteristic and the actual population value of that characteristic. [If β is plotted instead of (1–β), the curve is analogous to the OC curve used in accept/reject acceptance plans.]

3.155 *precise*—see *precision*.

3.156 *precision*—(1) the degree of agreement among a randomly selected series of measurements; or (2) the degree to which tests or measurements on identical samples tend to produce the same results.

3.157 *prescriptive specifications*—see *method specifications*.

3.158 *present serviceability index (PSI)*—a mathematical combination of values obtained from certain physical measurements of a large number of pavements, so formulated as to predict a serviceability rating for those pavements within prescribed limits.

3.159 *price adjustment schedule*—see *pay adjustment schedule*.

3.160 *price adjustment system*—see *pay adjustment system*.

3.161 *primary prediction relationship*—an equation that can be used to predict stress, distress, or performance from particular combinations of predictor variables that represent traffic, environmental, roadbed, and structural conditions. Some examples of predictor variables are annual rate of equivalent single axle load accumulation, annual precipitation, roadbed soil modulus, and concrete flexural strength.

3.162 *probability factor*—a tabular value which, when multiplied by the standard deviation of a group of measurements, indicates the frequency or probability of occurrence of measurements within a specified range.

3.163 *probability sample*—one in which every increment in the lot has a known chance of inclusion. [A probability sample in which each increment in the lot has an equal probability of being chosen is known as a random sample.]

3.164 *probability sampling*—a method of making use of the laws of chance for the purpose of selecting increments on which measurements are to be made.

3.165 *process control*—see *quality control*.

3.166 *process control materials and construction (M&C) variable*—a characteristic of materials and/or construction whose specification enhances the control of another M&C variable. An example of a process control M&C variable is soil moisture content to control density and compaction.

3.167 *process under statistical control*—see *controlled process*.

3.168 *product reliability*—see *reliability*.

3.169 *Q table*—a table of values that relates the quality indices (Q_U or Q_L) to the estimated percent within limits (PWL) or percent defective (PD) for a sample of a particular size (n).

3.170 *qualified technician*—a technician that has been determined to be qualified (i.e., meeting some minimum standard) to perform specific duties. [A qualified technician may or may not be certified. See *certified technician*.]

3.171 *quality*—(1) the degree of excellence of a product or service; (2) the degree to which a product or service satisfies the needs of a specific customer; or (3) the degree to which a product or service conforms with a given requirement.

3.172 *quality assurance (QA)*—(1) all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service; or (2) making sure the quality of a product is what it should be. [QA addresses the overall process of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, QA includes the elements of quality control, independent assurance, acceptance, dispute resolution etc. The use of the term QA/QC or QC/QA is discouraged and the term QA should be used. QA involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction, and maintenance, and the interactions of these activities.]

3.173 *quality assurance specifications*—specifications that require contractor quality control and agency acceptance activities throughout production and placement of a product. Final acceptance of the product is usually based on a statistical sampling of the measured quality level for key quality characteristics. [QA specifications typically are statistically based specifications that use methods such as random sampling and lot-by-lot testing, which let the contractor know if the operations are producing an acceptable product.]

3.174 *quality characteristic*—a product attribute that is measured either for quality control (QC) purposes or for conformance with acceptance requirements. [Quality characteristics are specific material properties which are evaluated by QC and acceptance sampling and testing. Quality characteristics which are specified are typically selected because they: (a) relate to initial and long-term performance; (b) are quantifiable or measurable; and (c) can be measured with good repeatability.]

3.175 *quality control(QC)*—also called “process control.” The system used by a contractor to monitor, assess and adjust their production or placement processes to ensure that the final product will meet the specified level of quality. Quality control includes sampling, testing, inspection and corrective action (where required) to maintain continuous control of a production or placement process.

3.176 *quality control plan*—a project-specific document prepared by the contractor that identifies all QC personnel and procedures that will be used to maintain all production and placement processes “in control” and meet the agency specification requirements. The document also addresses actions to be taken in the event that a process goes “out of control”.

3.177 *quality index (Q)*—a statistic which, when used with appropriate tables, provides an estimate of either the percent within limits (PWL) or the percent defective (PD) for a Lot. [It is typically computed from the mean and standard deviation of a set of sample values. The lower quality index (Q_L) is computed relative to the lower specification limit (LSL). The upper quality index (Q_U) is computed relative to the upper specification limit (USL).]

$$Q_L = \frac{\bar{X} - L}{s} \tag{11}$$

where:

$\bar{X}$ = sample mean, and

s = sample standard deviation,

or

$$Q_U = \frac{U - \bar{X}}{s} \tag{12}$$

L = lower specification limit, and

U = upper specification limit.

3.178 *quality-level analysis (QLA)*—a statistical procedure that provides an estimate of the percentage of a given lot that is within specification limits (PWL) or outside specifications limits (PD).

3.179 *quality limits*—the upper or lower limiting values provided in the specifications that are used to evaluate the acceptability of materials produced or placed. [There are three general types of quality limits that are typically included in quality assurance specifications. They include: specification limits, engineering limits, and acceptance limits. Although each type of quality limit serves a different specific function, they are used together to evaluate the acceptability of a lot.]

3.180 *quality measure*—any one of several mathematical tools that are used to quantify the level of quality of an individual quality characteristic. [Typical quality measures used in quality assurance are selected because they quantify the average quality, the variability, or both. Examples of quality measures that may be used include; mean, standard deviation, percent defective (PD), percent within limits (PWL), average absolute deviation (AAD), moving average, and conformal index (CI). PWL or PD are the quality measures that are recommended for use in quality assurance specifications.]

3.181 *quantified checklist*—a list of characteristics that are classified by attribute state, and the results converted to numbers by calculating the percent conforming.

3.182 *quota sampling*—a procedure in which samples are obtained at the discretion and convenience of the sampler to satisfy the required number of samples for a lot. [This procedure may result in random or non-random samples being obtained.]

3.183 *R chart*—a control chart that plots the range (*R*) values for subgroups of measurements or test values against statistically derived control limits.

3.184 *random*—depending entirely on chance.

3.185 *random distribution*—a distribution of values resulting from chance alone.

3.186 *random error of result*—a component of the error, which in the course of a number of test results for the same characteristic, varies in an unpredictable way.

3.187 *random locations*—sampling locations determined by the use of random numbers.

3.188 *random number*—a number selected entirely by chance as from a random number table or a random number generator.

3.189 *random number table*—a collection of digits, randomly displayed in columns and rows, that are used to determine random numbers.

3.190 *random sample*—a sample in which each increment in the lot has an equal probability of being chosen. [Samples are taken at times or locations chosen by a method not influenced by opinion or judgment thus eliminating any bias.]

3.191 *random sampling*—a sampling procedure whereby each sample obtained from the lot has an equal probability of being selected.

3.192 *range*—the difference between the highest individual value and the lowest individual value in a set of sample values.

3.193 *realistic values*—Values that can be expected to be obtained under normal conditions.

3.194 *recipe specifications*—see *methods specifications*.

3.195 *rejectable quality level (RQL)*—the level of established actual quality for a quality characteristic that is rejectable when using a particular quality measure. [For example, when the quality measure used is percent within limits (PWL), the RQL is the established (not estimated) PWL at which the quality characteristic is rejected. It is desired to require removal and replacement, corrective action, or the assignment of a relatively low pay factor when RQL work is detected.]

3.196 *reliability*—the degree to which a test produces consistent or dependable results. [Test reliability is increased as both precision and accuracy are improved.] Reliability can also refer to product reliability, defined as (1) the degree of conformance or failure of the specific product to meet the consumer's quality needs; and (2) the probability of a product performing without failure a specified function under given conditions for a specified period of time. In (1) and (2), reliability is that aspect of quality assurance that is concerned with the quality of product function over time. Another quality assurance usage of the term reliability is within the context of pavement design, where a reliability factor is employed to address the uncertainty associated with predicting pavement performance at the time of design.

3.197 *repeatability*—degree of variation among the results obtained by the same operator repeating a test on the same material. The term repeatability is therefore used to designate test precision under a single operator.

3.198 *repeatability conditions*—conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. [See *precision.* The "same operator, same equipment" requirement means that for a particular step in the measurement process, the same combination of operator and equipment is used for every test result. Thus, one operator may prepare the test specimens, a second measure the dimensions and a third measure the mass in a test method for determining density. By "within short intervals of time" is meant that the test results, at least for one material, are obtained in a time period not less than in normal testing and not so long as to permit significant change in test material, equipment or environment.]

3.199 *repeatability limit (r)*—the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with a probability of approximately 0.95 (95 percent). [The repeatability limit is 2.8 ($\approx 1.96\sqrt{2}$) times the repeatability standard deviation. This multiplier is independent of the size of the interlaboratory study, as explained in ASTM E 177.2. The approximation to 0.95 is reasonably good (say 0.90 to 0.98) when many laboratories (30 or more) are involved, but is likely to be poor when fewer than eight laboratories are studied.]

3.200 *repeatability standard deviation* (S_r)—the standard deviation of test results obtained under repeatability conditions. [It is a measure of the dispersion of the distribution of test results under repeatability conditions. In an interlaboratory study, this is the pooled sample standard deviation of test results obtained under repeatability conditions. See ASTM E 691. The repeatability standard deviation, usually considered a property of the test method, will generally be smaller than the within-laboratory standard deviation.]

3.201 *replicate sample*—two or more samples taken under identical conditions. [Replicate samples may be taken to estimate sampling and testing variability, for possible use if a dispute arises, or simply because they are required to calculate a test result (e.g., the average of two cylinders to calculate the compressive strength of concrete). See *split sample.*]

3.202 *replication*—(1) the act or process of duplicating or repeating something; an iteration; or (2) the execution of an experiment more than once to increase precision and to obtain a better estimate of the residual variation (i.e., the remaining variation in a set of data after the variation due to certain effects, factors, and interactions has been removed). [Replication, as opposed to iteration, is the preferred term for use with respect to experimental design.]

3.203 *representative sample*—a single, non-random sample which, in the opinion of the sampler, represents an average condition of a material or an item of construction.

3.204 *reproducibility*—degree of variation among the test results obtained by different operators performing the same test on the same material. [It measures the human influence or human error in the execution of a test. The term reproducibility is used to designate inter-laboratory test precision.]

3.205 *reproducibility conditions*—conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment.

[Identical test items means either the same test units or test specimens are tested by all the laboratories as for a nondestructive test or test units or test specimens are taken at random from a single quantity of material that is as nearly homogeneous as possible. A different laboratory of necessity means a different operator, different equipment, different location, and under different supervisory control.]

3.206 *reproducibility limit (R)*—the value below which the absolute difference between two test results obtained under reproducibility conditions may be expected to occur with a probability of approximately 0.95 (95 percent). [The reproducibility limit is 2.8 ($\approx 1.96\sqrt{2}$) times the reproducibility standard deviation. The multiplier is independent of the size of the interlaboratory study (that is, of the number of laboratories participating), as explained in ASTM E 177.2. The approximation to 0.95 is reasonably good (e.g., 0.90 to 0.98) when many laboratories (30 or more) are involved but is likely to be poor when fewer than eight laboratories are studied.]

3.207 *reproducibility standard deviation (S_R)*—the standard deviation of test results obtained under reproducibility conditions. [The reproducibility standard deviation includes, in addition to between-laboratory variability, the repeatability standard deviation and a contribution from the interaction of laboratory factors (i.e., differences between operators, equipment and environments) with material factors (i.e., the differences between properties of the materials other than that property of interest).]

3.208 *re-sampling*—the process of obtaining a new sample, if warranted, to replace the original sample for an individual sublot. [See *re-testing*.]

3.209 *residual error*—the difference between the observed result and the predicted value (estimated treatment response), i.e., the observed result minus predicted value.

3.210 *response variable*—also called *dependent variable*. The variable that shows the observed results of an experimental treatment.

3.211 *re-testing*—the process of performing another test to confirm the initial test. Re-testing should be performed using a second test portion or specimen prepared from the same original sample. [See *re-sampling.*]

3.212 *risk of a Type I error*—see *seller's risk*.

3.213 *risk of a Type II error*—see *buyer's risk*.

3.214 *robustness*—insensitivity of a statistical test to departures from underlying assumptions. [Many statistical test procedures depend on the form of the assumed distribution of the population sampled to obtain exact values for the probability statements. If departures from the assumed distribution do not materially affect the decisions that would be based on the statistical tests involved, the test is considered robust. For example, tests based on an assumption of normality that compare averages generally are robust even though the underlying distribution of individual items in the population is not normal. On the other hand, the F-statistic for comparing variances may be an indicator of lack of normality rather than a simple variance comparison. The term robustness can also refer to the condition of a product or process design that remains relatively stable, with a minimum of variation, even though factors that influence operations or usage, such as environment and wear, are constantly changing.]

3.215 *root-mean-square deviation (RMS)*—a measure of the dispersion of a series of results around their average, expressed as the square root of the quantity obtained by summing the squares of the deviations from the average of the results and dividing by the number of observations.

$$RMS = \sqrt{\sum\left(X_i - \bar{X}\right)^2 / n} \qquad (13)$$

[Both sample standard deviation (*s*) and RMS give biased estimates of the population standard deviation (σ). However, the sample variance (s^2) provides an unbiased estimate of the population variance (σ^2).]

3.216 *rounding*—the process of dropping one or more digits so that the reported value contains only those digits which are significant or necessary in subsequent computations.

3.217 *ruggedness*—insensitivity of a test method to departures from specified test or environmental conditions. [An evaluation of the ruggedness of a test method or an empirical model derived from an experiment is useful in determining whether the results or decisions will be relatively invariant over some range of environmental variability under which the test method or the model is likely to be applied.]

3.218 *ruggedness test*—a planned experiment in which environmental factors or test conditions are deliberately varied in order to evaluate the effects of such variation. [Since there usually are many environmental factors that might be considered in a ruggedness test, it is customary to use a "screening" type of experiment design which concentrates on examining many first order effects and generally assume that second order effects such as interactions and curvature are relatively negligible. Often in evaluating the ruggedness of a test method, if there is an indication that the results of a test method are highly dependent on the levels of the environmental factors, there is a sufficient indication that certain levels of environmental factors must be included in the specifications for the test method, or even that the test method itself will need further revision. See ASTM E 1325.]

3.219 *run*—(1) an uninterrupted sequence of occurrences of the same attribute or event in a series of observations, or (2) a consecutive set of successively increasing run-up or successively decreasing run-down values in a series of variable measurements. [In control chart applications, some variable measurements are treated as attributes in determining runs. For example, a run might be considered a series of a specified number of consecutive points above or below the central line.]

3.220 *run chart*—also called *music bar chart*. A control chart that presents individual measurements or test values for a specific quality characteristic on a vertical axis and the individual sample numbers (in consecutive order) on a horizontal axis.

3.221 *sample*—also called *materials sample* when intended to mean: (1) a small physical quantity of material or a measurement obtained, in some manner so that the portion (i.e., sample) is representative of the whole, or (2) a quantity of material fabricated in a lab on which future tests can be run. [A sample may be made up of one or more increments of equal size that are combined.] Also called *statistical sample* when intended to mean: (1) all of the individual samples obtained from a lot which provide information that may be used to quantify the quality of the entire lot, or (2) the integer number of random material samples obtained from a sublot or lot. [The context in which the word sample is used determines its meaning. For example, "obtain a sample here" could mean either obtain a physical quantity of material at this location or take a test (obtain a measurement) at this location; while "the sample size equaled 9" would mean that a total of 9 individual material samples were obtained in a random manner and thus comprised the statistical sample of size $n = 9$.]

3.222 *sample size (referring to a materials sample)*—the size of a physical sample (e.g., 5 kg or 100 ml). [The preferred terminology when referring to a materials sample is "size sample" or "size of sample".] See *sample size (n) (referring to a statistical sample).*

3.223 *sample size (n) (referring to a statistical sample)*—the number of random individual observations, (i.e., data points, test results, measurements, etc.) under consideration or comprising a sublot or lot. [The sample size (i.e., number of random observations) has important implications on how representative the information is of the population. The greater the sample size (n), the greater the degree of confidence in inferences made about the population.] See *sample size (referring to a materials sample).*

3.224 *sample standard deviation (s)*—a biased measure of the dispersion of a series of results around their mean, expressed as the square root of the quantity obtained by summing the squares of the deviations from the mean of the results and dividing by the number of observations minus one.

$$S = \sqrt{\frac{\sum (x - \bar{x})^2}{n-1}} \qquad (14)$$

3.225 *sample variance (s^2)*—an unbiased measure of the dispersion of a series of results around their mean, expressed as the sum of the squares of the deviations from the mean of the results divided by the number of observations minus one.

$$S^2 = \frac{\sum (x - \bar{x})^2}{n-1} \qquad (15)$$

3.226 *sampling with replacement*—a procedure used with some probability sampling plans in which a selected unit is replaced after any step in the selection process so that the same sampling unit is available for selection again at the next step of selection or at any other succeeding step of the sample selection procedure.

3.227 *secondary relationship*—an equation that shows how one or more materials and construction variables are related to at least one predictor variable. The equation $S_f = 9.5\sqrt{S_c}$ (where S_f is concrete flexural strength and S_c is concrete compressive strength) is an example of a secondary relationship.

3.228 *segments*—arbitrary divisions of a lot which may be either real or imaginary.

3.229 *selective sampling*—a non-random procedure in which a sample is obtained only for informational purposes to guide quality control or acceptance actions.

3.230 *seller's risk* (α)—also called "contractor's risk," or "risk of a Type 1 or alpha (α) error." The risk to the contractor of having acceptable quality level (AQL) material or workmanship rejected. [For an accept/reject acceptance plan, it is the probability that an acceptance plan will erroneously reject AQL material or workmanship with respect to a single acceptance quality characteristic. For variables acceptance plans using adjusted pay schedules, it is equivalent to α_{PF}, where $PF = 100$. It is the probability that a variable payment acceptance plan will erroneously accept AQL material or workmanship at less than 100 percent pay with respect to a single acceptance quality characteristic.]

3.231 *significant digits*—also called "significant figure." (1) Any of the digits 0 through 9, except leading zeros and some trailing zeros, which are used with their place value to denote a numerical quantity to some desired approximation. (2) The digits of the decimal form of a number beginning with the leftmost nonzero digit and extending to the right to include all digits warranted by the accuracy of measuring devices used to obtain the numbers.

3.232 *significant figures*—see *significant digits*.

3.233 *significance level (α)*—the probability of rejecting a null hypothesis when it is in fact true. [This probability, often denoted by α, is generally specified before any samples are drawn, so that results will not influence the level selected.]

3.234 *simple linear regression*—a means of fitting a straight line to data so that one can predict a dependent (response) random variable *Y*, using a known independent variable *X*. $Y = aX + b$ is an example of a simple linear regression equation.

3.235 *skewness*—a lack of symmetry in a probability distribution. When the distribution has a greater tendency to tail to the right, it is said to have positive skewness. When the distribution has a greater tendency to tail to the left, it is said to have negative skewness. For the normal distribution (as well as for any other symmetrical distribution), the skewness coefficient equals 0.

Population skewness coefficient: $\gamma_2 = \sum \left(X_i - \mu \right)^3 \Big/ 2n\sigma^3$

Sample skewness coefficient: $g_2 = n \sum \left(X_i - \bar{X} \right)^3 \Big/ \left[s^3 \left(n-1 \right) \left(n-2 \right) \right]$

3.236 *specification limit(s)*—the statistically based limiting values(s) placed on a quality characteristic which are applied with a particular quality measure (such as PWL) to evaluate the quality of a lot. [Specification limits are usually comprised of an upper specification limit (USL), a lower specification limit (LSL), or both. It is important to recognize that since specification limits are statistical limits, individual sample test results may fall beyond the USL or LSL and still be included in the acceptance determination. The specification limits are used for computation of quality levels (e.g., PWL), which are used in calculating pay factors for a lot.]

3.237 *specimen*—also called *test portion*. A portion of a material sample that is prepared and tested. Some test methods require material samples to be split into multiple specimens for testing. [The part of a sample actually tested. Usually obtained by reducing the sample by quartering, riffling, or taking an aliquot quantity. The portion of a test unit needed to obtain a single test determination. In inter-laboratory evaluation of test methods and other statistical procedures, it is best to reserve the word sample for the total amount of material involved and not the individual test specimens, pieces, or portions being tested.]

3.238 *split sample*—a sample that has been divided into two or more portions representing the same material. [Split samples are sometimes taken to verify the acceptability of an operator's test equipment and procedure. This is possible because the variability calculated from differences in split test results is comprised solely of testing variability. See *replicate sample.*]

3.239 *standard deviation (s, s_p or σ)*—a measure of the variability of a set of values which is represented by the principal square root of the variance. See *sample standard deviation, pooled sample standard deviation,* and *population standard deviation.*

3.240 *standard deviation known acceptance plan*—also called a *variability known acceptance plan.* A variables acceptance plan developed with the assumption that the standard deviation of the process is known. [Typically, for highway construction processes, the standard deviation cannot be presumed to be known. See *standard deviation unknown acceptance plan.*]

3.241 *standard deviation unknown acceptance plan*—also called a *variability unknown acceptance plan.* A variables acceptance plan developed with the assumption that the standard deviation of the process is unknown. [Typically, for highway construction processes, the standard deviation cannot be presumed to be known. With the standard deviation unknown (and the mean unknown), the beta distribution is used to estimate percent within limits or percent defective.]

3.242 *standard error (of statistic)*—the standard deviation(s) of the sampling distribution of a statistic. For example, the standard error of the mean ($\bar{X}$) is the standard deviation of the sampling distribution of $\bar{X}$ (i.e., $s_{\bar{X}} = s/\sqrt{n}$).

3.243 *standard error of estimate (SEE)*—in regression analysis, the standard deviation of the errors of estimate in dependent (response) variable *Y*.

$$SEE = \sqrt{\sum\left(Y_i - \hat{Y}_x\right)^2 \Big/ (n-2)} \qquad (16)$$

3.244 *standardization*—a process that determines (1) the correction or correction factor to be applied to the result of a measuring instrument, measuring system, material measure, or reference material when its values are compared to the values realized by standards, (2) the adjustment to be applied to a piece of equipment when its performance is compared with that of an accepted standard or process. [Standardization in case (1) is a simplified form of calibration that estimates systematic error but does not identify random error. Standardization, therefore, does not address all of the elements of uncertainty of measurement and does not lead to traceable measurements. An example of case (2) standardization is adjusting the number of blows of a mechanically operated hammer so it applies the energy equivalent to that of a manually operated hammer. See *calibration.*]

3.245 *standard normal distribution*—a mathematical construct of a continuous probability distribution having a symmetrical, asymptotic bell-shaped curve that is fully defined by μ and σ, where μ = 0 and σ = 1, and for which the mean, median, and mode are all equal. All distribution curves having a similar shape can be modeled by the standard normal distribution via the *z*-score transformation. [The standard normal distribution is defined by the following equation:

$$f_{(x)} = \frac{1}{\sqrt{2\pi}} e^{\frac{-\left(\frac{x-\mu}{\sigma}\right)^2}{2}}$$

The *z*-score transformation is defined as follows: $Z = \dfrac{x - \bar{x}}{s}$

Most construction data exhibit an approximately normal distribution and can be transformed to the standard normal distribution using the transformation.]

3.246 *statistic*—a quantity calculated from a sample of observations, most often to form an estimate of some population parameter.

3.247 *statistical control chart*—see *control chart.*

3.248 *statistical measure*—statistic or mathematical function of a statistic. [The word "statistical" emphasizes that measures are subject to inherent errors and that, in estimating a population parameter, they represent a sample, with inherent sampling variability, e.g., sample standard deviation (*s*) or sample mean ($\bar{X}$).]

3.249 *statistical sample*—see *sample*.

3.250 s*tatistical specifications*—see statistically based specifications.

3.251 *statistically based specifications*—also called "statistical specifications" or "statistically oriented specifications." Specifications based on random sampling, and in which properties of the desired product or construction are described by appropriate statistical parameters.

3.252 *statistically defensible acceptance decisions*—decisions based on data obtained by random sampling. Such decisions have been evaluated by the use of statistical procedures.

3.253 *statistically oriented specifications*—see *statistically based specifications*.

3.254 *statistics*—a branch of mathematics that deals with the collection, analysis, interpretation, and presentation of masses of numerical data. Statistics uses mathematical theories of probability to impose order and regularity on sets of data.

3.255 *stratified random sampling*—a sampling procedure whereby samples are randomly obtained from each sublot.

3.256 *student t distribution*—also called "Student's *t* distribution." A family of continuous sampling distributions employed in small sampling theory where the standard deviation is unknown. The probability density function of the *t* distribution of *Z* is defined as:

$$fz(x) = \frac{1}{\sqrt{n}B\left(\frac{n}{2},\frac{1}{2}\right)}\left(1+\frac{x^2}{n}\right)^{-\frac{n+1}{2}} \qquad (17)$$

where:

$$B(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)}$$

and Γ is the gamma function.

3.257 *subgroup*—a set ($n > 1$) of quality control sample values from within a lot whose mean or range are plotted on a control chart. [Also (1) object sense, a set of units or quantity of material obtained by subdividing a larger group of units or quantity of material, and (2) measurement sense, a set of groups of observations obtained by subdividing a larger group of observations.]

3.258 *sublot*—a subdivision of a lot.

3.259 *surrogate materials and construction (M&C) variable*—a characteristic of materials and/or construction that can be used to substitute for a performance-related M&C variable. For example, concrete compressive strength can be a surrogate for concrete flexural strength.

3.260 *systematic sampling*—see *uniform interval sampling*.

3.261 *table of random numbers*—see *random number table*.

3.262 *target miss*—the difference between the desired (i.e., intended) process average and the actual process average.

3.263 *target value*—the value that is placed on a quality characteristic that represents the mean of the expected distribution of the specified population.

3.264 *t (tee) test*—see *independent t-test* and *paired t-test.*

3.265 *test determination*—(1) the process of deriving from one or more test observations (observed values) the presence or absence of an attribute or the value of a characteristic or dimension of a single test specimen, or (2) the attribute (presence or absence) or value derived from the process [See *specimen*.]

3.266 *test observation*—see *observation.*

3.267 *test portion*—see *specimen*.

3.268 *test result*—the value of a characteristic obtained by carrying out a specified test method. [The test method should specify that one or a number of individual observations be made and their average or another appropriate function, such as the median or the standard deviation, be reported as the test result. It also may require standard corrections to be applied, such as correction of gas volumes to standard temperature and pressure. A test result, therefore, can be a result calculated from several observed values. In the simple case, the test result is the observed value itself.]

3.269 *test specimen*—see *specimen*.

3.270 *test unit*—the total quantity of material (containing one or more test specimens) needed to obtain a test result as specified in the test method.

3.271 *tolerance limit(s)*—the limiting value(s) placed on a quality characteristic to define its absolute conformance boundaries such that nothing is permitted outside the boundaries. [A distinction between tolerance limit(s) and specification limit(s) is that tolerance limit(s) apply to process control and specification limit(s) to statistical acceptance.]

3.272 *tolerances*—see *tolerance limit(s).*

3.273 *total quality management (TQM)*—a comprehensive and structured approach to organizational management that seeks to improve the quality of products and services through ongoing refinements in response to continuous feedback. The goal is to imbed awareness of quality in all organizational processes. It is a philosophy of doing the right thing the first time.

3.274 *treatment*—also called "treatment combination." A combination of the levels of each of the factors assigned to an experimental unit.

3.275 *treatment combination*—see *treatment*.

3.276 *trueness*—the closeness of agreement between the population mean of the measurements or test results and the accepted reference value. [The measure of trueness usually is expressed in terms of bias. Greater bias means less favorable trueness. Population mean is, conceptually, the average value of an indefinitely large number of test results. Trueness is the systematic component of accuracy.]

3.277 *unbiased*—not influenced by opinion or judgment.

3.278 *unbiased estimator*—a statistic whose mathematical expected value (i.e., average value over the long run) is equal to the value of the population parameter being estimated. For example, the sample mean is an unbiased estimator of the population mean. On the other hand, the sample range is a biased estimator of the population range.

3.279 *uncertainty*—an indication of the variability associated with a measured value that takes into account two major components of error: (1) bias, and (2) the random error attributed to the imprecision of the measurement process. [Quantitative measures of uncertainty generally require descriptive statements of explanation because of differing traditions of usage and because of differing circumstances. For example: (1) the bias and imprecision may both be negligible; (2) the bias may not be negligible while the imprecision is negligible; (3) neither the bias nor the imprecision may be negligible; (4) the bias may be negligible while the imprecision is not negligible.]

3.280 *uniform interval sampling*—a procedure in which samples are obtained at fixed intervals of material production or material quantity. [Sample selection procedure in which every k^{th} element is selected from the universe or population; for example, u, $u + k$, $u + 2k$, $u + 3k$, etc., where u is in the interval 1 to k. If $k = 20$ and $u = 7$ is the initial unit selected, then sampling units 7, 27, 47, 67, …, would comprise the sample. When *N/k* is not an integer, there is a small bias due to the end effect. When *u* is selected by a chance process and *N*/*k* is an integer, the systematic sample will provide unbiased estimates of the population average or total. Situations for which *N*/*k* is not an integer usually ignore the small or negligible bias in estimating the mean or total. Schemes have been developed for non-integer *N*/*k* to overcome sampling bias. Estimation of the precision of an average computed from a systematic sample is a difficult problem that has no generally satisfactory solution. Independent replicate systematic samples provide an approach to variance estimation, but have been rejected by some writers. In some ASTM situations where replicate samples may be obtained on a routine basis, the technique may be useful.]

3.281 *unit*—an object on which a measurement or observation may be made. [The word unit is commonly used in the sense of a unit of product (service, etc.), the entity of product inspected in order to determine its classification, or its measurements. This entity may be a single article, a set of like articles treated collectively, a subassembly, a stated quantity of material, etc. The unit of product or service need not be the same as the unit of purchase, supply, production, or shipment.]

3.282 *upper control limit (UCL)*—the statistically established control chart limit for values above the central line (target) of a control chart. [The UCL for a control chart plotting individual values ($n = 1$) is established at +2 standard deviations from the control chart target. The UCL for a control chart plotting subgroups of data ($n > 1$) is established at +3 standard deviations from the control chart target. (See *control chart limits*.)]

3.283 *upper specification limit (USL)*—the upper statistically based limiting value associated with a quality characteristic and used with a quality measure to evaluate the quality of a lot.

3.284 *upper tolerance limit (UTL)*—a tolerance limit applicable to the upper conformance boundary.

3.285 *use value*—the obtained characteristics and qualities of a material, product, or item of construction, associated with accomplishment of functional performance.

3.286 *validation*—the mathematical comparison of two independently obtained sets of data (e.g., agency acceptance data vs. contractor data) to determine whether it can be assumed they came from the same population.

3.287 *value engineering*—an organized effort directed at analyzing the function of highway components with the purpose of achieving the required function at the lowest possible cost.

3.288 *variability*—differences in measured test values for a given quality characteristic within a stable pattern due to chance, or outside this normal pattern due to an assignable cause(s).

3.289 *variability known acceptance plan*—see *standard deviation known acceptance plan*.

3.290 *variability unknown acceptance plan*—see *standard deviation unknown acceptance plan*.

3.291 *variable*—a measurement that can have a series of different values.

3.292 *variables, method of*—measurement of quality by the method of variables consists of measuring and recording the numerical magnitude of a quality characteristic for each of the units in the group under consideration. [This involves reference to a continuous scale of some kind.]

3.293 *variables acceptance plan*—a statistical acceptance procedure where quality is evaluated by (1) measuring the numerical magnitude of a quality characteristic for each of the units or samples in the group under consideration, and (2) computing statistics such as the average and the standard deviation of the group.

3.294 *variables data*—measurements which vary and may take any of a specified set of numerical values. [The term “random variable” or “variant” is often used to indicate that each of the specified set of values is associated with a specified relative frequency or probability, and that each is a random sample from a continuous or a discrete, or discontinuous, population encompassing the specified values.]

3.295 *variance*—a measure of dispersion of a set of values from their mean, expressed as a function of the sum of all squared deviations from the mean. See *sample variance, pooled sample variance,* and *population variance.*

3.296 *variation*—see *variability*.

3.297 *verification sampling and testing*—see *acceptance sampling and testing*.

3.298 *warning limits (upper, lower)*—boundaries established within the upper and lower control chart limits on control charts that plot subgroups of data. They are used to warn of possible problems in the production or placement process that may lead to the process going “out of control.” [Warning limits are established at ±2 standard deviations from the control chart target. Warning limits are not used with control charts that plot individual sample values (i.e., run charts).]

3.299 *within-laboratory standard deviation*—the standard deviation of test results obtained within a laboratory for a single material under conditions that may include such elements as different operators, equipment, and longer time intervals. [Because the training of operators, the agreement of different pieces of equipment in the same laboratory and the variation of environmental conditions with longer time intervals depend on the degree of within-laboratory control, the within-laboratory standard deviation is likely to vary appreciably from laboratory to laboratory.]

3.300 *workmanship inspection*—examination or measurement for determination of conformance to requirements of construction processes, components, or products.

3.301 $\bar{X}$ *Chart*—a control chart that plots the mean ($\bar{X}$) values for subgroups of measurements or test values against statistically derived control limits.

3.302 *zero defects*—a total quality management philosophy, aimed at preventing problems or defects from occurring, which is stated as: “Do the job right the first time.”

Standard Practice for

Regulatory Information for Chemicals Used in AASHTO Tests

AASHTO Designation: R 16-04 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Regulatory Information for Chemicals Used in AASHTO Tests

AASHTO Designation: R 16-04 (2009)

1. SCOPE

1.1. This standard practice provides a reference listing of chemicals used in the various AASHTO Test Methods (see Table 1). It includes current regulatory codes and hazard classifications. The list does not include radiation hazards. This practice is not intended as a substitute for law or regulation.

1.2. The chemical list must be provided to all laboratory employees engaged in performing AASHTO tests. In addition, all laboratory employees must be trained in proper handling procedures as stated in the OSHA 1910.1200 Hazard Communication Standard or governing state regulation. Laboratories performing AASHTO tests shall establish a Chemical Hygiene Plan as set out in 29 CFR 1910.1450, including the training requirements therein.

1.3. This practice supplements data found in MSDSs supplied by manufacturers. This practice is for quick reference ability and is not intended to replace MSDSs.

2. INTRODUCTION

2.1. In an effort to assure uniform compliance with regulations, the following definitions are cited:

2.1.1. A hazardous chemical includes any substance that is in the definition of health hazard adopted by the United States Occupational Safety and Health Administration.

2.1.2. A hazardous waste includes, but is not limited to, any substance that has been assigned a code number from the EPA “Unlisted (Characteristic) Hazardous Wastes” code. All hazardous waste must be disposed of in accordance with EPA, state, and local regulations.

2.2. Should there be any questions regarding whether a substance is hazardous, contact the local governing authority.

3. CHEMICAL LIST

3.1. This section contains definitions of the terms and abbreviations contained in the list. All information is valid as of the date of this practice.

3.2. CAS NO. is the number assigned to a substance by the Chemical Abstracts Service.

3.3. TEST METHOD refers to the AASHTO test method in which the chemical is used.

3.4. NIOSH REL is the Recommended Exposure Limit established by the National Institute for Occupational Safety and Health. The value corresponds to the concentration in air to which the employee may be exposed. These limits are a time-weighted average for an eight-hour workday.

3.4.1. Abbreviations under NIOSH REL and OSHA PEL:

- ppm is parts per million
- mg/m^3 is milligrams per cubic meter
- $\mu g/m^3$ is micrograms per cubic meter
- CL is Ceiling Limit
- STEL is Short-Term Exposure Limit, which is for a 15-minute duration
- f is fume
- d is dust
- rf is respirable fraction

3.5. OSHA PEL is the Permissible Exposure Limit established by the Occupational Safety and Health Administration. These PELs went into effect September 1, 1989. The PELs are time-weighted average concentrations just as the NIOSH RELs are.

3.5.1. See Section 3.4.1 for abbreviations used.

3.6. CARCIN denotes substances which are listed as carcinogens in one of the following three sources:

3.6.1. NTP denotes a substance listed on National Toxicology Program's Annual Report on Carcinogens.

3.6.2. IARC denotes a substance listed in the International Agency for Research on Cancer's Monographs, Groups I and II.

3.6.3. OSHA's 29 CFR 1910 subpart Z.

3.7. SKIN—An "X" in this column denotes a substance for which skin contact is to be avoided as it may be a route of entry. This includes mucous membranes and eyes.

3.8. DOT LABEL denotes Department of Transportation Hazard Class for transportation of these substances.

3.8.1. Abbreviations under DOT LABEL

- FLAM. is flammable
- LIQ. is liquid
- ST. ANDR. † is St. Andrew's Cross (poison label)

3.9. RCRA NO. is the number assigned to a substance under the Resource Conservation and Recovery Act.

3.10. SHIP CODE is the identification number assigned by the U.S. Department of Transportation in the Emergency Response Guidebook to hazardous materials for international and domestic shipment.

3.11. DOT GUIDE is a number assigned by the U.S. Department of Transportation for providing guidance primarily during the initial phases of an incident.

Table 1—Chemicals Used in AASHTO Test Procedures

Substance	CAS No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Acetic Acid	64-19-7	105 192 260 281	10 ppm 25 mg/m^3	10 ppm 25 mg/m^3			Corrosive Flam. Liq.		UN2789 UN2790	29
Acetone	67-64-1	151 201 202 250	250 ppm 590 mg/m^3	750 ppm 1800 mg/m^3			Hazardous Flam. Liq.	U002	UN1090	26
Acetylene	74-86-2	—	1 ppm 14 mg/m^3	CL 2500 ppm			Hazardous Flam. Gas		UN1001	17
Alumina (Aluminum oxide)	1344-28-1	105	—	rf: 5 mg/m^3 td: 15 mg/m^3						
Ammonium Acetate	631-61-8	105							NA9079	31
Ammonium Carbonate	10361-29-2	111 143 164								31
Ammonium Chloride	12125-02-9	105 143	X	10 mg/m^3 STEL 20 mg/m^3					NA9085	31
Ammonium Hydroxide	1336-21-6	105 143 144 250					Corrosive			60
Ammonium Molybdate	12027-67-7	105		5 mg(Mo)/m^3						
Ammonium Nitrate	6484-52-2	105 144					Oxidizer Explosive		NA1942 UN2067 UN2426	35 43
Ammonium Oxalate	1113-38-8	105 143 144								31
Ammonium Persulfate	7727-54-0	—					Oxidizer			35
Ammonium Phosphate	7783-28-0	143					Oxidizer			
Ammonium Sulfate	7782-20-2	250								
Anhydrous Denatured Alcohol	64-17-5	255	X	1000 ppm			Flammable Liquid		UN1170	26
Antimony Trichloride	10025-91-9	65 213		0.5 mg(Sb)/m^3			Corrosive		UN1733	60
Antimony Reagent	7440-36-0	—	0.5 mg(Sb)/m^3	0.5 mg(Sb)/m^3			Poison St. Andr.†		UN2871	53
Antimonyl Tartrate	X00001-05-8	—	0.5 mg(Sb)/m^3	0.5 mg(Sb)/m^3			Poison St. Andr.†			53
Arsenic	7440-38-2	—	2μg/m^3		IARC 1 NTP X		Poison B		UN1558	53
Arsenic Trioxide	1327-53-3	105	2μg(As)/m^3				Poison B	P012	UN1561	53
Barium Chloride	10361-37-2	104	0.5 mg/m^3	0.5 mg/m^3						

Continued on next page.

Table 1—Chemicals Used in AASHTO Test Procedures *(Continued)*

Substance	Case No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Barium Hydroxide	17194-00-2	105	0.5 mg/m^3	0.5 mg/m^3						
Benzene	71-43-2	62 110	0.1 ppm CL 1 ppm	10 ppm CL 50 ppm	IARC 1 NTP X OSHA X		Flammable Liquid	U019	UN1114	27
Bromine	7726-95-6	105	0.1 ppm 0.7 mg/m^3 0.3 ppm STEL 2 mg/m^3 STEL	0.1 ppm 0.7 mg/m^3		X	Corrosive		UN1744	59
Cadmium	7440-43-9	—	Lowest Feas. Lim.	f: 0.1 mg/m^3 d: 0.2 mg/m^3	IARC 28 NTP X					
Cadmium Chloride	10108-64-2	105							NA2570	53
Calcium Carbide	75-20-7	217					Flammable Solid			40
Calcium Carbonate	471-34-1	105 260		d: 15 mg/m^3 rf: 5 mg/m^3						
Calcium Chloride	10043-52-4	59 210								
Calcium Hydroxide	1305-62-0	106 132 143 160	X	5 mg/m^3		Irr.	Caustic			
Calcium Metasilicate	1344-95-2	278 279	X	d:15 mg/m^3 rf: 5 mg/m^3						
Calcium Oxide	1305-78-8	218 219 220 258	X	5 mg/m^3					UN1910	60
Carbon Dioxide	124-38-9	170	10000 ppm	10000 ppm STEL 3000 ppm			Non-Flam. Gas		UN1013 UN1845 UN2187	21
Carbon Disulfide	75-15-0	42	1 ppm	4 ppm		X		P022	UN1131	28
5-Chloro-2-methyl-4-isothiazolin-3-one	26172-55-4	176				X	Corrosive	D002		
Chloroacetic Acid	79-11-8	—					Corrosive			50
Chloroform	67-66-8	105 151	2 ppm	2 ppm	IARC 28 NTP X		Poison B	U044	UN1888	55
Chromic Acid	1308-14-1	72 201 202		CL 0.1 mg/m^3			Corrosive			60
Cobalt Naphthenate	61789-51-3	278 279					Flammable Solid			32
Copper	7440-50-8	—	1 mg/m^3	1 mg/m^3						
Copper Sulfate	7758-98-7	—							NA9109	
Creosote	8001-58-9	62					Toxic		UN1993	27
m-CRESOL	108-39-4	—	2.3 ppm	5 ppm			Poison	U052		
Dibutyl Phtalate	84-74-2	153	5 mg/m^3							
Dichlorofluorescein	76-54-0	143								

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Table 1—Chemicals Used in AASHTO Test Procedures *(Continued)*

Substance	Case No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Dioctylsodium Sulfosuccinate	577-11-7	59								
Ethanol	64-17-5	103 105 126 219 260 264	X	1000 ppm			Flammable Liquid		UN1170	26
EDTA	60-00-4	—							NA9117	
Ethylene Glycol	107-21-1	53 79 151	X	CL 50 ppm						26
Ferric Chloride	10025-77-1	—								31
Ferric Sulfate	10028-22-5	194							NA9121	31
Ferrous Ammonium Sulfate	7783-85-9	—								31
Ferrous Sulfate	7720-78-7	105 194								31
Formaldehyde	50-00-0	176	0.016 ppm	0.75 ppm 2.00 ppm STEL	IARC-2a	X	Flammable	U122	UN1198	29
Glutaraldehyde (1,5-Pentanedial)	111-30-8	176				X			UN2810	
Glycerol	56-81-5	105	X	d: 10 mg/m^3 rf: 5 mg/m^3						
Gypsum	7778-18-9	22 24 126 177 231 276	X	d: 15 mg/m^3 rf: 5 mg/m^3						
Heptane	142-82-5	102	85 ppm	400 ppm			Flam. Liq.		UN1206	27
Hexane	100-54-3	250	50 ppm	50 ppm			Flammable		UN1208	27
Hydrochloric Acid	7647-01-0	42 65 105 143 144 178 192 211 213 219 232 250 257 264 281	X	CL 5 ppm CL 7 mg/m^3			Corrosive Non-Flam. Gas		UN1050 UN1789 NA1789 UN2186	60
Hydrofluoric Acid	7664-39-3	105 178	3 ppm STEL 5 ppm	3 ppm STEL 5 ppm			Corrosive Poison	U134	UN1052 UN1790	39
Hydrogen Peroxide	7722-84-1	105 260	X	1 ppm			Oxidizer		UN2014 UN2984	45 47 60
Hydrogen Sulfide	7783–06-4	22 24 126 177 231 276	10 ppm	10 ppm 14 mg/m^3				U135	UN1053	
Isobutanol	78-83-1	105	50 ppm	50 ppm			Flam. Liq.	U140	UN1212	26
Isooctane	540-84-1	55					Flam. Liq.			27
Isopropanol	67-63-0	23 103 113 126 152 157 159 160 161 196 199 260 271	400 ppm CL 800 ppm	400 ppm			Flammable Liquid		UN1219	26
Kerosene	8008-20-6	98 113 133 250 270					Flam. Liq.			27

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Table 1—Chemicals Used in AASHTO Test Procedures *(Continued)*

Substance	Case No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Lead Acetate	301-04-2	—			NTP X		Poison	U144	UN1616	53
Lubricating Oil	No CAS #	270								27
Magnesium Chloride	7786-30-3	176								
Magnesium Nitrate	10377-60-3	176					Oxidizer		UN1474	
Magnesium Perchlorate	10034-81-8	105				X	Oxidizer		UN1475	35
Magnesium Sulfate	7487-88-9	104								40
Manganese Sulfate	7785-87-7	—		5 mg(Mn)/m^3						
Manganous Sulfate Monohydrate	10034-96-5	—		5 mg(Mn)/m^3						
Mercuric Chloride	7487-94-7	264	0.05 mg/m^3	0.1 mg/m^3			Poison B		UN1524	53
Mercuric Nitrate	10045-94-0	—	0.05 mg/m^3	0.1 mg/m^3			Poison B Oxidizer		UN1625	42
Mercuric Sulfate	7783-35-9	—	0.05 mg/m^3	0.1 mg/m^3			Poison B		UN1645	53
Mercury	7439-97-6	92 153	0.05 mg/m^3	0.05 mg/m^3 CL 0.1 mg/m^3		X		U151	UN2809 NA2809	60
Methanol	67-56-1	260	200 ppm CL 800 ppm	200 ppm STEL 250 ppm	NTP X	X	Poison Flam. Liq.	U154	UN1230	28
Methylene Chloride	75-09-2	164 170	Lowest Feas. Lim	500 ppm CL 1000 ppm	IARC X		Poison St. Andr.†	U080	UN1593	74
25-Methyl-4-isothiazolin-3-one	2682-20-4	176				X	Corrosive	D002		
Methyl Ethyl Ketone	78-93-3	250	200 ppm 590 mg/m^3	200 ppm STEL 300 ppm			Flammable Liquid	U159	UN1193	26
Methyl Ethyl Ketone Peroxide	1338-23-4	278 279	X	CL 0.7 ppm			Forbidden	U160	UN2127 UN2550	51
Methyl Methacrylate	80-62-6	—	X	100 ppm 410 mg/m^3			Flammable Liquid	U162	UN1247	26
Methyl Orange	547-58-0	26 105 143 260								60
Methyl Red	493-52-7	105								
Mineral Spirits	64475-85-0	49 201 202								27
n-Propyl Bromide	106-94-5	319				X	Flammable Liquid		UN2344	2344
Naphtha	8030-30-6	55 102	X	100 ppm 400 mg/m^3			Flammable Liquid		UN1255 UN1256 UN2553	27
Nitric Acid	7697-37-2	105 143 144 260 264 281	2 ppm 5 mg/m^3	2 ppm STEL 4 ppm			Corrosive Oxidizer		NA1760 UN2031	44

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Table 1—Chemicals Used in AASHTO Test Procedures *(Continued)*

Substance	Case No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Nitrogen	7727-37-9	244 266					Non. Flam. Gas			21
Nonylphenoxy poly (ethyleneoxy) ethanol	9016-45-9	252 294								
Paraffin	8002-74-2	233 275	X	fume: 2 mg/m^3						
Perchloric Acid	7601-90-3	105					Corrosive Oxidizer			45 47
Petroleum Oil	8002-05-9	24 126 157 177 231 244 266					Flammable Liquid			27
Polyester Resin	109-16-0	278 279								26
Potassium Bromate	7758-01-2	105					Oxidizer			35
Potassium Chlorate	3811-04-9	—					Oxidizer			35 44
Potassium Chromate	7789-00-6	143		CL: 0.1 mg $(Cr0_3)/m^3$					NA9142	31
Potassium Cyanide	151-50-8	—		5 mg(CN)/m^3			Poison B	P098	UN1680	55
Potassium Dichromate	7778-50-9	21 105 194		CL: 0.1 mg $(Cr0_3)/m^3$					NA1479	35
Potassium Nitrate	7758-09-0	105					Oxidizer			35
Potassium Permanganate	7722-64-7	105 143 144 250		CL 5 mg(Mn)/m^3			Oxidizer			35
Potassium Pyrosulfate	7790-62-7	105					Corrosive		UN2509	
Pyridine	110-86-1	—	X	5 ppm 15 mg/m^3			Flam. Liq. Poison	U196	UN1282	26
Silicic Acid	7699-41-4	178		6 mg/m^3						
Silicon	7440-21-3	227	X	d: 10 mg/m^3 rf: 5 mg/m^3			Flammable Solid		UN1346	
Silicon Dioxide	7631-86-9	278 279	r: 50 μg/m^3	rf: 0.1 mg/m^3						
Silver Nitrate	7761-88-8	105 143 194 260		0.01 mg(Ag)/m^3			Oxidizer		UN1493	45
Silver Sulfate	10294-26-5	194		0.01 mg(Ag)/m^3						45
Soda Lime	8006-28-8	280					Corrosive			60
Sodium Arsenite	7784-46-5	—					Poison B St. Andr.†		UN1686	53
Sodium Bisulfate	7681-38-1	—		5 mg/m^3			Corrosive			60

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Table 1—Chemicals Used in AASHTO Test Procedures *(Continued)*

Substance	Case No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Sodium Chromate	7775-11-3	143		CL: 0.1 mg (Cr0$_3$)/m^3					NA9145	31
Sodium Cyanide	143-33-9	—	5 mg/m^3	5 mg(CN)/m^3		X	Poison B Corrosive	P106	UN1689	55
Sodium Hexametaphosphate		88								
Sodium Hydroxide	1310-73-2	21 71 105 143 178 213 219 227 257 264 277 303	Ceil: 2 mg/m^3	Ceiling: 2 mg/m^3			Corrosive		UN1823 UN1824	60
Sodium Nitrate	7631-94-4	105 260					Oxidizer			35
Sodium Nitrite	7632-00-0	—					Oxidizer		UN1500	35
Sodium Oleate	143-19-1	59								
Sodium Phosphate	7601-54-9	—							NA9148	31
Sodium Pyrosulfate	7681-38-1	105					Corrosive			
Sodium Sulfate	7757-82-6	104								
Sodium Thiosulfate	772-98-27	264								
Sodium Tripolyphosphate	7758-29-4	88							NA9148	
Stannous Chloride	7772-99-8	105 213		2 mg(5n)/m^3						60
Stibine	7803-52-3	64 213	0.1 ppm	0.1 ppm					UN2676	18
Strontium Nitrate	10042-76-9	105					Oxidizer			35
Sulfamic Acid	5329-14-7	—				Irr	Corrosive			60
Sulfuric Acid	7664-93-9	21 105 143 144 178 194 250 264 281	1 mg/m^3	1 mg/m^3					UN1830 UN2796	39
Terpene		164					Flammable		UN2319	27
1,1,2,2,-Tetra Bromoethane	79-27-6	113	1 ppm	1 ppm 14 mg/m^3			Poison B St. Andr.†		UN2504	58
Thioacetamide	62-55-5	—			NTP X			U218		
Thorium Nitrate	13823-29-5	—								
Titanium Dioxide	13463-67-7	105 250	5 mg/m^3	10 mg/m^3						64
Toluene	108-88-3	49 55 110 250	100 ppm	100 ppm			Flammable	U220	UN1294	27
1,1,1,-Trichloroethane	71-55-6	44 164	X	350 ppm STEL 450 ppm			Poison B St.Andr. †	U226	UN2831	74

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Table 1—Chemicals Used in AASHTO Test Procedures *(Continued)*

Substance	Case No.	Test Method	NIOSH REL	OSHA PEL	Carcin	Skin	DOT Label	RCRA No.	SHIP Codes	DOT Guide
Trichloroethylene	79-01-6	42 44 49 59 164 170 201 202	25 ppm	50 ppm STEL 200 ppm		X	Poison B St. Andr. †	U228	UN1710	74
1,1,2,- Trichloro-1,2,2,-Trifluoro-ethane	76-13-1	—	X	1000 ppm STEL: 1250 ppm						12
Xylene	1330-20-7	55 59 102 110	100 ppm 435 mg/m^3	100 ppm STEL 150 ppm			Flammable Liquid	U239	UN1307	27
Zinc Acetate	557-34-6	264								
Zinc Bromide	7699-45-8	113							NA9156	31
Zinc Chloride	7646-85-7	113 210	X	fume: 1 mg/m^3 STEL 2 mg/m^3			Corrosive		UN1840 UN2331	60
Zinc Oxide	1314-13-2	105	f: 5 mg/m^3	f: 5 mg/m^3						37, 76
Zinc Sulfate	7733-02-0	105							NA9161	31
Zirconyl Chloride Octahydrate	7699-43-6	—		5 mg(Zr)/m^3						

Standard Practice for

Technician Training and Qualification Programs

AASHTO Designation: R 25-00 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Technician Training and Qualification Programs

AASHTO Designation: R 25-00 (2009)

1. SCOPE AND LIMITATION

1.1. This document provides a guideline for establishing evaluation and qualification procedures for personnel engaged in sampling and testing of soils, aggregates, hot mix asphalt, and portland cement concrete in accordance with AASHTO test methods. The guideline is intended for use by organizations providing qualification of sampling and testing technicians at the basic testing level for acceptance of materials and independent assurance testing.

1.2. The terms used in this standard regarding “technician” or “qualification” are meant to be generic descriptions. Each state will need to use appropriate terminology consistent with state law and practices.

1.3. This guideline does not purport to address all possible events and procedures inherent in the administration and use of a technician qualification program (TQP).

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards and Publications*:

- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T l9M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 21, Organic Impurities in Fine Aggregates for Concrete
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 87, Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 100, Specific Gravity of Soils
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 113, Lightweight Pieces in Aggregate
- T 119M/T 119, Slump of Hydraulic Cement Concrete

- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 194, Determination of Organic Matter in Soils by Wet Combustion
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 267, Determination of Organic Content in Soils by Loss of Ignition
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
- T 287, Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method
- T 304, Uncompacted Void Content of Fine Aggregate
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- "Guidelines for Establishing a Technician Training and Certification Program," National Quality Initiative Steering Committee, September 1997
- *Implementation Manual for Quality Assurance*
- *Quality Assurance Guide Specification*

2.2. *ASTM Standards*:

- C 1064, Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
- D 1560, Standard Test Methods for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus
- D 4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- D 5821, Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate

2.3. *Federal Highway Administration*:

- "Quality Control/Quality Assurance—Technician Training and Certification/Qualification," June 1997, National Task Group for Technician Training and Certification, sponsored by FHWA

3. INTRODUCTION

3.1. This guideline is provided to:

(a) Help individual states, and where desired, combinations of states and other public agencies develop a TQP for use in conjunction with quality assurance (QA) specifications as described in the *Implementation Manual for Quality Assurance* and the *Quality Assurance Guide Specification*.

(b) Describe the activities and organizational needs for the development and operation of a technician qualification program that provides a flexible and effective means for ensuring qualified personnel perform sampling and testing.

(c) Describe coverage for Level I tests, the basic tests performed to identify material or product characteristics, for acceptance and/or payment under project contracts incorporating soils, aggregates, portland cement concrete, and hot mix asphalt. Examples of the basic tests that could be included under Level I are shown in Appendix A.

(d) More advanced levels of training and qualification within a TQP are not covered by this guideline but may be considered to address mix designs, plant control, and quality control/quality assurance (QC/QA) operations.

3.1.1. A successful TQP requires the full support and commitment from agencies and industry that have a vested interest in technician training and qualification. Involvement of all those with a common interest in technician training and qualification helps in understanding the multiple perspectives of the team members, and this, in turn, helps develop policies and procedures that will be supported by their respective organizations.

3.1.2. Development of an agreement at the program inception and prior to major changes is recommended as the best means for gaining the needed understanding and support for the program.

3.1.3. Consideration of reciprocal agreements between states, and where feasible, regions, regarding materials technician qualification acceptance is a means of addressing economy and business process efficiencies and should be an integral part of all TQPs.

3.2. *Background:*

3.2.1. Historic roles and responsibilities of industry and agencies have changed for sampling and testing activities under QA specifications. QA specifications allow the use of contractor test results in making acceptance decisions, and the use of consultants in independent assurance and verification sampling and testing programs, for materials and construction quality control.

3.2.2. Qualification programs and associated training have been shown to be an effective tool for improving the quality of highways and bridges by verifying that essential knowledge and skills are possessed by agency or industry personnel who monitor, inspect, and control construction operations. Qualification programs for personnel have proven to be useful, common “yardsticks” for measuring expertise and performance among public transportation agencies, private construction contractors, and independent materials laboratories.

3.2.3. As the use of QC/QA specifications increases, the need for TQPs as an equitable means for test result comparison and credibility between contract parties has become apparent. Each state using QC/QA specifications should have provisions requiring the use of qualified technicians involved in construction project testing and inspection activities.

(b) Industry contributions;
(c) State Planning and Research (SP&R) Funds;
(d) Federal Highway Administration;
(e) Contributed time, facilities or equipment from industry, consultants, and academia; or
(f) Other innovative funding mechanisms, such as loans paid back from generated income for courses.

4.5.1. Multi-state or regional involvement may result in additional funding sources and a decrease in costs to the individual participants.

4.5.2. Course fees should be reasonable but adequate to enable the program to become self-sufficient. It is necessary to make a long-term commitment and conduct the program as if it were a business, knowing that the program may lose money initially but should become self-sufficient after several years of operation. Areas where operational support may be available include the following:
(a) Manuals that are developed for qualification and training may be sold publicly, provided that copyright laws are followed;
(b) Continued financial support from the agency and industry;
(c) Continued use of contributed facilities, equipment, etc., from the agency and industry.

4.6. *Organizational Task Groups*—Task groups should be formed as soon as possible to simultaneously address the many TQP start-up issues. Each task group should be made up of four to six members with its chairman coming from the oversight committee. Other participating members may or may not be on the oversight committee. All members of the task group should have a working relationship and experience with the function of the particular task group. The task groups should be established and used to develop programs, plans, and policies for presentation and approval from the oversight committee. Recommended areas where task groups should be formed initially include the following:

4.6.1. A funding task group:
(a) To identify areas of financial support; and
(b) To develop operational budgets and cost review of courses, manuals, etc.

4.6.2. An administrative task group:
(a) To set guidelines and write contracts for third-party administrators (e.g., director, university or consultant);
(b) To work with oversight committee to ensure proper representation and replacement as necessary;
(c) Conduct program reviews;
(d) Address and resolve candidates issues; and
(e) Identify roles and responsibilities of operational components of the program.

4.6.3. A record-keeping and documentation task group:
(a) To establish security guidelines for records and designate support staff; and
(b) To provide storage and security of applications, test results, test papers, etc.

4.6.4. A task group for each qualification area (hot mix asphalt, portland cement concrete, soils, and aggregates:
(a) To develop requirements for training and qualification programs;
(b) To establish experience and hands-on performance requirements;

(c) To establish course outlines; and

(d) To establish examinations criteria.

4.7. Options for leading the development, administration, and implementation of TQP qualification programs have been developed and implemented through cooperative partnerships among public agencies, private sector organizations, and educational institutions. Options should be considered when determining who will be asked to lead the development, administration, and implementation of a state or regional TQP.

4.7.1. *Agency In-House*—Agency in-house TQPs usually assign responsibilities for developing, administering, and implementing a TQP into technical services, personnel/human resources, or product quality management areas.

4.7.1.1. The main advantages of an in-house TQP are:

(a) Lower costs to contractors;

(b) No cost to DOT employees;

(c) Trainers knowledgeable of subject matter and familiar with specifications;

(d) Control of material being instructed; and

(e) In-house knowledge of TQP requirements for technician's skills, experience, qualifications, requalification, and disqualification.

4.7.1.2. The main disadvantages of the program are:

(a) Turnover of instructors;

(b) Fewer employees available to be instructors; and

(c) Fiscal and manpower costs to the SHA.

4.7.2. *Consultants*—Using a third-party consultant to develop, administer, and implement a state or regional TQP is similar to outsourcing other non-core tasks within a government agency. The third-party consultant may be designated as a program director responsible for the day-to-day operations reporting directly to the oversight committee. The program director, ideally, would have no relationship with either the state(s) or industry in order to eliminate potential appearance of a conflict of interest. Advantages of a third-party consultant include the availability of time and commitment to organizational needs, independence from all interested parties, and facilitating and overseeing the development of various programs to provide consistency between programs. A third-party consultant may also bring expertise and focus to the organization and provide the necessary staffing to expedite the product delivery schedule.

4.7.3. *University/College*—The advantages of using a university or college to develop, administer, and implement a state or regional TQP are:

(a) Access to the diverse expertise found at a university or college; and

(b) Support facilities and services, e.g., mail, guest housing, meals, printing, janitorial, accounting, classrooms, laboratories, computers, fleet vehicles, student workers, and administration support staff.

4.7.4. *Public/Private*—State and regional qualification programs have been developed and implemented through cooperative partnerships among public agencies, private sector organizations, and educational institutions. These types of programs foster a cooperative agreement between industry groups and state agencies that will be very beneficial to everyone involved in this field. All the partners can contribute their expertise to people from both industry and agencies. This training to mixed groups will assure greater understanding and cooperation when constructing the project.

4.7.5. *Private National Engineering and Technical Organizations*—Several national engineering and technical organizations have created more generic qualification programs that are available to personnel from both agencies and industry.

5. TRAINING AND QUALIFICATION POLICIES

5.1. In developing state and regional TQPs, the following guiding principles should be followed:

(a) Develop the TQP using AASHTO sampling and testing procedures whenever possible. A state may require an additional endorsement to the TQP to cover unique or additional procedures in their state;

(b) Address soils, aggregates, hot mix asphalt (HMA), and portland cement concrete (PCC) as the primary qualification topics; and

(c) Address a technician qualification Level I that involves basic sampling procedures and test methods initially, with additional qualification levels developed as the scope of the TQP progresses.

5.2. *Focus*—In order to support the overall objective of improving the quality of the construction of highways through the improved work performance of those involved with the construction project, the TQP *must be directly work-related*. The scope and content of all qualification testing must be based on realistic and practical work needs. Because the TQP focuses on work performance, everyone involved—managers, supervisors, program administrators, and participants—should treat qualification activities as natural extensions of their work duties and responsibilities.

5.3. *Leveraging and Aligning Activities and Programs between States and Regions*—There is a wide variation in the development and implementation of TQPs between states and regions. This is an opportunity and a challenge for states and regions considering, or just beginning, TQP initiatives. No single “best way” to implement a TQP has emerged, but there is much to be learned from states and regions with established TQPs.

5.3.1. Whenever possible, consideration should be given to developing state technician qualification requirements by participating in a regional TQP. Participating in a regional program has the positive benefit of pooling and leveraging state resources and also of allowing qualified technicians to work across state boundaries without having to retrain and requalify. Gaining these benefits will lower the states’ and contractors’ cost of doing business while still ensuring that high-quality testing is performed.

5.3.2. To facilitate reciprocity and efficiency, consideration should be given to developing qualification policies based on AASHTO standard test procedures. If an AASHTO test procedure is not available, then a state or region should adopt ASTM procedures or another agreed-upon method.

5.3.3. The SHA should have a written policy regarding reciprocity. The policy should be clear to applicants seeking reciprocity. Any requirements for classroom training, performance, or written examinations should be identified. If participating in a regional approach to training and qualification is not selected, SHAs should specify if, when, and how qualification from other states or regions can be used. Conducting regional qualification conferences to share questions between states and discuss the best practices for policies, procedures, and specifications is an effective means for streamlining and improving TQP implementation.

5.3.4. Once policies and procedures for developing a TQP are established, the next challenge is implementation. Given the experiences of states and regions that have already implemented TQPs, it is recommended that program elements be tested as pilots before fully implementing them as an integrated program. Well-designed pilots will maximize feedback and learning and help gain the support of those in government and industry that will be affected by the changes.

5.4. *Consideration of Prerequisites*—In addition to the required training, work experience may be used as an integral part of the qualification process to ensure technicians have the required knowledge, skills, and abilities. This assurance may be accomplished by establishing prequalification relevant work experience or education requirements, establishing work experience criteria prerequisites for participation in advanced qualification levels, or requiring relevant work experience to maintain and validate the requalification process.

5.4.1. The TQP should consider any prerequisites necessary for entry-level training. Demographics and the characteristics of the labor pool available to the state may need to be considered as a starting point. Minimum requirements in reading level and math skill capabilities may need to be identified as an entry-submittal gateway. If there is a problem noted with the applicants' reading and math skills that would hinder their performance, establishment of training to correct these deficiencies for the applicants may be advisable.

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6. TRAINING

6.1. A well-planned and supportive training program is the basis for a successful qualification program. A good training program will ensure qualified technicians and testers will be performing inspection on construction projects.

The training program should be offered to all individuals including those from SHAs, local agencies, contractors, producers, or consultants. The program should be administered the same for all individuals.

6.1.1. Training should be structured to fit the qualification test criteria. Since the program is directed toward highway construction, AASHTO test procedures should be used to the maximum extent.

6.1.2. When training is part of a qualification program, the training portion of the program should be developed prior to the qualification program. Development and maintenance of a training program may be handled by:

(a) State highway agency;
(b) University or vocational-technical school;
(c) Consultants; or
(d) Public/private consortium.

6.1.3. The program administration requires the following resources:

(a) Funding and fees;
(b) Staffing (instructors, coordinators, proctors, etc.);
(c) Training facilities;
(d) Materials (manuals and equipment);
(e) Record keeping;
(f) Governing board/advisory committee; and
(g) Organizational task groups.

6.1.4. The above resources need to be considered when choosing who will handle the development and maintenance of the program.

6.1.4.1. Training materials may be developed solely for the TQP or developed with another state/region. There are also existing training manuals and aides that are available for use.

6.1.4.2. Training may include lecture, hands-on training, or self-study methods. Inclusion of hands-on training will help to ensure that the technician is competent and should raise their comfort level in performing materials sampling and testing.

6.1.4.3. Qualified technicians will need to be kept aware of specification, equipment, or administration changes in the training program. This need may be satisfied by requalification training, update courses, or special training efforts.

6.1.4.4. Trainers need to have the technical knowledge and presentation skills necessary to instruct the courses. Competence and conduct criteria for the instructors, examiners, and proctors need to be defined and enforced.

7. EXAMINATION AND METHODS

7.1. A successful qualification program must have documented policies and procedures for examination methods to ensure consistent and fair administration by all examiners and proctors.

7.1.1. The program oversight committee should empower and formally task an individual, such as a TQP manager, to direct and coordinate all qualification examination activities. Typical duties of this individual are scheduling of examinations; registration of applicants; maintaining and ensuring the security of examination materials; notifying participants of their success or failure in their examination; and maintaining all completed examination materials.

7.1.2. Written and performance examinations should be given to determine if the applicants possess the knowledge and skills necessary to satisfy the established qualification requirements. “Grandfathering” technicians and testers, or a waiver of training and testing in lieu of qualification examination should not be permitted. If actually performing the tests, a licensed professional engineer should demonstrate competency according to the TQP.

7.2. *Examination Controls and Integrity*—To avoid conflicts of interest, the examiner should not be the immediate supervisor of those being qualified. Examination procedures should be documented and included in the policy and procedures manual. The documentation should include procedures to:

(a) Develop and revise qualification exams;
(b) Establish examination pass-fail criteria;
(c) Determine examination duration;
(d) Determine disciplinary action for cheating;
(e) Document examination security procedures;
(f) Develop the detailed plan for conducting examinations;
(g) Develop retesting policy and procedures;
(h) Design a process to notify individuals of examination times and results;
(i) Develop procedures to ensure the confidentiality of score reporting;
(j) Establish requirements for examiners and proctors; and
(k) Establish a procedure to update or change tests when there is a change in a test method or specification.

7.3. *Examination Methods*—Written and performance examinations should be given to ensure that applicants have a complete understanding of the materials and calculations as well as the ability to perform test procedures. Care and good judgment are needed in developing fair and impartial written and performance examinations.

Prior to the examinations, the proctors should thoroughly explain to the applicants:

(a) The examination process and rules;

(b) What the exams will be comprised of;

(c) Minimum scores necessary to pass; and

(d) The retesting policy.

7.3.1. *Written Examination*—The written examination may be closed- or open-book and should have a designated time limit. Examinations may consist of various types of questions, including true/false, multiple choice, essay, fill-in-the-blank, word problems, and calculations.

A large database of questions for use in the written examination of each qualification area should be developed and a set of questions randomly selected for each examination given. The use of randomly selected questions will assist in ensuring the credibility of the process by providing a different set of questions for each examination. To protect examination integrity, course participants should not retain a copy of their completed written examinations.

7.3.2. *Performance Examination*—Performance examinations measure the applicants' ability to properly perform the prescribed test methodology. All proctors and examiners should evaluate each applicant's proficiency by using standardized checklists that identify specific test method steps or tasks. The degree of detail of the performance checklists will be influenced by whether the performance examination is open- or closed-book. Inspection checklists developed by AMRL and CCRL are excellent references for the evaluation of AASHTO and ASTM test methods. Time limits can be set for the complete performance of each test method. The examinee may be asked to explain various steps of the procedure to reduce the full test time.

7.4. *Re-Examination Policy–Written/Performance*—Whenever a participant fails a written/performance qualification examination, some allowance should be provided for retesting. A policy should be established to address the following areas:

(a) Maximum number of retests allowed;

(b) When retesting will be permitted;

(c) Maximum time limit for retaking the written/performance examination; and

(d) Guidelines if the applicant fails the retest.

7.4.1. The number of retests allowed and the time limits are needed to avoid frivolous, trial-and-error attempts and encourage the participants to properly prepare for testing. The re-examination policy will also influence the size of the test question database needed for written examinations.

7.5. *Notification of Results*—Notification of an applicant's successful or unsuccessful completion of the qualification requirements should be mailed to the applicant promptly after completion of the examination. If the applicant is unsuccessful, the procedure for re-examination should be explained.

7.6. *Confidentiality of Records*—Personal information and records of the examination are generally considered to be confidential and not to be released publicly. Confidential information includes:

(a) Personal and professional information provided by the participants applying for testing and qualification; and

(b) Specific test results and scores for participants.

7.7. *Examination Materials Security*—The qualification training program should provide specific procedures and precautions for establishing and maintaining the security of examination materials at all times. Violation of security compromises the integrity and validity of the qualification process. Applicants should not retain a copy of the written examination. After the performance test, examiners and proctors may inform the applicants of their weaknesses and the details of correct procedures.

7.8. *Examiner and Proctor Qualifications*—Examiners and proctors should complete an orientation or training session. Examiners for the performance examination must be qualified in that examination area. Examiners may be employees of agencies, contractors, or industry associations.

7.9. *Examination Appeals*—An applicant wishing to register a complaint or protest regarding an examination or examiner must do so in writing to the TQP Manager within a specified period of time. The written complaint must specify the examination date, the examiner, and the nature of the complaint or protest.

7.9.1. Complaints and protests should be reviewed and a recommendation made to the oversight committee. All complaints and protests should be promptly answered in writing.

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8. QUALIFICATION

8.1. Each qualifying agency that issues through their TQP the status of qualification or certification must maintain a written policy for administration of their TQP.

8.2. Each agency must maintain a registry of trained technicians who have successfully completed a training program. The registry should include:

(a) Name, Social Security number or qualification identification number, and address;
(b) Courses, and dates completed; and
(c) Course content:
    Test methods included;
    Lecture or laboratory;
    Written examination; and
    Performance examination.

8.3. The qualifying agency shall provide the qualified technician with documentation of the qualification. This documentation may be in the form of a registration card or letter. The document should include any expiration date.

8.3.1. The qualifying agency may require the registered technician to maintain a current address on file as a condition of registration.

8.4. Establishing a registration policy is the responsibility of the TQP Manager. A registration application should include:

(a) Program administration and information contact(s);
(b) Listing of qualification training courses and examinations and fee schedule;
(c) Refund policy;
(d) Payment policy;
(e) Enrollment and lodging information;

(f) Participant and employer information; and

(g) Resume application.

8.5. Enrolling and scheduling course participants and collecting fees can become a tedious and cumbersome task. It is highly recommended that a database software package be used to expedite the registration and record-keeping process.

8.6. The qualifying agency must adopt a policy to protect the privacy of all qualified technician's records.

8.6.1. The TQP should establish a period for which the qualification remains valid.

8.7. The TQP should include a requalification policy. The requalification process may include refresher courses, observations, and/or retesting.

8.8. The TQP should include a written policy regarding the removal of qualification status or disciplinary measures regarding technician performance. Progressive levels of discipline that lead up to disqualification may be provided.

9. TECHNICIAN LEVEL I TEST METHODS

9.1. Each state or region should develop a set of test methods to support a Level I TQP. This level depends, to some extent, upon the specifications and materials requirements. It is hoped that a Level I TQP will be the starting point for reciprocity between the SHAs. The list of tests shown in Appendix A was developed as an example during the November 1996 Technician Certification Program Workshop and represents some of the tests available to each state when selecting those tests to include in their TQP.

10. SUMMARY

10.1. Training and qualification programs can result in significant improvements in the quality of the American transportation system. TQPs can improve the abilities of technicians and help ensure validity of their testing, thereby resulting in fewer claims, legal disputes, and less adversarial relationships between all parties. Improved worker skills reduce the risks to both the owner/agency and contractor/producer and better identify the quality of each component and the final product. Training will improve the quality standards of highway workers, giving them more confidence and pride in the performance of their jobs. TQPs can be used to establish a career path for SHA and industry employees, providing promotional opportunities based on merit. Improved worker performance should lead to longer-lasting roads and a more effective use of taxpayer dollars, while providing an improved infrastructure for the traveling public.

APPENDIXES

(Nonmandatory Information)

X1. QUALIFYING TESTS—SOILS AND AGGREGATES

Recommended Test and Corresponding AASHTO Test or Other Test

X1.1. *Gradation*

- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 100, Specific Gravity of Soils

X1.2. *Liquid Limit, Plastic Limit, and Plasticity Index*

- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils

X1.3. *Compaction/Density*

- T 99/T 180, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

X1.4. *Moisture Content*

- T 255, Total Evaporable Moisture Content of Aggregate by Drying

X1.5. *Sampling and Splitting*

- T 2, Sampling of Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

X1.6. *Deleterious Materials*

- T 21, Organic Impurities in Fine Aggregates for Concrete
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 194, Determination of Organic Matter in Soils by Wet Combustion
- T 267, Determination of Organic Content in Soils by Loss of Ignition

X1.7. *Lightweight Pieces*

- T 113, Lightweight Pieces in Aggregate

X1.8. *Dry Rodded Unit Weight*

- T l9M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate

X1.9. *Soil Preparation*

- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test

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X2. QUALIFYING TESTS—PORTLAND CEMENT CONCRETE

Recommended AASHTO or Other Test Designations

X2.1. Sampling

- T 141, Sampling Freshly Mixed Concrete

X2.2. Aggregate Gradations

- T 27, Sieve Analysis of Fine and Coarse Aggregates

X2.3. Moisture Content of Coarse and Fine Aggregate

- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

X2.4. Aggregate Specific Gravity

- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate

X2.5. Air Content by Pressure Method

- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method

X2.6. Air Content by Volume Method

- T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

X2.7. Slump and Temperature

- T 119, Slump of Hydraulic Cement Concrete
- ASTM C 1064, Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete

X2.8. Fabrication and Curing of Compressive Strength Specimens (Cylinders and Beams)

- T 23, Making and Curing Concrete Test Specimens in the Field

X2.9. *Capping and Testing Cylinders*

- T 22, Compressive Strength of Cylindrical Concrete Specimens

X3. QUALIFYING TESTS—HOT MIX ASPHALT

Recommended AASHTO or Other Test Designation

X3.1. *Aggregate Gradation*

- T 27, Sieve Analysis of Fine and Coarse Aggregates

X3.2. *Asphalt Content (Ignition, Solvent, Nuclear)*

- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 287, Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

X3.3. *Bulk Specific Gravity of Compacted Specimens*

- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens

X3.4. *Sampling Methods and Techniques*

- T 168, Sampling Bituminous Paving Mixtures

X3.5. *Voids and VMA*

- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

X3.6. *Maximum Theoretical Specific Gravity*

- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)

X3.7. *Specific Gravity of Aggregates*

- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate

X3.8. *Percent Passing 75-µm (No. 200) Sieve*

- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

X3.9. *Moisture Content*

- T 255, Total Evaporable Moisture Content of Aggregate by Drying

X3.10. *Sand Equivalent*

- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- ASTM D 1560, Standard Test Methods for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus

X3.11. *Fine Aggregate Angularity*

- T 304, Uncompacted Void Content of Fine Aggregate

X3.12. *Coarse Aggregate Angularity*

- ASTM D 5821, Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate
- ASTM D 4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

X3.13. *Moisture Susceptibility*

- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

Standard Practice for

Evaluating Deicing Chemicals

AASHTO Designation: R 34-03 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Evaluating Deicing Chemicals

AASHTO Designation: R 34-03 (2008)

1. SCOPE

1.1. This practice includes a set of test procedures for the evaluation of deicing chemicals.

1.2. *This procedure may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *SHRP Documents*:

- SHRP H-332, Handbook of Test Methods for Evaluating Chemical Deicers
- SHRP H-332—Appendix B, Containing the following 11 tests:
  - SHRP H-205.1, Ice Melting Capacity of Solid Deicing Chemicals
  - SHRP H-205.2, Ice Melting Capacity of Liquid Deicing Chemicals
  - SHRP H205.3, Ice Penetration of Solid Deicing Chemicals
  - SHRP H205.4, Ice Penetration of Liquid Deicing Chemicals
  - SHRP H-205.5, Ice Undercutting by Solid Deicing Chemicals
  - SHRP H-205.6, Ice Undercutting by Liquid Deicing Chemicals
  - SHRP H205.7, Evaluation of Corrosive Effects of Deicing Chemicals on Metals
  - SHRP H-205.8, Rapid Evaluation of Effects of Deicing Chemicals on Concrete
  - SHRP H-205.9, Evaluation of Scaling Effects of Deicing Chemicals on Concrete Surfaces
  - SHRP H-205.10, Evaluation of Frictional Characteristics of Deicing Chemicals
  - SHRP H-205.12, Evaluation of Corrosive Effects of Deicing Chemicals on Steel Reinforcement in Concrete

3. GENERAL PROVISIONS

3.1. It is recommended that the procedures included in Section 2 be used for the complete characteristics of deicing chemicals.

Standard Practice for

Independent Assurance (IA) Programs

AASHTO Designation: R 44-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Independent Assurance (IA) Programs

AASHTO Designation: R 44-07

1. SCOPE AND LIMITATIONS

1.1. *Independent Assurance (IA)*—Independent assurance is used in industry as an internal audit and review to support the accuracy of data and processes. In the highway industry it is the outgrowth of a report from the Congressional House Committee on Oversights and Investigations ("Blatnik Committee") that requires state departments of transportation (DOTs) to perform IA sampling and testing whenever federal funds are involved.

1.2. *Purpose of IA*—Independent assurance is an unbiased and independent assessment of all sampling, testing, and workmanship. This assessment includes evaluation of procedures and equipment used for the acceptance of highway materials and construction. 23 CFR Part 637 requires each state to have an IA Program. Independent assurance is used for verification of sampling procedures, testing procedures, and testing equipment.

1.3. Independent assurance is distinct from, and not intended as an acceptance process or for use in, verification of contractor sampling and testing results. Independent assurance is distinct from, and not intended for, quality control (QC) purposes. If IA results indicate a potential problem with quality, the results may be used to initiate additional testing.

1.4. Independent assurance sampling shall be done in such a manner as to minimize variability. In order to eliminate material and process variability, split samples should be used. Independent assurance samples may be taken independently of verification or acceptance samples, or may be a split of a verification or an acceptance sample.

1.5. Deficiencies in acceptance or QC processes that are identified through the IA program must be investigated and resolved. Otherwise, there is no purpose in identifying deficiencies.

1.6. This standard practice is applicable to design/build and warranty specifications as well as more conventional contracting methods. As a management principle, IA is a responsibility of the DOT that cannot be delegated to the contractor. (For example, contractors shall not hire their own IA inspectors or testers.)

1.7. Independent assurance is an essential tool that helps to ensure integrity within the quality assurance (QA) program. Independent assurance helps to prevent fraud and other criminal activities by evaluating sampling and testing procedures and competency. Independent assurance must be consistent throughout the agency. (It keeps the honest people honest by providing a "level playing field" for all contractors.)

Note 1—Many of the principles included herein have universal application. Although this standard practice for IA programs is developed specifically for construction materials, it can be applied to other processes. The principles inherent in the use of unbiased, consistent, and reliable information are applicable for any management effort. For example, construction workmanship is frequently inspected by either measurement or examination.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 9, Acceptance Sampling Plans for Highway Construction
- R 10, Definition of Terms Related to Quality and Statistics as Used in Highway Construction
- R 18, Establishing and Implementing a Quality System for Construction Materials Testing Laboratories
- R 25, Technician Training and Qualification Programs
- R 38, Quality Assurance of Standard Manufactured Materials

2.2. *ASTM Standards*:

- D 3665, Standard Practice for Random Sampling of Construction Materials
- E 177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods

2.3. *Other Documents*:

- FHWA NHI-02-022, *Materials Control and Acceptance-Quality Assurance*, NHI Course No. 134042, Federal Highway Administration, December 2000
- FHWA–RD–02–095, *Optimal Procedures for Quality Assurance Specifications,* Federal Highway Administration, 2003
- FHWA Technical Advisory T 6120.3, *Use of Contractor Test Results in the Acceptance Decision, Recommended Quality Measures, and the Identification of Contractor/Department Risks*, HIPT-10, August 2004
- Final Rule, 23 CFR 637, Quality Assurance Procedures for Construction, *Federal Register*: June 29, 1995 (Volume 60, Number 125, 33712)
- Title 23 Code of Federal Regulations, Part 637, Subpart B, *Quality Assurance Procedures for Construction* [Revised as of April 1, 2003, CITE: 23 CFR 637]
- Transportation Research Circular Number E-C074, *Glossary of Highway Quality Assurance Terms*, Transportation Research Board, 2005

2.4. *Web sites*:

- http://www.fhwa.dot.gov/pavement/materials/techqual.cfm.
- http://www.fhwa.dot.gov/pavement/materials/labqual.cfm
- http://www.fhwa.dot.gov/pavement/materials/matqa.cfm#labqual
- http://www.fhwa.dot.gov/legsregs/directives/fapg/0637bsup.htm

3. DEFINITIONS (REFERENCE R 10)

3.1. *acceptance sampling and testing*—sampling and testing performed by the agency, or its designated agent, to evaluate acceptability of the final product. Also called verification sampling and testing when specifically used to validate the contractor’s data.

3.2. *accredited laboratories*—laboratories which are recognized by a formal accrediting body as meeting quality system requirements including demonstrated competence to perform standard test procedures.

3.3. *certified technician*—a technician certified by some agency as proficient in performing certain duties. [A certified technician is considered to be qualified. A qualified technician may or may not be certified.]

3.4. *independent assurance (IA)*—activities that are an unbiased and independent evaluation of all the sampling and testing (or inspection) procedures used in the QA program. [Independent assurance provides an independent verification of the reliability of the acceptance (or verification) data obtained by the agency and the data obtained by the contractor. The results of IA testing or inspection are not to be used as a basis of acceptance. Independent assurance provides information for quality system management.]

3.5. *independent sample*—a sample taken without regard to any other sample that may also have been taken to represent the material in question. [An independent sample is sometimes taken to verify an acceptance decision. This is possible because the data sets from independent samples, unlike those from split samples, each contain independent information reflecting all sources of variability, i.e., sampling, testing, materials, and construction.]

3.6. *quality assurance (QA)*—(1) all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service; or (2) making sure the quality of a product is what it should be. [QA addresses the overall process of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible. Within this broad context, QA includes the elements of QC, IA, acceptance, dispute resolution, etc. The use of the term QA/QC or QC/QA is discouraged, and the term QA should be used. QA involves continued evaluation of the activities of planning, design, development of plans and specifications, advertising and awarding of contracts, construction and maintenance, and the interactions of these activities.]

3.7. *split sample*—a sample that has been divided into two or more portions representing the same material. [Split samples are sometimes taken to verify the acceptability of an operator's test equipment and procedure. This is possible because the variability calculated from differences in split test results is comprised solely of testing variability. See *replicate sample* in Section 3.201 of R 10.]

3.8. *validation*—the mathematical comparison of two independently obtained sets of data (e.g., agency acceptance data vs. contractor data) to determine whether it can be assumed they came from the same population.

3.9. *workmanship inspection*—examination or measurement for determination of conformance to requirements of construction processes, components, or products.

4. DEVELOPMENT OF IA PROGRAMS

4.1. Independent assurance programs can be administered by project, system, or a combination of the two. There are advantages to all three bases:

4.1.1. *Independent Assurance by Project*—The project basis, based on a quantity, may provide an easier way to monitor compliance and ensure that all materials are covered on an individual project. This basis may fit better when the DOT can accurately estimate initial quantities and the rest of the QA program is quantity-based.

4.1.2. *Independent Assurance by System*—The system basis is typically administered statewide. It is personnel-related rather than project-related and allows easier tracking of individuals. This basis is usually applied on a time-based, rather than a quantity-based frequency.

4.1.3. *Independent Assurance by Combination of Project and System*—The combination basis is both time-based and quantity-based. Thus, it is possible to use the advantages of both the project and system bases.

4.2. *Independent Assurance Applied to Testing*—IA provides an independent validation of the reliability of the acceptance or verification data obtained by the DOT and the data obtained by either the DOT or the contractor. The results of IA testing or inspection are not to be used as a basis of acceptance, but all IA-identified discrepancies should be resolved before acceptance is completed.

4.3. *Independent Assurance Applied to Documentation*—IA provides a management tool that can be used to audit test results for completeness and suspicious, erroneous, or missing data. [This is most efficiently done by establishing a database of all test results, including IA, with the data entered into a laboratory information management system (LIMS).]

4.4. *Independent Assurance Applied to Training*—IA should be used to evaluate the effectiveness of the training and qualification process as defined in Section 5. The IA evaluation can be linked directly to the qualification process to provide an effective feedback loop.

4.5. *Independent Assurance Applied to Certified Products*—IA should be used to assure a certified product meets the specifications required by the state DOTs. An example of this is the DOTs observation of a certified product technician performing tests. It is important to verify through a QA program that certified products meet specifications.

4.6. *Resolution of IA Issues*—Final project material certification requires the resolution of exceptions, deficiencies, etc. This is a primary ingredient in an IA program.

4.7. *Independent Supervision*—Independence in supervision and reporting should be maintained. However, this is not always practical. There should be no overlap in the direct supervision of the IA and other QA functions.

4.8. *Communication*—IA should allow facilitation of communication between the IA personnel and those that oversee the QA program independent of project, district, or region personnel.

4.9. *Observations, Standardization Checks, Split Samples, and Proficiency Samples*—The use of observations, standardization checks, split samples, and proficiency samples are tools to help assure that testing personnel and equipment are obtaining proper results.

4.10. *Initial and Periodic IA Testing*—IA testing is most effective near start-up for each project as well as when acceptance personnel change or are newly employed. Periodic IA testing is necessary throughout the project to identify equipment malfunction and maintain integrity of personnel.

5. QUALIFIED PERSONNEL (REFERENCE R 25)

5.1. *General Requirements*—The primary objective in establishing technician qualification programs is to assure that technicians are capable of performing the appropriate sampling and testing procedures correctly. In addition, it is likely that technicians will continue to perform the test correctly if they understand the importance of the test and the consequences of conducting improper sampling and testing procedures. The ultimate objective is to assure that cost-effective QC and highway materials are incorporated into the finished highway infrastructure element.

5.2. Technician qualification programs can vary in format while achieving the primary objective of producing qualified technicians. Currently, several DOTs have combined to develop regional programs that promote reciprocity in establishing qualification requirements. Similarly, many individual DOTs are pursuing their own programs. While DOT or regional flexibility for a technician qualification program format is readily supported, the following items are recommended fundamental elements of a complete qualification program:

- Formal training of personnel including all sampling and testing procedures with instructions on the importance of proper procedures and the significance of test results.
- Hands-on training to demonstrate proficiency of all sampling and testing to be performed.
- A period of on-the-job training with a qualified individual to assure familiarity with applicable procedures.
- A written examination and the hands-on demonstration of the various sampling and testing methods.
- Requalification at prescribed intervals (data from the IA program can be used as one element of requalification).
- The qualification program should have a documented process for removing or re-educating personnel that perform the sampling and testing procedures incorrectly.
- “Grandfathering”, the acceptances of a Professional Engineer or Engineer-in-Training certificate, or lifetime qualification are not considered to be appropriate criteria for achieving or maintaining qualification status.
- The qualification of IA personnel should exceed that of personnel doing QC or acceptance testing because when differences are found within the testing results or procedures, IA personnel should have the knowledge to identify the cause of the difference and correct the problem.
- A feedback loop that uses the IA database to improve training and qualification programs should be established.

6. QUALIFIED LABORATORIES (REFERENCE R 18)

6.1. *General Requirements*—Capable laboratories are as defined by appropriate programs established by each DOT. As a minimum, the qualification program shall include provisions for checking test equipment, and the laboratory shall keep records of standardization checks. Standardization is used as a generic term to represent calibration, checks, standardization, validation, or verification. The correct basis is dependent on the actual equipment and desired outcome.

6.2. The primary objective in establishing laboratory accreditation and qualification requirements is to ensure the capabilities of the laboratories. The ultimate objective is to assure that maximum QC and superior highway materials are incorporated into the finished highway infrastructure element.

6.3. *Equipment Documentation*—A list or record of all laboratory equipment requiring standardization is necessary for a qualified laboratory under 23 CFR Part 637.

6.4. DOTs should develop test procedures or test manuals referencing standard testing procedures, handling, identification, conditioning, storage, retention, and disposal of test samples.

6.5. *Testing Proficiency*—Testing personnel and equipment should be routinely evaluated by observations, standardization checks, split samples, or proficiency samples in order to provide appropriate reviews for laboratories.

6.6. *Evaluation Frequency*—Laboratory evaluations should be made on a prescribed cycle; ideally 12 to 18 months. Data from the IA program along with observations during IA tests should be used as part of the ongoing evaluation of the laboratory.

7. INDEPENDENT ASSURANCE PROJECT BASIS

7.1. *Advantages of IA Project Basis*—Since the IA project basis is quantity-based, it may fit better when the DOT can accurately estimate initial quantities and when the rest of the QA program is quantity-based. It facilitates establishing IA sample requirements at contract award and ensures key materials are tested on each project.

7.2. *Goal*—The goal is to evaluate the sampling and testing skill level of DOT project inspectors and technicians and contractor technicians performing tests used in the acceptance decision on DOT projects.

7.3. *Frequency*—This should be related to the risk for the test as related to quality. Most DOTs test at the rate of 10 percent of the rate used for acceptance tests. For an effective IA program, this rate should be considered a minimum if risk data are not available.

7.4. *Reporting*—A project materials certification by the DOT is required by 23 CFR Part 637 for each project. The CFR requires the certification to include a statement that all IA samples and tests fall within the tolerance limits of the program. A compilation of these reports provides an opportunity for DOTs to analyze trends, identify training needs, and make DOT-wide improvements.

8. INDEPENDENT ASSURANCE SYSTEM BASIS

8.1. *Advantages of IA System Basis*—Since the IA System Basis is technician-based, it allows an agency to ideally target all test equipment and personnel. Agencies with projects that are remote or located far apart may prefer this basis as well as those that have a large number of “small” quantity projects. It facilitates personnel testing when testers move between projects frequently and agrees with the overall QA system philosophy.

8.2. *Goal*—See Section 7.2.

8.3. *Frequency*—Each person conducting tests should be evaluated a minimum of once each calendar year. However, on critical projects, the personnel evaluations should exceed this minimum.

8.4. *Annual Report*—23 CFR Part 637 requires that if the DOT uses the system basis to the IA program, the DOT shall provide an annual report to the FHWA summarizing the results of the IA program. These reports provide an opportunity for DOTs to analyze trends, identify training needs, and make DOT-wide improvements.

8.4.1. Examples of desirable information to include in the annual report are:

- The number or percent of technicians evaluated;
- How often the technicians were evaluated;
- A general statement as to why all technicians were not evaluated, when appropriate;
- What, if any, problems occurred and why; and
- A general statement as to how any problems that were reported were resolved.

9. INDEPENDENT ASSURANCE COMBINATION BASIS

9.1. *Advantages of IA Combination Basis*—While not specifically addressed by 23 CFR Part 637, various combinations of the project and system bases are possible. This combination provides an opportunity for DOTs to maximize the effectiveness of their IA system. Examples include:

- Some DOT districts/regions use the system basis, and other districts/regions use the project basis.
- Some materials are IA-tested by the system basis, and other materials are IA-tested by the project basis.

10. COMPARISON OF TEST RESULTS

10.1. Independent assurance typically uses split samples to determine if the results of the testing devices used and personnel performing the tests compare within statistically determined limits. Both the means and the variabilities of the results can be compared.

10.2. There are at least two procedures for comparing the means; the difference two-sigma (d2s) limits and the paired *t*-test. The comparison of a single split sample by using the d2s limits is simple and can be done for each split sample that is obtained. However, since it is based on comparing only single data values, it is not very powerful for identifying differences when they exist. It is recommended that each individual split sample be compared using the d2s limits, and then, when possible, the paired *t*-test also be used on the accumulated split-sample results to allow for a comparison with more discerning power. If either of these comparisons indicates a difference, then an investigation to identify the cause of the difference should be initiated.

10.2.1. *d2s Difference Two-sigma Limits*—This procedure uses the difference between two tests and compares this difference to an allowable difference established for the specific test method. The allowable difference might be taken from an AASHTO or ASTM precision statement for the test procedure, or it may be developed based on split-sample data collected by the agency. The d2s is an index that indicates a maximum acceptable difference between two results obtained on test portions of the same material. It is the difference between two individual test results that would be equaled or exceeded in the long run in only one case in 20. $\text{d2s} = 2 \times \sqrt{2} \times (1\text{s})$, where 1s is the standard deviation. This is the simplest, but least powerful comparison that can be made because it includes a comparison between only two test values.

10.2.1.1. *Setting d2s Limits*—If d2s limits are used, it is essential that the multilaboratory d2s values be used, and not the single-operator limits. It is not appropriate to use either specification or acceptance limits for establishing d2s limits.

10.2.1.2. Using d2s limits is easy and requires little to no effort by the DOT. The advantage is that it is easily implemented and requires no expenditure of either personnel or funding by the DOT. It also lets the DOT implement the IA basis immediately.

10.2.1.3. The disadvantage of using AASHTO or ASTM d2s limits is that the limits are determined from a national pool of data and are not state-specific. They may or may not apply well to a given DOT with state-specific procedures and contractors. AASHTO and ASTM have test procedures with multiple test options that tend to increase the d2s values. For these reasons, many DOTs establish their own limits based on statewide “round-robin” test results.

10.2.1.4. The limits should be evaluated periodically (e.g., every five years) by round-robin testing programs to continually update the 1s value. If the 1s values change, then the d2s limits would also change. The 1s values from the previous study and the 1s values from the new study should be compared to see if they are significantly different. If not, the limits should be left as they are, or possibly combined with the results from both “round-robin” programs to determine the new 1s value to use to set the d2s value.

10.2.2. *Paired t-Test*—It is desirable, when possible, to compare the means of more than one set of tests. For this purpose, a second statistical process, the *t*-test for paired measurements (referred to as a paired *t*-test), can be used. Both the d2s and paired *t*-test procedures are based on the same underlying principle. However, since more data are employed, the paired *t*-test is more powerful at detecting differences when they exist. After the split samples are collected and tested, the *t*-test for paired measurements can be performed. This test uses the difference between each pair of tests and determines whether the difference is statistically different from 0. Thus, it is the difference *within* pairs, not *between* pairs, that is being tested. The equation for the *t*-test for paired measurements is provided in Equation (1):

$$t = \frac{\left|\overline{X}_d\right|}{\frac{s_d}{\sqrt{n}}} \qquad (1)$$

where:

$\overline{X}_d$ = average of the differences between the split-sample test results,

s_d = standard deviation of the differences between the split-sample test results, and

n = number of split-samples.

The calculated t value is then compared to the critical value, t_{crit}, obtained from a *t*-table with $n - 1$ degrees of freedom and for a pre-selected level of significance, α (usually 0.05 or less). Since it is of interest to determine whether the means are *different*, a *two-sided* test must be conducted. Therefore, if the *t*-table used is based on a two-sided test, then use $t_{\text{crit}} = t_\alpha$. If the *t*-table used is based on a one-sided test, then use $t_{\text{crit}} = t_{\alpha/2}$.

10.2.2.1. One of two decisions will be made:

10.2.2.1.1. The difference between the paired *t*-test results is greater than the critical t value, and is likely to occur from chance if they are actually equal (when $t \geq t_{\text{crit}}$).

10.2.2.1.2. There is no reason to believe that the paired *t*-test results are different because the average difference is not so different from 0 as to be unlikely to have occurred from chance if they are actually equal (when $t < t_{\text{crit}}$).

Note 2—A table of critical *t* values can be found in *Materials Control and Acceptance-Quality Assurance*, 2000; *Optimal Procedures for Quality Assurance Specifications*, 2003; and most basic statistics textbooks. Most computer spreadsheet programs contain statistical test procedures for the paired *t*-test.

10.2.2.2. The power of the test (i.e., the ability to determine differences when they exist) improves as the number of paired samples increases. As an example, when comparing three split-sample pairs, the probability of detecting a difference of 1s between the means of two populations is less than 20 percent for a two-sided test and a little over 30 percent for a one-sided test, whereas the same probabilities are nearly 100 percent for 20 split-sample pairs.

10.3. An *F*-test is used to test the variabilities of the two sets of test results. The following procedure is used to test whether or not the variances, i.e., standard deviations squared, of the two samples are different at a pre-selected level of significance (α).

10.3.1. Let the two sample sizes be n_1 and n_2 and denote the two sample variances by s_1^2 and s_2^2.

10.3.2. Let $s_{\max}^2$ be the larger of s_1^2 and s_2^2, and let $s_{\min}^2$ be the smaller of s_1^2 and s_2^2.

10.3.3. Then calculate *F* from Equation (2):

$$F = \frac{s_{\max}^2}{s_{\min}^2} \qquad (2)$$

The calculated *F* value is compared to the critical *F*-value, F_{crit}, which is the value for $F_{\alpha/2}$ determined from tables of the *F*-distribution for the appropriate degrees of freedom in the numerator and in the denominator. The degrees of freedom for the two samples are $df_1 = n_1 - 1$ and $df_2 = n_2 - 1$. The *F*-distribution is defined by these two degrees of freedom, and it is important to make sure that the appropriate degrees of freedom are used for the numerator and the denominator. For example, if s_2^2 is the larger variance, then its degrees of freedom are in the numerator. Also note that since the test indicates whether or not the two variances are *equal*, i.e., a *two-sided* test, the critical *F*-value is determined at $\alpha/2$ rather than at α.

10.3.4. Once the value for F_{crit} is determined from the table (making sure the appropriate degrees of freedom for the numerator and denominator are used), one of two decisions will be made:

10.3.4.1. If the difference between the *F*-test results is greater than the critical *F value*, and is likely to occur from chance if they are actually equal (when $F \geq F_{\text{crit}}$), then conclude that the two sets of tests have significantly different variabilities.

10.3.4.2. There is no reason to believe that the variabilities are significantly different when $F < F_{\text{crit}}$.

Note 3—A table of critical *F* values can be found in *Materials Control and Acceptance-Quality Assurance*, 2000; *Optimal Procedures for Quality Assurance Specifications*, 2003; and most basic statistics textbooks. Most computer spreadsheet programs contain statistical test procedures for the *F*-test.

11. KEYWORDS

11.1. Independent assurance; quality assurance; quality assurance, program; quality control.

Standard Specification for

Epoxy Resin Adhesives for Bonding Traffic Markers to Hardened Portland Cement and Asphalt Concrete

AASHTO Designation: M 237-96 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Epoxy Resin Adhesives for Bonding Traffic Markers to Hardened Portland Cement and Asphalt Concrete

AASHTO Designation: M 237-96 (2009)

1. SCOPE

1.1. This specification covers epoxy resin adhesives for bonding traffic markers to pavement surfaces.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 200, Epoxy Protective Coatings
- T 48, Flash and Fire Points by Cleveland Open Cup
- T 79, Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93.3ºC (200ºF)
- T 192, Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve
- T 237, Testing Epoxy Resin Adhesive

2.2. *ASTM Standards*:

- D 97, Standard Test Method for Pour Point of Petroleum Products
- D 185, Standard Test Methods for Coarse Particles in Pigments
- D 281, Standard Test Method for Oil Absorption of Pigments by Spatula Rub-out
- D 476, Standard Classification for Dry Pigmentary Titanium Dioxide Products
- D 1208, Standard Test Methods for Common Properties of Certain Pigments
- D 1209, Standard Test Method for Color of Clear Liquids (Platinum-Cobalt Scale)
- D 1210, Standard Test Method for Fineness of Dispersion of Pigment-Vehicle Systems by Hegman-Type Gage
- D 1257, Standard Specification for High-Gravity Glycerin
- D 1483, Standard Test Method for Oil Absorption of Pigments by Gardner-Coleman Method
- D 1514, Standard Test Method for Carbon Black—Sieve Residue
- D 1544, Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)
- D 1747, Standard Test Method for Refractive Index of Viscous Materials

- D 2752, Standard Test Methods for Air Permeability of Asbestos Fibers
- D 3272, Standard Practice for Vacuum Distillation of Solvents From Solvent-Reducible Paints For Analysis

2.3. *Federal Standards*:

- Fed. Std. No. 141, Paint, Varnish, Lacquer and Related Materials; Methods of Inspection, Sampling and Testing, Method 4184 Percent Air, Method 4242 Color, Heilige-small
- Fed. Std. No. 595, Colors used in Government Procurement

3. CLASSIFICATION

3.1. *Type I*—Rapid Setting, High Viscosity, Epoxy Adhesive. This type of adhesive provides rapid adherence of traffic markers to the surface of the pavement.

3.2. *Type II*—Standard Setting, High Viscosity, Epoxy Adhesive. This type of adhesive is recommended for adherence of traffic markers to pavement surfaces when rapid set is not required.

3.3. *Type III*—Rapid Setting, Low Viscosity, Water Resistant, Epoxy Adhesive. This type of rapid setting adhesive, due to its low viscosity, is appropriate only for use with embedded traffic markers. It is more water-resistant than Type I or Type II.

3.4. *Type IV*—Standard Set Epoxy for Blade Deflecting-Type Plowable Markers.

4. MATERIALS

4.1. The material shall be furnished in two separate components for combining in equal volumes immediately prior to use.

4.2. *Composition*:

4.2.1. The composition of the components for Type I and Type II shall conform to the requirements prescribed in Table 1.

4.2.2. The composition of the components for Type III shall conform to the requirements prescribed in Table 2.

4.2.3. The components for Type IV shall conform to the requirements prescribed in Table 3.

4.2.4. Other epoxies meeting the physical requirements of Sections 4.3 and 4.4 for the type specified may be used with the approval of the purchaser.

Table 1—Chemical Composition of Ingredients of Composition for Type I and Type II Epoxy

	Parts by Mass	
	Type I	Type II
Component A		
Epoxy Resin[a]	90.00	87.00
Orthocresyl Glycidyl Ether[b]	10.00	
Aliphatic Glycidyl Ether[c]		13.00
Titanium Dioxide ASTM D 476, Type I or Type II	3.00	3.00
Talc[d]	50.00	30.00
Fibrillated Polyethylene Fiber[e]	2.00*	4.00**
Glycerin, ASTM D 1257	0.50	
Silicone Anti-Foam, Type DB100, 100% Solids		0.005
Component B		
High Functionality Polymercaptan Hardener[f]	60.00	
2, 4, 6-Tri (Dimethylaminomethyl) Phenol[g]	7.00	
Polysulfide Polymer[h]	35.00	
N-Aminoethyl Piperazine[i]		23.16
Nonylphenol[j]		52.00
Furnace Black[k]	0.10	0.10
Talc[d]	50.00	70.00
Fibrillated Polyethylene Fiber[e]	2.00*	0.70**
Silicone Anti-Foam, Type DB100, 100% Solids	0.01	0.005

* A range of 11.5 to 2.5 parts is permitted in the A component and in the B component to achieve the required viscosity and thixotropy. Small preproduction batches should be made to determine the fiber level best suited for manufacturing equipment level.

** A range of 3.0 to 5.0 parts is permitted in the A component and 0.3 to 1.0 parts in the B component, to achieve the required viscosity and shear ratio.

[a] Di-glycidyl ether of bisphenol A: Brookfield viscosity, 10–16 Pa·s (100–160 poise) at 25˚C; epoxide equivalent 180–200; color. Gardner 1933, 3 maximum.

[b] Brookfield viscosity at 25˚C, MPa·s (5–10 centipoise); density kg/m_3, 1078–1090 kg/m_3 (weight per gallon 9.00–9.10 pounds; epoxide equivalent 180–200).

[c] Aliphatic mono functional reactive glycidyl ether, derived from an aliphatic alcohol: Brookfield viscosity at 25˚C, 1 to 15 MPa·s (1 to 15 centipoise); epoxide equivalent 220–250; specific gravity 0.88–0.95.

[d]

Specific Gravity	2.68 to 2.86
Hegman Rating	3.25 to 6.0
Particle Shape	Platey
Maximum Particle Size, Microns	55
Percent passing 45-µm (U.S. No. 325) Screen, minimum	99
Dry Brightness, minimum	86

[e] High density, fluff dried, pure fibrillated polyethylene; melting point 120˚C–130˚C; specific gravity, 0.915–0.965; molecular mass, 30000–150000; fiber size, average length, 0.90-mm diameter, 10 microns; fiber strength, 31.4–39.2 MPa; elongation at rupture, 45–57 percent; moisture content, less than 2 percent.

[f] Liquid polymercaptan resin: Brookfield viscosity, 10–13 Pa·s (100–130 poise) at 25˚C; specific gravity 1.14–1.16; mercaptan value, 3.6 meg/gram: color, Gardner 1933, 1. Infrared curve shall match the printed curve in this specification.

[g] Formula weight 265; specific gravity at 25˚C; 0.937 refractive index 1.514 at 25˚C; vacuum distillation. 96 percent shall have been distilled over a temperature between 130 and 160˚C, 66.7 to 200.0 Pa absolute pressure (0.5 to 1.5-mm Hg vacuum pressure); flash point, Tag Open Cup, 149˚C minimum; water content 0.06 percent maximum.

[h] Specific gravity, 1.24–1.30 at 20˚C/20˚C: Brookfield viscosity, 0.7–1.2 Pa·s (700–1200 centipoise) at 25˚C; pH water extract 6.0–8.0; moisture content, 0.1 percent maximum; pour point, –26˚C; average molecular mass, 1000; flash point, Cleveland Open Cup, 93˚C (200˚F) minimum; sulfur content, 36–40; color, Heilige, 9–12. The product shall be a dysfunctional mercaptan made from 98 mole percent of bis (2-chloroethyl) formal and 2 mole percent of trichloropropane.

[i] Color (APHA), 100 maximum; amine value based on titration which reacts with the three nitrogens in the molecule (1250–1350); appearance, clear and substantially free of suspended matter.

[j] Color (APHA), 100 maximum; parn. nonylphenol, 85 percent minimum; water (Karl Fischer) 0.05 percent maximum.

[k] Surface area, 5–185, m_2/g; particle diameter, 18–30 millimicrons; fixed carbon (moisture free), 96–98 percent; volatile matter, 1–4 percent.

Table 2—Chemical Composition of Type III Epoxy

	Parts by Mass
Component A	
[Density = 1878 kg/m^3 (15.67 lb/gal)]	
Epoxy Resin[a]	20.03
Epoxy Resin[b]	14.69
Aliphatic Epoxy Resin[c]	9.78
Titanium Dioxide ASTM D476 Type I or II	2.18
Calcium Silicate[d]	21.14
Barium Sulfate[e]	32.05
Fluorinated Alkyl Ester Surfactant[f]	0.13
Component B (Hardner)	
[Density = 1950 kg/m^3 (16.27 lb/gal)]	
*Precatalyzed Polymercaptan Hardner[g]	30.17
*Precatalyzed Polymercaptan Hardner[h]	5.45
Mercapto Silane[i]	0.72
Calcium Silicate[d]	26.78
Barium Sulfate[e]	40.10
Carbon Black[j]	0.10
*2, 4, 6, Tri (Dimethyl Amino Methyl) Phenol	0.57

* Available from Diamond Shamrock Corporation.

[a] Epoxide equivalent 176–181; Brookfield viscosity at 25°C, 35–70 Pa·s (350–700 poise); color, Gardner, max 2: the reactive diluent shall be neopentylglycoldiglycidal ether.

[b] Epoxide equivalent 180–190; Brookfield viscosity at 25°C, 7–10 Pa·s (70–100 poise); color, Gardner, max 2: the reactive diluent shall be neopentylglycoldiglycidal ether.

[c] 1–4 butane dioldiglycyl ether, viscosity 25°C, 19 MPa·s (19 cps); epoxide equivalent mass 136.

[d] Specific gravity 2.9, pH (Aqueous solution), 9.9; refractive index 1.63.

[e] Specific gravity, 25°C, 2.9, pH, Aqueous solution, 3.8–4.5; refractive index 1.64; oil absorption, 11 percent by mass.

[f] Brookfield viscosity, 25°C, 15 Pa·s (15000 cps); specific gravity, 25°C, 1.15; refractive index, 25°C, 1.445; active ingredients, 100 percent.

[g] Brookfield viscosity, 25°C, 0.25 Pa·s (250 cps); specific gravity, 25°C, 1.06; mercaptan value meg/g 5.75; color, Gardner, max, 2.

[h] Brookfield viscosity, specific gravity, 25°C, 106; mercaptan value meg/g 552; color, Gardner, max, 2.

[i] Brookfield viscosity, 25°C, 3.0 MPa·s (3.0 centipoise); density or unit mass, 25°C, 984 kg/m_3 (8.208 lb/gal); color, water white; refractive index, 25°C, 1.43; boiling point, 1.3 kPa absolute pressure (10 mm-Hg), 106°C.

[j] Surface area 115–130 m_2/g; particle diameter 18–30 millimicrons; pH, 7.0–8.5; fixed carbon (moisture free), 96–98 percent; volatile matter, 1–4 percent; oil absorption, stiff past endpoint 0.80–0.90 mL/g.

Table 3—Chemical Composition of Type IV Epoxy

	Parts by Mass
Component A	
Epoxy Resin Epon 828, Shell (or equal)	100.00
Titanium Dioxide (TT-P-442, Type III, Class A)	7.68
Talc #13 (or equal)	36.64
Component B	
N-Aminoethyl Piperazine Jefferson (or equal)	25.10
Nonylphenol	50.03
Talc Fiberene C-400, Sierra (or equal)	69.28
Molacco Black (or equal)	0.23

4.3. *Physical Requirements—Individual Components*:

4.3.1. Requirements for components A and B are the same for all types except as noted.

4.3.2. Viscosity, Pa·s (Poise), TE Helipath Spindle at 25 ± 1ºC (77 ± 2ºF). Type I, 350 to 500 (3500 to 5000), Type III, 4 to 6 (40 to 60). Viscosity, Pa·s (Poise), TD Helipath at 25 ± 1ºC (77 ± 2ºF). Type II, 100 to 300 (1000 to 3000).

4.3.3. Shear ratio, 25ºC (77ºF), 2 minimum, for Types I and II.

4.3.4. Density, kilograms per cubic meter (pounds per gallon) at 25ºC (77ºF):

	Component A	Component B
Type I	1402 to 1462 (11.7 to 12.2)	1402 to 1462 (11.7 to 12.2)
Type II	1270 to 1306 (10.6 to 10.9)	1354 to 1390 (11.3 to 11.6)
Type III	1797 to 1893 (15.0 to 15.8)	1929 to 1965 (16.1 to 16.4)
Type IV	1414 to 1438 (11.8 to 12.0)	1390 to 1414 (11.6 to 11.8)

4.3.5. Skinning (original container), none.

4.3.6. Percent air, two maximum.

4.3.7. *Infrared Curves*—Components A and B shall match curves originally approved by the purchaser.

4.3.8. *Storage Stability*:

4.3.8.1. The Components A and B shall not change in viscosity and shear ratio by more than ±15 percent when stored for 14 days in closed containers at 47.0 ± 1.8ºC (115 ± 3ºF). All measurements shall be made at 25 ± 1ºC (77 ± 2ºF) using the same spindle and apparatus as in Section 4.3.2 above.

4.3.8.2. The adhesive shall meet all other requirements for 12 months from date of manufacture. Any settling of the fillers must be easily redispersible with a paddle.

4.4. Physical Requirements for the Mixed Epoxy (Component A mixed with Component B) Types I, II, III, and IV.

4.4.1. *Gel time, minutes*:

- Type I, 6–10
- Type II, 6–10
- Type III, 6–10
- Type IV, 6–10

4.4.2. *Bond strength to concrete*, maximum time, minutes to reach 1380 kPa (200 psi). (See Table 4.)

Table 4—Bond Strength to Concrete

	Type I	Type II, Type IV	Type III
at 25 ± 1°C (77 ± 2°F), max	35	210	35
at 10 ± 1°C (50 ± 2°F), max	45	—	45
at –1 ± 1°C (31 ± 2°F), max	85	—	85

4.4.3. *Slant shear strength* (See Table 5.)

Table 5—Slant Shear Strength

	Type I	Type II, Type IV	Type III
24 h at 25 ± 1°C, kPa (psi), min	6895 (1000)	13 790 (2000)	6895 (1000)
24 h at 25 ± 1°C, plus water soak, kPa (psi), min	5516 (800)	10 342 (1500)	6895 (1000)

4.4.4. *Tensile adhesion and cohesion,*

4.4.4.1. *Ceramic marker bottom, kPa (psi), minimum*:
- Type I, 4830 (700)
- Type II, 4830 (700)
- Type III, 4830 (700)
- Type IV, 4830 (700)

4.4.4.2. *Ceramic marker bottom, including post cure, kPa (psi), minimum*:
- Type I, 4830 (700)
- Type II, 4830 (700)
- Type III, 4830 (700)
- Type IV, 4830 (700)

4.4.4.3. *Reflective pavement marker, bottom kPa (psi), minimum*:
- Type I, 3450 (500)
- Type II, 3450 (500)
- Type III, 3450 (500)
- Type IV, 3450 (500)

4.4.5. *Color*—Color for all types shall be approximately that of Color 26132 to 26152 of Federal Standard No. 595.

4.5. *Certificate of Compliance*—The manufacturer shall furnish to the purchaser a Certificate of Compliance for Component A, Component B, and for the mixed epoxy. The certificate shall certify conformance to this specification. Test results shall be maintained and available upon request.

4.6. *Test Methods*:

4.6.1. *Brookfield Viscosity*—AASHTO T 237.

4.6.2. *Epoxide Equivalent*—AASHTO T 237.

4.6.3. *Color, Gardner*—ASTM D 1544.

4.6.4. *Color, Heilige*—Fed. Std. No. 141, Method 4242.

4.6.5. *Color, APAH*—ASTM D 1209.

4.6.6. *Gel Time*—AASHTO T 237.

4.6.7. *Oil Absorption*—ASTM D 1483.

4.6.8. *pH*—ASTM D 1208.

4.6.9. *Hegman Rating*—ASTM D 1210.

4.6.10. *Maximum Particle Size*—ASTM D 185.

4.6.11. *Percent Passing 45-μm (No. 325) Screen*—AASHTO T 192.

4.6.12. *Infrared Curve*—AASHTO T 237.

4.6.13. *Refractive Index*—ASTM D 1747.

4.6.14. *Vacuum Distillation*—ASTM D 3272.

4.6.15. *Flash Point, Tag Open Cup*—AASHTO T 79.

4.6.16. *Flash Point, Cleveland Open Cup*—AASHTO T 48.

4.6.17. *Water Content*—ASTM D 1208.

4.6.18. *Pour Point*—ASTM D 97.

4.6.19. *Specific Gravity*—AASHTO T 237.

4.6.20. *Surface Area*—ASTM D 2752.

4.6.21. *Bond Strength to Concrete*—AASHTO T 237.

4.6.22. *Tensile Adhesion and Cohesion*—AASHTO T 237.

4.6.23. *Slant Shear Strength*—AASHTO T 237.

4.6.24. *Shear Strength*—AASHTO T 237.

4.6.25. *Shear Ratio*—AASHTO T 237.

4.6.26. *Percent of Air*—Fed. Std. No. 141, Method 4184.

5. PACKAGING AND MARKING

5.1. Components shall be packaged and marked as set forth under "Packaging" in M 200 except that the proper mixing ratio shall always be specified.

6. RECOMMENDED PRACTICE

6.1. *Surface Preparation*:

6.1.1. Road surface must be cleaned by sandblasting the area to which marker is to be bonded except for recessed or sawn installations. Sand must be clean and dry.

6.1.2. When markers are to be placed over existing traffic paint stripes, all old paint and primer, if present, must be removed.

6.2. *Adhesive Mixing and Metering*:

6.2.1. Machine mixer and applicator must be capable of accurately and uniformly proportioning Component A to Component B in a volume ratio of 1 to 1 within ±5 percent by volume of each component (i.e., within range of 47.5 percent to 52.5 percent for each compound).

6.2.2. Mixing chamber must produce the mixed adhesive with a uniform gray color with no visible evidence of streaks of either black or white on the surface or within the mixed adhesive.

6.2.3. Voids in a cured undisturbed sample 1.6 mm ($^1/_{16}$ in.) thick from the extrusion nozzle shall not exceed 4 percent.

6.2.4. Periodic checks of the proportioning equipment shall be made to determine the actual volume ratio of A to B. This shall be done by placing containers before the mixing chamber and the actual volume of A and B measured.

6.2.5. The ambient temperature during application of Types II and IV epoxy shall be at least 10ºC (50ºF) and preferably higher than 15.6ºC (60ºF). These adhesives harden relatively slow at 10ºC (50ºF) but the hardening rate rapidly accelerates as temperature increases.

Standard Specification for

Glass Beads Used in Pavement Markings

AASHTO Designation: M 247-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Glass Beads Used in Pavement Markings

AASHTO Designation: M 247-09

1. SCOPE

1.1. This specification covers glass beads to be dropped or sprayed upon pavement markings so as to produce a reflectorized pavement marking.

1.2. *Types*:

1.2.1. *Type 0*—shall be known as a uniform gradation.

1.2.2. *Type 1*—shall be known as a standard gradation.

1.2.3. *Types 2, 3, 4, and 5*—shall be known as modified gradations.

1.3. *Coatings*:

1.3.1. *Flotation*—Any of the above gradation types may be obtained with oleophobic properties at the request of the purchaser (Note 1).

1.3.2. *Moisture Resistance*—Any of the above types may be obtained with hydrophobic properties if so specified by the purchaser.

1.3.3. *Adherence*—Any of the above types may be obtained with an adhesion coating if so specified by the purchaser.

Note 1—Any of the above types of beads may be specified with a combination of two of the above coatings. Dual coated beads must test positive for the presence of both specified properties.

1.4. The values stated in SI units are to be regarded as the standard.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards:*

- D 75, Standard Practice for Sampling Aggregates
- D 1214, Standard Test Method for Sieve Analysis of Glass Spheres

- D 1155, Standard Test Method for Roundness of Glass Spheres
- D1213-54 (1975), Test Method for Crushing Resistance of Glass Spheres (Withdrawn 1983)
- E 105, Standard Practice for Probability Sampling of Materials
- E 1617, Standard Practice for Reporting Particle Size Characterization Data
- E 1994, Standard Practice for Use of Process Oriented AOQL and LTPD Sampling Plans

2.2. Federal Standards:

- Federal Standard No. 40, CFR 261.24, Table 1 Maximum Concentration of Contaminants for the Toxicity Characteristic

2.3. Other Standards:

- ANSI/ASQ Z.4 and Z1.9, Sampling Procedure and Tables for Inspection by Attributes

3. GENERAL REQUIREMENTS

3.1. The beads shall be transparent, clean, colorless glass, smooth and spherically shaped, free from milkiness, pits, or excessive air bubbles and conform to the following specific requirements:

3.2. The glass beads must not exhibit a characteristic of toxicity, relative to heavy metals, when tested in accordance with EPA 40 CFR 261.24.

4. SPECIFIC PROPERTIES

4.1. *Gradation*—The beads shall meet the gradation requirements for type as given in Table 1.

Table 1—Gradation of Glass Beads

Sieve Designation		Mass Percent Passing					
Standard, mm	Alternate No.	Type 0	Type 1	Type 2	Type 3	Type 4	Type 5
2.35	8						100
2.00	10					100	95–100
1.70	12				100	95–100	80–95
1.40	14				95–100	80–95	10–40
1.18	16		100	100	80–95	10–40	0–5
1.00	18				10–40	0–5	0–2
0.850	20		95–100	90–100	0–5	0–2	
0.710	25				0–2		
0.600	30	100	75–95	50–75			
0.425	40	90–100		15–45			
0.300	50	50–75	15–35	0–15			
0.180	80	0–5	0–5				
0.150	100		0–5				

4.2. *Roundness*—The glass beads shall have a minimum of 70 percent true spheres.

4.3. *Refractive Index*—The glass beads shall have a refractive index of 1.50–1.55.

4.4. *Coatings: Flotation, Flow, Moisture Resistance, and Adherence*—When tested in accordance with Section 5.3, the presence of the purchaser specified coatings will be unambiguous. Beads will flow properly when tested in accordance with the procedure in Section 5.3.1 unless they are specified to be moisture resistant, in which case the procedure in Section 5.3.2 will be followed.

4.5. The beads shall be dry and free of lumps and clusters.

5. METHODS OF SAMPLING AND TESTING

5.1. *The sampling shall be random in the following ratios*—45 kg (100 lb) of sample (in full bags) per 4535 kg (10000 lb) shipped. Upon arrival material shall be reduced in a sample splitter to a size of approximately 1 kg (2 lb). Alternatively, Statistical Process Control Methods following ASTM E 105 and E 1994, and D 75 or ANSI/ASQ Z1.4 and Z1.9 may be used to monitor the quality of the product so that it meets the requirement of the applicable detail specification. The supplier shall state in a Declaration of Conformity the sampling plans and test methods used.

5.2. The following requirements shall be tested with the following test methods:

5.2.1. *Gradation*—ASTM D 1214. Alternatively a mechanical, optical or instrumental method with traceable standards is acceptable provided that it correlates to acceptable results obtained using ASTM D 1214, or documentation showing correlation to the referee method referenced in ASTM D 1214, and follows ASTM E 1617. In the event of nonconformity, ASTM D 1214 “Hand Sieve” will be the referee method.

5.2.2. *Roundness*—ASTM D 1155. Alternatively a mechanical, optical, or instrumental method with traceable standards is acceptable provided that it correlates to acceptable results obtained using ASTM D 1155, or documentation showing correlation to the referee method referenced in ASTM D 1155, and follows ASTM E 1617. In the event of nonconformity, ASTM D 1155, Procedure B, will be the referee method.

5.2.3. *Refractive Index* shall be tested by a liquid immersion method (Becke Line Method or equal) at a temperature of 25 ± 5°C (77 ± 9°F).

5.3. *Coatings Tests*:

5.3.1. *Flow Characteristics Test*—Referee Method.

5.3.1.1. A 100 g sample of beads is placed in a Corning 3140 crystallizing dish (or equivalent), 100-mm diameter by 50-mm depth. Place the dish in a Corning 3080 Desiccator (or equivalent) 250-mm inside diameter by 330-mm overall height and 130-mm chamber depth, which shall be filled with a sulfuric acid-water solution having a specific gravity of 1.10 (approximately 94 percent humidity) to a point 25.4 mm below the top of a size 5 Coors 60003 Desiccator Plate (or equivalent). The sample shall remain in the covered Desiccator at 25 ± 5°C for 4 hours. Remove the sample from the Desiccator and transfer the beads to a metal pan. The beads shall flow without stoppage when poured slowly through a standard glass funnel (Corning 6120 or equivalent), 127-mm diameter, 102-mm stem length, and 11-mm stem inside diameter (Note 2).

Note 2—The test operations should be performed immediately on removal of the beads from the Desiccator.

5.3.2. *Moisture Resistant Coating Test*—Referee Method.

5.3.2.1. A 100-g sample of beads is placed in a 600-mL beaker. With the beaker held at approximately a 45-degree angle, 100 mL of distilled water is slowly added to the beaker. The water is carefully poured down the side of the tilted beaker. The beads are to remain undisturbed. The beaker is allowed to stand, undisturbed, for 5 minutes. At the end of the standing time, the water is carefully poured from the beaker. It may be necessary to slightly rotate the beaker to avoid trapping pockets of water. Holding the beaker at the "pour angle," the beads are transferred to a clean, dry 600-mL beaker. A thin, even layer of beads may coat the inside of the original beaker. The second beaker is allowed to stand, undisturbed, for five minutes. At the end of the standing time, the beads are slowly poured into a standard glass funnel (Corning 6120 or equivalent), 127 mm in diameter, 102-mm stem length and 11-mm stem inside diameter. The beads should flow through the funnel stem without stopping. Slight initial agitation to start the flow of beads through the funnel is permissible.

5.3.3. *Flotation Test*—Referee Method.

5.3.3.1. Determine the mass of approximately 1 g to the nearest 0.0005 g, evenly distribute beads into a clean standard 100-mm glass Petri dish previously weighed to the nearest 0.0005 g. The dish is vibrated slightly to attain as near as possible a monolayer of beads. Xylene, C.P. Grade, is introduced at one side of the dish at a rate of 10 to 15 mL per minute from a burette until 30 mL has been added. The floating beads are then carefully drawn off by suction through a suitably constricted delivery tube connected to a receiving flask. Excess xylene is drawn off so that no remaining beads are lost and the dish dried in an oven at 110 ± 5ºC. The dish is weighed and the percentage of floating beads calculated.

5.3.4. *Adherence Coating Oven Test*—Referee Method.

5.3.4.1. Prepare a solution by weighing 0.2 grams of dansyl chloride and dissolving in 25 ml of acetone. (See Note 3.) This solution can be used for several tests during the day, but must be kept refrigerated in a closed dark container between uses. Make a fresh solution daily.

Warning—Dansyl chloride is hazardous. Do not allow skin contact or touch the beads after testing.

Note 3—Dansyl chloride tests for the presence of amino functional groups which are present in most common adhesion coatings. If the supplier is using alternate adhesion chemistry, a comparable simple test must be supplied. Dansyl chloride will oxidize on prolonged contact with air and light. Solutions should be stored in a dark, brown glass jar. Fresh solutions are a pale, yellow green. Unusable stale solutions are yellow brown.

5.3.4.2. Weigh 10 grams of beads and place in aluminum trays. Saturate the glass bead sample with the dansyl chloride solution using an eyedropper. Dry the beads in an oven at 60°C (140°F) for 15 minutes. Beads will be yellow and agglomerated. Rinse the beads by placing them in the funnel containing new filter paper and pouring 100 ml of acetone over them. Use suction during the step. Remove the beads from the funnel, and again place in aluminum trays. Dry the beads in the oven until free flowing. Place the beads on glass filter paper and inspect them under ultra-violet light. Inspection must be in a dark room. A yellow-green fluorescence will be observed if adherence coating present. (See Notes 3 and 4.) If all beads have a yellow-green fluorescence with the oven test, the beads are properly coated with adherence coating. If some or no beads have a yellow-green fluorescence then this is cause for rejection.

Note 4—Fluorescence is proportional to the intensity of the incident UV light. Longwave UV lamps designed for quality control, industrial inspection, and nondestructive testing are typically 100W. Portable lamps with 6 or 8W bulbs will show much less fluorescence on the same samples. Longwave UV bulbs emit at 365 nm wavelength. Shortwave UV lamps, 254 or 302 nm, and low-watt penlight lamps are not sufficient for this test.

5.3.5. *Alternative Flotation Test*—As Permitted by Purchasing Agency

5.3.5.1. A 15 to 20 g sample of beads is placed in a 60 mL (2 oz.) aluminum weighing dish, 57-mm inside diameter by 16-mm depth. The filled dish should be placed on a flat surface and shaken lightly so that the beads present a flat surface. Carefully place small drops of hexadecane [approximately

5 mm (0.187 in.) in diameter or 0.05 mL volume] on the test beads in three locations so that the drops are not touching. The dish should be left flat and the drops should be put in the center of the dish. Do not touch the beads with the dropper tip. A positive test for the presence of coating occurs if all three drops applied show clear, well-rounded appearance with high contact angle, i.e., the test liquid beads up. A negative test for coating shows the loss of contact angle of the drop, i.e., if wetting of the beads as evidenced by a darkening of the surface or sinking of the drop into the surface or bead interface occurs within 2 min ± 10 s.

5.3.6. *Alternative Moisture Resistance Test*—As Permitted by Purchasing Agency.

5.3.6.1. The above Alternative Flotation test in Section 5.3.6 is performed with three distilled water drops instead of hexadecane.

5.3.7. *Alternative Adherence Test*—As Permitted by Purchasing Agency.

5.3.7.1. The test in Section 5.3.4 is performed with the following exceptions:

5.3.7.2. One eyedropper full (1.0 ml) of 0.02 wt% dansyl chloride (5-dimethylaminonaphthalene-1-sulfonyl chloride) solution in acetone is dropped around the center of the 10 grams of beads. Do not disturb or mix the beads after wetting. After 30 minutes a positive test for the presence of coating occurs if the wetting area shows clear fluorescence, a bright green to blue glow, under strong long UV light (365 nm) against a dark background in a darkened room or stray light-free enclosure. A negative test for coating occurs if the wetted surface of the beads shows no fluorescence. The reaction may be speeded by heating the tested sample to 60 ± 5°C (140 ± 9°F) for 5 min. It is best practice to use heat and simultaneously test the sample alongside beads known to have no adhesion coating. A positive presence of coating should be unambiguous.

6. PACKAGING AND MARKING

6.1. Glass beads shall be furnished in kilogram (pound) lots as specified by the purchaser and packaged in moisture-proofed bags. Containers are to be guaranteed to furnish dry and undamaged beads. Each package shall contain the following information: name and address of manufacturer, shipping point, trademark or name, the wording “glass beads,” the specification number, number of kilograms (pounds), the lot or batch number and the month and year of manufacture.

Standard Specification for

Ready-Mixed White and Yellow Traffic Paints

AASHTO Designation: M 248-91 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Ready-Mixed White and Yellow Traffic Paints

AASHTO Designation: M 248-91 (2007)

1. SCOPE

1.1. This specification covers alkyd resin type, ready-mixed white and yellow traffic paints for use on bituminous and portland cement concrete pavements.

1.2. Intended use of the traffic paint.

1.2.1. These paints may be reflectorized for night visibility by adding reflective spheres before the paint film dries or sets, using the drop-on or pressurized methods. Generally, the reflective spheres are evenly dispersed to a wet film of 0.38 mm (15 mils) at a rate of 600 to 720 kg/m (5 to 6 lb/gal) of paint. The amount may be altered by the purchaser.

1.3. *Types*:

1.3.1. *Type S Traffic Paint*—This type is a slow drying paint which shall be used in areas where coning is acceptable for 1 hour or more.

1.3.2. *Type N Traffic Paint*—This type has immediate drying properties and shall be used in areas where coning of roadway is acceptable for 15 to 30 minutes.

1.3.3. *Type F Traffic Paint*—This type shall be used where faster drying time is required with a minimum of coning. With good drying conditions, this paint should dry in 3 to 6 minutes if heated to 51.5 ± 2.5ºC (125 ± 5ºF) in the applicator.

1.4. The values stated in SI units are to be regarded as the standard.

Note 1—It is advisable to consult local air pollution regulations regarding solvents prior to selecting type of paint to be used.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- D 79, Standard Specification for Zinc Oxide Pigments
- D 211, Standard Specification for Chrome Yellow and Chrome Orange Pigments
- D 476, Standard Classification for Dry Pigmentary Titanium Dioxide Products
- D 362, Specification for Industrial Grade Toluene (Withdrawn 1989)
- D 600, Standard Specification for Liquid Paint Driers
- D 605, Standard Specification for Magnesium Silicate Pigment (Talc)
- D 711, Standard Test Method for No-Pick-Up Time of Traffic Paint

- D 740, Standard Specification for Methyl Ethyl Ketone
- D 1199, Standard Specification for Calcium Carbonate Pigments

2.2. *Federal Standards*:

- TT-N-95 Naphtha, Aliphatic
- Fed. Std. No. 595, Colors Used in Government Procurement
- Fed. Std. No. 141, Paint, Varnish, Lacquer, and Related Materials: Methods of Inspection, Sampling and Testing

2.3. *Military Standards*:

- MIL-C-429, Chlorinated Paraffin, Technical

3. CLASSIFICATION

3.1. *Types*—Ready-mixed alkyd resin type paint covered by this specification shall be furnished in the following types, as specified in the invitation for bids, contracts, or order:

3.1.1. *Type S*—Medium oil soya modified alkyd resin. Primary solvent is VM and P Naphtha.

3.1.2. *Type N*—Medium oil soya-modified pentaerythritol alkyd resin; chlorinated rubber, 4 to 1. Primary solvent is toluene.

3.1.3. *Type F*—Medium oil soya/linseed alkyd resin; chlorinated rubber; chlorinated paraffin; 1.03 to 1.30 to 1.00. Primary solvent is MEK.

4. MATERIALS

4.1. The materials used in manufacture shall conform to the requirements of the following specifications:

4.1.1. *Lead Chromate*—ASTM D 211, Type III.

4.1.2. *Titanium Dioxide*—ASTM D 476, Type III Rutile (T_1O_2 80 percent purity, minimum).

4.1.3. *Calcium Carbonate*—ASTM D 1199, Type GC-II.

4.1.4. *Magnesium Silicate*—ASTM D 605.

4.1.5. *Zinc Oxide*—ASTM D 79.

4.1.6. *Alkyd Resin Solution Type S*—The resin shall be supplied as a 60 mass percent solution in VM and P naphtha. The resin solids shall be a medium oil soya modified resin. No rosin shall be permitted. The oil fatty acids shall be either alkali refined soya oil or fatty acids of soya oil having an iodine number of 115 to 130. No recovered oil, marine or soya food fatty acid derivatives shall be used. The resin shall comply with the requirements in Table 1.

Table 1—Characteristics of Alkyd Resin Solutions

Characteristics	Alkyd Resin Type S	Alkyd Resin Type N	Alkyd Resin Type F
Solids, mass percent	60 ± 1	60 ± 1	60 ± 1
Phthalic acid, mass percent	30 min	30 min	33–37
Oil acid, mass percent	50 min	54 min	48–55
Iodine No.	115–130	115–130	115 min
Color, gardner, (max)	9	9	9
Acid number, (max)	8	8	8
Viscosity:			
Reduced to 45 mass-percent solids	D to H	D to H	D to G

4.1.7. *Alkyd Resin Type N*—The resin shall be supplied as a 60 mass percent solution in toluene. The resin solids shall be a medium oil soya-modified pentaetythritol resin. No rosin shall be permitted. The oil fatty acids shall be either alkali refined soya oil or the fatty acids of soya oil having an iodine number of 115 to 130. No recovered oil, marine, or soya food fatty acid derivatives shall be used. The resin shall comply with the requirements in Table 1.

4.1.8. *Alkyd Resin Type F*—The resin shall be supplied at 60 mass percent solids in VM and P naphtha. The resin solids shall be either alkali refined soya oil or linseed oil or mixture of the two, having an iodine number of 115 minimum.

4.1.8.1. The solution must tolerate a 500 mass percent dilution with VM and P naphtha. A solution containing 100 g of 20 MPa·s (20 centipoise) chlorinated rubber, 130 g of resin solution, and 290 g of methyl ethyl ketone shall be clear, transparent, and show no separation after 24 hours of storage at 27 ± 3ºC (80 ± 5ºF) in a $^{3}/_{4}$ full test tube.

4.1.8.2. The alkyd resin, reduced to 45 percent solids with VM and P and Naphtha, shall have a viscosity of D to G. The resin shall comply with the requirements in Table 1.

4.1.9. *Chlorinated Rubber*—The rubber shall have a fixed chlorine content of 65.0 percent minimum when previously dried at 100 ± 5ºC (212 ± 9ºF) for 24 hours.

4.1.9.1. A 20 mass percent solution in toluene shall have a maximum color of 4 (Gardner) and a Brookfield viscosity of 9 to 25 MPa·s (9 to 25 centipoises).

4.1.10. *Chlorinated Paraffin*—MIL-C-429A.

4.1.11. *VM and P Naphtha*—TT-N-95.

4.1.12. *Toluene*—ASTM D 362.

4.1.13. *Methyl Ethyl Ketone*—ASTM D 740.

4.1.14. *Driers*—ASTM D 600 Class B.

4.1.15. *Suspending Agent*—Organo Montmorillonite.

4.1.16. *Chlorinated Rubber Stabilizer for Types N and F paint*—Epichlorohydrin or propylene oxide.

5. REQUIREMENTS

5.1. *Color*—The yellow paint shall match color chip No. 33538 of Fed. Std. No. 595a.

5.2. *Pigment*—The pigment used in the formulation of the paint shall conform to Tables 2 and 3 for the respective types and color.

5.2.1. The extracted pigment upon analysis shall conform to the quantitative requirements of Tables 2 and 3 for the respective types.

5.3. *Vehicles*—All vehicles shall be free from rosin and rosin derivatives. The component parts of the vehicle used shall be as indicated in Table 4 for the respective types.

Table 2—Composition of Pigment White Traffic Paint

	Mass, Percent					
	Type S		Type N		Type F	
Pigment Ingredients	Min	Max	Min	Max	Min	Max
Titanium dioxide	29	31	29	31	34.0	36.0
Calcium carbonate	34	36	34	36	25.0	27.0
Magnesium silicate	34	36	34	36	30.0	32.0
Zinc oxide	—	—	—	—	8.0	10.0

Table 3—Composition of Pigment Yellow Traffic Paint

	Mass, Percent					
	Type S		Type N		Type F	
Pigment Ingredients	Min	Max	Min	Max	Min	Max
Lead chromate	33.0	36.0	34.0	36.0	34.0	36.0
Magnesium silicate	30.0	33.0	11.0	13.0	11.0	13.0
Calcium carbonate	35.0	38.0	53.0	55.0	53.0	55.0

Table 4—Composition of Nonvolatile Vehicle White and Yellow Traffic Paint

	Mass, Percent					
	Type S		Type N		Type F	
Vehicle Ingredients	Min	Max	Min	Max	Min	Max
Alkyd resin solids	100	—	79	81	30	32
Chlorinated rubber	—	—	19	21	38	40
Chlorinated paraffin	—	—	—	—	29	31

5.3.1. Types N and F shall contain two percent stabilizer based on the mass of chlorinated rubber.

5.4. *Quantitative Requirements for the Paint*—The paint shall meet the requirements specified in Tables 5 and 6 for the respective type and color.

Table 5—Quantitative Requirements of White Paint

	Requirements					
	Type S		Type N		Type F	
Characteristics	Min	Max	Min	Max	Min	Max
Pigment, percent	61.0	63.0	57.0	59.0	48.0	50.0
Total solids, percent	77.0	—	75.0	—	69.5	—
Nonvolatile vehicle, percent, by mass of vehicle	42.0	—	41.0	—	41.0	—
Density, kg/m^3 (lb/gal)	1510 (12.6)	—	1582 (13.2)	—	1426 (11.9)	—
Viscosity, Krebs units	70	80	70	80	70	80
Fineness, Hegman	3	—	3	—	4	—
Drying time, minutes[a]	—	60	—	15	—	5

[a] ASTM D 711.

Table 6—Quantitative Requirements of Yellow Paint

	Requirements					
	Type S		Type N		Type F	
Characteristics	Min	Max	Min	Max	Min	Max
Pigment, percent	61.0	63.0	60.0	62.0	50.0	52.0
Total solids, percent	77.0	—	76.5	—	70.5	—
Nonvolatile vehicle, percent, by mass of vehicle	42.0	—	42.0	—	40.5	—
Density, kg/m^3 (lb/gal)	1510 (12.6)	—	1678 (14.0)	—	1486 (12.4)	—
Viscosity, Krebs units	70	80	70	80	70	80
Fineness, Hegman	3	—	3	—	4	—
Drying time, minutes[a]	—	69	—	15	—	5

[a] ASTM D 711.

5.5. *Qualitative Requirements*:

5.5.1. *Condition in Container*—The respective types of paint shall not show excessive settling, gelling, or curdling and shall be easily redispersed with a hand paddle to a smooth, homogeneous state. After storage for periods up to six months from date of packaging, the pigment shall be readily dispersed and viscosity of the paint shall not have changed more than 5 KU from that of the freshly delivered paint.

5.5.2. *Spraying Properties*—The paint as received shall have satisfactory spraying and hiding properties when applied through a nozzle on a conventional traffic striper to a metal plate at a wet film thickness of 0.38 mm (15 mils).

5.5.3. *Appearance*—The sprayed film shall dry to a smooth uniform finish free from roughness, unevenness, and other surface imperfections.

5.5.4. *Skinning*—The paint shall not skin within 48 hours in a three-quarters-filled, tightly closed container.

6. PACKING AND MARKING

6.1. The paint shall be delivered in such containers as may be specified in the contract. Each container shall bear a label with the following information shown thereon: name and address of manufacturer and contractor, shipping point, trade mark or trade name, kind of paint, formula, number of liters (gallons), date of manufacture and lot number, title and number of this specification, and type of paint.

7. METHODS OF SAMPLING AND TESTING

7.1. Except as shown in Section 6.2 the paint shall be sampled and tested in accordance with the appropriate method in Fed. Std. No. 141. If no method exists in the Federal Test Method, the appropriate ASTM Method shall be used.

Note 2—Because of the volatility of the solvents used, extreme care must be taken when testing Type F paint for pigment and solids. It is recommended that closed containers, weighing bottles and transfer devices such as syringes or pipettes be used. High results for pigments and solids can be expected if weighing precautions are not taken.

7.2. The purchaser may utilize X-ray analysis, gas chromatography, infra-red, or ultra-violet spectral analysis of the paint or its components to determine whether specified ingredients were used. Evidence of adulteration or improper formulation shall be cause for rejection.

Standard Specification for

White and Yellow Reflective Thermoplastic Striping Material (Solid Form)

AASHTO Designation: M 249-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

White and Yellow Reflective Thermoplastic Striping Material (Solid Form)

AASHTO Designation: M 249-09

1. SCOPE

1.1. This specification covers a reflectorized thermoplastic pavement striping material that is applied to the road surface in a molten state by mechanical means with surface application of glass beads at a rate specified by the purchaser. Upon cooling to normal pavement temperature, it produces an adherent reflectorized stripe of specified thickness and width capable of resisting deformation by traffic.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 247, Glass Beads Used in Pavement Markings
- T 250, Thermoplastic Traffic Line Material

2.2. *ASTM Standard*:

- D 36, Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)
- E 313, Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates

2.3. *Federal Standards*:

- Fed. Std. No. 141, Paint, Varnish, Lacquer, and Related Materials: Methods of Inspection, Sampling and Testing
- Fed. Std. No. 595b, Colors

3. MATERIALS

3.1. The thermoplastic material shall be homogeneously composed of pigment, filler, resins, and glass reflectorizing spheres.

3.1.1. The thermoplastic material shall be available in both white and yellow.

3.1.2. The resin shall be alkyd or hydrocarbon as specified by the purchaser.

3.1.3. The vendor shall have the option of formulating the material according to his own specifications. However, the physical and chemical properties contained in this specification shall apply regardless of the type of formulation used. The material, upon heating to application temperature, shall not exude fumes that are toxic, or injurious to persons or property. The pigment beads and filler shall be well dispersed in the resin. The material shall be free from all skins, dirt, and foreign objects.

3.1.4. *Glass Beads (Pre-Mix)*—The beads shall be uncoated and conform to AASHTO M 247, Type I.

3.1.5. Yellow pigment shall be lead and lead-chromate free.

4. REQUIREMENTS

4.1. *Specific Gravity*—The specific gravity of the white and yellow thermoplastic traffic line material shall not exceed 2.15.

4.2. *Composition*—The pigment, beads, and filler shall be uniformly dispersed in the resin. The material shall be free from all skins, dirt, and foreign objects and shall comply with requirements according to Table 1.

Table 1—Composition (percent by weight)

Component	White	Yellow
Binder	18.0 min	18.0 min
Glass beads	30–40	30–40
Titanium dioxide	10.0 min	—
Calcium carbonate and inert fillers	42.0 max	See Note 1.
Yellow pigments	—	—

Note 1—Amount of yellow pigment, calcium carbonate, and inert fillers shall be at the option of the manufacturer, providing all other requirements of this specification are met.

4.2.1. The material shall be provided in either granular or block form as specified by the purchaser.

4.3. *Physical Characteristics*:

4.3.1. *Color*—The thermoplastic material after heating for 240 ± 5 minutes at 218 ± 2ºC (425 ± 3ºF) and cooled to 25 ± 2ºC (77 ± 3ºF) shall meet the following:

White: Daylight reflectance at 45 degrees–0 degrees—75 percent minimum. For highway use the color shall match Federal Test Standard Number 595b, Color 17886.

Yellow: Daylight reflectance at 45 degrees–0 degrees—45 percent minimum.

(a) For highway use, the color shall match Federal Test Standard Number 595b—Color 13538.
(b) For airport use, the color shall comply with the requirements established by the FAA. The chromaticity and luminance factors shall be within the limits in Table 2 when determined under standard conditions:
    (a) angle of illumination, 45 degrees;
    (b) direction of view, perpendicular to surface; and
    (c) illuminant, CIE standard illuminant D65.

Note 2—The chromaticity and luminance factors of ordinary colors and colors of retro-reflecting materials shall be determined under the following standard conditions:

(a) angle of illumination: 45 degrees;
(b) direction of view: perpendicular to surface; and
(c) illuminant: CIE standard illuminant D65.

Table 2—CIE Equations

Yellow	
Orange boundary	$y = 0.130 + 0.636x$
White boundary	$y = 0.910 - x$
Green boundary	$y = 1.35x - 0.093$
Luminance factor	ß = 0.27 (mnm)
White	
Purple boundary	$y = x$
Blue boundary	$y = 0.610 - x$
Green boundary	$y = 0.040 + x$
Yellow boundary	$y = 0.710 - x$
Luminance factor	ß = 0.35 (mnm)

4.3.2. *Drying Time*—When applied at a temperature range of 211 ± 7ºC (412.5 ± 12.5ºF) and thickness of 3.2 to 4.8 mm ($^1/_8$ to $^3/_{16}$ in.), the material shall set to bear traffic in not more than 2 minutes when the air temperature is 10 ± 2ºC (50 ± 3ºF) and not more than 10 minutes when the air temperature is 32 ± 2ºC (90 ± 3ºF).

4.3.3. *Cracking Resistance at Low Temperature*—After heating the thermoplastic material for 240 ± 5 minutes at 218 ± 2ºC (425 ± 3ºF), applying to concrete blocks, and cooling –9.4 ± 1.7ºC (15 ± 3ºF), the material shall show no cracks.

4.3.4. *Impact Resistance*—After heating the thermoplastic material for 240 ± 5 minutes at 218 ± 2ºC (425 ± 3ºF) and forming test specimens, the impact resistance shall be a minimum of 1.13J (10 in.-lb).

4.3.5. *Softening Point*—After heating the thermoplastic material for 240 ± 5 minutes at 218 ± 2ºC (425 ± 3ºF) and testing in accordance with ASTM D 36 the materials shall have a softening point of 102.5 ± 9.5ºC (215 ± 15ºF).

4.3.6. *Flowability*—After heating the thermoplastic material for 240 ± 5 minutes at 218 ± 2ºC (425 ± 3ºF) and testing for flowability, the white thermoplastic shall have a maximum percent residue of 18 and the yellow thermoplastic shall have a maximum percent residue of 21.

4.3.7. *Yellowness Index*—The white thermoplastic material shall not exceed a yellowness index of 0.12.

4.3.8. *Flowability—Extended Heating*—After heating the thermoplastic material 8.0 ± 0.5 hours at 218 ± 2ºC (425 ± 3ºF), with stirring the last six hours, and tested for flowability, the thermoplastic shall have a maximum percent residue of 28.

4.4. *Storage Life*—Thermoplastic material shall meet the above requirements and melt uniformly with no evidence of skins or unmelted particles for a period of 1 year. Any material not meeting the above requirements shall be replaced by the manufacturer.

5. APPLICATION PROPERTIES

5.1. The thermoplastic material shall be capable of being applied by spraying, screed extrusion, or ribbon extrusion, as specified by the purchaser, at temperatures of 211 ± 7ºC (412 ± 12.5ºF) from approved equipment to produce a line 3.2 to 4.8 mm ($^1/_8$ to $^3/_{16}$ in.) thick which shall be continuous and uniform in shape having clear and sharp dimensions, particularly when extruded.

5.2. The material shall not exude fumes that are toxic, obnoxious, or injurious to persons or property when it is heated during applications.

5.3. The application of additional surface dressing glass beads shall be by means of a pressurized bead dispenser or by drop-on methods at a rate specified by the purchaser and agreed upon by the applicator.

6. PACKAGING AND MARKING

6.1. The thermoplastic material shall be packaged in suitable containers to which it will not adhere during shipment and storage.

6.1.1. In granular form, it shall be in white or yellow plastic bags of a suitable size to contain approximately 23 kg (50 lb) and shall be made of a material that when introduced into the mix hopper of the application equipment, it will become a part of the mix without any adverse effect to the performance of the thermoplastic material.

6.1.2. In block form, blocks of cast thermoplastic material shall be approximately 300 by 915 by 51 mm (12 by 36 by 2 in.) and shall have a mass of approximately 23 kg (50 lb).

6.1.3. Each container label shall designate the color, manufacturer’s name, batch number, and date of manufacture. Each batch manufactured shall have its own separate number. The label shall specify that the material shall be heated to 211 ± 7ºC (412 ± 12.5ºF) during application.

6.2. The contractor shall assume all cost resulting from the use of patented materials, equipment, devices, or processes used on or incorporated in the work, agrees to indemnify and save harmless the purchaser and his duly authorized representatives from all suits at law, or action of every nature for or on account of the use of any patented materials, equipment, devices, or processes.

7. SAMPLING

7.1. The minimum size batch of thermoplastic traffic striping material sampled and tested shall not be less than 1360 kg (3000 lb) unless the total order is less than this amount. Any manufacturer not familiar with the technique of making this material should consult the purchaser. A small trial batch should be made prior to making the thermoplastic traffic striping material in large quantities to make certain the finished product will comply with all the requirements of this specification.

8. TESTING

8.1. The material shall be tested in accordance with T 250 or with the appropriate method in Federal Standard No. 141 or ASTM designation.

Standard Specification for

Retroreflective Sheeting for Flat and Vertical Traffic Control Applications

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AASHTO Designation: M 268-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Retroreflective Sheeting for Flat and Vertical Traffic Control Applications

AASHTO Designation: M 268-10

1. SCOPE

1.1 This specification covers retroreflective sheeting, translucent ink, and overlay film intended for traffic control applications. The sheeting serves as the reflectorized background for sign messages and legends and symbols applied to the reflectorized background. Messages may be applied in opaque black or transparent colors.

1.2 All material furnished under this specification shall have been manufactured within 18 months of the delivery date. All material shall be supplied by the same manufacturer.

1.3 The values stated in inch-pound units are to be regarded as the standard.

1.4 *This specification does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- B 209, Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
- B 449, Standard Specification for Chromates on Aluminum
- D 523, Standard Test Method for Specular Gloss
- E 308, Standard Practice for Computing the Colors of Objects by Using the CIE System
- E 810, Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry
- E 811, Standard Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions
- E 991, Standard Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method
- E 1164, Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation
- E 1347, Standard Test Method for Color and Color-Difference Measurement by Tristimulus Colorimetry
- E 1349, Standard Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional (45:0 or 0:45) Geometry
- E 2152, Standard Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data
- E 2153, Standard Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color

- E 2301, Standard Test Method for Daytime Colorimetric Properties of Fluorescent Retroreflective Sheeting and Marking Materials for High Visibility Traffic Control and Personal Safety Applications Using 45°:Normal Geometry
- G 151, Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

2.2 *Federal Standards*:

- Standard Color Tolerance Charts, Federal Highway Administration, Washington, DC

2.3 *Other Documents*:

- *Commission Internationale de l'Eclairage* (CIE) Standard Colorimetric System
- *Commission Internationale de l'Eclairage* (CIE) Standard Illuminant D 65

3. DISCUSSION

3.1 The retroreflective sheeting classifications established in this specification are not intended to describe any specific materials, but are instead intended to establish meaningful minimum retroreflectivity intervals. These intervals are correlated with human performance factors by which sheeting may be classified.

3.2 Classifications are provided as a means for differentiating functional performance based on minimum retroreflectivity levels at standard combinations of entrance and observation angles. The combinations of entrance and observation angles shown in this specification provide a mechanism to categorize retroreflective sheeting materials into Type classifications. It should be recognized that performance characteristics outside these standard geometries cannot always be reasonably predicted, especially for retroreflective sheeting of microprismatic construction, and may vary between particular products meeting the same Type. It is the responsibility of the user of this specification to determine the suitability of any reflective sheeting material for its intended application.

3.3 When tested in accordance with ASTM E 810, the average coefficient of retroreflection (R_A) for a set of three samples taken from the same roll must not vary more than 20 percent between R_A measured at 0, 45, 90 and 120 degrees of rotation in order to be considered rotationally insensitive. Other rotational angles can be specified for testing by the user. The test shall be conducted at an observation angle of 0.5 degrees and an entrance angle of –4.0 degrees. Other combinations of observation and entrance angle can be specified for testing by the user. Calculate the percent difference by dividing the absolute difference between R_A (0) and R_A (45) by R_A (0). Repeat the calculation replacing R_A (45) with R_A (90) and R_A (120). R_A (0) is established with the sheeting aligned in its optimum rotation.

3.3.1 For sheeting not meeting the 20 percent maximum rotational sensitivity requirement, the manufacturer must provide identification marks or other features (such as a datum mark, tiles, or distinct seal pattern) in or on the sheeting face denoting the optimum orientation of the sheeting. The markings or features must be visible from a minimum distance of 2 ft and must be arrayed in such a manner that they will be readily distinguishable on cut-out legends, symbols, or borders. The manufacturer must provide fabrication guidelines outlining optimum sheeting orientation upon user request.

3.3.2 When utilizing sheeting (for permanent signs) that does not meet the 20 percent maximum rotational requirement, fabricate signs by applying white sheeting for cut-out legends, symbols, borders, and route marker attachments within the parent sign face in the optimum rotation according to the identification markings; and apply all background sheeting uniformly oriented.

3.4 *Delineators*—Retroreflective sheeting materials suitable for use on delineators are typically of microprismatic construction. The Type of retroreflective sheeting shall be specified by the user.

4. CLASSIFICATIONS

4.1 This specification establishes four Types of retroreflective sheeting, with successively increasing minimum coefficients of retroreflection. Retroreflective sheeting materials shall meet all of the performance requirements in Section 5 to qualify as a particular Type under this specification. Minimum coefficients of retroreflection are shown in Tables 4, 5, 6, and 7 for retroreflective sheeting Type A, Type B, Type C, and Type D respectively. The designated Type is exclusive to the highest specified minimum R_A satisfied at observation angle of 0.5 degrees and an entrance angle of –4.0 degrees. Using higher retroreflectivity sheeting to manufacture signs where lower retroreflectivity sheeting Types are specified must be approved by the end user.

4.2 The following are general descriptions of the Types of retroreflective sheeting established by this specification. These are provided for descriptive information only and are not intended to be limitations or recommendations.

Note 1—The *Manual on Uniform Traffic Control Devices* (MUTCD) requires that traffic control signs, unless illuminated, be retroreflective to show the same shape and similar color both day and night. Therefore, any retroreflective sheeting materials meeting this specification would satisfy that requirement. However, when determining the appropriateness of a particular Type of sheeting for a particular application, consideration should be given to the pertinent highway characteristics where the materials will be installed, such as traffic volumes, traffic speeds, and roadway geometrics, as well as available resources. Brighter materials (meeting Type B, C, or D) should be considered for use on complex roadway environments where the driving task may be more involved.

4.2.1 *Type A*—Retroreflective sheeting materials meeting Type A are typically constructed of encapsulated microscopic glass bead lens construction.

4.2.2 *Type B*—Retroreflective sheeting materials meeting Type B are typically constructed of unmetallized microprismatic optics. These triangular microprismatic materials do not have a significant 1-degree observation angle performance.

4.2.3 *Type C*—Retroreflective sheeting materials meeting Type C are typically constructed of unmetallized microprismatic optics. These triangular microprismatic materials have a significant 1-degree observation angle performance.

4.2.4 *Type D*—Retroreflective sheeting materials meeting Type D are typically constructed of unmetallized microprismatic optics. These materials have 0.5- and 1-degree observation angle performance approximately two times greater than Type C materials.

4.3 *Adhesive Backing Classes*—The adhesive backing classes shall be specified by the end user and shall be classified as follows:

4.3.1 *Class 1*—The adhesive backing shall be pressure-sensitive and require no heat, solvent, or other preparation for adhesion to smooth, clean surfaces.

4.3.2 *Class 2*—The adhesive backing shall be activated by applying heat and pressure to the material. The temperature necessary to form a durable permanent bond shall be a minimum of 66°C (150°F). Reflective sheeting materials with Class 2 adhesive shall be repositionable under normal shop conditions and at substrate temperatures up to 38°C (100°F) without damage to the sheeting.

Reflective sheeting materials with Class 2 adhesive may be perforated to facilitate removal of air in heat-vacuum laminators, but the perforations must be of a size and frequency such that they do not cause objectionable blemishes in the finished sign.

4.3.3 *Class 3*—The adhesive backing shall be a positionable low-tack pressure-sensitive adhesive that requires no heat, solvent, or other preparation for adhesion to smooth, clean surfaces. Reflective sheeting materials with Class 3 adhesive shall be repositionable up to a temperature of 38°C (100°F) without damage to the sheeting.

4.3.4 *Class 4*—The adhesive backing shall be a low-temperature pressure-sensitive adhesive that permits sheeting applications down to –7°C (+20°F) without the aid of heat, solvent, or other preparation for adhesion to smooth, dry, and clean surfaces.

5. SHEETING PROPERTIES

5.1 *Test Conditions*—Unless otherwise specified in this specification, condition all adhesively bonded and unbonded test samples and specimens at a temperature of 73 ± 3°F (23 ± 2°C) and 50 ± 5 percent relative humidity for 24 hours prior to testing.

5.2 *Panel Preparation*—Unless otherwise specified in this specification, when tests are to be performed using test panels, apply the specimens of retroreflective material to smooth aluminum cut from Alloy 6061-T6 or 5052-H38, in accordance with Specification ASTM B 209 or B 209M. The sheets shall be 0.020 in. (0.508 mm), 0.040 in. (1.016 mm), or 0.063 in. (1.600 mm) in thickness, and a minimum of 8 by 8 in. (200 by 200 mm). Prepare the aluminum in accordance with Specification ASTM B 449, Class 2, or degrease and lightly acid etch before the specimens are applied. Apply the specimens to the panels in accordance with the recommendations of the retroreflective sheeting manufacturer.

5.3 *Adhesive*—For testing purposes, subject two pieces of reflective sheeting, each 2 in. by 6 in. (51 mm by 152 mm) in size, to a temperature of 160°F (71°C) and a pressure of 2.5 lb/in.^{2} (0.176 kg/cm^2) for 4 hours. Bring the pieces to equilibrium at standard conditions and cut one, 1 in. by 6 in. (25 mm by 152 mm) specimen from each piece, and remove the liner by hand. Apply 4 in. (102 mm) of one end of each specimen to a test panel. Condition as specified in Section 5.1. Suspend the panels in a horizontal position with the specimen facing downward. The adhesive backing of the retroreflective sheeting shall produce a bond that will support a $1^3/_4$-lb (0.79-kg) weight for adhesive classes 1, 2, and 3 or a 1-lb (0.45-kg) weight for adhesive Class 4 for 5 minutes, without the bond peeling for a distance of more than 2 in. (51 mm). The test panel must have a minimum thickness of 0.040 in. (1.016 mm).

5.4 *Liner Removal*—The liner, when provided, shall be easily removed without soaking in water or other solutions, and shall not break, tear, or remove adhesive from the sheeting. The protective liner, if any, shall be easily removed following accelerated storage for 4 hours at 160°F (71°C) under a weight of 2.5 psi (17.2 kPa).

5.5 *Daytime Color*—Determine the chromaticity and luminance factor percent *Y* for CIE standard illuminant D65 and the 1931 CIE (2-degree) standard observer in accordance with ASTM E 308, E 991, E 1164, E 1347, E 1349, E 2152, E 2153, and E 2301, as applicable. The luminance factor is the sum of the reflectance luminance factor and the fluorescence luminance factor. Bispectral measurement provides the individual factors, while measurement with simulated ASTM D 65 provides their sum.

For fluorescent specimens, it is necessary either that the physical illumination of the specimen be a good approximation to illuminant ASTM D 65, requiring an instrument with an appropriately filtered light source, or else that a bispectral photometer conforming to ASTM E 2301 be used.

There are three types of 45/0 (0/45) instruments: annular, circumferential, and uniplanar. Measurement of prismatic sheeting with circumferential instruments may require multiple measurements. Measurement of prismatic sheeting with uniplanar instruments will require multiple measurements.

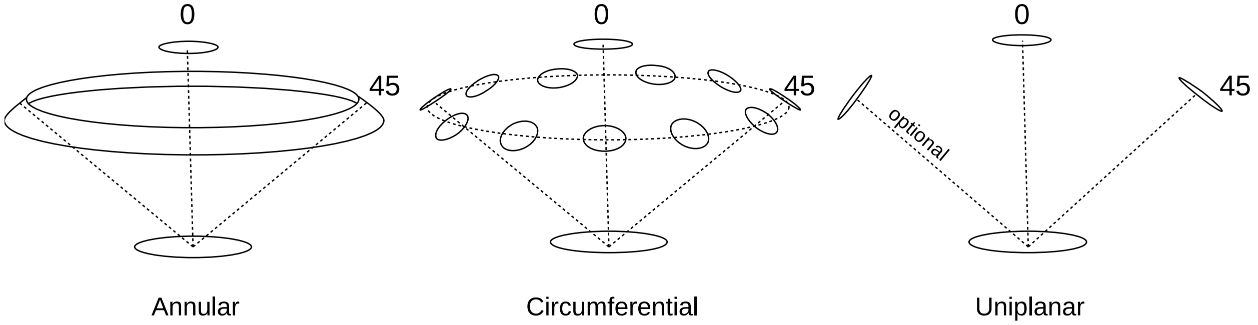


Figure 1—Types of 45/0 (0/45) Instruments

If the measurement geometry is circumferential, then the testing laboratory must verify that the apertures in the ring are sufficiently close for acceptable approximation to an annular measurement. This may depend on the optical construction of the specimen, and must be determined by the testing laboratory. Multiple measurements of the same specimen area at different rotations may be averaged to improve the approximation to an annular measurement.

If the measurement geometry is uniplanar, then a sequence of measurements shall be made on the same specimen area at incremental rotations, and the measurement values shall be taken as averages over all the rotations. The number of rotations shall be large enough for acceptable approximation to an annular measurement. The number depends on the optical construction of the specimen and must be determined by the testing laboratory.

Instruments (spectrophotometers, colorimeters) used to measure daytime color shall have 45/0 or 0/45 illumination and viewing geometry. The referee instrument shall have 10-degree apertures for both illumination and viewing. Use of aperture sizes deviating from these may affect the measurement results.

Table 1—Daytime Luminance Factor (%*Y*) for Types A, B, C, and D

Color	Minimum	Minimum for Higher Daytime Conspicuity[a]	Maximum
White	27	40	—
Yellow	15	24	45
Orange	12	14	30
Green	3.0	—	12
Red	2.5	—	15
Blue	1.0	—	10
Brown	1.0	—	9.0
Fluorescent Yellow-Green[b]	60	—	None
Fluorescent Yellow[b]	45	—	None
Fluorescent Orange[b]	25	—	None

[a] Minimum values for higher daytime conspicuity are supplementary requirements that apply when specified by the end user.

[b] The luminance factors for fluorescent colors shown in Table 1 consist of the sum of a reflectance luminance factor and fluorescence luminance factor. The luminance factor may be determined using a good approximation to illuminant D65, requiring an instrument with an appropriately filtered light source, or a bispectral photometer conforming to ASTM E 2301 be used.

Table 2—Color Specification Limits (Daytime) for Types A, B, C, and D[a]

Color	1		2		3		4	
	x	*y*	*x*	*y*	*x*	*y*	*x*	*y*
White	0.303	0.300	0.368	0.366	0.340	0.393	0.274	0.329
Yellow	0.498	0.412	0.557	0.442	0.479	0.520	0.438	0.472
Orange	0.558	0.352	0.636	0.364	0.570	0.429	0.506	0.404
Green[b]	0.026	0.399	0.166	0.364	0.286	0.446	0.207	0.771
Red	0.648	0.351	0.735	0.265	0.629	0.281	0.565	0.346
Blue[b]	0.140	0.035	0.244	0.210	0.190	0.255	0.065	0.216
Brown	0.430	0.340	0.610	0.390	0.550	0.450	0.430	0.390
Fluorescent Yellow-Green	0.387	0.610	0.369	0.546	0.428	0.496	0.460	0.540
Fluorescent Yellow	0.479	0.520	0.446	0.483	0.512	0.421	0.557	0.442
Fluorescent Orange	0.583	0.416	0.535	0.400	0.595	0.351	0.645	0.355

[a] The four pairs of chromaticity coordinates determine the acceptable color in terms of the *Commission Internationale de l'Eclairage* (CIE) Standard Colorimetric System measured with CIE Standard Illuminant D 65.

[b] The saturation limit of green and blue may extend to the border of the CIE chromaticity locus for spectral colors.

5.6 *Nighttime color*—Nighttime color shall be determined in accordance with ASTM E 811 and evaluated using the CIE system in ASTM E 308. (The saturation limit shall be considered to extend to the boundary of the chromaticity locus of spectral colors.) Measure using CIE Illuminant A, observation angle of 0.33 degrees, entrance angle of +5 degrees, source, and receiver apertures not exceeding 10 minutes of arc, CIE 1931 (2-degree) standard observer.

Table 3—Color Specification Limits (Nighttime) for Types A, B, C, and D

Color	1		2		3		4	
	x	*y*	*x*	*y*	*x*	*y*	*x*	*y*
White (NA)								
Yellow	0.513	0.487	0.500	0.470	0.545	0.425	0.572	0.425
Orange	0.595	0.405	0.565	0.405	0.613	0.355	0.643	0.355
Green	0.007	0.570	0.200	0.500	0.322	0.590	0.193	0.782
Red	0.650	0.348	0.620	0.348	0.712	0.255	0.735	0.265
Blue	0.033	0.370	0.180	0.370	0.230	0.240	0.091	0.133
Brown	0.595	0.405	0.540	0.405	0.570	0.365	0.643	0.355
Fluorescent Yellow-Green	0.480	0.520	0.473	0.490	0.523	0.440	0.550	0.449
Fluorescent Yellow	0.554	0.445	0.526	0.437	0.569	0.394	0.610	0.390
Fluorescent Orange	0.625	0.375	0.589	0.376	0.636	0.330	0.669	0.331

5.7 *Color*—When evaluated according to Sections 5.5 and 5.6, the sheeting shall be uniform in color and devoid of streaks throughout the length of each lot or roll. Sheeting used for side by side overlay applications shall have a Hunter Lab Delta E of less than 3 units. The sheeting shall conform to the daytime and nighttime color requirements of the following tables.

5.8 *Coefficient of Retroreflection*—The coefficient of retroreflection (R_A) is expressed using the units of cd/lux/m^2 (cd/fc/ft^2) and determined in accordance with ASTM E 810. When no rotation angle is specified, measurements are taken at 0 and 90 degrees and then averaged. Compliance with the minimum coefficient of retroreflection for the 1.0-degree observation angle is required for Types C and D. Compliance with the minimum coefficient of retroreflection for the 1.0-degree observation angle is required for Types A and B when specified by the end user.

Table 4—Minimum Coefficient of Retroreflection (R_A) for Type A Sheeting

Observation Angle, degree	Entrance Angle (deg.)	White	Yellow	Orange	Red	Green	Blue	Brown
0.2	–4	240	180	90	35	25	12	7.5
0.2	+30	120	90	45	20	12	6.0	3.5
0.5	–4	95	70	35	15	9.5	4.5	3.0
0.5	+30	50	35	20	7.0	4.5	2.5	1.5
1.0	–4	4.5	3.5	1.8	0.7	0.5	0.3	0.2
1.0	+30	2.5	2.0	1.0	0.5	0.3	0.2	0.1

Table 5—Minimum Coefficient of Retroreflection (R_A) for Type B Sheeting

Observation Angle, degree	Entrance Angle (deg.)	White	Yellow	Orange	Red	Green	Blue	Brown	FYG	FY	FO
0.2	–4	335	250	125	50	35	17	10	270	200	100
0.2	+30	120	85	45	17	12	6.0	3.5	95	70	35
0.5	–4	135	100	50	20	14	6.5	4.0	110	80	40
0.5	+30	45	35	17	7.0	4.5	2.5	1.5	35	25	15
1.0	–4	15	12.5	6.5	2.5	1.5	1.0	0.5	15	10	5.0
1.0	+30	5.5	4.5	2.5	1.0	0.5	0.3	0.2	4.5	3.5	1.5

Table 6—Minimum Coefficient of Retroreflection (R_A) for Type C Sheeting

Observation Angle, degree	Entrance Angle (deg.)	White	Yellow	Orange	Red	Green	Blue	Brown	FYG	FY	FO
0.2	–4	580	440	220	85	60	30	17	465	350	175
0.2	+30	200	150	75	30	20	10	6.0	160	120	60
0.5	–4	235	175	85	35	25	12	7.0	190	140	70
0.5	+30	80	60	30	10	8.0	4.0	2.5	65	50	25
1.0	–4	60	45	20	8.5	5.5	3.0	1.8	45	35	17.5
1.0	+30	20	15	7.5	3.0	2.0	1.0	0.5	15	12	6.0

Table 7—Minimum Coefficient of Retroreflection (R_A) for Type D Sheeting

Observation Angle, degree	Entrance Angle (deg.)	White	Yellow	Orange	Red	Green	Blue	Brown	FYG	FY	FO
0.2	–4	580	440	220	85	60	30	17	465	350	175
0.2	+30	200	150	75	30	20	10	6.0	160	120	60
0.5	–4	465	350	175	70	45	23	14	375	280	140
0.5	+30	160	120	60	25	16	8.0	5.0	130	95	50
1.0	–4	120	85	45	17	10	6.0	3.5	95	70	35
1.0	+30	40	30	15	6.0	4.0	2.0	1.0	35	25	12

5.9 *Accelerated Laboratory Weathering*—Accelerated laboratory weathering may be used for provisional qualification of sheeting before the results from accelerated outdoor weathering are available. When they become available, the results from outdoor weathering take precedence over the results from laboratory-accelerated weathering tests.

5.10 Accelerated laboratory weathering testing will be performed for 2200 hours according to ASTM G 151 and G 155, Cycle 1. Following weathering, gently wash the panels using a soft cloth or sponge and clean water or a dilute solution of a mild detergent (1 percent by weight in water, maximum concentration). After washing, rinse thoroughly with clean water, and blot dry with a soft clean cloth. Following cleaning, the applied sheeting shall show no appreciable discoloration, cracking, streaking, crazing, blistering, or dimensional change. The sheeting shall exhibit a Hunter Lab Delta E of 5 or less when compared to the sample prior to exposure. In addition, the chromaticity coordinates, after exposure, must remain within the appropriate four pairs of chromaticity values listed in Tables 2 and 3. Following accelerated laboratory weathering, the sheeting shall exhibit a minimum of 80 percent of the coefficient of retroreflection for the particular Type as listed in Tables 4, 5, 6, and 7.

5.11 Accelerated laboratory weathering testing may be performed by an alternate method, as identified in ASTM G 151, as approved by the user.

5.12 *Accelerated Outdoor Weathering*—Accelerated outdoor weathering will be performed at an acceptable location as approved by the user, or by default, in climates equivalent to Phoenix, AZ and Miami, FL. Sheeting material shall be open backed and placed on an outdoor rack with a 45-degree angle facing the equator. Labeling, conditioning and handling of panels prior to exposure and during evaluation periods shall be in accordance with ASTM G 147. The sheeting will be evaluated annually for 3 years. Following weathering, gently wash the panels using a soft cloth or sponge and clean water or a dilute solution of a mild detergent (1 percent by weight in water, maximum concentration). After washing, rinse thoroughly with clean water, and blot dry with a soft clean cloth. After washing and drying, condition the panels at room temperature for at least 2 hours prior to conducting any measurements. After panels have been washed, dried, and conditioned, the applied sheeting shall show no appreciable discoloration, cracking, streaking, crazing, blistering, or dimensional change. The sheeting shall exhibit a Hunter Lab Delta E of 5 or less when compared to the sample prior to exposure. In addition, the chromaticity coordinates, after exposure, must remain within the appropriate four pairs of chromaticity values listed in Tables 2 and 3. Following accelerated outdoor weathering, the sheeting shall exhibit a minimum of 80 percent of the coefficient of retroreflection for the particular Type as listed in Tables 4, 5, 6, and 7.

5.13 *Shrinkage*—Condition a 9 in. (230 mm) by 9 in. (230 mm) retroreflective sheeting specimen with liner, a minimum of 1 hour at standard conditions (see Section 5.1). Remove the liner and place the specimen on a flat surface with the adhesive side up. Ten minutes after the liner is removed and again after 24 hours, measure the specimen to determine the amount of dimensional change. The sheeting shall not shrink in any dimension more than $^1/_{32}$ in. (0.8 mm) in 10 minutes and not more than $^1/_8$ in. (3 mm) in 24 hours.

5.14 *Workability*—The sheeting shall show no cracking, scaling, pitting, blistering, edge lifting, inter-film splitting, curling, or discoloration when processed and applied using mutually acceptable processing and application procedures.

5.15 *Positionability*—Sheeting, with Class 3 adhesive, used for manufacturing legends and borders shall provide sufficient positionability during the fabrication process to permit removal and reapplication without damage to either the legend or sign background and shall have a plastic liner suitable for use on bed cutting machines. Thereafter, all other adhesive and bond requirements contained in the specification shall apply.

Positionability shall be verified by cutting 4-in. (100-mm) letters E, I, K, M, S, W, and Y out of the positionable material. The letters shall then be applied to a sheeted aluminum blank using a single pass of a 2-lb (0.9 kg) roller. The letters shall sit for 5 minutes and then a putty knife shall be used to lift a corner. The thumb and fore finger shall be used to slowly pull the lifted corner to lift letters away from the sheeted aluminum. The letters shall not tear or distort when removed.

5.16 *Thickness*—The thickness of the sheeting without the protective liner shall be less than or equal to 0.015 in. (0.4 mm), or 0.025 in. (0.6 mm) for prismatic material.

5.17 *Processing*—The sheeting shall permit cutting and color processing according to the sheeting manufacturer's specifications at temperatures of 60 to 100°F (15 to 38°C) and within a relative humidity range of 20 to 80 percent. The sheeting shall be heat resistant and permit forced curing without staining the applied or unapplied sheeting at temperatures recommended by the manufacturer. The sheeting shall be solvent resistant and capable of being cleaned with VM&P naphtha, mineral spirits, and turpentine.

5.17.1 Transparent color and opaque black inks shall be single component and low odor. The inks shall dry within 8 hours and not require clear coating. After color processing on white sheeting, the sheeting shall show no appreciable discoloration, cracking, streaking, crazing, blistering, or dimensional change when tested for durability (Sections 5.9 and 5.10). The ink on the weathered, prepared panel shall exhibit a Hunter Lab Delta E of 5 or less when compared to the original.

5.17.2 Transparent color electronic cutting films shall be acrylic. After application to white sheeting, the films shall show no appreciable discoloration, cracking, streaking, crazing, blistering, or dimensional change when tested for durability (Sections 5.9 and 5.10). The films on the weathered, prepared panel shall exhibit a Hunter Lab Delta E of 5 or less when compared to the original.

5.17.3 Black screen ink, when applied to white sheeting, must be completely opaque.

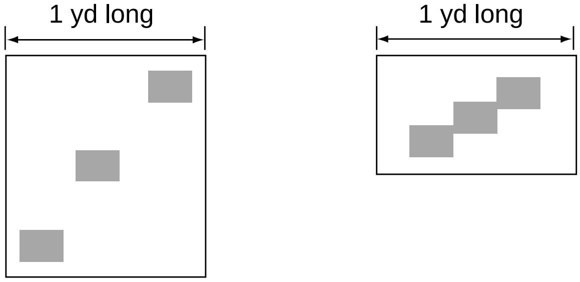
5.18 Transparent colors screened, or transparent acrylic electronic cutting films, on white sheeting, shall meet the minimum coefficient of retroreflection values as listed in Tables 4, 5, 6, and 7 for the color applied. After accelerated laboratory and accelerated outdoor testing, the colors shall retain a minimum 80 percent of the coefficient of retroreflection as listed in Tables 4, 5, 6, and 7.

5.19 *Identification*—The sheeting shall have a distinctive overall pattern in the sheeting unique to the manufacturer. If material orientation is required for optimum retroreflectivity, permanent orientation marks shall be incorporated into the face of the sheeting. Neither the overall pattern nor the orientation marks shall interfere with the reflectivity of the sheeting.

5.20 *Packaging*—Both ends of each box shall be clearly labeled with the sheeting type, color, adhesive type, manufacturer's lot number, date of manufacture, and supplier's name. Material Safety Data Sheets and technical bulletins for all materials shall be furnished to the Agency with each shipment.

6. SAMPLING

6.1 *Sampling*—A full width by 1-yard (0.9-m) long sample is selected at random to represent the entire sheet, roll, or lot. For the purpose of testing the coefficient of retroreflectivity, three samples shall be spaced evenly across (left, center, and right) and spaced evenly down the specimen as shown in Figure 2.



(a) (b)

Figure 2—Selecting Samples

6.1.1 For determining conformance to all other requirements, single samples taken at random shall be tested.

6.1.2 For the purpose of testing and qualification, producers shall include a physical sample with the following information:

6.1.2.1 Company name;

6.1.2.2 Physical and mailing address;

6.1.2.3 Company's material designation (product name, style number, etc.);

6.1.2.4 Contact person and phone number;

6.1.2.5 AASHTO sheeting type; and

6.1.2.6 AASHTO backing class.

APPENDIX

(Nonmandatory Information)

X1. PROCEDURE FOR ESTABLISHMENT OF MINIMUM COEFFICEINTS OF RETROREFLECTION

X1.1. The retroreflective sheeting grades established in this specification are not intended to describe any specific materials. The following information serves to explain the theory and research applied to the creation of the values.

X1.1.1. *White Sheeting*—for white sheeting within a particular grade, the relationships for minimum coefficients of retroreflection for the various standard combinations of observation and entrance angles are shown in Table X1.1.

Note X1—The basic facts for each value listed in the tables for the coefficient of retroreflection are found in Table X1.2.

X1.1.2. *Color Sheeting*—For color sheeting within a particular grade, the factors shown in Table X1.3 are applied to the minimum coefficients of retroreflection obtained for white sheeting for that grade in Table X1.1.

Table X1.1—Minimum Coefficients of Retroreflection (R_A) for White Sheeting within a Grade[*]

Observation Angle	Entrance Angle	AASHTO Sheeting Type			
		A	B	C	D
0.2	–4	240	335	580	580
0.2	30	120	120	200	200
0.5	–4	95	135	235	465
0.5	30	50	45	80	160
1.0	–4	4.5	15	60	120
1.0	30	2.5	5.5	20	40

[*] Notes:
1. Build a simple specification table that is supported through research findings; for instance, psychophysical principles of vision vetted through over a century of research have shown through such mechanisms as threshold versus intensity relationships that human visual performance is roughly approximated using Weber's Law. In other words, as the baseline condition increases (in this case, sign luminance through retroreflective materials), we need larger differences to observe measureable changes.
2. Maintain known alpha and beta geometries from ASTM D 4956.
3. The lowest class is to be based on encapsulated beaded materials.
4. Previous work has shown that of all the current ASTM D 4956 alpha/beta geometries, the 0.5/–4.0 combination is best correlated with performance.

   Using geometry of 0.5/–4.0, this specification uses increasing multipliers to set thresholds for class distinctions. Research has shown that the Class B and C materials have statistically longer legibility distances than Class A materials. While Classes B and C have about the same total light return, the returned light is spread more for Class C materials than it is for Class B materials. The wider spread of returned light may be useful for signs with small letters such as street name signs. Class D materials are similar to C materials in terms of the light distribution but Class D materials are more efficient with the light returned to the driver.

Table X1.2—Specific Notes for the Development of the Recommendations

Observation Angle	Entrance Angle	AASHTO Sheeting Type			
		A	B	C	D
0.2	−4	$a \times 2.5$	$b \times 2.5$	$c \times 2.5$	$c \times 2.5$
0.2	30	$a \times 1.25$	$b \times 0.875$	$c \times 0.875$	$c \times 0.875$
0.5	−4	a	$b = \sqrt{2} \times a$	$c = \sqrt{3} \times b$	$d = \sqrt{4} \times c$
0.5	30	$a \times 0.5$	$b \times 0.35$	$c \times 0.35$	$d \times 0.35$
1.0	−4	$a \times 0.05$	$b \times 0.125$	$c \times 0.25$	$d \times 0.25$
1.0	30	$a \times 0.05$	$b \times 0.04375$	$c \times 0.0875$	$d \times 0.0875$

Table X1.3—Minimum Coefficient of Retroreflection (R_A) Factors for Color Sheeting[a]

Yellow	Orange	Red	Green	Blue	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.75	0.38	0.15	0.10	0.05	0.03	0.80	0.60	0.30

[a] The above factors, when applied to the coefficients for white sheeting established in Table X1.1, establish minimum coefficients of retroreflection for color sheeting materials.

Standard Specification for

Acrylic Prismatic Reflectors and Embossed Aluminum Frames for Signs

AASHTO Designation: M 290-96 (2008)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Specification for

Acrylic Prismatic Reflectors and Embossed Aluminum Frames for Signs

AASHTO Designation: M 290-96 (2008)

1. SCOPE

1.1 This specification covers acrylic prismatic reflectors and embossed aluminum frames used in cut-out letters, symbols, and accessories on signing projects.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 257, Instrumental Photometric Measurements of Retroreflective Materials and Retroreflective Devices

2.2 *ASTM Standards*:

- B 117, Standard Practice for Operating Salt Spray (Fog) Apparatus
- B 209, Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
- D 788, Standard Classification System for Poly(Methyl Methacrylate) (PMMA) Molding and Extrusion Compounds
- D 1730, Standard Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting

2.3 *ANSI Standard*:

- ANSI D6.1, *Manual on Uniform Traffic Control Devices*

2.4 *Federal Standard*:

- L-P 380, Plastic Molding Material, Methacrylate

3. DESCRIPTION OF TERMS

3.1 *legend*—the entire message and border for a sign.

3.2 *message*—a group of words, numbers, and/or symbol for a sign.

4. ORDERING INFORMATION

4.1 Orders for material under this specification shall include the following information:

4.1.1 Quantity;

4.1.2 Name of material;

4.1.3 Style of letter and size, or size of reflector;

4.1.4 Color (colorless, yellow, red, green);

4.1.5 Legend description; and

4.1.6 AASHTO designation and date of issue.

5. MATERIALS

5.1 The reflector lens shall be methylmethacrylate meeting requirements of the latest version of one of the following specifications:

5.1.1 Federal Specification L-P-380, Type 1, Class 3; and

5.1.2 ASTM D 788, Grade 8.

5.2 The purchaser shall specify the type, class, or grade of methylmethacrylate to be used in the manufacture of the reflectors.

5.3 Legend frames shall be fabricated from aluminum sheet, ASTM B 209, Alloy 3003-H14.

6. MANUFACTURE

6.1 Reflectors shall consist of a transparent acrylic plastic face, herein referred to as the lens, and a light-colored, opaque back of similar material fused to the lens under heat and pressure around the entire perimeter. The reflector shall form a unit permanently sealed against dust, water, and water vapor. The reflector lens shall be colorless, yellow, red, or green as required by the plans.

6.2 The lens shall consist of a smooth front surface free from projections or indentations, which are detrimental to the reflectance of the unit. The manufacturer’s trademark shall be molded legibly into the face of the lens. The rear surface of the lens shall have a prismatic configuration such that it will cause adequate internal reflection of light.

6.3 Reflectors shall be designed so as to facilitate insertion into accurately sized holes in embossed legend frames. When installed in the legend frame, reflectors shall be restrained so as to prevent their displacement. The retention of reflectors in frames by use of adhesive tape is not acceptable. The reflector size shall be such as to permit free movement in the mounting hole to allow for differences of expansion and contraction between plastic reflector and aluminum sign frame.

6.4 Frames shall be embossed and shall be fabricated from aluminum sheet having a thickness of 1 mm (0.040 in.). The form of the legend shall conform to the requirements of ANSI D6.1 and the plans and specifications for the project. Mounting holes shall be provided within the frames to permit the use of an approved fastener. The size and spacing of reflector holes for reflectorized frames shall be such as to afford maximum night legibility and visibility to the finished cut-out figure. Legend frames, which are not intended to be reflectorized, shall not contain holes for reflectors. After metal fabrication has been completed, the frames shall be degreased, etched, neutralized, and treated with an amorphous chromate coating in accordance with ASTM D 1730. Frames shall be finished with the material and color specified by the purchaser.

7. PHYSICAL REQUIREMENTS

7.1 *Specific Intensity per Unit Area (SIA)*:

7.1.1 The SIA of each colorless reflector intended for use in cut-out letters, symbols, and accessories shall be equal to or exceed the minimum values in Table 1 when tested in accordance with T 257. SIA is expressed in candelas per lux per square meter (candelas per foot-candle per square foot).

Table 1—Required Specific Intensity per Unit Area Values for Colorless Reflectors

Observation Angle, Degrees	Entrance Angle, Degrees	Specific Intensity per Unit Area	
		$cd/lx/m^2$	$cd/fc/ft^2$
$^1/_{10}$	0	2020	2020
$^1/_{10}$	20	806	806
$^1/_6$	0	1440	1440
$^1/_6$	20	576	576
$^1/_3$	0	1010	1010
$^1/_3$	20	403	403

Note: For yellow reflectors the SIA shall be 60 percent of the listed value. For green or red reflectors the SIA shall be 25 percent of the listed value for colorless reflectors.

7.2 *Seal*:

7.2.1 The seal test shall be used to determine if a reflector is adequately sealed against dust and water. Not more than four percent of the reflectors tested shall show evidence of water intake when tested as specified in Section 10.2.

7.3 *Heat Resistance*:

7.3.1 The heat resistance test shall be used to determine the durability of the reflectors. No specimen shall show significant change in shape and general appearance when tested as specified in Section 10.3 and compared with unexposed control standards.

7.4 *Corrosion*:

7.4.1 The salt fog cabinet test of the legend specimen shall be used to evaluate the durability of the legend and its coating. No significant peeling, cracking, or disbonding of the coating shall be observed after 1000 hours under test as specified in Section 10.4.

8. SAMPLING

8.1 For qualification of product, 53 sample reflectors of each size, type, and color to be used shall be submitted by the manufacturer for testing from each manufacturer's lot of 25,000 or fewer reflectors.

8.2 For project acceptance purposes, 53 reflectors of each size, type, and color to be used shall be sampled at random by the purchaser from each shipment of reflectors, when they are received separately from the legend frames, or from the finished legend when these are received already made up. Specimens used in the seal and heat resistance tests shall not be used to perform reflectance tests. If the same specimens are used to perform seal and heat resistance tests, the heat resistance tests shall be performed last.

8.3 The sampling procedure for reflectors incorporated into legend shall be such as will provide the desired degree of randomness, but not unduly delay the production or delivery of signs.

Note 1—One method could be to list in the plans or specifications the extra legend that the manufacturer is to furnish, which will provide the required number and size of reflectors for test. The engineer will substitute this extra legend at random for legend intended for sign usage. The legend for which substitutions are thus made shall be the legend used for laboratory testing as set forth in this specification. A degree of randomness of sampling is obtained in that the supplier does not know which of several letters or symbols intended for sign usage will ultimately be used to supply reflectors for testing.

9. RETESTING

9.1 *Specific Intensity per Unit Area (SIA)*:

9.1.1 Failure of a reflector to meet the SIA minimum shall constitute failure of the reflector being tested. Upon failure of more than two but less than four of the 50 specimens tested, a resample of 100 reflectors shall be tested. Failure of more than three of these specimens shall be cause for rejection of the lot. Failure of four or more of the reflectors in the original sample of 50 shall be cause for rejection of the lot without retest.

9.2 *Seal*:

9.2.1 Upon failure of more than two but fewer than four of the specimens, a resample of 100 reflectors shall be tested. Failure of more than three of these specimens shall be cause for rejection of the lot. Failure of four or more of the reflectors in the original sample of 50 shall be cause for rejection of the lot without retest.

9.3 *Heat Resistance*:

9.3.1 No failure of the initial three specimens will be permitted, and no retest will be allowed.

9.4 *Corrosion*:

9.4.1 No failure of the initial three specimens will be permitted, and no retest will be allowed.

10. TEST PROCEDURES

10.1 *Optical (Photometric) Tests*:

10.1.1 Photometric tests shall be conducted in accordance with T 257, with the reflector spinning at a rate such that the meter reading is steady.

10.2 The seal test is performed by submerging 50 specimens in a water bath at room temperature. The submerged specimens are subjected to a vacuum of 16.9 kPa (5 in. of mercury) for 5 minutes.

Restore atmospheric pressure and leave the specimens submerged for an additional 5 minutes. Examine the specimens for water intake.

10.3 The heat resistance test is performed by placing three reflectors in a horizontal position on a grid or perforated shelf in a circulating air oven. The oven shall be operated at 52º ± 3ºC (125º ± 5ºF). The specimens shall remain in the oven for 4 hours and shall not interfere with the free flow of air. At the conclusion of the test the samples shall be removed from the oven and permitted to cool to room temperature in air and visually examined.

10.4 *Corrosion Test*—Three assembled cut-out letters, symbols or accessories shall withstand the combined corrosion test set forth in ASTM B 117.

11. PACKAGING

11.1 Each cut-out letter, symbol, or accessory, completely assembled with reflectors, shall be supplied in an individual package with contents marked thereon.

11.2 Individual reflectors and separate legends, if so furnished, shall be packed so as to avoid damage by abrasion or other means.

Standard Specification for

Inorganic Zinc-Rich Primer

AASHTO Designation: M 300-03 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Inorganic Zinc-Rich Primer

AASHTO Designation: M 300-03 (2007)

1. SCOPE

1.1. This specification covers self-curing inorganic zinc-rich primers for use on iron and steel surfaces.

1.2. *Intended use of the primers*.

1.2.1. Types I and II are intended for use on bridges, similar structural steel, and other ferrous metal surfaces subject to corrosive atmospheric environments such as marine, industrial, and high humidity.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. Reference to standard specifications, testing procedures and other standard procedures contained in this document shall be the latest edition of the published document at the date of this "Evaluation Criteria."

2.1.1. *AASHTO Standard*:

- *Standard Specifications for Highway Bridges*

2.1.2. *ASTM Standards*:

- B 117, Standard Practice for Operating Salt Spray (Fog) Apparatus
- D 185, Standard Test Methods for Coarse Particles in Pigments
- D 512, Standard Test Methods for Chloride Ion In Water
- D 520, Standard Specification for Zinc Dust Pigment
- D 521, Standard Test Methods for Chemical Analysis of Zinc Dust (Metallic Zinc Powder)
- D 562, Standard Test Method for Consistency of Paints Measuring Krebs Unit (KU) Viscosity Using a Stormer-Type Viscometer
- D 610, Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
- D 1475, Standard Test Method For Density of Liquid Coatings, Inks, and Related Products
- D 1640, Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature
- D 1654, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
- D 1735, Standard Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus
- D 2247, Standard Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity

- D 2369, Standard Test Method for Volatile Content of Coatings
- D 2371, Standard Test Method for Pigment Content of Solvent-Reducible Paints
- D 3363, Standard Test Method for Film Hardness by Pencil Test
- D 4417, Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel
- D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D 4752, Standard Practice for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub
- D 4940, Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives
- D 5894, Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
- D 6580, Standard Test Method for The Determination of Metallic Zinc Content in Both Zinc Dust Pigment and in Cured Films of Zinc-Rich Coatings

2.1.3. *Federal Standards*:

- Fed. Std. No. 141, Paint, Varnish, Lacquer, and Related Materials: Methods of Inspection, Sampling and Testing
- Fed. Std. No. 29, CFR 1910.1200 OSHA Hazard Communication Standard
- Fed. Std. No. 40, CFR, Part 59, Subpart D, Section 59.400 Through 59.413 National Volatile Organic Compound Emission Standards for Architectural Coatings

2.1.4. *ANSI Standards*:

- American National Standards Institute (ANSI) B94.50, Style E

2.1.5. *The Society for Protective Coatings (SSPC) Standards*:[1]

- AB-3, Abrasive Specification Number 3, Newly Manufactured or Re-Manufactured Steel Abrasive
- SP-5, White Metal Blast Cleaning

2.1.6. *Other Documents*:

- Commercial Item Description (CID) A-A-1689B; Tape, Pressure-Sensitive Adhesive, Plastic Film[2]

3. CLASSIFICATION

3.1. *Types*—Inorganic zinc-rich primers covered by this specification shall be furnished in the following types, as specified in the invitation for bids, contract, or order.

3.1.1. *Type I*—Inorganic zinc-rich primer solvent-base multiple components.

3.1.2. *Type II*—Inorganic zinc-rich primer water-base multiple component system.[3]

4. MATERIALS

4.1. The materials used in the manufacture of the primer shall conform to the requirements of the following specifications.

4.1.1. *Zinc Dust*—ASTM D 520, Type II

4.1.2. Vehicle shall be either a solvent solution or water solution of silicates, curing aids, tinting colors, suspension, and pot life control agents of the manufacturer's choosing if no changes are made after initial approval of the primer.

4.1.3. The Volatile Organic Compound (VOC) content shall be stated by the manufacturer in accordance with Section 6.2.

4.1.4. *Pigment*—The pigment used in the formulation shall be basically zinc dust. Small amounts of color and extender pigments may be used if the quantitative requirements of the complete paint are met.

5. REQUIREMENTS

5.1. *Color*—The color of the inorganic zinc primer shall be as mutually agreed upon and such that a definite contrast between it and the color of blasted steel is readily apparent.

5.2. *Pigment*—The extracted pigment upon analysis shall conform to the minimum quantitative requirements specified in Table 1, and shall not vary more than a –2 percent or +3 percent metallic zinc content from the initially approved primer.

5.2.1. The x-ray diffraction pattern of the extracted pigment shall be obtained for the initially approved primer.

5.3. *Primer Quantitative Requirements*—The mixed primer shall meet the quantitative requirements specified in Table 1. Primer must meet applicable VOC content limitations for its intended use categories (shop or field application) as defined by Federal and local regulations. Primers for field coating shall comply with the requirements of 40 CFR, Part 59, Subpart D, Section 59.400 through 59.413. If thinning is necessary for application, the maximum amount of solvent added shall be such that the final product still complies with all the requirements of this section, including the VOC requirements.

Table 1—Requirements

Characteristics	Minimum Requirement	Test Method
Total solids, percent by mass of paint	78	ASTM D 2369
Pigment, percent by mass of total solids	85	ASTM D 2371
Metallic zinc, percent by mass of pigment	85	ASTM D 521
Metallic zinc, percent by mass of total solids	72	ASTM D 6580 or ASTM D 521

5.4. *Physical Properties*—The mixed primer shall meet the physical requirements of Table 2.

Table 2—Properties of Mixed Paint

Characteristics	Minimum Requirement	Maximum Requirement	Test Method
Density, kg/m^3 (lb/gal)	2217 (18.5)		ASTM D 1475
Viscosity, KU @ 25°C (77°F)	Manufacturer's recommendation		ASTM D 562
Set to touch, minutes @25°C (77°F) wet film thickness of 75 to 100 μm (3 to 4 mils)	—	30	ASTM D 1640
Dry hard, hours @ 25°C (77°F) wet film thickness of 75 to 100 μm (3 to 4 mils)	—	24	ASTM D 1640
Pot life @ 25°C (77°F), hours	8		Section 5.5.3.1

5.5. *Primer Qualitative Requirements*—The primer shall meet the following qualitative requirements.

5.5.1. *Mixing*—The raw materials of the liquid portion of the inorganic primer shall be mixed and dispersed as required to produce a product that is uniform, stable, free from grit, and conforms to the requirements of this specification.

5.5.2. The pigment portion of multi-component paints, prior to mixing, shall be dry and loosely packed. After mixing, all types of coarse particles and skins as residue retained on a standard 250-µm (60-mesh) screen shall be no more than 0.5 percent by mass of total paint, regardless of type, in accordance with ASTM D 185.

5.5.3. *Storage Life*—The vehicle component shall not show thickening, curdling, gelling, gassing, or hard caking after being stored unmixed for nine months from date of manufacture in a tightly covered, unopened container at a temperature of 10 to 32ºC (50 to 90ºF).

5.5.4. *Working Properties*—The mixed paint shall spray easily, and shall show no streaking, running, sagging, or other objectionable features when tested in accordance with Federal Standard No. 141, Methods 4331, and 4541.

5.5.4.1. *Pot Life*—After mixing, the pot life shall be determined by placing 350 to 400 mL of the mixed paint into a 500 mL (1 pint) double-friction, top-round paint can and sealing the lid. Place the sealed can into a water bath maintained at a temperature of 25°C (77°F). After 8 hours the mixed paint shall not show curdling, gelling, gassing, hard caking, or a change in viscosity greater than ±5 KU from the initial viscosity of the sample when determined in accordance with ASTM D 562.

5.5.5. *Test Panel Preparation*—Steel test panels (ASTM A 36 hot-rolled steel, or equivalent), measuring 100 by 150 by 1.5 mm (4 by 6 by $^{1}/_{16}$ in.) unless otherwise designated shall be blast cleaned and coated with the zinc-rich primer. The panels shall be cleaned and coated on both sides and all edges.

5.5.5.1. The panels shall be cleaned in accordance with SSPC-SP5 using recyclable metallic abrasives in accordance with SSPC-AB3. The abrasives shall have a maximum chloride content of 15 ppm determined in accordance with ASTM D 512 and a maximum conductivity of 150 micromhos/cm determined in accordance with ASTM D 4940. The abrasive mixture shall be approximately 60 percent SAE shot number S230 and 40 percent SAE grit number G40. Both the shot and grit shall have a Rockwell hardness of C45 ± 3. The surface profile of the cleaned panels shall be 40 to 65 μm (1.5 to 2.5 mils) when determined in accordance with ASTM D 4417, Method C. The profile shall be clean, sharp, and free of embedded friable material, with adequate roughness to insure effective adhesion of the primer.

5.5.5.2. The primer shall be applied to the cleaned test panels using airless spray equipment except when the paint manufacturer's application information specifically states only other methods of application are to be used. All primers shall be applied to panels mounted vertically at a distance of 530 mm (21 in.) from the tip of the spray gun. The equipment shall be capable of developing sufficient pressure to properly atomize the primer. The orifice size, application pressure, pump type and ratio, hose size and length, and any atypical application requirements shall be reported. If the pressure used varies by more than 10 percent from the suggested pressure listed in the manufacturer's application data information, the actual pressure used and a statement explaining the deviation shall be reported.

5.5.5.3. The dry film thickness shall be 65 to 90 μm (2.5 to 3.5 mils) unless otherwise designated. Before any exposure tests, all panels shall be aged 14 days at 24 to 26°C (75 to 79°F) and 45 to 55 percent relative humidity. After aging of the test panels to be evaluated for salt fog resistance, cyclic weathering resistance, bullet hole immersion, and humidity tests, the panels shall have the edges sealed and protected by applying vinyl tape around the outside edges. The vinyl tape shall extend 5 mm ($^3/_{16}$ in.) onto the coated surface from the edge of the panel. The vinyl tape shall be in accordance with CID A-A-1689B and have an approximate vinyl thickness of 110 μm (4.3 mils) with an approximate neoprene adhesive thickness of 25 μm (1 mil).

5.5.5.4. The test panels for salt fog resistance and cyclic weathering resistance shall be scribed in accordance with ASTM D 1654. The scribe shall be a single "X" centered on the test panel with rectangular dimensions of 50-mm (2-in.) top width and 100-mm (4-in.) height. To insure proper positioning, cleanliness, and depth of the scribe, a template and a scribe cutting tool shall be used. The scribe cutting tool shall be a straight shank tungsten carbide tip, lathe cutting tool in accordance with ANSI B 94.50, Style E. The operator shall bear down hard and go over each arm of the scribe twice to insure a clean scribe of sufficient depth to remove any zinc particles from the scribe and to expose clean steel. The exposed steel in the cut of the scribe shall be verified with a microscope.

5.5.6. *Mudcracking*—The coating, when applied in accordance with Sections 5.5.5 through 5.5.5.3 to a 125- to 150-μm (5- to 6-mil) dry film thickness, shall show no mudcracking that is visible to the unaided eye.

5.5.7. *Adhesion*—The coating, when applied and hardened in accordance with Sections 5.5.5 through 5.5.5.3, shall be tested for adhesion in accordance with ASTM D 4541, using apparatus under Appendix A4. The adhesive used to perform this test shall be a two-compound epoxy, containing no solvents (e.g., 100 percent solids). A minimum of four tests shall be performed on each panel. The average of the tests shall be a minimum pull-off adhesion value of 2.4 MPa (350 psi).

5.5.8. *Salt Fog Resistance*—This is an optional test, as determined by the purchaser. The coating, when applied, hardened, and scribed in accordance with Sections 5.5.5 through 5.5.5.4, shall pass 5000-hour minimum exposure to salt fog (ASTM B 117) without any blistering or rusting of the coated portion, with no undercutting from the scribe. (Slight rusting in the scribe mark will be permissible and resulting staining should be ignored.) Strips 6 mm ($^1/_4$ in.) wide along the edges of the panel may be ignored. Testing shall be done in triplicate.

5.5.9. *Cyclic Weathering Resistance Test*—Suitable size panels shall be prepared in accordance with Sections 5.5.5 through 5.5.5.4 and tested in accordance with ASTM D 5894, Cyclic Salt Fog/UV Exposure of Painted Metal (Alternating Exposures in a Fog/Dry Cabinet). The coating shall pass fifteen 336-hour cycles without any blistering or rusting of the coated portion, with no undercutting from the scribe. (Slight rusting in the scribe mark will be permissible and resulting staining should be ignored.) Strips 6-mm ($^1/_4$-in.) wide along the edges of the panel may be ignored. Testing shall be done in triplicate.

5.5.10. *Bullet Hole Immersion Test*—The coating shall be applied in accordance with Sections 5.5.5 through 5.5.5.3 at a dry film thickness of 75 to 90 μm (3.0 to 3.5 mils) except for the panel size, which shall be 75 by 150 by 1.5 mm (3 by 6 by $^1/_{16}$ in.). A circular area of 38.1 mm (1.5 in.) in diameter, in the middle of each panel, shall be left uncoated. A small magnet may be used to hold a circular template in place for this purpose. Coat only the face of the panel with the primer being tested. The backside shall be coated with an electrochemically inert barrier-type coating such as a vinyl or epoxy barrier coating. After curing in accordance with Section 5.5.5.3 each panel shall be immersed in a 1-liter (1-quart) jar containing a 5.0 percent solution of sodium chloride. The jars must be tightly covered to prevent evaporation of water. The 5.0 percent salt water must be changed weekly. After immersion at 23 ± 3ºC (75 ± 5ºF), for 650 hours, no rusting or corrosion as determined by ASTM D 610 shall have occurred either within the circular bare area or over the zinc-rich painted surface.

5.5.11. *Humidity Test*—The coating when applied and hardened in accordance with Sections 5.5.5 through 5.5.5.4 shall show no rust, blistering, or loss of adhesion after 4000 hours of exposure using ASTM D 1735.

5.6. *Primer Field Performance Requirements*—Documented information detailing the past history and experience with the coating in terms of service life under specific conditions shall be required. It must be shown that less than one percent rust has occurred after three years of service in a coastal or marine environment. All details relative to surface preparation and application of the coatings shall be supplied. Sufficient identifiable characteristics shall be provided to permit laboratory test verification of coating identity. These characteristics shall include formulation information readily verifiable in a laboratory, including the general nature of the vehicle, pigment and volatile portions, the density, the percent solids by mass and volume, an infrared spectrum (2.5 to 15 microns) of the vehicle component of each coat, and other procedures used for the quality control during manufacture of the coating.

5.6.1. New products that do not have three-year field performance information can be accepted under an experimental basis.

Note 1—Manufacturers must specify a minimum cure before top coating. Either ASTM D 4752 or D 3363 shall be used to determine cure.

5.7. Primers having a slip coefficient requirement shall meet the AASHTO Class B slip coefficient of not less than 0.5 as defined by the AASHTO *Standard Specifications for Highway Bridges*.

5.8. *Material Quality Assurance*:

5.8.1. In order to determine the acceptability of a lot or batch of a qualified product, the paint shall meet the requirements of Sections 5.2 through 5.4.

5.8.2. Viscosity of the mixed paint shall be determined in accordance with ASTM D 562. Variance shall be within ±10 Krebs Units or equivalent units of another viscometer of the viscosity of the initially approved primer.

5.8.3. Density of the mixed paint shall be determined in accordance with ASTM D 1475. Variance shall be within 48 kg/m^3 (0.4 lb/gal) of the density of the initially approved primer.

5.8.4. Solids percent by mass of the mixed paint shall be determined in accordance with ASTM D 2369. The percent solids by mass shall be no less than that specified in Table 1. Variance shall be within ±2 percent of the percent solids by mass of the initially approved primer.

5.8.5. The infrared spectrum (2.5 to 15 microns) of the vehicle component shall agree with the infrared spectrum of the vehicle component from the paints used in Sections 5.5 through 5.5.5.11. Agreement shall be both in peak position and relative intensity of the peaks, or by other analytical procedure.

5.8.6. The x-ray diffraction pattern of the extracted pigment shall match that of the initially approved primer. This test shall be performed at the discretion of the purchaser.

5.8.7. The solids percent by mass of the vehicle component shall not vary more than ±2 percent of the solids content of the vehicle component from the initially approved primer. The solids content shall be determined in accordance with ASTM D 2369.

6. PACKAGING AND MARKING

6.1. The primer shall be delivered in such containers as may be specified in the contract. Each container shall bear a label with the following information shown thereon: name and address of manufacturer, trademark or trade name, kind of paint, date of manufacture and lot number, mixing instructions, and equipment cleanup instructions. The label on the containers must also contain all appropriate health and physical hazard warnings as described in 29 CFR 1910.1200 OSHA Hazard Communication Standard.

6.2. The VOC content shall be stated on label, and/or product data sheet, and/or Material Safety Data Sheet, or all three.

7. RECOATABILITY

7.1. The primer shall show adequate recoatability when tested in accordance with the following method:

7.1.1. Panels primed in accordance with Sections 5.5.5 through 5.5.5.3 shall be placed into humidity cabinet per Section 5.5.11. Panels are then cleaned in accordance with the manufacturer’s recommendation and recoated and cured in accordance with Sections 5.5.5 through 5.5.5.3. Adhesion testing shall be performed in accordance with ASTM D 4541, using apparatus under Appendix A4. The adhesive shall be in accordance with Section 5.5.7. A minimum of four tests shall be performed on each panel. The average of the tests shall be a minimum pull off adhesion value of 2.4 MPa (350 psi).

8. TOPCOATABILITY

8.1. Topcoats shall show adequate adhesion when tested in accordance with the following method:

8.1.1. Panels primed in accordance with Sections 5.5.5 through 5.5.5.3 shall be placed into humidity cabinet per Section 5.5.11. The panels shall then be cleaned and the topcoat for the system shall be applied in accordance with the manufacturer’s requirements. The topcoated panels shall then be aged in accordance with Section 5.5.5.3. Aged panels shall be exposed for 30 days in accordance with ASTM D 2247. After exposure, adhesion testing shall be performed in accordance with ASTM D 4541, using apparatus under Appendix A4. The adhesive shall be in accordance with Section 5.5.7. A minimum of four tests shall be performed on each panel. The average of the tests shall be a minimum pull-off adhesion value of 2.4 MPa (350 psi).

9. METHODS OF SAMPLING AND TESTING

9.1. The primer shall be sampled by lot for testing. The material can be sampled either at the manufacturer or after reaching its destination.

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[1] Available from The Society for Protective Coatings, Building 40, 24th Street, Pittsburgh, PA 15222-4645.

[2] Available from GSA Specification Department, Federal Supply Services, Specification Section, 470 East L'Enfant Plaza, S.W., Suite 8100, Washington, DC 20407.

Standard Practice for

Evaluation of Protective Coating Systems for Structural Steel

AASHTO Designation: R 31-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Evaluation of Protective Coating Systems for Structural Steel

AASHTO Designation: R 31-09

1. SCOPE

1.1. This standard practice covers testing criteria for evaluation of protective coating systems for use on iron and steel surfaces. It is not recommended for the evaluation of hot-dip galvanizing or metalizing.

1.2. The protective coating systems are intended for use on bridges, similar structural steel, and other ferrous metal surfaces, both new and existing, prepared by abrasive blast cleaning, which are subject to corrosive atmospheric environments, such as marine, industrial, deicing chemicals, and high humidity.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard practice may involve hazardous materials, operations, and equipment. It does not purport to address all safety problems associated with its use. It is the responsibility of the user of this standard practice to establish the appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 1—The testing format for this standard practice has been developed around a three-coat system consisting of a zinc primer, epoxy or urethane intermediate, and an aliphatic urethane finish coat.

2. REFERENCED DOCUMENTS

2.1. Reference to standard specifications, testing procedures, and other standard procedures contained in this document shall be the latest edition of the published document at the date of this "Evaluation Criteria."

2.1.1. *AASHTO Standards*:

- M 300, Inorganic Zinc-Rich Primer
- T 337, Non-Instrumental Determination of Metallic Zinc in Zinc-Rich Primers
- T 338, Analysis of Structural Steel Coatings for Hindered Amine Light Stabilizer (HALS)
- T 339, Analysis of Structural Steel Coatings for Isocyanate Content
- *Standard Specifications for Highway Bridges*

2.1.2. *ASTM Standards*:

- A 36/A 36M, Standard Specification for Carbon Structural Steel
- A 490, Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength

- A 572, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
- B 117, Standard Practice for Operating Salt Spray (Fog) Apparatus
- D 476, Standard Classification for Dry Pigmentary Titanium Dioxide Products
- D 512, Standard Test Methods for Chloride Ion In Water
- D 520, Standard Specification for Zinc Dust Pigment
- D 521, Standard Test Methods for Chemical Analysis of Zinc Dust (Metallic Zinc Powder)
- D 523, Standard Test Method for Specular Gloss
- D 562, Standard Test Method for Consistency of Paints Measuring Krebs Unit (KU) Viscosity Using a Stormer-Type Viscometer
- D 610, Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
- D 714, Standard Test Method for Evaluating Degree of Blistering of Paints
- D 1475, Standard Test Method For Density of Liquid Coatings, Inks, and Related Products
- D 1640, Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature
- D 1652, Standard Test Method for Epoxy Content of Epoxy Resins
- D 1654, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
- D 2073, Standard Test Methods for Total, Primary, Secondary, and Tertiary Amine Values of Fatty Amines, Amidoamines, and Diamines by Referee Potentiometric Method (Withdrawn 2007)
- D 2196, Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield type) Viscometer
- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- D 2244, Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates
- D 2369, Standard Test Method for Volatile Content of Coatings
- D 2371, Standard Test Method for Pigment Content of Solvent-Reducible Paints
- D 2697, Standard Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings
- D 2698, Standard Test Method for Determination of the Pigment Content of Solvent-Reducible Paints by High-Speed Centrifuging
- D 3335, Standard Test Method for Low Concentrations of Lead, Cadmium, and Cobalt in Paint by Atomic Absorption Spectroscopy
- D 3718, Standard Test Method for Low Concentrations of Chromium in Paint by Atomic Absorption Spectroscopy
- D 3723, Standard Test Method for Pigment Content of Water-Emulsion Paints by Low-Temperature Ashing
- D 3960, Standard Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings
- D 4017, Standard Test Method for Water in Paints and Paint Materials by Karl Fischer Method
- D 4060, Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
- D 4285, Standard Test Method for Indicating Oil or Water in Compressed Air
- D 4400, Standard Test Method for Sag Resistance of Paints Using a Multinotch Applicator
- D 4417, Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel

- D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D 4940, Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives
- D 5894, Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
- D 6133, Standard Test Method for Acetone, p-Chlorobenzotrifluoride, Methyl Acetate or t-Butyl Acetate Content of Solventborne and Waterborne Paints, Coatings, Resins, and Raw Materials by Direct Injection Into a Gas Chromatograph
- D 6580, Standard Test Method for The Determination of Metallic Zinc Content in Both Zinc Dust Pigment and in Cured Films of Zinc-Rich Coatings
- D 7091, Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
- E 11, Standard Specification for Woven Wire Test Sieve Cloth Standard Test Sieves
- E 1349, Standard Practice for the Occupational/Environmental Health View of the Electronic Health Record
- G 92, Standard Practice for Characterization of Atmospheric Test Sites
- G 140, Standard Test Method for Determining Atmospheric Chloride Deposition Rate by Wet Candle Method

2.1.3. *Federal Standards*:[1]

- Fed. Std. No. 40, CFR 51.100(s) Volatile Organic Compound Definition
- Fed. Std. No. 40, CFR 59.406(a) Volatile Organic Compound Compliance Provision
- Fed. Std. No. 40, CFR Part 59, Subpart D, Section 59.400 Through 59.413 National Volatile Organic Compound Emission Standards for Architectural Coatings
- Fed. Std. No. 40, CFR 261.24, Table 1 Maximum Concentration of Contaminants for the Toxicity Characteristic
- Fed. Std. No. 595, Colors Used in Government Procurement
- EPA SW 846, Method 1311 Toxicity Characteristic Leaching Procedure (TCLP)
- American National Standards Institute (ANSI) B94.50, Style E

2.1.4. *The Society for Protective Coatings (SSPC) Standards*:[2]

- AB-2, Abrasive Specification No. 2 Cleanliness of Recycled Ferrous Metallic Abrasives
- AB-3, Abrasive Specification Number 3, Newly Manufactured or Re-Manufactured Steel Abrasive
- Guide 9, Guide for Atmospheric Testing of Coatings in the Field
- PA 2, Measurement of Dry Paint Thickness with Magnetic Gauges
- Paint 20, Zinc-Rich Primers
- SP 5, White Metal Blast Cleaning
- SP 6, Commercial Blast Cleaning
- SP 10, Near-White Blast Cleaning

2.1.5. *Other Documents*:

- Commercial Item Description (CID) A-A-1689B; Tape, Pressure Sensitive Adhesive, Plastic Film[3]
- Commission Internationale de l’Eclairage (CIE) 1976 L*a*b*

- "Appendix A, Testing Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints," *Specification for Structural Joints Using ASTM A 325 or A 490 Bolts,* as approved by the Research Council on Structural Connections[4]

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *volatile organic compound (VOC)*—any organic compound that participates in atmospheric photochemical reactions, that is, any organic compound other than those which the U.S. EPA Administrator designates as having negligible photochemical reactivity. For a list of compounds that the U.S. EPA Administrator has designated as having negligible photochemical reactivity, also referred to as exempt compounds, refer to 40 CFR 51.100(s).

3.1.2. *VOC content*—the weight of VOC per volume of coating, calculated according to the procedures in 40 CFR 59.406(a).

3.1.3. *dry film paint thickness*—the depth of coating to the top of the surface profile peaks, measured in accordance with SSPC PA 2.

3.1.4. *minimum (laboratory) recoat time*—the period of time required to sufficiently cure the applied coating when applied within the manufacturers' recommended wet film thickness range and obtain dry film thickness readings of the coating (without causing physical damage to the applied film).

4. CLASSIFICATION

4.1. *Primer*—Primers act as the initial barrier over the prepared steel substrate. Single-coat systems shall consist only of the primer. Primers recommended for use on structures with painted connections designed for Class B allowable stress will be evaluated for Class B slip coefficient as detailed in Section 9.1 of this standard practice. Primers intended only for use on structures as maintenance applications (i.e., blast and recoat) may not be evaluated for Class B slip coefficient as detailed in Section 9.1 of this standard practice.

4.2. *Touch-Up Primer*—The touch-up primer shall be as recommended by the manufacturer at the time of application. Touch-up procedures for the intermediate and finish coats shall be detailed in the product data sheets or by written submission.

4.3. *Intermediate Coat*—The intermediate coat for a three-coat system serves as a tie coat between primer and finish coat as well as a protective barrier for the structural steel. The manufacturers for each (three-coat) coating system submitted for evaluation shall recommend the appropriate intermediate coat.

4.4. *Finish Coat*—The finish coat for each system evaluated serves as the final barrier coating and provides the desired aesthetic finish for the surface of the structure. The manufacturers for each coating system submitted for evaluation shall recommend the appropriate finish coat.

5. MATERIALS

5.1. The materials used in the manufacture of the system shall conform to the requirements of the following specifications:

5.1.1. *Zinc Dust*—ASTM D 520, Type II.

5.1.1.1. Manufacturers shall submit a certificate of analysis from the zinc suppliers showing conformance with the requirements.

5.1.1.2. Each coating (primer, intermediate, and finish coat) shall be tested by an NLLAP (National Lead Laboratory Accreditation Program) accredited laboratory to determine its total lead content. The total lead content shall be determined using a dry film sample in accordance with ASTM D 3335. The percentage of total lead in each coating shall not exceed 0.01 percent (100 ppm).

6. GENERAL REQUIREMENTS

6.1. *Color*—For production, the color of the coatings shall be as mutually agreed, except that the intermediate coat shall contrast in color a minimum of 10.0 ΔE* from the primer to the finish coat. For testing purposes, the finish coat color shall comply to Section 8.2.7.

6.2. *Pigment*—Prime pigments shall be used except for shaders. Leachable, heavy-metal compounds shall not exceed the regulatory limits of 40 CFR, 261.24, Table 1, when tested in accordance with Section 9.7.4. Total levels of lead, cadmium, and chromium shall not exceed 20 times the specified limits for these elements. If titanium dioxide is used in the finish coat, it shall meet the requirements of ASTM D 476, Type IV.

6.3. *Slip Coefficient for Primer*—Primer coatings for use on new and rehabilitated structures with painted connections designed for Class B allowable stress shall meet the Class B slip coefficient requirements specified in the AASHTO *Standard Specifications for Highway Bridges*. The test data indicating compliance shall also state the type and quantity of reducer, cure time, and maximum coating thickness for that coating as tested.

7. MANUFACTURER'S REQUIREMENTS

7.1. The manufacturer shall supply chemical test results that will define the character and nature of the coating system being submitted. Actual results shall be verified by the select laboratory, and shall be part of the select laboratory's report. Properties (determined in a mixed condition) shall be stated on the informational spreadsheet, certified Product Data Sheet and/or the MSDS as follows:

7.1.1. Total solids, percent by mass in accordance with ASTM D 2369.

7.1.2. Volatile organic compound content in accordance with ASTM D 3960.

7.1.3. EPA exempt solvents, identify compound and percent by volume.

7.1.4. Water, percent by mass, in accordance with ASTM D 4017.

7.1.5. Pigment, percent by mass, in accordance with ASTM D 2371 or D 3723.

7.1.6. Metallic zinc content, percent by mass, in the primer shall be determined in accordance with ASTM D 6580. An optional test method is T 337.

7.1.7. Total solids, percent by volume, in accordance with ASTM D 2697.

7.1.8. Mass per volume (grams per liter) in accordance with ASTM D 1475.

7.1.9. Viscosity (Stormer at 25°C) KU in accordance with ASTM D 562 (not suitable for viscosities above 143 KU).

7.1.10. Viscosity (Brookfield at 25°C) cP in accordance with ASTM D 2196. The instrument model (i.e., LV, DV, DVII+), spindle size, and revolutions per minute shall be reported.

7.1.11. Pot life in hours, at specified temperature and specified humidity, shall be evaluated in the laboratory through viscosity measurements taken at regular intervals and reported in Krebs Units. Materials with manufacturer's stated pot life shall be evaluated at 25, 50, 75, and 100 percent of the stated pot life. Materials without manufacturer's stated pot life shall be evaluated at 2-hour increments for 8 hours.

7.1.12. Sag resistance (Leneta) in micrometers wet film thickness in accordance with ASTM D 4400.

7.1.13. Recommended film thickness in micrometers.

- Minimum and maximum wet film thickness.
- Minimum and maximum dry film thickness.
- Maximum allowable dry film thickness for the primer on faying surfaces.

7.1.14. Minimum (and maximum when applicable) drying time in accordance with ASTM D 1640 at 25°C and 50 percent relative humidity.

- Dry to touch.
- Dry to handle.
- Dry to recoat.

7.1.15. Mixing ratio for multi-component coatings, by volume.

7.1.16. Mixing ratio for multi-component coatings, by mass.

7.1.17. Shelf life of each component stored at 25°C.

7.1.18. Total heavy metals content for mixed coatings in accordance with ASTM D 3335 and D 3718. Heavy metals to be tested will include lead, chromium, and cadmium for each coating.

7.1.19. Leachable heavy metals content for mixed coatings in accordance with ASTM D 3335 and D 3718. Analysis shall include Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, and Silver for each coating.

7.1.20. Epoxide values determined in accordance with ASTM D 1652, Method A.

7.1.21. Amine values determined on the amine or amidomine contained in the appropriate component of two component epoxy coatings, in accordance with ASTM D 2073.

7.1.22. Isocyanate group content determined in accordance with T 339.

7.1.23. Hindered amine light stabilizers (HALS) determined in accordance with T 338.

7.1.24. Ultraviolet (UV) absorbers.

7.1.25. The minimum and maximum surface profile requirements (height in micrometers).

7.1.26. Application requirements for
- Ambient temperature
- Surface temperature
- Material temperature
- Humidity
- Tip size
- Application pressure

8. TESTING REQUIREMENTS

8.1. *General*:

8.1.1. Tests must be administered or performed by an authorized testing facility as approved by AASHTO's National Transportation Product Evaluation Program (NTPEP). The principal facility evaluating a specific coating system or any laboratory performing testing for the principal facility must obtain prior approval from the NTPEP before initiating any testing.

8.1.2. All testing equipment shall be cleaned prior to performance of each testing cycle, unless specifications require more frequent cleaning.

8.1.3. *Coating Evaluation Requirements*:

8.1.3.1. *Manufacturer*—Before any testing, the manufacturer shall contact the NTPEP Lead State or the NTPEP Coordinator and obtain a current copy of the Structural Steel Coatings Work Plan and all necessary application forms for submission of a coating system.

8.1.3.2. *NTPEP Lead State*—The NTPEP Lead State will provide reporting criteria and system numbers to the selected testing laboratory. The NTPEP Lead State will also determine the coating systems that shall be used as system monitors for the testing.

8.1.3.3. *Testing Laboratory*—The following information will be provided to the NTPEP Lead State by the testing laboratory:

8.1.3.3.1. Identify what test the Principal Testing firm will perform. Provide Standard Operating Procedures for each test performed.

8.1.3.3.2. Identify what tests will be performed by an authorized outside firm, the name, address and telephone number of the firm and the contact person for the firm. Provide Standard Operating Procedures for each test performed by the authorized outside firm.

8.1.4. The Principal Testing firm performing the testing shall be responsible for application of protective coatings to test panels.

8.1.5. Upload testing results for all samples, panels, or tests performed to the appropriate SSC Module of DataMine. Manufacturers will be allowed the option of not having the final test results for their system made public information.

8.2. *Test Panel Requirements for Test (Applicable to Test Nos. 2 through 8)*

8.2.1. All steel test panels, except Test No. 4 panels, shall be ASTM A 36 or A 572 hot-rolled steel or equivalent with dimensions shown below. Certified mill test reports shall be provided as prepared by the steel manufacturer or testing laboratory for all ASTM A 36 or A 572 steel identifying actual physical and chemical analysis of the material. Test panels for Test No. 4 shall be standard Taber panels, meeting the requirements of ASTM D 4060.

Test Panel Dimensions

Test	Width (mm)	Length (mm)	Thickness (mm)
2,3,5,6	100	150	6
8	102	305	6

8.2.2. Three test panels shall be prepared for each complete system for each test, except Test 8, which shall require five. Test 5 requires three additional test panels to be prepared with the primer only. Test 3 requires three additional test panels to be prepared. The additional panels for Test 3 shall not be scribed.

8.2.3. Control panels shall be coated in bulk lots by a single applicator for use by all selected laboratories. The location and date of application shall be reported. All control panels utilized during the testing evaluation of a system shall be from the same lot. The quantity of control panels to be coated, the control system to be used, and the application parameters shall be approved by NTPEP. During transportation and storage, control panels shall be protected such that coating damage will not occur. Beyond 30 days, the storage temperature and relative humidity for these panels shall be 25 ± 5°C and 50 ± 20 percent.

8.2.4. The panels shall be cleaned in accordance with SSPC-SP 5 using recyclable metallic abrasives in accordance with SSPC AB3. The abrasives shall have a maximum chloride content of 15 ppm determined in accordance with ASTM D 512 and a maximum conductivity of 150 micromhos per cm determined in accordance with ASTM D 4940. The abrasive mixture shall be approximately 60 percent SAE shot number S230 and 40 percent SAE grit number G40. Both the shot and grit shall have a Rockwell hardness of C 45 ± 3. The surface profile of the cleaned panels shall be 65 to 90 µm when determined in accordance with ASTM D 4417, Method C. The profile shall be clean, sharp, and free of embedded friable material, with adequate roughness to insure effective adhesion of the applied primer.

Note 2—The SP 5 is required rather than SP 10 only for the convenience of the laboratory in order to guarantee that all panels are prepared identically and to assure comparative testing results. Steel surfaces prepared to a lesser degree may not yield same performance.

8.2.5. Each coating shall be applied within the dry film thickness (DFT) range recommended by the manufacturer. If no DFT range is recommended, apply the coating at the recommended DFT ± 13 µm.

8.2.6. *Dry Film Paint Thickness*—The dry film paint thickness shall be taken in accordance with ASTM D 7091, with the following exception:

8.2.6.1. Measure the dry film coating thickness on each test panel utilizing a Type II dry film thickness gauge calibrated according to SSPC PA2 as follows: Take two gauge readings from the top third, the middle third, and the bottom third of the test panel. Readings should be taken at least 25 mm from any edge. To facilitate consistent measurements at fixed positions on the panel, the laboratory shall use a template providing six fixed locations on the panels. Discard any gauge reading that cannot be repeated consistently. The average of the acceptable gauge readings shall be no less than the manufacturer's recommended thickness. No single gauge reading shall be less than 80 percent of the manufacturer's recommended minimum. The average of the acceptable gauge readings shall be no more than 120 percent of the manufacturer's recommended maximum. Recommended maximum dry film thickness must be detailed on the product submission.

8.2.6.2. All products shall be applied using proper airless equipment except when this method is specifically not allowed by the coating manufacturer. All coatings shall be applied to panels mounted vertically at a distance of 530 mm from the tip of the spray gun. The equipment shall be capable of developing sufficient pressure to properly atomize the coating. Orifice size, application pressure, pump type and ratio, hose size and length, and any atypical application requirements shall be recorded. If the pressure used varies by more than 10 percent from the suggested pressure listed in the manufacturer's application data information, the actual pressure used and a statement explaining the deviation shall be provided in the final report.

8.2.7. For testing purposes the color of the final topfinish coat shall conform to Federal Standard No. 595 Color Chip No. X6134 (grey) ("X" signifies that the gloss is undesignated). Acceptable finish coat color shall be within 3.0Δ* of the required standard.

8.2.8. Each sample shall be marked and identified by a NTPEP-assigned system code number. The identification code number shall be placed on the back of each panel with permanent yellow paint stick. It will also be typed and placed in front of the corresponding panel when photographs are taken. The number will have a minimum height of 10 mm and will identify the following information, which will be part of the final report:

8.2.8.1. Test number being performed.

8.2.8.2. Replica test being performed (i.e., salt No. 3).

8.2.8.3. Date of panel preparation.

8.2.8.4. Date that the test evaluation was performed.

8.2.9. Coatings shall be applied to test panels at the minimum (laboratory) recoat time as defined in Section 3 of this specification. Curing of the coated test panels, for the complete system, shall be a minimum of 30 days and no more than 45 days. The curing climate shall be at 25 ± 2°C and 55 ± 5 percent relative humidity. The back of all test panels shall be coated with the primer for one and two coat systems and primer and intermediate for three coat systems.

8.2.10. After preparation of the test panels with the coating system to be evaluated, the edges shall be sealed and protected by applying vinyl tape around the entire outside edge. The vinyl tape shall extend 5 mm onto the coated surface from the edge of the panel and shall be applied after the coating has cured. The vinyl tape shall meet the requirements of CID A-A-1689B and have an approximate vinyl thickness of 110 µm with an approximate neoprene adhesive thickness of 25 µm.

8.2.11. Test panels shall be scribed in accordance with ASTM D 1654 with parallel 100 mm lines centered on the panel 25 mm from the edges of the panel and separated by 50 mm. The scribing tool shall be a straight-shank tungsten carbide tip, lathe cutting tool (ANSI B94.50, Style E). The entire length of the scribe shall expose the steel substrate as verified with a microscope.

8.3. Photographic Requirements (applicable to Test Nos. 1 through 7).

8.3.1. Color photographs of each sample or panels shall be taken as follows:

8.3.1.1. All photographs shall include the code identification number for each sample or panel and the number of hours.

8.3.1.2. A photograph of the coated surface of each sample or panel shall be taken after the application of the entire system to be evaluated.

8.3.1.3. *Test No. 1*—Surface of each sample prior to and after each test.

8.3.1.4. *Test No. 2 and No. 3*:

8.3.1.4.1. Each time frame designated.

8.3.1.4.2. The panel shall be photographed and its condition documented at the end of every third 336-hour cycle for the ASTM D 5894 Cyclic Weathering Resistance Test and 1,000 hours for ASTM B 117 Salt Fog Resistance Test.

8.3.1.4.3. Rust creepage evaluation: (1) after washing and prior to scraping of the scribe, and (2) after scraping of the scribe.

8.3.1.5. *Test Nos. 4, 5, and 6*—At the completion of each test.

8.4. *Dry Film Paint Thickness*—The dry film paint thickness shall be taken in accordance with ASTM D 7091, with the following exception.

8.4.1. Measure the dry film coating thickness on each test panel utilizing a Type II dry film thickness gauge calibrated according to SSPC PA 2 and as follows: Take two gauge readings from the top third, the middle third, and the bottom third of the test panel. Readings should be taken at least 25 mm from the edge. To facilitate consistent measurement at fixed positions on the panel, the laboratory shall use a template, providing six fixed locations on the panels. Discard any gauge reading that cannot be repeated consistently. The average of the acceptable gauge readings shall be no less than the manufacturer's recommended minimum thickness. No single gauge reading shall be less than 80 percent of the manufacturer's recommended minimum. The average of the acceptable gauge readings shall be no more than 120 percent of the manufacturer's recommended maximum. Recommended maximum dry film thickness must be detailed on the product submission.

9. TESTS TO BE PERFORMED BY SELECTED LABORATORY

9.1. *Test No. 1*—Slip Coefficient Test.

9.1.1. All primers shall be tested and the results reported for slip coefficient according to the *Standard Specifications for Highway Bridges*, Division I, Section 10.32.3.3.3. Tests are to be performed in accordance with "Appendix A, Testing Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints," *Specifications for Structural Joints Using ASTM A 325 or A 490 Bolts*, as adopted by the Research Council on Structural Connections (RCSC). Primers with a slip coefficient of not less than 0.5 shall meet Class B.

9.1.2. *Sample Preparation Requirements for Slip Coefficient*:

9.1.2.1. The surface shall be prepared in accordance with SSPC-SP 5. The surface shall be abrasive blasted using 100 percent steel shot (selected to create a worst-case scenario). The steel shot shall conform to the requirements of SAE shot number S 280 and SSPC AB-3. The steel shot shall have a hardness of Rockwell C 45 ± 3. The surface profile shall be between 50 and 90 μm as determined using ASTM D 4417 Method C.

9.1.2.2. The thickness of coating to be tested on each surface shall be 50 μm greater than the film thickness recommended in Section 6.4.3.10.1. The maximum thickness tested shall be reported by the testing laboratory.

9.1.2.3. A minimum cure time as recommended by the manufacturer is required for primer testing. Curing of the coated test panels shall be 25 ± 2°C and 65 ± 5 percent relative humidity.

9.2. *Test No 2*—Salt Fog Resistance Test.

9.2.1. A salt fog resistance test shall be performed in accordance with ASTM B 117. The complete system shall be exposed for durations of 4,000 and 5,000 hours.

9.2.2. *Evaluation*—Evaluate each panel for Blistering and Rust Creepage at each 1,000-hour increment of exposure and after scraping in accordance with ASTM D 1654, Method 2, Scraping, (where applicable after cleaning).

9.2.2.1. Blistering shall be evaluated in accordance with ASTM D 714. Blister size and frequency shall be converted to a numerical value using Table 1.

Table 1—Blister Value Conversion Table (No blisters equals a conversion number of 10.)

Blister	Blister Frequency			
Size	Few[a]	Medium	Medium Dense	Dense
#8	9	8	7	6
#6	8	7	6	5
#4	7	6	5	4
#2	6	5	4	3
#1	5	4	3	2

[a] Adjustment Values for "Few" Blister Frequency.

Number of Blisters	Value
1	x.8
2	x.6
3	x.4
4	x.2
5 or more	x.0

Note: If a specific number of blisters is reported under the frequency "Few" then use the appropriate decimal "Value" provided above. Example: A report of two #6 blisters converts to a value of 8.6.

9.2.2.2. *Rust Creepage at the Scribe*—Rust creepage (a.k.a. cutback, undercut, loss of adhesion, deterioration, disbondment) shall be measured perpendicular from the center of the scribe to the furthest point of cutback. Cutback shall be measured in millimeters to the nearest 0.5 mm. For both intermediate and final evaluations, the maximum cutback shall be measured at 5-mm intervals along the scribe on each side of the scribe. (For each 100-mm scribe line, 40 measurements are required.) Report the average and maximum cutback measurements. Defects at the scribe having the appearance of a "blister" will be defined to be rust creepage (cutback).

9.3. *No. 3*—Cyclic Weathering Resistance Test.

9.3.1. A cycling weathering resistance test shall be performed in accordance with ASTM D 5894 for the following durations:

Test Panel Cycle Requirements

	(Number of 336-h Cycles)				
Test Panels: Complete System	3	6	9	12	15

9.3.2. Color change testing shall be performed in accordance with ASTM D 2244 to obtain calculations of color differences from instrumentally measured color coordinates CIE 1976 L*a*b*. Testing shall be performed in accordance with ASTM E 1349 using Illuminant D 65 and 2-degree observer. Report color changes as ΔE*. Specular gloss retention shall be performed in accordance with ASTM D 523 using an incidence angle of 60 degrees. The difference in color, gloss values, and percent of gloss retention shall be reported.

9.3.3. *Evaluation*—Follow evaluation procedures of Section 9.2.2. All testing intervals shall be evaluated.

9.4. *Test No. 4*—Abrasion Resistance Test.

9.4.1. A test for abrasion shall be performed in accordance with ASTM D 4060 using CS-17 wheel and 1 kg weight for 1,000 cycles. The test shall be performed on panels coated with the full system to be tested (i.e., primer/intermediate/finish). The hardness of the abrasive wheel shall be checked in accordance with ASTM D 2240 for each test performed.

9.4.2. *Reporting Data*—The system shall be tested to identify its “wear index” in milligrams per cycle and “weight loss” in milligrams.

9.5. *Test No. 5*—Adhesion Test.

9.5.1. A test for adhesion shall be performed in accordance with ASTM D 4541, using a Type IV tester as described in Annex A, Section A4. The adhesive used to perform this test shall be a two-component epoxy, containing no solvents (e.g., 100 percent solids). The test shall be performed on panels having the primer coat only and on panels having the complete system. A minimum of four tests shall be performed on each panel.

9.6. *Test No. 6*—Freeze Thaw Stability.

9.6.1. Prepared panels shall be exposed to a 30-day freeze/thaw/immersion cycle. One 24-h cycle shall consist of 16 h at –30 ± 5°C followed by 4 h of thawing at 50 ± 5°C and four hours tap water immersion at 25 ± 2°C. This work is done with the panels remaining in the freezer mode on weekends and holidays. Upon completion of the test, adhesion tests shall be performed as required in Section 9.5.

9.7. *Test No. 7*—Coating Identification Tests.

9.7.1. An analysis of vehicle solids by Fourier transform infrared (FT/IR) spectroscopy consisting of 32 scans minimum per sample shall be performed as follows:

9.7.1.1. For zinc primer solvent-based coats infrared spectrum (2.5 to 15 µm) of each liquid vehicle component via the potassium bromide sandwich technique.

9.7.1.2. For two-component, solvent-based finish coats infrared spectrum (2.5 to 15 µm) of each single component via the potassium bromide sandwich technique, and of the mixed and dried components in appropriate mixing ratios (dried film) via the potassium bromide single-pellet technique.

9.7.1.3. For zinc primer water-based coats infrared spectrum (2.5 to 15 µm) of the liquid vehicle component after drying and applying the potassium bromide single-pellet technique.

9.7.1.4. For two-component water-based finish coats infrared spectrum (2.5 to 15 µm) of each single component after drying and applying the potassium bromide single-pellet technique and also, of the mixed and dried components in appropriate mixing ratios (dried film) via the single-pellet technique.

9.7.2. The volatile organic compound (VOC) content shall be determined on unthinned, mixed coatings in accordance with the ASTM D 3960 for primers, intermediates, and finish coats. Multi-component coatings will be blended together in the specified mixing ratios prior to testing.

9.7.3. Analyze mixed coatings for total heavy metals content (lead, chromium, and cadmium) in accordance with ASTM D 3335 and D 3718.

9.7.4. Dry film analysis for leachable heavy metals shall include Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, and Silver for each coating. The dried film shall be removed from a non-metallic glass test panel and pulverized to pass through a 250-µm sieve. The pulverized film passing the 250 µm sieve shall be extracted in accordance with the TCLP, Method 1311 of EPA SW 846. The extract shall then be analyzed for heavy metals using the appropriate EPA SW 846 test method for each metal.

9.7.5. Epoxide values can be determined in accordance with ASTM D 1652, Method A. This method measures a quantity called the weight per epoxy equivalent (WPE), which is defined as the grams of resin containing one gram equivalent of epoxy groups. However, since this method was intended for raw materials, the WPE of the epoxy component of a two-component coating will actually be the grams of that component (not the grams of actual resin) which contains one gram equivalent of epoxy groups.

9.7.5.1. For clear components, the method can be used as written. For pigmented compounds, the sample must first be weighed into a centrifuge tube, then thinned 50 to 100 percent with xylene or toluene. If a glass stirring rod is used to aid in dispersing the sample in a thinner, it may be necessary to use an additional small amount of thinner to rinse residues off of the rod and back into the centrifuge tube.

9.7.5.2. The sample is then centrifuged to remove the pigment, and the supernatant should then be transferred to the container in which the ASTM D 1652 procedure will be done. The pigment in the bottom of the centrifuge tube should then be redispersed in 2 or 3 mL of solvent, recentrifuged, and the supernatant combined with the original supernatant for analysis.

9.7.6. Amine values can be determined on the amine or amidoamine contained in the appropriate component of two component epoxy coatings, in accordance with ASTM D 2073. This method is only applicable to clear, unpigmented component. If the component is pigmented, the following modification to ASTM D 2073 will be necessary:

9.7.6.1. Weigh 1.0 g of the pigmented component to the nearest 0.1 mg into a glass centrifuge tube and thin with approximately one milliliter of methylene chloride. If a glass stirring rod is required to disperse the pigmented component with the methylene chloride, it may be necessary to use a small additional amount of methylene chloride to rinse any material off of the glass stirring rod before removing it from the centrifuge tube.

9.7.6.2. Separate the pigment by high-speed centrifugation, and transfer the supernatant into a 25-mL low-form beaker. The pigment in the bottom of the centrifuge tube should be redispersed in an additional 2 to 3 mL of methylene chloride, recentrifuged, and the supernatant combined with the original supernatant for analysis. At this point, follow the titration procedure described in ASTM D 2073.

Note 3—Even though the titration is followed potentiometrically and the end points will not be obscured by the color of the pigment, the pigment must still be removed to prevent the possibility of any basic pigments reacting with the hydrochloride acid used in the titration procedure.

9.7.7. Isocyanate group content will be determined in accordance with T 339.

9.7.8. The presence of hindered amine light stabilizers (HALS) in the polyol portion of a two-component urethane coating will be verified in accordance with T 338.

9.7.9. Verify the following coating characterization tests reported by the manufacturer for mixed single and multiple component coatings. Also, perform single component characterization on multiple component coatings for the properties noted below with an asterisk:

9.7.9.1. *Total solids, percent by mass in accordance with ASTM D 2369.

9.7.9.2. Volatile organic compound content in accordance with ASTM 3960.

9.7.9.3. EPA exempt solvents, identify compound and percent by volume.

9.7.9.4. Water, percent by mass, in accordance with ASTM D 4017.

9.7.9.5. *Pigment, percent by mass, in accordance with ASTM D 2371 or D 3723.

9.7.9.6. Metallic zinc content, percent by mass, in the primer shall be determined in accordance with ASTM D 6580. An optional test method is T 337.

9.7.9.7. *Total solids, percent by volume, in accordance with ASTM D 2697.

9.7.9.8. *Mass per volume (grams per liter) in accordance with ASTM D 1475.

9.7.9.9. *Viscosity (Stormer at 25°C) KU in accordance with ASTM D 562 (not suitable for viscosities above 143 KU).

9.7.9.10. *Viscosity (Brookfield at 25°C) cP in accordance with ASTM D 2196. The instrument model (i.e., LV, DV, DVII+), spindle size, and revolutions per minute shall be reported.

9.7.9.11. Pot life in hours, at specified temperature and specified humidity, shall be evaluated in the laboratory through viscosity measurements taken at regular intervals and reported in Krebs Units. Materials with manufacturer's stated pot life shall be evaluated at 25, 50, 75, and 100 percent of the stated pot life. Materials without manufacturer's stated pot life shall be evaluated at 2-h increments for 8 h.

9.7.9.12. Sag resistance (Leneta) in micrometers wet film thickness in accordance with ASTM D 4400.

9.7.9.13. Rating of application properties, including mixing, setting, and ability to spray, shall be evaluated and reported in accordance with Annex A1.

9.8. *Test No. 8*—2-Year Atmospheric Testing.

9.8.1. Each complete system shall be subjected to a 2-year atmospheric test at a location designated by the NTPEP Structural Steel Coatings project panel. The distance from high tide to the ocean side test fence shall be monitored every 30 days. This data shall be included in the final report from the test facility. The test panels shall be exposed within 10.7 m of the ocean from the fence. Corrosion rate of bare steel shall be measured in accordance with ASTM G 92. The bare steel panels used to monitor rate of corrosion shall be from the same heat of steel as the test panels.

9.8.2. Five test panels meeting the materials, surface preparation, application, and curing requirements of Section 8.2 shall be prepared with the complete system. Panels shall be a 6 by 102 by 305 mm with a single 100-mm scribe in the center of the panel. The panel edges shall be coated up to 6 mm in from the edge with an embedding compound, such as Morton International 1-12 epoxy resin, after the complete system has cured. Panels will be oriented to face the ocean and be inclined from the oceanside at an angle of 30 degrees from level along the long leg. The panels shall be exposed for 2 years and then inspected and photographed in accordance with ASTM D 1654, D 610, and D 714. Total UV, total solar energy, temperature (minimum, maximum, average), relative humidity (minimum, maximum, average), average dew point, time of wetness, and rain fall will be monitored and documented in a monthly summary. These values will be made part of the final report.

10. INSPECTION OF TESTING

10.1. Authorized specifying agency representatives will be permitted (at any time) access to inspect testing procedures being performed and/or review test records of any coating systems being evaluated under this specification.

11. TEST REPORT AND PROTECTIVE COATING INFORMATION

11.1. The principal testing firm will be responsible for compiling and entering all required data into the Structural Steel Coatings Module for Data Mine.

11.2. The required data shall, at a minimum, consist of the following:

11.2.1. Digital color photographs.

11.2.2. Individual test results for each test performed.

11.2.3. Specification information for the specific coating system contained in the report as follows:

11.2.3.1. Name, address, telephone number, and fax number of the manufacturer, and the manufacturer's technical representative.

11.2.3.2. Product name and/or identification number for each coating tested (primer, intermediate, and finish coat).

11.2.3.3. The manufacturer's recommended minimum and maximum dry film thickness (in micrometers) for each coating (primer, intermediate, and finish coat).

11.2.3.4. The manufacturer's recommended minimum (recoat) time, (hours), with specified temperature (°C), and relative humidity (%) for each coating.

11.2.3.5. Requirements of Section 7.

11.3. Certificate of Testing (see Figure 1) uploaded to DataMine as a portable document file (PDF).

ORGANIZATION LETTERHEAD
(Testing Firm)

“AASHTO” CERTIFICATE OF TESTING

We hereby certify that this coating system manufactured by

____(coating manufacturer)

______________________ ______________________ ______________________,
(prime coat) (intermediate coat) (finish coat)

was tested in accordance with the requirements for each applicable test as defined by AASHTO R 31, its support specifications, and that all information presented is truthful and without bias.

All record and documents pertaining to this certificate and not submitted herewith will be maintained available by the undersigned for a period of not less than seven years.

(OPTIONAL)

(1) ______________________________________
(Signature of Manufacturer’s Representative)

____
(Name–Type or Print)

(2) ______________________________________
(Signature of Testing Supervisor)

____
(Name–Type or Print)

(3) ______________________________________
(Signature of Principal–Testing Firm)

____
(Name–Type or Print)

Title:______________________________________
(Title of Testing Firm Principal)

Subscribed and sworn before me this

______day of ___________, 20 _______

____
(Notary Public)

with commission expiring on ___________
(date)

Figure 1—Certificate of Testing

12. REQUALIFICATION

12.1. Requalification shall occur every 5 years from the date of system acceptance. If changes in formulation occur at any time, complete retesting will be required. Any change in an ingredient amount, quality, or type will constitute a formulation change. If the formulation has remained unchanged, the 5-year requalification will include only the physical property tests, and chemical property tests (includes instrumental identification test). Requalification at 10 years will require complete retesting. Continued requalification will require this testing cycle be continued at 5-year intervals. Significant changes in the testing standard could result in partial or complete retesting at the end of any 5-year cycle.

ANNEX

(Mandatory Information)

A1. RATING OF APPLICATION PROPERTIES

A1.1. *Scope*—The Testing Laboratory shall include ratings for each of the following parameters. Products requiring special application procedures or equipment by manufacturers' recommendation shall also be detailed in the report.

A1.1.1. *C1 Mixing*—During mixing of the products, evaluate each product on a 10-to-1 scale. Place a checkmark across from the mixing characteristic exhibited by the product.

Characteristic	Rating	√
One component—Little or no settling; easily mixed by hand	10	☐
One component—Some settling, but easily mixed by hand.	9	☐
One component—Blends easily when mixed with mechanical agitation, typically in less than thirty seconds with 3/8" drill motor and a jiffy mixer for a gallon sample.	8	☐
One component—Mixes with some difficulty, typically requiring more than three minutes with 3/8" drill motor and a jiffy mixer for a gallon sample. **Two components**—Both components and their blend mix easily as defined in Rating 8.	7	☐
One component—Mixes with difficulty, typically requiring more than three minutes with 3/8" drill motor and a jiffy mixer for a gallon sample. Settled layer about one inch thick or very hard to agitate. Thin material on top requires effort to prevent splash out of can. **Two components**—Both components settled and mixed as defined in Rating 7; blend mixes easily or one of the components is a powder.	6	☐
One component—Same as Rating 6, but had to scrape bottom of can. **Two components**—One of the components mixes with difficulty as in Rating 6. Blend settles ten to thirty minutes after mixing; continuous agitation required. **Multi-component systems**—One of the components is a powder. All components and their blend mix easily.	5	☐
One component—Extremely thick; must first break up settled material by hand, then mix with power equipment. **Two components**—Both components mix with difficulty as in Rating 6. **Multi-component systems**—One of the components is a powder and one of the liquid components is difficult to mix as in Rating 6.	4	☐
Two components—One of the components is extremely thick. Must first break up settled materials by hand, then mix with power equipment. **Multi-component systems**—One of the components is a powder and both the liquid components are difficult to mix as in Rating 6.	3	☐
Considerable effort is needed to mix products with normal job site mixing equipment.	2	☐
Heavily settled; cannot re-disperse products with normal job site mixing equipment.	1	☐

A1.1.2. *C2 Spray-Ability*—During the spraying of the products, evaluate their respective atomization characteristics on a 10 to 1 scale. Place a checkmark across from the atomization characteristic(s) exhibited by the product.

Characteristic	Rating	√
Excellent Atomization—Excellent definition to spray pattern. No runs or sags if sprayed in one pass. Easy to control film build. No tip plugging. Positive shut off of coating material at tip. No dripping from spray tip. No mist coat required.	10	☐
Good Atomization—Good definition to spray pattern. No runs or sags if sprayed in one pass. Easy to control film build. No tip plugging, but some build-up on spray tip. Mist coat required to prevent out-gassing. Less than 2-minute wait necessary between mist and full coats.	9	☐
Atomizes satisfactorily, but lacks some definition of spray pattern—Less than two tip plugs per gallon. Some build-up on spray tip. Mist coat required to prevent out-gassing. Two 5-minute waits necessary between mist and full coats.	8	☐
Atomizes satisfactorily, but lacks definition of spray pattern—Two to four tip plugs per gallon. Spray tip requires occasional wiping. Mist coat somewhat difficult to apply consistently over the surfaces.	7	☐
Atomizes, but poor definition of spray pattern—Four to six tip plugs per gallon. Frequent drips from spray tip. Mist coat difficult to apply consistently over the surfaces.	6	☐
Poor atomization with airless, but coating levels satisfactory—Seven or more tip plugs per gallon. Consistent mist coat cannot be applied without multiple passes. Some out-gassing evident.	5	☐
Poor Atomization with airless, and coating levels poorly—Consistent mist coat impossible to apply. Out-gassing impossible to eliminate.	4	☐
Cannot be applied using airless equipment, but can be applied satisfactory with conventional equipment.	3	☐
Can be sprayed with conventional equipment with special effort.	2	☐
Cannot be sprayed with conventional or airless equipment.	1	☐

A1.1.3. *C3 Settling*—During the application of the products, evaluate the settling characteristics of the mixed coating on a 10-to-1 scale. Place a checkmark across from the settling characteristic(s) exhibited by the product.

Characteristic	Rating	√
No agitation required after mixing.	10	☐
No agitation required after mixing, but settles over night (16 h).	9	☐
No agitation required after mixing, but settles in 8 h.	8	☐
Agitation required, some settling after 4 h.	7	☐
Agitation required, some settling after 2 h but not noticeable settling in 30 min.	6	☐
Agitation required, some settling after 1 h but not noticeable settling in 30 min.	5	☐
Settles in 10 to 30 min, material easily re-dispersed with stirring stick	4	☐
Settles in 10 to 30 min, mechanical agitation required to re-disperse material.	3	☐
Settles in less than 10 min.	2	☐
Falls out of suspension immediately. Cannot maintain suspension.	1	☐

APPENDIXES

(Nonmandatory Information)

X1. CHARACTERIZATION TESTS FOR PRODUCT VERIFICATION

X1.1. The following tests are recommended for determining if the coatings supplied are the same quality as the manufacturer's materials originally tested and certified for acceptance. The most pertinent and feasible ones may be selected to verify compliance.

X1.1.1. *Group I Tests*—Most commonly used tests.

X1.1.1.1. Infrared analysis: see requirements of Section 9.7.1.

X1.1.1.2. For zinc prime coats infrared spectrum (2.5 to 15 µm) of non-zinc containing vehicle component(s).

X1.1.1.3. For two-component finish coats infrared spectrum (2.5 to 15 µm) of each single component and also of the mixed components (when applicable) in appropriate mixing ratios.

X1.1.1.4. Viscosity of mixed coating and individual components determined in accordance with ASTM D 562.

X1.1.1.5. Mass per volume (grams per liter) of mixed coating and individual components in accordance with ASTM D 1475.

X1.1.1.6. Total solids, percent by mass of mixed coating and individual components in accordance with ASTM D 2369.

X1.1.1.7. Dry time of mixed coating in accordance with ASTM D 1640.

X1.1.1.8. Pigment, percent by mass of total solids of mixed coating and individual components in accordance with ASTM D 2371.

X1.1.2. *Group II Tests*—Less frequently used tests because they pertain to zinc content and are useable only with zinc primers.

X1.1.2.1. Metallic zinc, percent by mass in the primer; see requirements of Section 6.4.3.3.

X1.1.2.2. Total zinc, percent by mass of pigment (zinc dust) in accordance with ASTM D 521.

X1.1.2.3. Metallic zinc, percent mass of pigment (zinc dust) in accordance with T 337.

X1.1.2.4. Zinc oxide, percent mass of pigment (zinc dust) in accordance with ASTM D 521.

X1.1.2.5. Lead and cadmium content of the mixed coating in accordance with ASTM D 3335.

Note X1—The coating evaluation tests use standard colors for uniform analysis of results. Use of different colors than those tested may change some of the baseline parameters.

X2. GUIDE FOR PROJECT VERIFICATION TESTING

X2.1. The extracted pigment upon analysis shall conform to the originally approved batch and the pigment content, percent by mass, shall not vary more than –2 percent or +3 percent. Allowances for the finish coats will be permitted in order to produce the desired color.

X2.2. *Vehicle*:

X2.2.1. The vehicle solids shall not be more than ±2 percent from the initially approved batch.

X2.2.2. The infrared spectra of the vehicle/resin shall match that of the initially approved batch.

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[1] Available from GSA Specification Department, Federal Supply Services, Specification Section, 470 East L'Enfant Plaza, S.W., Suite 8100, Washington, DC 20407.

[2] Available from The Society for Protective Coatings, Bldg. 40, 24th Street, Pittsburgh, PA 15222-4645.

[3] Available from GSA Specification Department, Federal Supply Services, Specification Section, 470 East L'Enfant Plaza, S.W., Suite 8100, Washington, DC 20407.

[4] Available from American Institute of Steel Construction, Inc., One East Wacker Drive, Suite 3100, Chicago, IL 60601-2001.

Standard Specification for

Inertial Profiler

AASHTO Designation: M 328-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Inertial Profiler

AASHTO Designation: M 328-10

1. SCOPE

1.1 The objective of this specification is to define the required attributes of an inertial profiler which, when combined with an operator, becomes a complete inertial profiling system (IPS). The system may be used to measure a longitudinal pavement profile for construction quality control and acceptance or for network data collection. The equipment may be added to a host vehicle as a single-function device or a component of a multifunctional data collection device. The equipment shall be able to calculate summary roughness indices, particularly the International Roughness Index (IRI). This specification is designed to apply to both low-speed and high-speed profilers.

1.2 The equipment shall be capable of outputting the pavement elevation profile as a temporary display, a printed record, and a data file.

1.3 It is not the intent of this specification to relieve the supplier from the final responsibility to provide an appropriate product for the intended function, nor is it intended to specify all the design details. The objective is to provide a sufficiently detailed specification that the function is clearly defined. It is intended to be sufficiently detailed that the data collected from multiple profilers will be identical.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- R 56, Certification of Inertial Profiling Systems

2.2 *ASTM Standards*:

- E 867, Standard Terminology Relating to Vehicle-Pavement Systems
- E 1926, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements
- E 2560, Standard Specification for Data Format for Pavement Profile

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *accelerometer*—transducer that provides an output proportional to acceleration.

3.1.2 *aliasing*—the term used to describe the error that can result when a signal is sampled at a rate less than twice the frequency of the various sinusoidal components that compose the signal. To avoid aliasing, the signal is band limited so that the sampling frequency used will be greater than twice as high as the highest frequency component in the signal. It is also described as the error that results from sampling a long wavelength signal that is mixed with a short wavelength noise signal.

3.1.3 *anti-aliasing filter*—a low-pass analog filter that suppresses short wavelength contamination of longer wavelength measurements to improve the accuracy of the sampling process.

3.1.4 *continuous IRI*—a series of IRI values calculated over a running interval, one for each profile data point throughout the test section. Each IRI value is provided at the midpoint of the running interval.

3.1.5 *filtering*—procedure to extract desired information from a signal that also contains unwanted information (commonly called noise). Digital filtering is a calculation procedure that takes one set of numbers and transforms them into another set in which the noise is reduced. Moving average is one type of such transformation or filter.

3.1.6 *index*—measure or standard. Within the context of this test method, a suitably chosen index quantifies the ride quality of a pavement.

3.1.7 *inertial profiler*-the combination of the profiling equipment and the host vehicle.

3.1.8 *low-pass filter*—smoothing type filter that reduces the effect of short wavelengths that are associated with rapid elevation changes such as expansion joint ribs.

3.1.9 *measurement range*—the detectable range of heights, accurately measurable by the sensor.

3.1.10 *moving average*—filtering process whereby each data point is replaced with the average value of several adjacent points or elevations. It is a smoothing process because the changes from one elevation point to the next will not be as significant due to the fact that that difference has been divided by the total number of data points in the averaging scheme. It is a type of low-pass filter.

3.1.11 *profile*—two-dimensional slice of the roadway surface, taken along an imaginary line, such as the wheel path, in the longitudinal or travel direction. It represents the perpendicular deviations of the pavement surface from an established reference parallel to the horizontal.

3.1.12 *repeatability*—consistency in successive measurements of the same quantity. It is a quantifier of the variability in measurement error.

3.1.13 *report interval*—the travel distance between the outputs of a profile *index* value.

3.1.14 *roughness*—according to ASTM E 867, the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage.

3.1.15 *running interval*—set longitudinal distance that is stepped through a test segment by an increment shorter than its length.

3.1.16 *sample interval*—the longitudinal distance between data capture points. The data include location, height, and accelerometer values. These data points are combined to create one profile data point. These points, in turn, may be combined to create a final value in the reported profile.

3.1.17 *sampling rate*—the rate at which the height sensor measures vertical displacement. A typical sampling rate provides many height measurements from which a single value is derived for reporting at the sample interval.

3.1.18 *sensors*—devices that measure physical quantities. They are responsive to a change in a physical measurement such as distance, temperature, and acceleration.

3.1.19 *transducer*—device that converts variables of one type (i.e., distance,) into those of another type (i.e., voltage). These conversions must conform to a known transformation (i.e., proportional) to be useful.

4. GENERAL EQUIPMENT REQUIREMENTS

4.1 *General*—The equipment shall function independently from the vehicle suspension dynamics and vehicle speed throughout the operating range of 20 to 70 mph for high-speed profilers and less than 25 mph for low-speed profilers.

Note 1—Due to system dynamics, profiles collected at low speeds may require a governor to keep the speed constant.

4.1.1 The equipment shall be equipped with various sensors, interface hardware, computer hardware, and software that, working together, perform the measurement and recording of the longitudinal profile. The profile of the traveled trace(s) is the combination of a processed elevation and the distance traveled. The data shall be stored internally during the test and transferable onto suitable high-density removable storage media after the test. The computer shall have the capability to process the collected data, to display and print the derived profile(s), and to report industry standard indices, including IRI. The computer shall be capable of producing profile files in formats described by University of Michigan Transportation Research Institute as an .ERD and by ASTM E 2560.

4.1.2 The equipment shall mount on or in the host vehicle with minimum disturbance to the vehicle and in a fashion that the driver or a passenger can conveniently and safely operate it.

4.2 *Measuring Profile*—The longitudinal pavement profile shall be measured using equipment in which three primary transducers are used. These transducers include (1) a height sensor that measures the distance between a vehicle reference point and the pavement while the vehicle is traveling; (2) an accelerometer that measures the vertical acceleration of the vehicle as it moves vertically in response to the pavement profile; and (3) a distance sensor that provides a location reference for the vehicle as it travels. The run-time software and post-processing software shall be used to combine these three measurements so that the effects of the vertical vehicle movement are eliminated, leaving the pavement profile of the traveled pavement. Each height sensor shall have an individual accelerometer to determine its reference plane.

4.2.1 In addition to a manual triggering system, an automated triggering system shall be provided that detects a reference mark to start, stop, and event mark the data collection process. The triggering system shall be capable of repeatability within 6 in. over the range of operating speeds.

4.2.2 The equipment shall have an undistorted response (profile amplitude error of less than 5 percent and location error of less than 17 percent) for all wavelengths between 1.0 and 150 ft when operated between 20 and 70 mph for high-speed profilers and 15 and 25 mph for low-speed profilers. It shall also have a minimum of a 30 percent reduction in profile amplitude for wavelengths shorter than 0.5 ft and longer than 300 ft. [These are the typical set-points for filters currently provided on the equipment.] The filters will have a minimum of a 70 percent reduction for wavelengths shorter than 0.3 ft and longer than450 ft.

4.2.3 The equipment shall be capable of obtaining and storing profile measurement data at selected longitudinal distance intervals of the distance transducer. It shall be capable of determining a profile value (sampling interval) every 2.0 in. or less at the maximum collection speed of the vehicle.

4.3 *Calculating Roughness Indices*—The roughness of each profile trace shall be computed in post processing using the data collected and stored on either internal or external storage media. The IRI shall be calculated and reported as described in ASTM E 1926, in inches per mile or selected SI units as required. When multiple traces are measured simultaneously, each trace shall have independent results available as well as averages.

4.3.1 The roughness of each profile trace shall be produced using any user-selected report interval chosen for the calculation. A plot of roughness using any report interval shall also be printable.

4.3.2 The computer shall also be capable of calculating a continuous IRI with a relatively short running interval 25 to 528 ft and reporting the value and location of continuous IRI values above a user settable threshold.

4.4 *Calibration*—The equipment shall have built-in provisions to facilitate the calibration and verification of each transducer signal. Any external devices required for calibration shall be included with the equipment. In addition, it shall have an alarm system that alerts the operator if speed, height, or acceleration signals are out of range. These systems, in conjunction with a calibration protocol specified by the supplier, shall ensure the accuracy of the data.

5. EQUIPMENT

5.1 *General Requirements*—The profiler shall meet the following requirements:

1. The profiler shall be capable of measuring profile on pavement with an IRI range of 5 in. per mile to 300 in. per mile for a (0.1mile) interval.
2. The profiler shall measure longitudinal distance data in feet, meters, kilometers, and miles in an incrementing or decrementing mode from a selected starting point and relate the longitudinal distance to any test point. Optionally, the equipment may also report in station format (especially bump locations) for ease of contractor interface.

Note 2—The measurements taken on a specific lane can differ significantly from the project stations due to the horizontal and vertical curvature of the pavement.

5.2 *Functional Hardware Modules*—The following minimum specifications shall apply to the profiler:

(a) Roadway roughness testing shall be supported at vehicle speeds up to 70 mph for high-speed profilers and 25 mph for lightweight units.
(b) Operating ambient temperature range shall be 35 to 110°F; non-operating temperature range shall be 0 to 140°F.
(c) Operating humidity should not exceed 90 percent (noncondensing), nonoperating humidity range shall not exceed 100 percent (noncondensing).
(d) Power consumption of all installed equipment shall not exceed the capacity of the equipment providing operating power. Complete discharge of this system shall not impact the vehicle's regular electrical system.

Note 3—Local environmental conditions may require extending the suggested temperature limits.

5.2.1 *Processing Subsystem*—The Owner-Agency should specify the processing subsystem to be compatible with their existing computer systems as they may require. They should specify computer system parameters, including memory, operating system, interfaces, removable storage, etc. Equipment must be ruggedized for the mobile environment.

5.2.2 *Data Display*—Data display parameters shall be specified by the Owner-Agency. The size and type of display(s) as well as the format of the displayed data should be specified.

5.2.3 *Keyboard*—The keyboard shall be specified by Owner-Agency. Specify the type of keyboard required and any auxiliary devices such as event pads.

5.2.4 *Printer*—The printer shall be specified by Owner-Agency. Specify type of printer required. The profiler shall not require the printer in order to function and shall be able to collect data without the printer being present.

5.2.5 *Event Marker*—The profiler should have a method for marking or recording various points of interest or events in the measurement process, such as bridges, intersections, etc. The method should be user configurable to minimize its size and maximize its effectiveness.

5.2.6 *Data Acquisition System (DAS)*—All real-time data collection shall be provided by the hardware and software components of the DAS interfaced to the processing subsystem. The DAS may be contained within the physical space of the processing subsystem in whole or in part as required by the design. The DAS shall provide all interfaces to collect data; to derive distance, speed, and location; and to develop profile data from the transducers mounted on the vehicle. It shall activate the tests, process the trigger signals, and process operator inputs from the keyboard and shall pass information on the feature and its location to the processing unit for display and logging.

5.2.6.1 *Distance Transducer*—A vehicle-mounted distance transducer shall be provided to produce a pulse for units of distance traveled by the vehicle on the roadway. (Optionally, an electronic interface shall be provided for vehicles with electronic odometer or antilock brake system pulse signals.) The DAS shall accept these pulses and, in combination with the DAS software, shall determine distance traveled and vehicle speed. The computer shall process the signals and record the data from the unit. The calibration procedure shall establish and record the data to allow the recorded distance pulses to be interpreted into the desired measurement units selected by the operator. The measured distance shall be accurate to 0.15 percent per mile for test vehicle speeds up to the maximum specified for the equipment utilized.

5.2.6.2 *Height Sensor*—The reference height of the vehicle above the pavement shall be obtained through a noncontact height sensor module.

Provisions shall be made to allow an accelerometer to be mounted to the height sensor case. The sensor module shall communicate with and receive power from the DAS.

The height sensor shall have a resolution of at least 0.001 in. and a sufficient linear measurement range to cover the vehicle suspension motion and variation in pavement elevation. The height sensor shall operate at a sufficient sampling rate (typically 15 samples per inch or finer) to provide accurate coverage at the maximum operating speed for equipment utilized. This sample frequency allows for the implementation of an anti-aliasing filter and has sufficient short wavelength data for dropping outliers and the implementation of a tire bridging algorithm. Moisture (except freestanding), temperature, coarse pavements, or color changes in the pavement shall not affect the functionality of the sensor. The samples shall be stored referenced to time or distance, or both, so that the height data may be aligned with the accelerometer and position data to provide a longitudinal profile.

Note 4—Coarse surface textures, such as those found on open-graded surface mixes, chip-sealed, tined (transverse or longitudinal), or grooved pavement, for example, are very challenging to inertial profilers with dot, single point height sensors. Coarse texture is likely to adversely affect the repeatability and accuracy of the profile and the calculated index. Adherence to the requirements of this standard on smooth-textured surfaces does not guarantee acceptable performance of inertial profilers on coarse-textured surfaces. Certification testing on surfaces with the same texture type expected in the final application is required.

5.2.6.3 *Vertical Acceleration Sensor*—The vertical displacement of the height sensor that is used to calculate elevation shall be sensed using an accelerometer. The DAS shall provide hardware and software to amplify and filter/integrate the accelerometer signal as required to obtain the vertical displacement values for storage and for further post-processing into the required profile values. A minimum of one accelerometer shall be mounted in vertical alignment with each height sensor. It shall be rigidly mounted to the height sensor with its sensitive axis perpendicular to the pavement surface. The frequency response, signal-to-noise ratio, and precision of the accelerometer must be commensurate with those required of the final profile given the operating speed range of the test vehicle.

5.3 *Functional Software Modules*—The equipment computer shall contain the necessary software modules to perform all tasks required. These functions include:

- Auto execution,
- Program initialization,
- Operation selection,
- Data collection and management,
- Data save,
- Direct data entry,
- Data retrieve,
- Data manipulation,
- Data output,
- Data transfer,
- Data display, and
- Equipment calibration.

5.3.1 *Auto Execution*—The equipment computer shall provide an automatic execution function that shall configure equipment components, load the main control program of the computer, and start up all required operations.

5.3.2 *Program Initialization*—The software shall provide a central program initialization function that shall be loaded by the operating software following all other drivers and reserved memory. The initialization program shall perform start-up initialization, activate the DAS, initialize program control parameters and system self-check, and activate a start up that requires no operator input.

5.3.3 *Operation Selection*—The operation selection function shall display a main menu of computer operation functions that can be performed when selected by the operator. The main menu selection instructions shall be displayed to the operator along with the main menu choices. The selection shall be provided via the computer keyboard or other input device.

5.3.4 *Equipment Operation Functions*—The equipment computer shall provide a set of operation functions selected by the operator main menu. The equipment operation functions shall provide everything necessary for the operator to perform data collection in a user-friendly manner. It shall not be necessary for the operator to use operating commands directly to perform any of the required functions with the exception of formatting and copying diskettes. The equipment operations shall:

1. Perform data collection;
2. Create data files and save data to them;
3. Provide for input and storage of IDs (driver, operator, and vehicle; see Section 5.3.4.1) that are changed infrequently, and other parameters that are changed for each test;
4. Perform data collection control setup;
5. Support operator-activated calibration and equipment checkout; and
6. Provide a data manipulation mode to transform the data using operator-selected filters and mathematical transformations to create the required output profiles and indices.

5.3.4.1 *IDs and Parameters*—The user shall be able to change and save calibration data; IDs for the vehicle, driver, and operator; date and time used; test location data, etc., and information about the computer files on storage media.

The equipment shall contain provisions to accept up to 16 variables, similar to those listed below, from the operator prior to testing a roadway section. The software shall ensure that the operator enters all required variables. Required numeric variables shall default to ASCII zeros. Alpha variables shall default to blanks. The variable data shall be saved in the files along with the test data for further post-processing.

Variable	Length	Type	Example
Project	25	A/N	Name 1
Route	15	A/N	IH 20
County	10	A/N	67
Direction	2	A	NB
Begin Ref.	7	N	45.678
Lane	5	A/N	R1
User Ref.	15	A/N	New Pmt.
Operator ID	10	A/N	RO5467
Driver ID	10	A/N	A124
Vehicle ID	10	A/N	9812
Equip. ID	10	A/N	MS6716
Software 1	10	A/N	P2356.9.1
Software 2	10	A/N	C4579.2.3
Average Speed	3	N	45.7
Maximum Speed	3	N	49.1
Minimum Speed	3	N	42.8

Abbreviations: A = alphabetic, N = numeric

Note 5—The variables defined in the table above are given only as examples. Specific variables and their definitions may differ among Owner-Agencies. For example, the lengths of the variables and their types may differ.

5.3.4.2 *Calibration*—The operational computer software shall allow the operator to perform a distance sensor calibration and use the calculated factor to perform the operational distance measurements. The calibration software shall also allow the operator to save the factor calculated or change the calibration factor to other than the calculated value. The operator shall only need to enter the distance traveled in feet, meters, kilometers, or miles and not make any calculations to determine the calibration factor.

The calibration software shall also allow the operator to perform a profile equipment calibration. This includes the verification of the height sensor using at least four gauge blocks provided by the supplier. The auto-calibrating function of the accelerometer shall be supported as required. The values determined in calibration shall be stored and recorded as above for use in data processing.

5.3.4.3 *Roadway Testing*—The operational computer software shall provide all necessary functions for the operator to select and perform roadway testing for a specific location. The beginning and ending points as well as any sectioning shall be automatically detected and stored along with the primary data. The testing software shall perform testing as required by the operator. The software shall also detect abnormal conditions in the test cycle and report the condition to the operator. The testing software shall save the displacement values from the height and DMI sensors, and the acceleration values as well as the derived elevation profile values generated by the DAS in internal memory during testing and output them to the monitor and printer for review. These results may also be transferred to removable media if selected by the operator.

The test software shall activate the testing using the timing and control parameters stored by the test control setup software. The software shall monitor the signals to verify that the testing is being performed properly and indicate detectable errors.

The test software shall receive, display, and store raw data received from the vehicle-mounted transducers. The test software shall receive, display, and store with each test the corresponding distance and test speed. The current distance measurement shall be displayed constantly on the monitor when in test mode.

The test software shall output collected data as well as an operator-selected profile index to the monitor in real-time.

The test software shall receive, display, and store pertinent feature data (entered by keyboard, etc.) relating to the test site observed during testing of a roadway; e.g., posted speed limit changes, surface changes, bridges, etc. It shall accept this operator input data in real-time as the vehicle moves down the highway. The corresponding reference point shall be stored at the time of the feature data entry.

The equipment shall be capable of calculating, displaying, and storing the average roughness value obtained from the stored data at user-specified intervals. The computer shall be capable of collecting and storing internally at least 25 miles of profile data. Additionally, the computer shall be capable of putting the accumulated roughness test results through mathematical functions and printing results when enabled by the operator. For example, the ability to compare multiple runs for the coefficient of variation and to tag outliers, or the ability to compare a verification run to runs made previously should be included to enhance the user friendliness of the equipment. These processes shall not necessarily be done in real time but in post-processing. The equipment shall be capable of performing all required post-processing operations.

5.3.5 *Equipment Shutdown*—The operational software shall provide equipment shutdown that shall be operator activated via the keyboard. Prior to shutting down, the computer shall save all active parameters to the internal storage media for retrieval the next time the equipment is started up. Preferably, the computer shall also store a backup file of the previous shutdown that can be retrieved in an emergency. These files shall be updated at each shutdown.

6. MOUNTING AND INSTALLATION OF EQUIPMENT

6.1 The supplier shall provide all parts and labor necessary for the installation of the equipment. Installation of the new equipment shall include a mounting arrangement that can be easily used by the driver or passenger operator as designated.

6.2 Careful consideration shall be given to the mounting and location of equipment. Mounting of equipment shall be made in a manner to withstand normal vibrations that occur while traveling at the normal operating speeds for the equipment utilized. The location of equipment shall be accessible to the operator and not impede safety.

6.3 Electronic components shall be restrained where possible with tie downs or other applicable methods.

7. PROFILER ACCURACY

7.1 *Profile Precision*—The precision shall be measured in accordance with the repeatability determined in R 56.

7.2 *Profile Bias*—The bias shall be measured in accordance with the accuracy determined in R 56.

8. MANUALS

8.1 Upon delivery of the profiler, the following shall be required:

1. Two copies of the operating procedures for all operational software.
2. Two copies of the schematics block diagrams, and wiring diagrams covering the electronic circuitry of the installed equipment.
3. Two complete parts lists detailing the components of all equipment used.

9. WARRANTIES

9.1 The equipment supplier shall warrant all components of the equipment for a period of not less than 1 year from date of acceptance to be free from defects in material and workmanship.

10. REFERENCES

10.1 Collins, R., W. Gulden, and D. Brown. Twenty-Five Years of Pavement Smoothness Specifications in Georgia. *Transportation Research Record 1545*. TRB, National Research Council, Washington, DC, 1996.

10.2 Fernando, Emmanuel, and Carl Bertrand. Application of Profile Data to Detect Localized Roughness. TRB#02-4050. *Transportation Research Board, 81st Annual Meeting*, Presented at National Academy of Sciences, Washington, DC, January 13–17, 2002.

10.3 Sayers, Michael W. On the Calculation of International Roughness Index from Longitudinal Road Profile. *Transportation Research Record 1501*. TRB, National Research Council, Washington, DC, January 1995, pp. 1–12.

10.4 Sayers, Michael W., and Steven M. Karamihas. *The Little Book of Profiling.* University of Michigan Transportation Institute, Ann Arbor, Michigan, 1998.

10.5 Sayers et al. The International Road Roughness Experiment: A Basis for Establishing a Standard Scale for Road Roughness Measurements. *Transportation Research Record 1084*. TRB, National Research Council, Washington, DC, 1986.

10.6 Selcom Laser Measurements, Product Guide. SELCOM General, LMI Technologies, Inc., Vancouver, BC, Canada, http://www.lmint.com/.

Standard Practice for

Evaluating Faulting of Concrete Pavements

AASHTO Designation: R 36-04 (2009)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Evaluating Faulting of Concrete Pavements

AASHTO Designation: R 36-04 (2009)[1]

1. SCOPE

1.1 This protocol describes a method for evaluating faulting in jointed concrete pavement surfaces.

Note 1—Faulting is defined as the difference in elevation across a transverse joint or transverse crack as shown in Figure 1.

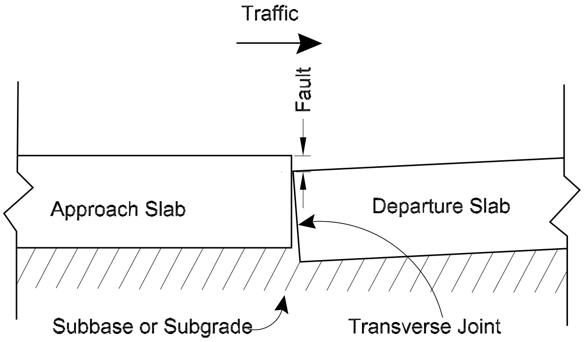


Figure 1—View of Longitudinal Section of Faulting at a Transverse Joint or Crack

1.2 Although the faulting is measured, detailed specifications are not included for equipment or instruments used to make the measurements. Any equipment that can measure with the accuracy stipulated herein and that can be adequately calibrated is considered acceptable.

1.3 *This standard practice may involve hazardous materials, operation, and equipment. The procedure does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this protocol to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. SIGNIFICANCE AND USE

2.1 This standard practice standardizes the procedures for estimating and summarizing faulting on concrete pavement surfaces. It provides consistent estimates of faulting for network-level pavement management. The procedure is intended to measure faulting with a vehicle traveling in the designated lane at highway speeds; however, the provisions for manual measurements are included.

3. FAULT MEASUREMENT

3.1 It is each agency's responsibility to designate the lane(s) and direction(s) of travel to be surveyed on the basis of sound engineering principles and pavement management needs within the agency.

3.2 Calculate faulting to the nearest 1 mm (0.04 in.) by the following formula:

$$F = \left|P_1 - P_2\right| \tag{1}$$

where:

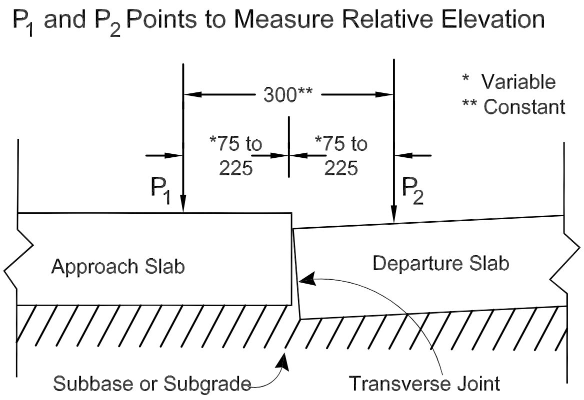
F = faulting that is the absolute value for the measured difference, mm; and

P_1, P_2 = heights measured on either side of a transverse joint or transverse crack in the outside wheelpath, mm.

4. RECORDING OF DATA

4.1 Maintain the length of the data summary interval of 0.1 km (0.1 mile). As a minimum, measure faulting across all transverse joints or transverse cracks in the outside wheelpath of the survey lane.

4.2 For automated surveys, take measurements at points 75 to 225 mm (3 to 8.8 in.) from the joint or crack and separated by 300 mm (11.8 in.) as shown in Figure 2.



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 2—Points to Measure for Faulting by Automated Measurements

4.3 For manual measurements, include the sampling rate level of at least 10 percent of all transverse joints or transverse cracks. The 10 percent sampling rate should be uniformly spaced (preferably every tenth joint or crack or more frequently) throughout the project to assess the condition. The location should be documented along with the measurement.

4.4 For automated methods, record faulting at all joints in a format amenable to automated plotting to assist in further evaluation of the data.

4.5 When using manual methods, record all faulting measured.

Note 2—Care must be taken to not measure spalling and classify it as faulting.

5. REPORT

5.1 At a minimum, record the following data:

5.1.1 *Section Identification*—List the following information, if available:

5.1.2 Length of the data collection section (m);

5.1.3 Maximum value of faulting for all joints per 0.1 km (0.1 mile);

5.1.4 Average and standard deviation for all joints per 0.1 km (0.1 mile);

5.1.5 *Optional*—Pavement surface temperature;

5.1.6 Date of collection (month/day/year);

5.1.7 Total number of transverse joints and transverse cracks with measurable faulting; and

5.1.8 Equipment axle loads and orientation of sensors to axles of influence.

Note 3—There may be variations in faulting as a result of the axle loads and orientation of sensors to axles of influence.

6. KEYWORDS

6.1 Concrete pavement; fault measurement; faulting; jointed concrete pavement; joints.

7. REFERENCES

7.1 *AASHTO Publication*:

- *Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, DC, 1993

7.2 *SHRP Standard*:

- SHRP-P-338, *Distress Identification Manual for the Long-Term Pavement Performance Project*, Strategic Highway Research Program, Washington, DC, 1993

APPENDIX

(Nonmandatory Information)

X1. GUIDELINES—QUALITY ASSURANCE PLAN

X1.1. *Quality Assurance Plan*—Each agency shall develop a quality assurance plan. The plan shall include survey personnel certification training records, accuracy of equipment, daily quality control procedures, and periodic and ongoing quality control. The following guidelines can be used for developing such a plan.

X1.2. *Certification and Training*—Agencies are individually responsible for training and/or certifying their data collection personnel and contractors for proficiency in using the profile measuring equipment according to this standard practice and other applicable agency procedures.

X1.3. *Equipment Calibration*—Equipment calibration (accelerometers and noncontact sensors) is done in accordance with specific manufacturer recommendations. The equipment must operate within the manufacturer's specifications. A regular maintenance and testing program is established for the equipment in accordance with the manufacturer's recommendations.

X1.4. *Verification Sections*—Verification sections are selected with known faulting. Faulting on these sections is measured by equipment operators on a regular basis. Evaluations of these measurements provide information about the accuracy of field measurements and give insight into needed equipment calibration. Verification sections are rotated on a regular basis in order to assure that the operators are not repeating previously known faulting values during the verification. As an alternate to verification sections, remeasure and compare up to five percent of the data as a daily or weekly quality check.

X1.5. *Quality Checks*—Additional quality checks can be made by comparing previous year's faulting statistics with current measurements. At locations where large changes occur, the pavement manager can require additional checks of the data.

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[1] This specification was first published as Provisional Standard PP 39 in May 1999.

Standard Practice for

Application of Ground Penetrating Radar (GPR) to Highways

AASHTO Designation: R 37-04 (2009)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Application of Ground Penetrating Radar (GPR) to Highways

AASHTO Designation: R 37-04 (2009)[1]

1. SCOPE

1.1 This standard practice provides guidance to the highway engineer in the application of noncontact ground penetrating radar (GPR) to transportation facilities. It is intended to instruct the engineer regarding the specific uses of noncontact radar for pavement layer thickness surveys, quality control of new pavement construction, evaluation of granular base material, identification of zones of asphalt stripping, and assessment of bridge decks. GPR has numerous applications for the transportation industry, but at this time requires extensive training in its use and interpretation of the data output, as well as experience in local pavement conditions.

2. REFERENCED DOCUMENTS

2.1 *ASTM Standard*:

- D 4748, Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar

2.2 *Federal Standard*:

- FHWA/TX-92/1233-1, Implementation of the Texas Ground Penetrating Radar System, Texas Transportation Institute with the Federal Highway Administration, 1992

2.3 *NCHRP Reports:*

- NCHRP Synthesis 255, Ground Penetrating Radar (GPR) for Evaluating Subsurface Conditions for Transportation Facilities: Synthesis of Highway Practice, Transportation Research Board, National Research Council, 1998
- NCHRP Report 237, Locating Voids Beneath Pavement Using Pulsed Electromagnetic Waves, Transportation Research Board, National Research Council, 1981

2.4 *SHRP Standards:*

- SHRP-H-672, Development of Ground-Penetrating Radar Equipment for Detecting Pavement Condition for Preventive Maintenance, Strategic Highway Research Program, National Research Council, 1993
- SHRP-P-397, Ground Penetrating Radar Surveys to Characterize Pavement Layer Thickness Variations at GPS Sites, Strategic Highway Research Program, National Research Council, 1994
- SHRP-S/FR-92-105, Condition of Concrete Bridges Relative to Reinforcement Corrosion, Vol. 3: Method for Evaluating the Condition of Asphalt-Covered Decks, Strategic Highway Research Program, National Research Council, 1992

2.5 *TRB Reports:*

- *Transportation Research Record 1304*, Bridge Deck Condition Surveys Using Radar: Case Studies of 28 New England Decks, Transportation Research Board, 1991
- *Transportation Research Record 1344*, Automated Pavement Subsurface Profiling Using Radar—Case Studies of Four Experimental Field Sites, Transportation Research Board, 1992

3. SUMMARY OF METHOD

3.1 *Principles of GPR*—GPR utilizes radio waves as an energy source. They are transmitted into the pavement and reflected at layer interfaces. Radio waves have free space wavelengths on the electromagnetic spectrum ranging from 0.001 m to 10 m. GPR operates in the range of 0.1 m to 10 m, which is the low end of the radio wavelength spectrum. As with all electromagnetic waves, radio waves travel through a vacuum at the speed of light. When the radar waves pass through a medium other than a vacuum, the velocity of propagation becomes a function of the dielectric constant of the medium. A dielectric is defined as an insulator between two electrical conductors; the dielectric constant for any material measures its effectiveness when used as the dielectric of a capacitor. For example, air has a dielectric constant of one. If air in a capacitor is replaced by mica, the resulting capacitance is six times greater, so mica has a dielectric constant of six. Some representative dielectric constant values for earth materials are given in Table 1.

Table 1—Dielectric Constants for Construction Materials (Reference 8.5)

Material	Relative Dielectric Constant ($\in_r$)
Air	1
Water (fresh)	81
Water (salt)	80
Sand (dry)	3–5
Sand (wet)	20–30
Silts	5–30
Clays	5–40
Granite	4–6
Limestone	4–8
Portland Cement Concrete (cured)	6–11
Bituminous concrete	3–6

3.2 The velocity of a radar wave through a given medium varies in inverse proportion to the square root of the material's relative dielectric constant $\in_r$. For example, if a material with a dielectric constant value of 4 has a radar wave passing through it, the wave does travel half as fast as it does through air ($\in_r = 1$) and twice as fast as it would through a material having an $\in_r$ value of 16. In general, radio waves propagate through dielectric materials, but are reflected from conductive materials. When there is a boundary between two materials having different dielectric properties, some of the radar energy will be reflected, and a portion will pass through the boundary. The time required for a radar pulse to travel from the source to an interface and back is the two-way travel time, and is dependent on the depth of the interface and the dielectric constant of the material overlying the interface. Converting two-way travel time to information about the depth to the interface can be done by means of the following formula:

$$d = v \times t/2 \qquad (1)$$

where:

d = depth,

v = velocity, and

t = two-way time.

3.3 The velocity of the radar wave is primarily dependent on the dielectric constant of the medium, and can be calculated with the following equation:

$$v = c/\sqrt{\in_r} \qquad (2)$$

where:

c = speed of light.

As can be seen from the data in Table 1, the moisture content has a large influence on the dielectric constant, and therefore affects the two-way travel time, so that the greater the amount of water saturation, the lower the radar wave velocity.

3.4 There is another electrical property upon which GPR depends, and that is conductivity. Attenuation of the radar waves (which causes the waves to decrease in amplitude and energy) is caused by higher conductivity of a medium and results in less depth of penetration. Attenuation is related to the frequency spectrum emitted by the radar—the higher the frequency, the greater the attenuation of the signal. For most pavement materials in dry condition, attenuation of the wave is not a serious problem. However, with some materials, particularly new concrete (within at least 180 days of placement), signal attenuation can have a significant impact on the amount of energy reflected from the pavement structure.

3.5 In discussing frequency of GPR antennae, it is to be noted that the signal output is not a single frequency, but rather is a frequency spectrum (bandwidth). An antenna that has a 1-GHz output actually produces a bandwidth frequency distribution having a mean value of 1GHz. This signal is produced in short pulses, with a comparatively long period of time between pulses, so that the reflected signals may be recorded. The electromagnetic signal pulse is on the order of 1 nanosecond in duration, while the time between pulses may be tens of thousands of nanoseconds. Higher-frequency signal pulses have shorter pulse periods; a 1-GHz signal will have a 1 nanosecond pulse, while a 2-GHz signal will have a pulse of 0.5 nanoseconds in duration.

4. SIGNIFICANCE AND USE

4.1 GPR is a geophysical technique that uses radio waves to acquire subsurface information. The system operates by transmitting energy waves into the earth and recording the waves that are reflected off interfaces between layers of material with different electrical properties. GPR has been used for several decades as a tool for geologic investigations, particularly for environmental and groundwater applications. In more recent times, a type of radar system developed specifically for transportation applications has evolved using high-frequency, noncontact antennas that can travel over highways and bridges at the speed of traffic while acquiring data. The information from these GPR systems can be used to find voids under pavement, study pavement layer thicknesses, evaluate moisture or density variations, and assess the condition of bridge decks.

4.2 GPR can be used as a nondestructive testing tool in assessing transportation facilities, particularly in the areas of pavement management and bridge deck evaluation. It is an evolving science that has not yet reached the stage of being common practice in state transportation departments, but it shows promise as an emerging technology to replace or augment more traditional and labor-intensive testing methods such as core drilling. The development of GPR is evolving rapidly, which is common to computer-dependent systems, so that it may become a more commonly used application in transportation engineering projects in the future, depending on the level of commitment to more sophisticated technology on the federal and state levels.

4.3 Agencies planning to use a great deal of GPR data; e.g., using GPR as part of a network-level pavement management system, are likely to find it most cost-effective to purchase one or more GPR systems and invest in the personnel training necessary for its usage. The cost of training is largely a function of the data processing software used to evaluate data. As the software packages become more user-friendly, there will be progressively less training required for the user.

4.4 Transportation agencies that plan to use a limited amount of GPR data, such as occasional distressed pavement examinations on discrete stretches of highway, may find it advantageous to hire consultant contractors to conduct the surveys and perform the analysis, rather than investing in the equipment and training necessary to do it themselves.

5. EQUIPMENT

5.1 *Types of GPR Systems*—There are two basic types of GPR systems, the difference being in the type of antenna used to produce the radar waves. Ground-coupled antennas are used primarily in geologic and environmental applications. They generate radar waves with frequencies of 50 to 500 MHz, although some systems can produce radar wave frequencies of greater than 1 GHz. As the name implies, ground-coupled radar antennas must keep in contact with the ground during a GPR survey so that they are dragged by hand or towed slowly (at speeds less than 10 kph). The antenna in a ground-coupled system is generally a bowtie (dipole) antenna that generates a signal that covers a wide area and has scattered reflections. The system is capable of providing subsurface information to a depth of up to 15 m or 16 m, depending on the geologic conditions encountered and selection of antenna frequency, but often will yield little information in the uppermost meter of the surface layer because of a phenomenon known as “ringing” caused by a bistatic coupling mismatch. This problem can be minimized by selecting a high-frequency GPR system if the desired target is known to be near the surface. Ground-coupled GPR systems are used for mapping bedrock and soil strata, detecting buried drums and pipelines, and tracing contaminant plumes.

5.1.1 The type of GPR system most used for transportation facilities, and which is the main focus of this standard practice, utilizes the noncontact horn antenna, which is suspended over the surface of the ground and which can perform surveys at speeds of up to 80 km/h. Usually, the antenna in this system is designed with a narrowly focused beam of electromagnetic energy, rather than the larger beam width used in ground-coupled GPR, resulting in less back scatter from the surrounding area. The operating center frequency range is typically around 1 GHz, but some systems are now available that have frequencies as low as 0.5 GHz and as high as 2.5 GHz. These high-frequency broadband radar signals yield excellent resolution, permitting identification of very thin layers. The noncontact systems have the advantage of providing near-surface information, unlike most ground-coupled GPR systems. The drawback of high-frequency signal generation is that, under typical conditions, the depth of penetration is limited to about 0.6 m. Therefore, noncontact GPR can yield information about pavement and subbase strata but will yield very little information below that.

5.2 *GPR Equipment*—A GPR system consists of the following components: a signal generator; an antenna that transmits and receives the radar pulse signal; a sampler/recorder that collects the returned signal and stores it; a signal processing system to convert the pulse data into a waveform; a monitor for viewing the data; and a recording system for storing data. The antenna is on a boom directly attached to the front or the back of the vehicle. All the other equipment is contained within the survey vehicle. A distance calibration system is tied into the GPR survey so that anomalies can be located precisely. It is useful to operate a synchronized video imaging system during the GPR survey so that a visual record of the pavement surface is available during the data processing. Two operators are recommended during the survey, one to devote full attention to the safe operation of the vehicle, and one to operate the equipment.

5.2.1 The minimum GPR configuration is a single antenna radar system. For pavement surveys, a single antenna pass per lane is adequate for thickness evaluation. For condition surveys (void mapping and bridge deck evaluation), multiple antenna passes per lane are preferable to achieve the required level of detail. This can be achieved by making multiple passes with a single antenna vehicle or by using a radar vehicle equipped with multiple antenna systems (Figure 1). Obviously, in a high-traffic area with limited highway access, the multiple antenna vehicle is more efficient to use for this type of survey as it requires less traffic protection and fewer cycles of entering and exiting the highway.

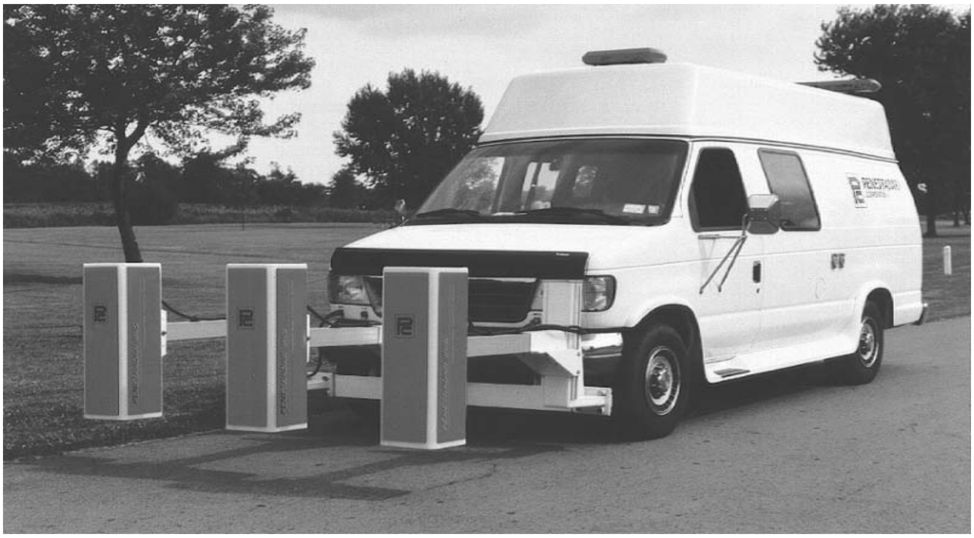
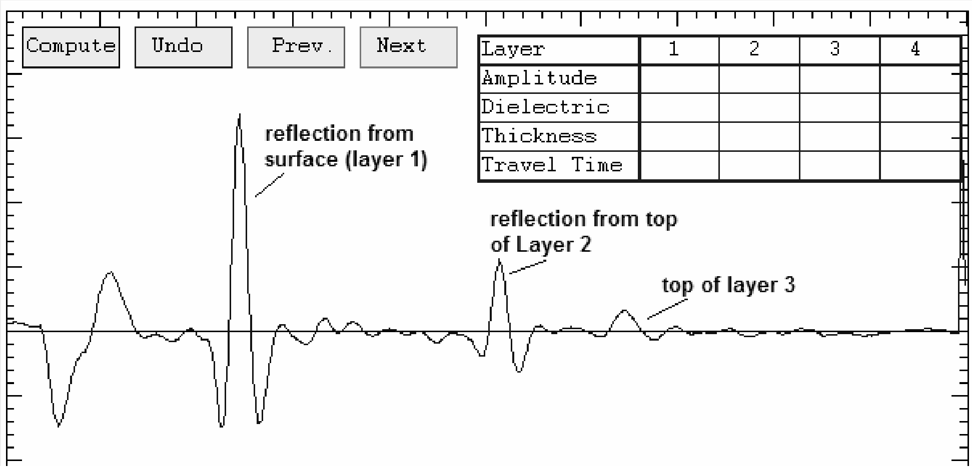


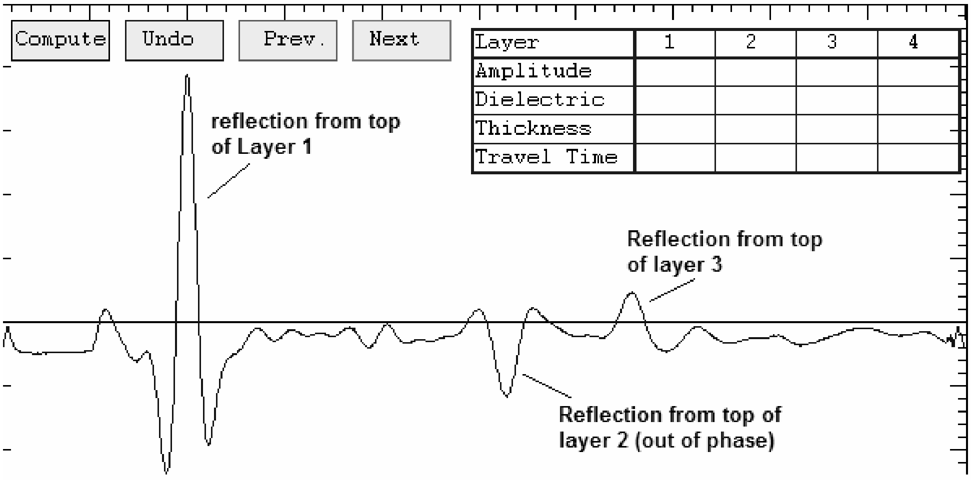
Figure 1—Multiple Antennae on a GPR Survey Vehicle

5.3 *Data Output*—When the GPR electromagnetic energy is directed into the ground, some of it is reflected from interfaces between materials of differing dielectric values and returns to the GPR receiver; the reflected pulses are the only part of the transmitted signal that is seen on the GPR monitor. The energy of the reflected radar pulse is converted to a waveform that is displayed on a monitor as a graph of amplitude (in volts) against time. Reflections are “in phase” with the emitted signal if the pulse travels from a layer with a low to a higher dielectric and “out of phase” if the signal goes from high to low dielectric (Figure 2). The waveforms can then be displayed in a variety of formats; one method is to use the stacked waveform approach (Figure 3). The most common way of viewing GPR data is by the use of a color transform system. The line scans shown in Figure 2 are color-coded based on signal amplitude, the individual waveforms are then stacked side by side to form a color-coded image of subsurface condition as shown in Figure 4.



Layer	1	2	3	4
Amplitude				
Dielectric				
Thickness				
Travel Time				

a) In-phase reflections (increasing dielectrics with depth)



Layer	1	2	3	4
Amplitude				
Dielectric				
Thickness				
Travel Time				

b) Out of phase reflections (layer 2 has a lower dielectric than layer 1)

Figure 2—Typical GPR Reflections

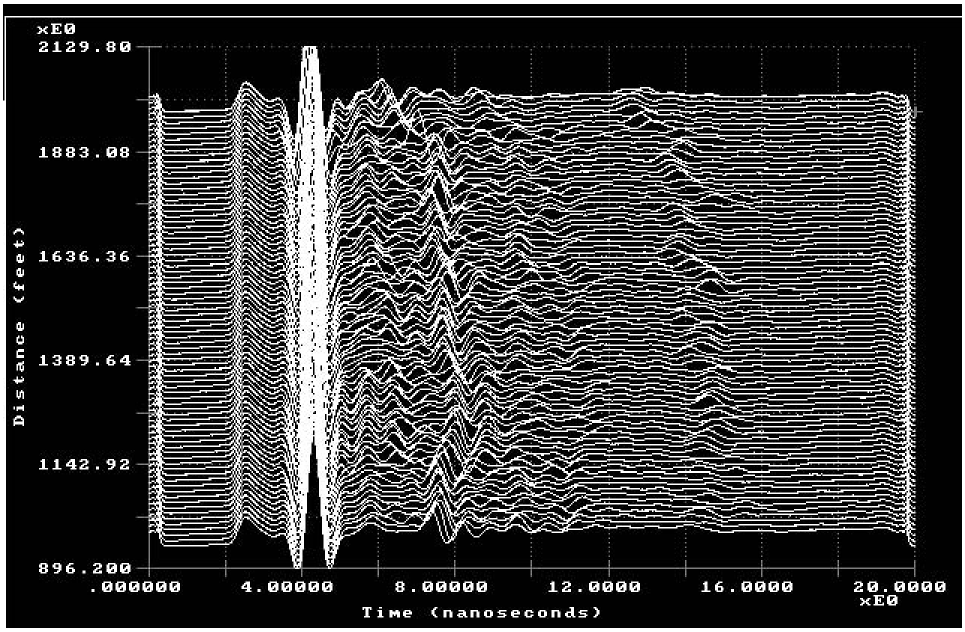


Figure 3—Stacked GPR Waveforms from a Section of Highway

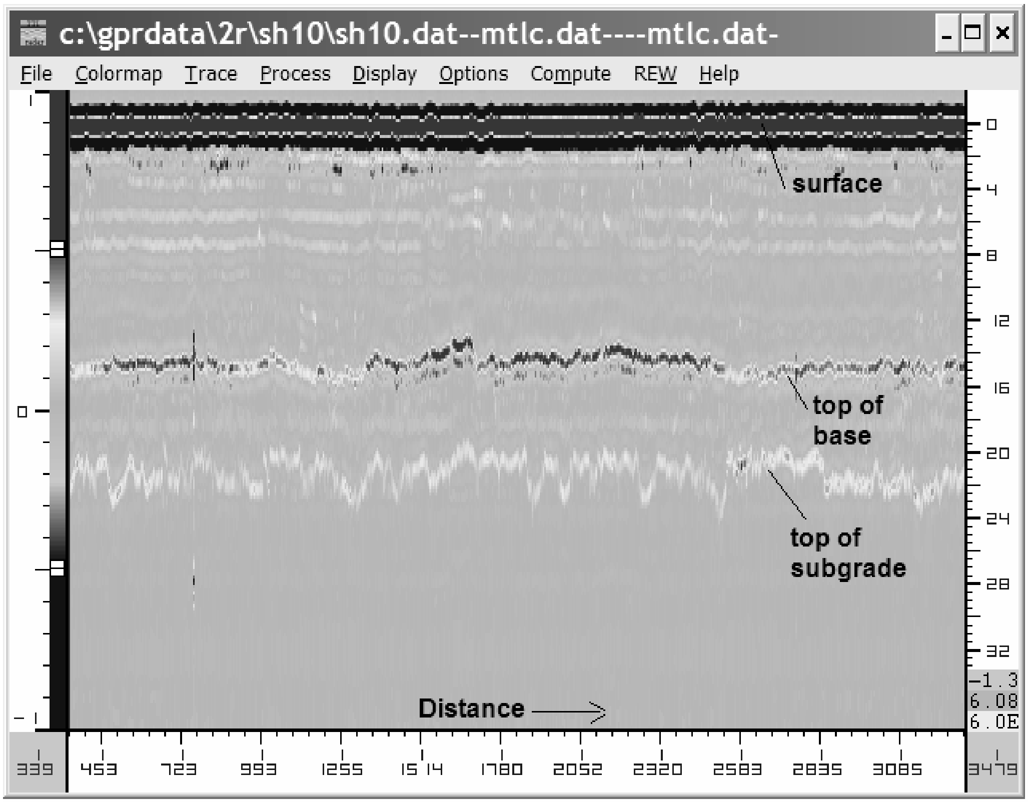


Figure 4—Color Transform Output. The depth scale is on the right of the figure and the distance along the highway is shown in the lower scale.

5.3.1 The amplitude of the displayed waveform is a function of the difference in dielectric constant between two material layers; the greater the contrast, the larger the waveform amplitude of the returned signal. Two layers may have different material characteristics, but unless they have differing dielectric constants as well, they will not yield a noticeable GPR reflection. The reflected amplitude is also a function of the conductivity of the material through which the radar pulse travels. Lossy dielectrics (i.e., material having higher conductivity) tend to attenuate the signal, reducing its amplitude and yielding a less distinct contrast between layers.

5.4 *Data Processing*—Current GPR units may produce waveforms at the rate of 50 per second, or 180 000 scans per hour (Section 8.1). It is recommended that computers are used to store the data output onto hard drives or CD-ROMs.

5.4.1 While great strides have been made in developing computer software for signal processing and storage, it should be noted that, for the most part, interpretation of the GPR profile is still done manually by experienced operators. Some forms of data interpretation software have been developed and are on the market, but at this stage they are proprietary and are used exclusively by GPR consultants, contractors, and a limited number of state agencies. Government agencies interested in the purchase of a GPR system must recognize that the operation of this equipment requires a substantial investment in training the operators. As an alternative, the agency can hire an expert vendor to perform the GPR surveys.

5.4.2 Pavement materials are complex, and the interpretation of overlapping signals from multiple thin layers can complicate the analysis. With anomaly detection projects (such as voids or stripping detection), ground truth in the form of cores is required to verify the interpretation. Limited coring and augering is recommended on all GPR projects to aid in calibrating and validating results.

6. GENERAL REQUIREMENTS

6.1 *Performance Specifications*—When purchasing GPR equipment for highway applications, the buyer is advised to consider the initial performance, long-term durability in daily highway use, and future product support from the manufacturer. The initial performance assessment of a system must include evaluation of the signal-to-noise ratio ("clutter") and signal stability ("jitter"), so that the user has a clean radar signal with which to work.

6.1.1 Specifications for equipment performance are available in Section 2 of the Texas Transportation Institute Research Report 1233-1, "Implementation of the Texas Ground Penetrating Radar System" (1992). These performance standards were developed for the Texas Department of Transportation and have since been used by transportation departments in Florida and North Carolina.

6.2 *Hiring Consultant Contractors*—State agencies that are interested in using GPR for a limited amount of work, and that do not wish to purchase their own GPR systems, are advised to hire consultant contractors to perform this work. The hiring agency needs to ensure that the consultant has the appropriate hardware and software for the job and has had experience working with a variety of transportation applications. The consultant must be able to provide references and a list of experience in the GPR application for which he or she is hired. The consultant's final output must be validated with cores as a quality control check.

6.3 *Environmental Effects*—GPR surveys are not recommended when there is standing water, snow, or ice on the surface of the pavement because the high dielectric value of water will cause attenuation of the electromagnetic signal and erroneous peak voltage amplitudes in the returned signal. The presence of deicing salts on the road surface has a similar detrimental effect.

7. APPLICATIONS TO TRANSPORTATION FACILITIES

7.1 GPR is a tool that can be used for a variety of highway applications, including pavement thickness surveys, quality control of new pavement construction, detection of voids under pavement, evaluation of granular base material, mapping zones of asphalt stripping, and bridge deck assessment.

7.2 *Pavement Thickness Surveys*—This is one of the most useful applications of GPR to transportation systems; for pavement management systems at the network or project level; the method has been described in ASTM D 4748. The GPR data can be used as a first step in pavement layer thickness surveys, to be followed by falling weight deflectometer surveys, with pavement coring as the final step. GPR can be used to obtain the thickness of the top pavement layer and identify significant changes in the structure (such as changes in base type). On a cautionary note, it is useful to recognize that it is difficult to identify base thickness of older pavements using GPR because the base and subgrade materials tend to intermingle over time so that there is no dielectric contrast between the layers, and there will be no clear radar reflection from their interface. In general, GPR works much better on flexible pavements than rigid ones because there is a more distinctive reflection between the asphalt and underlying strata than there is with concrete pavement, and concrete tends to attenuate the radar signal more than asphalt. If concrete pavement overlies cement stabilized base layers, there will be virtually no reflections produced because the two materials share a similar dielectric value. *Additionally, GPR should not be attempted on concrete pavements* fewer *than 180 days old due to their potentially high moisture content.*

7.2.1 The great advantages of using GPR for pavement thickness surveys are that it provides continuous coverage, is nondestructive, and can be performed without closing lanes to traffic.

7.3 *Quality Control of New Pavement Construction*—GPR works well on asphalt paving projects as a postconstruction tool for quality control. The interfaces between the pavement base and the top of subgrade normally yield clear radar reflections. GPR can be used to check for proper pavement thickness and can also locate construction defects and asphalt segregation. A homogeneous and defect free layer will generate a reflection from the top and bottom of the layer. If a defect is present within the layer, it will appear as an extra reflection between the reflections from the top and bottom of the layer.

7.3.1 *Segregation Detection with GPR*—The amplitude of the surface reflection from a new asphalt surface is related to the density of that layer. Significant decreases in amplitude would identify areas that are lower in density. Asphalt “end load” segregation and poorly compacted longitudinal construction joints will cause localized decreases in the amplitude of surface reflection and the computed surface dielectric. Examples of GPR from a normal and segregated asphalt surface are shown in Figure 5.

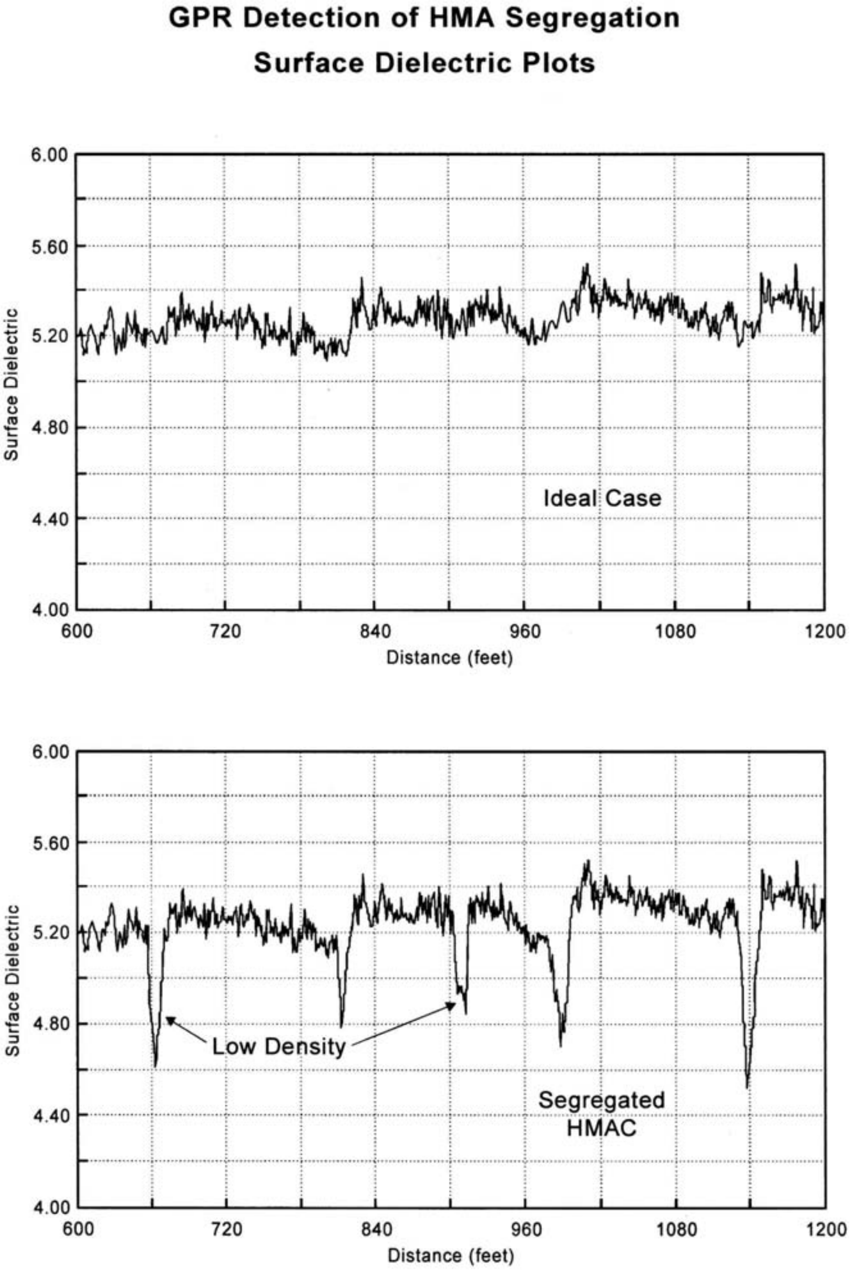


Figure 5—Surface Dielectric Profiles from a Well-Compacted Asphalt Surface and a New Asphalt Surface with "End-Load" Segregation

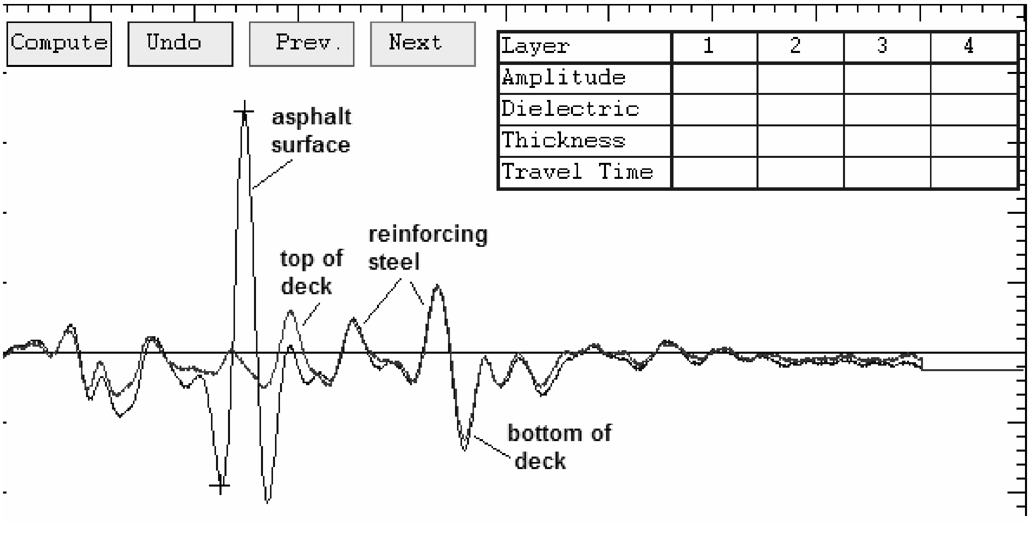
7.4 GPR does not work well on newly constructed concrete pavements because radar waves are strongly attenuated by fresh concrete due to its potentially high moisture content. Thus, it is recommended that GPR not be used within 180 days of placement.

7.5 *Detection of Voids Under Pavement*—Voids can develop beneath concrete pavements, particularly under joints. GPR is effective in determining the location of moisture filled voids. However, it is not effective at finding the volume of moisture filled voids, and it is difficult to distinguish between water filled voids and areas of saturated base. GPR can also be used to locate air filled voids under concrete, but the air filled voids need to be at least 15 mm thick. If voids are caused by loss of material at a significant depth below the pavement;—e.g., migration of soil through a defective culvert or buried pipeline which causes a void to travel up toward the surface—a ground-coupled radar system may be used to determine the size and location of the deep voids. This could be done as a two-step GPR survey, with an air horn antenna system used to detect voids immediately under the pavement and the ground-coupled system used to see whether there are void problems at depth.

7.6 *Evaluation of Granular Base Material*—Radar reflections from the top of the base layer will have an amplitude that is a function of the dielectric constant of the granular base material; the wetter the base, the higher the amplitude of reflection and calculated dielectric value. The higher the reflection, the higher the moisture content of the base. Dielectric values of 10 to 16 signify a moist base, while values above 16 indicate a wet area with potentially low shear strength and susceptibility to freeze–thaw damage (Section 8.2).

7.7 *Detection of Asphalt Stripping*—Stripping in asphalt is a phenomenon by which the bond between asphalt and aggregate deteriorates, with a resulting low-density zone. The stripped layers should be removed before repaving, either by patching or by milling if large areas of stripping are present. A stripped layer will show up on a radar survey as an out of phase reflection peak (similar to that shown in Figure 2b) because the radar wave is traveling from a higher dielectric material to a lower one; the low dielectric is a function of the low density of the dry, stripped material.

7.8 *Bridge Deck Assessment*—Delaminations in bridge decks are the result of separation of the concrete from reinforcing steel bars and are caused by corrosion of the steel; the steel corrosion is exacerbated by chlorides from deicing salts diffusing through the concrete. Traditional methods of delamination detection, such as hammer and chain drag, do not work well on asphalt-covered decks and sampling cores is time-consuming and disruptive to traffic. GPR has become a means of locating areas of delamination on bridge decks with asphalt overlays. One GPR analysis method is to measure the dielectric values of the concrete under the asphalt. If the concrete has high moisture and chloride contents as a result of corrosion and concrete breakdown, it will produce an anomalously large reflection at the asphalt/concrete interface (Section 8.3). Another method is to measure the amplitude of the reflection at the bottom of the deck, where the radar wave reenters the air and shows as a negative reflection (Figure 6). If the radar signal has been strongly attenuated as a result of moisture and chloride within the concrete deck, the amplitude of the reflected signal will be greatly reduced (Section 8.1).



Layer	1	2	3	4
Amplitude				
Dielectric				
Thickness				
Travel Time				

Figure 6—Typical Radar Return Waveform from Asphalt-Covered Bridge Deck (with some processing to show the "true" reflection from concrete deck). Delamination problems are anticipated if either the reflection from the top of the deck increases significantly or the reflection from the bottom of the deck decreases.

7.8.1 GPR will not be effective in assessing bridge decks if the structures have standing water on them, deicing salts on the surface, or are at subfreezing temperatures; all of these factors affect the dielectric properties of the concrete in such a way as to render the radar data ineffective.

8. SELECTED REFERENCES

8.1 Scullion, T. and T. Saarenketo. "Applications of Ground Penetrating Radar Technology for Network and Project Level Pavement Management Survey Systems," Proceedings of the 4th International Conference on Managing Pavements, Durban, South Africa, 1998.

8.2 Scullion, T., C. Lau, and T. Saarenketo. "Performance Specifications of Ground Penetrating Radar," from Proceeding, 6th International Conference on GPR, Sendai, Japan, 1996.

8.3 National Cooperative Highway Research Program, Project 20-5, Topic 26-08, "Ground Penetrating Radar for Evaluating Subsurface Conditions for Transportation Facilities: A Synthesis of Highway Practice," Transportation Research Board, 1997.

9. KEYWORDS

9.1 Asphalt stripping; bridge deck; delamination; dielectric constant; dielectric properties; GPR; granular base; ground penetrating radar; moisture; pavement evaluation; pavement forensics; pavement thickness; quality control; reinforcing steel; segregation; voids.

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[1] This standard practice was first published in April 2000 as a provisional standard. First published as a full standard in 2004.

Standard Practice for

Measuring Pavement Profile Using a Rod and Level

AASHTO Designation: R 40-10[1,2]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Measuring Pavement Profile Using a Rod and Level

AASHTO Designation: R 40-10[1,2]

1. SCOPE

1.1 The rod and level can be used to accurately measure the profile of a pavement. The profile data can be used to evaluate the roughness of the pavement by computing a roughness index such as international roughness index (IRI) or to evaluate effects such as frost heave or swelling of soils. In computing roughness indices, only the relative elevations and not the absolute elevations are needed. The guidelines in this standard practice can be applied to conventional survey equipment such as an optical level and graduated staff, which require the readings to be manually recorded, as well as automated equipment that is capable of automatically storing the measured data.

1.2 *This standard practice may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENT

2.1 *ASTM Standard*:

- E 1364, Standard Test Method for Measuring Road Roughness by Static Level Method

3. SUMMARY OF METHOD

3.1 To measure the pavement profile using the rod and level, two persons are generally needed. One person is needed to hold the rod (rod-person) and another to operate the level and take readings (instrument operator). If the level is not capable of automatically recording the readings, an additional person (record keeper) to record the readings will make the process quicker. An experienced crew of three would require fewer than 10 seconds to obtain one reading. This involves the positioning of the rod by the rod-person, reading the level by the instrument operator, and recording the measurements by the record keeper.

3.2 Relative elevations are measured along the roadway at prescribed intervals. A rod is set on the roadway, and the rod reading is recorded.

3.3 Rod readings are then converted to either a true elevation or a reference elevation from which profile statistics are then computed.

4. SIGNIFICANCE AND USE

4.1 Longitudinal profile measurements are used during construction to assess the smoothness of new pavement. Elevation profiles, when converted to roughness measurements, are also gathered for estimating the performance of in-service pavements which can then be utilized in a pavement management system.

5. APPARATUS

5.1 The rod and level used in routine surveying and road construction generally will not have the resolution needed for pavement profile measurements. For pavement profile measurements, precision leveling instruments are required. The instrument used for profile measurement shall satisfy the resolution criteria noted in ASTM E 1364, Table 1.

5.2 The rod used shall be equipped with a bubble level so that it can be held vertical accurately. A suitable base shall be selected for the rod in order to reduce the sensitivity to small variations in rod placement. For smooth-textured pavements, any type of base is suitable. For textured surfaces, a circular pad with a diameter of at least 2.0 cm (0.8 in.) is recommended. As only relative elevations are required for computing roughness indices, no correction is required for attaching a pad to the bottom of the rod.

Note 1—It is recommended that an invar rod be used to minimize the effects of temperature changes. This is particularly important for Class 1 surveys on smooth roads, for which the resolution requirements given in ASTM E 1364, Table 1 are more stringent.

6. EQUIPMENT MAINTENANCE, ADJUSTMENT, AND VERIFICATION

6.1 *Maintenance*—Use shockproof packaging when transporting the instrument. Clean the instrument after completing a profile measurement. Before cleaning the lenses, blow the dust off the lenses. Clean the lenses using a soft cloth. Do not touch the lenses with the fingers. If the instrument becomes wet in the field, dry it completely before packing. Inspect the tripod regularly to ensure that the connections are not loose.

6.2 *Adjustment*—The user manual for the level shall be consulted on how to perform adjustments of the instrument. Different makes and models of levels will require different adjustments to be performed. The following are some common adjustments that are required in levels in order to obtain accurate measurements. The user manual for the level shall be consulted to determine whether the following adjustments are needed for the level being used and, if so, how to perform the specific adjustment.

6.2.1 *Make Axis of Level Bubble Perpendicular to Vertical Axis*—After setting up the level, center the bubble. Move the telescope 180 degrees about the vertical axis. If the bubble moves, the instrument needs adjustment.

6.2.2 *Adjust Horizontal Crosshairs*—This adjustment will ensure that the horizontal crosshairs are truly horizontal when the instrument is leveled.

6.2.3 *Adjust Line of Sight*—This adjustment will make the axis of sight perpendicular to the vertical axis and parallel to the axis of the level. The method of adjustment for this error is commonly referred to as the two-peg method.

6.3 *Verification*—Verify the accuracy of the markings on the rod using a standardized tape.

7. SITE INSPECTION AND PREPARATION

7.1 Identify the two wheelpaths in the lane to be profiled.

7.2 Clean loose stones and debris from both wheelpaths to prevent slippage of the rod during measurements.

7.3 *Locate the center of the travel lane using the following guidelines*:

7.3.1 Case I—Where the wheelpaths can be easily identified, consider the center of the travel lane to be midway between the two wheelpaths.

7.3.2 Case II—Where the wheelpaths are not clearly identifiable, but the two lane edges are well defined, consider the center of the travel lane to be midway between the two lane edges.

7.3.3 Case III—Where only one lane edge is well defined, consider the center of the travel lane to be 1.8 m (6 ft) from the edge.

7.4 Use a chalk line to mark a straight line in each wheelpath. Position the line 0.8 m (32.5 in.) from the center of the travel lane.

7.5 Record the method used to locate the wheelpaths in the comment field of the data collection form or logbook. This will help in locating the wheelpaths used for profile measurements at a future date.

7.6 The measurement of pavement profiles using the rod and level is labor intensive and time consuming. Measurements will be taken along the wheelpaths at typical intervals of 70 mm (2.75 in.). Measurement accuracy must be verified at regular intervals by establishing a set of control points along the wheelpath; for example, at 30.5-m (100-ft) intervals starting from the beginning of the section. Determine the locations at which readings are to be taken, including control points, using one of the following methods:

7.6.1 Lay a surveyor's tape along the chalk line and mark distances on the pavement at 70-mm (2.75-in.) intervals using a suitable marker. Make markings along the entire length of the section on both wheelpaths.

7.6.2 Place a surveyor's tape on the wheelpath with the zero of the tape corresponding to the start of the section. Secure both ends of the tape with a weight or adhesive tape. Reference distances along the section from the tape.

8. LONGITUDINAL PROFILE MEASUREMENT

8.1 Record the required information in the data collection form or logbook.

8.2 Set up the level at a suitable location, taking into account the range of the level. With some instruments, it might be possible to cover the entire test length from one instrument setup located near the center of the test section. Place the level where it will not be disturbed by passing traffic and where it will not settle. When setting the tripod, set it as low as practical to reduce the error caused by the rod not being exactly vertical. Thereafter, level the instrument using the leveling screws.

8.3 The rod-person shall place the rod at the zero position of the section and use the bubble level attached to the rod to hold the rod vertical. When the rod is vertical, the rod-person shall signal to the instrument operator to take a reading. If the readings are recorded manually by a third crew member, the instrument operator shall call out the reading to the record keeper, who shall record it on a form or in the logbook. If an automated system is used, the instrument operator shall make sure that the reading is saved.

8.3.1 The rod-person shall place the rod 70 mm (2.75 in.) away from the initial reading, and a new reading shall be recorded. This process shall be continued until either the entire test section is surveyed, the next control point is reached, or the horizontal range or the vertical range of the level is exceeded. Relocate the level whenever the vertical or horizontal range is exceeded.

Note 2—The horizontal range of the level is exceeded if the distance between the level and the rod is too short or too long to focus properly. The vertical range of the level is exceeded if the rod cannot be read due to the slope of the road.

8.3.2 After taking measurements for a distance of 30.5 m (100 ft), place the rod at the previous control point and repeat the measurement at that point. The readings must agree within the resolution of the instrument. If the readings do not agree, take new readings for the length of pavement between the control points.

8.3.3 Use this procedure even if the level is not relocated between the two control points being considered. If the level is relocated between two control points, apply the same procedure, treating the pivot point (Section 8.5) as a control point.

8.4 When the level requires relocation, mark the location at which the rod was held for the last reading. This position is called a pivot point. Place the rod at the location where the first reading was taken with the current setup of the level and take a reading. Compare this reading with the first reading that was taken at this location.

8.4.1 If the readings do not agree within the required resolution of the instrument as determined in Section 5.1, repeat all readings taken from the current position of the level.

8.4.2 If the readings agree, place the rod on the pivot point and record the last reading from the current setup of the instrument (foresight) and relocate the level. Place the rod at the pivot point and take a reading (backsight). Continue the measuring process as described in Section 8.3 at intervals of 70 mm (2.75 in.). If the level must be repositioned, follow the procedure described in Section 8.5.

Note 3—The first reading taken after the level is set up is referred to as a backsight, while the last reading taken at that setup before the level is moved is referred to as a foresight. Other readings taken between a backsight and a foresight are referred to as intermediate sights.

8.5 At the end of the test section, if the entire survey is performed from one level position, place the rod at the zero position (the point from which the survey began) and take a reading. This reading must agree with the first reading taken at this location at the start of the survey within the resolution of the instrument. If the readings do not agree, repeat all profile measurements.

8.6 At the end of the test section, if the level was repositioned during the survey, place the rod at the last pivot point and take a reading. This reading must agree with the previous reading taken at the same position within the resolution of the instrument. If it does not agree, repeat the profile measurements from the last pivot point to the end of the section.

9. INTERFERENCES

9.1 If the level is sensitive to temperature variations, cover it with an umbrella to protect it from direct sunlight.

9.2 Avoid making measurements during windy conditions. Movement of the level could occur.

9.3 If the level has to be set up at more than one position during profile measurements, make the length to backsights and foresights equal. This will eliminate errors due to curvature and refraction at turning points.

9.4 If the line of sight is set too close to the layer of air above the ground, significant refraction can occur under certain atmospheric conditions.

10. CALCULATIONS

10.1 During field profile measurements, the crew is expected only to record the readings of the level using the procedures described in Section 8. The computation of the elevation profile from this data will be done in the office in the following manner:

10.1.1 For profile computations, the elevation of the location where the first reading (first backsight) was measured is needed. However, as only relative elevations are needed to compute roughness indices (such as IRI), an arbitrary value can be selected for the elevation of this point. Obtain the relative elevation of any point measured from the initial instrument setup using the following equations:

$$\text{Instrument Height } (IS) = BM + RR_1 \qquad (1)$$

$$\text{Relative Elevation of a Point} = IS - RR \qquad (2)$$

where:

IS = initial instrument height;

BM = elevation of point where the first backsight was taken (assume any value; e.g., 10 m (32.8 ft));

RR_1 = rod reading at first backsight; and

RR = rod reading at any point from the initial instrument setup.

10.1.2 Once the position of the level is changed, the instrument height will also change. Obtain the new instrument height using the following equation:

$$Nht = Oht + BS - FS \qquad (3)$$

where:

Nht = new instrument height;

Oht = old instrument height;

BS = backsight at pivot point with the instrument at new setup location; and

FS = foresight at pivot point with the instrument at the previous setup.

10.1.3 Relative elevation of points measured from a new instrument location can be determined by using Equation 2 and substituting the new instrument height for the initial instrument height.

11. QUALITY CONTROL

11.1 *Field Quality Control*—Field quality control measurements shall be made to ensure that the level has not moved in the current position. Field quality control measurements are made before the level is moved and at the end of the survey. These measurements are described in Sections 8.6, 8.7, and 8.8.

11.2 *Office Quality Control*—The computation of the elevation profile from the raw field data shall be performed in the office using a computer. Using the computer will prevent mathematical errors during computation. The quality control used in the field will not detect an incorrect reading being recorded at an intermediate location. The plot will only allow for the detection of significant erroneous readings.

12. REPORT

12.1 *Use the data collection form or a logbook to record readings and report the following information*:

12.1.1 Serial number and identification of rod and level used;

12.1.2 Date information was collected;

12.1.3 Names of instrument operator, rod-person, and data recorder;

12.1.4 Roadway identification;

12.1.5 Location of the wheelpaths (for longitudinal profiles); and

12.1.6 Rod readings as measured at each point.

13. KEYWORDS

13.1 Longitudinal profile; pavement profile; rod and level.

14. REFERENCES

14.1 Karamihas, Steven M. *Critical Profiler Accuracy Report*. Federal Highway Administration Transportation Pooled Fund study, TPF 5(063), *Improving the Quality of Pavement Profiler Measurement*, Chapter 6, Sampling and Footprint Requirements, *pp*. 61–84, http://www.pooledfund.org/projectdetails.asp?id=280&status=4.

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[1] This standard is based on SHRP Product 5014.

[2] Originally approved in November 1996, this standard was first published in June 1997, reconfirmed in January 2000, revised in 2004, and published as a full standard in 2005.

Standard Practice for

Measuring Pavement Profile Using a Dipstick$^{\text{fi}}$

AASHTO Designation: R 41-05[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Measuring Pavement Profile Using a Dipstick$^{\text{fi}}$

AASHTO Designation: R 41-05[1]

1. SCOPE

1.1. This standard practice is used to manually collect precision profile data utilizing the Face Technologies Dipstick®. The dipstick measures profiles (relative elevation differences) at a rate and accuracy greater than traditional rod and level surveys. Procedures for measuring both longitudinal and transverse profiles are described.

1.2. Experienced operators have been able to obtain 500 readings per hour using this procedure.

1.3. *This standard practice may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENT

- *Dipstick Manual*. Face Technologies, Norfolk, Virginia.

3. DEFINITIONS

3.1. *dipstick*—the dipstick is a manually operated device that houses an inclinometer and measures relative elevation differences from one foot to the other. The dipstick measurements can either be recorded manually or stored in a handheld computer using either a trigger or an automatic storage method.

4. SUMMARY OF PRACTICE

4.1. For longitudinal profile measurements, the wheelpaths are first located then cleared of any excess debris. Chalk lines are established to ensure the same path is surveyed in both directions. The dipstick is then moved along the chalk line and measurements are recorded at 0.3-m (1-ft) intervals. The dipstick is "walked" up and back along the same line, thereby allowing a closure error to be calculated. If the closure error exceeds a given amount, the recorded measurements are questionable and the survey may need to be repeated. Collected information can then be used to calculate various roughness indices such as the international roughness index.

4.2. Transverse dipstick measurements are conducted in a fashion similar to the longitudinal. That is, the location for the transverse measurement is established, a chalk line is snapped perpendicular to the travel lane, the dipstick is walked over and back across the lane, and the closure error is calculated. Measurements are recorded at 0.3-m (1-ft) intervals and can be used to calculate rutting using various computational methods.

5. SIGNIFICANCE AND USE

5.1. Longitudinal profile measurements are used during construction to assess the pavement smoothness and are often used to determine contractor pay factors. Elevation profiles, when converted to roughness measurements, are also gathered for estimating the performance of in-service pavements, which can then be utilized in a pavement management system. Increasingly, dipstick measurements are being utilized to check high-speed profiling devices.

5.2. Transverse dipstick measurements are used to develop a cross-profile of the roadway. Cross-profiles are then used to calculate rut depths along a given roadway. This method of rut depth determination can be more accurate than using a straightedge and allows rut depths to be calculated based on differing standards such as a 3.6-m (12-ft) wire line, 1.8-m (6-ft) straightedge, or 1.2-m (4-ft) straightedge.

6. EQUIPMENT

6.1. *The Face Technologies Dipstick*—A manually operated device for the collection of precision profile measurements at a rate and accuracy greater than traditional rod and level survey procedures for individual readings.

6.1.1. The body of the dipstick houses an inclinometer (pendulum), LCD panels, and batteries for power supply. The sensor of the dipstick is mounted in such a manner that its axis and the line passing through the contact points of the footpads are coplanar. The sensor becomes unbalanced as the dipstick is pivoted from one leg to the other as it is moved down the pavement, causing the display to become blank. After the sensor achieves equilibrium, the difference in elevation between the two points is displayed.

6.1.2. The dipstick is equipped with a choice of hardened-steel spike feet or ball-and-swivel footpads. The swivel pads shall be used on pavements.

6.2. The profile that is computed from dipstick measurements may have a shift from the true profile. This shift can be eliminated by applying a bias correction to distribute the closure error.

7. DIPSTICK MAINTENANCE

7.1. *Maintenance*—Specific, detailed maintenance procedures are contained in the manuals provided with each individual piece of equipment, and the operator shall become intimately familiar with the maintenance recommendations contained in all equipment manuals.

7.1.1. It is not the intention of this standard practice to supersede manufacturers’ minimum services and service intervals, but to provide supplementary service requirements. Where there is a conflict between this guide and the manufacturers’ instructions, the more stringent requirements shall be followed.

7.1.2. *Routine Maintenance*—Routine maintenance includes those functions that can be easily performed by the operator with minimal disassembly of a particular device. Routine maintenance for the dipstick includes the cleaning and lubrication of the ball and socket joints on the footpads, replacement of the batteries, and cleaning of the battery contacts. These items are basic and easily performed preventive measures and shall always be completed prior to operation of the equipment.

7.1.3. *Major Maintenance*—Major preventive services shall include much more than the routine checks and will require some disassembly of the equipment by personnel with technical capabilities beyond the skill of the operators such as the manufacturer. Items such as battery connector replacement would fall into the major maintenance category. The appropriate service intervals are outlined in the equipment manufacturer's manual.

8. DIPSTICK PREOPERATIONAL CHECKS

8.1. Check the condition of footpads and replace if necessary. Clean and lubricate the ball-and-socket joints on the footpads to ensure smooth pivoting of the instrument. When the joint is dirty, pivoting becomes difficult and slippage of the footpad can occur. A cleaning agent such as WD-40 and a light oil for lubrication will work for the ball-and-socket joint.

8.2. Install a fresh set of batteries in the instrument and securely close the battery compartment. Batteries shall be changed after 4 hours of usage to ensure continuity of measurements.

8.3. Check and, if necessary, retighten the handle on the instrument.

8.4. *Zero Check, Manual Dipstick*—Perform the zero check prior to and after any dipstick measurements. This test shall be performed on a smooth, clean surface where the instrument can be properly positioned (the carrying case for the dipstick or a flat board will suffice). After positioning the dipstick, draw two circles around the two footpads, and note the reading on the display (reading = $R1$). The instrument shall then be rotated 180 degrees, and the two footpads placed on the two circles that were drawn earlier. Note the reading obtained (reading = $R2$). If the readings from the two placements ($R1$ and $R2$) add up to within ±0.1mm (0.003 in.), the dipstick has passed the zero check. If the addition of two readings does not fall within these limits, zero adjustment is necessary. The zero adjustment shall be performed using the following procedure.

8.4.1. Obtain the average of the two dipstick readings in Equation 1:

$$e = 0.5\,(R1 + R2) \qquad (1)$$

Then subtract this value from $R2$ to obtain $R2o$ in Equation 2:

$$R2o = R2 - e \qquad (2)$$

8.4.2. With the dipstick still in the $R2$ reading position, loosen the setscrew. Adjust the start end, moving the pin up or down so that the display reads $R2o$. Thereafter, tighten the setscrew and rotate the dipstick back to the $R1$ reading position and read the display (reading = $R1o$). Now the addition of $R1o$ and $R2o$ should be within tolerance. If this sum is not within tolerance, repeat the adjustment procedure until the two readings are within tolerance.

8.4.3. This zero adjustment is the only adjustment the operator is allowed to make on the dipstick.

8.5. *Zero Check, Automated Dipstick*—This check should be performed on a smooth, clean, and stable surface (carrying case for the dipstick or a flat board will suffice) where the instrument can be properly positioned. Circles shall be drawn around the two footpads and the CAL button depressed once. The instrument should then be rotated 180 degrees, and the two footpads placed in the circles drawn earlier. The CAL button should again be depressed once. The display will flash 'CAL' three times, after which the error is automatically stripped out of the readings. Note the reading at switch end of dipstick. Rotate dipstick and place two footpads in the circles, and note reading at switch end. If the two readings that were noted add up to within ±0.1 mm (±0.003 in.), the dipstick has passed the zero check. The zero check can only be performed once. If check is not successful, the dipstick must be turned off, turned back on, and the zero check repeated.

8.6. *Calibration Check, Manual and Automated Dipstick*—Check the calibration of the device before and after any dipstick measurements, after the zero check and zero adjustments are performed. To check the calibration, place the 3.2 mm (0.125 in.) calibration block under one of the dipstick footpads. The reading displayed, minus 3.2 mm (0.125 in.), should equal the previous reading plus 0.1 mm (0.003 in.). If the answer is not within this tolerance, Face Technologies shall be contacted to repair the dipstick.

8.6.1. Both the zero check and calibration check shall be performed at the beginning and end of data collection.

9. CALIBRATION

9.1. *Dipstick Calibration*—Calibration of the dipstick is fixed during manufacture and cannot be altered by the user. Factory calibration accuracy is stated to be 0.038 mm (0.0015 in.) per reading. The user can verify the calibration against a standard calibration block that is provided with the dipstick. If the dipstick fails the calibration test, it shall be returned to the manufacturer for repair.

9.2. *Gauge Block Calibration*—The gauge block used during the calibration check shall be calibrated to an accuracy of 3.175 ± 0.025 mm (0.125 ± 0.001 in.) using a local calibration laboratory or a calibration micrometer to ensure the minimum 4:1 ratio of accuracy of gauge blocks to the dipstick. The gauge block shall be recalibrated once every year, or more frequently, depending on (1) presence of oxidation, (2) evidence of erosion, and (3) possible damage caused by accidental mishandling in the field.

9.2.1. If the calibration block (gauge block) thickness is not within 3.175 ± 0.025 mm (0.125 ± 0.001 in.), all data collected since the last check of the block are suspect and may have to be disregarded.

10. SITE INSPECTION AND PREPARATION

10.1. *General Pavement Condition*—The pavement shall be clear of ice, snow, and puddles of water before profile measurements can be taken with the dipstick, as such conditions can affect the profile measurements. Clean loose stones and debris from the area to be profiled to prevent slippage of the dipstick footpads during measurements.

10.2. *Identify Wheelpaths*—For longitudinal profiles, use a chalk line to mark a straight line in each wheelpath 0.8 m (32.5 in.) from the center of the travel lane. The center of the travel lane shall be located using the following guidelines:

10.2.1. *Case I*—Where the wheelpaths can be easily identified, consider the center of the travel lane to be midway between the two wheelpaths.

10.2.2. *Case II*—Where the wheelpaths are not clearly identifiable, but the two lane edges are well defined, consider the center of the travel lane to be midway between the two lane edges.

10.2.3. *Case III*—Where only one lane edge is well defined, consider the center of the travel lane to be 1.8 m (6 ft) from the edge.

10.2.4. A comment in the data collection sheet or field book shall be made on how the centerline of the lane was defined. This information will help to collect consistent data in future profile measurements at that location.

10.3. *Identify Transverse Profile Locations*—Lay out and mark straight lines for transverse profile measurements. The lines shall be perpendicular to the edge of the pavement at specified testing intervals. The location of lines shall be adjusted to avoid raised pavement markings and similar anomalies. The need for and magnitude of such adjustments are to be recorded on the data sheets.

11. LONGITUDINAL PROFILE TEST PROCEDURE

11.1. To start profile measurements, the dipstick shall be placed on a marked wheelpath line at the start point with the "start arrow" pointing forward. A clockwise rotation is recommended because the handle can start to unscrew if you use a counterclockwise rotation. However, it is prudent to keep the same motion for all measurements so that any potential errors introduced by the rotational direction are consistent in all dipstick data.

11.1.1. As the dipstick is walked along the marked wheelpath, the readings shall be recorded each time the dipstick is rotated. If a manual dipstick is used, the data shall be recorded on a data sheet or in a field book; in the auto-read dipstick, the readings are stored in the computer attached to the dipstick. In this case, the operator shall use either the trigger to instruct the computer to store the reading or the automatic storage scheme in the lowest production rate possible. The trigger is preferred because this ensures adequate time for the pendulum to stabilize. Use of the automatic storage mode, even at the lowest production rate, may not allow adequate time for stabilization, thus introducing possible errors in the data.

11.2. Frequently, an operator will introduce bias in the readings by leaning the dipstick handle laterally from a true vertical position during operation. The operator must not apply any lateral pressure on the handle while the reading is taken. Two runs on each wheelpath of the section shall be undertaken by the dipstick operator, consisting of one run up the wheelpath and one run back down the same wheelpath. This will accomplish a closed-loop survey for each wheelpath.

11.3. Minor localized cracks and holes in the pavements as well as open joints shall be avoided during the dipstick profile measurement process (e.g., instances where one footpad sinks into a crack or hole or into an open or faulted joint). Also, care shall be exercised not to place the footpad partially on top of an opening or very wide crack as this may cause slippage during the next advance motion of the dipstick. If the use of swivel pads is not feasible for some reason, then the operator shall avoid isolated depressions by locating the test point on either side of small cracks or holes. If the crack or hole is too big to avoid in this manner, then most likely it should be measured as part of the surface profile and its presence noted in the comment section of the data sheet or in the field log book.

11.4. The dipstick measurements for each wheelpath shall be taken continuously. However, if, for any reason, the operator has to stop measurements (e.g., a sudden heavy storm), the point where the last reading was taken shall be clearly marked (draw a circle around the footpad). The operator may continue the dipstick measurements later from this position after placing a comment on the data collection sheet assuming that this point is clearly identifiable on the pavement.

11.5. After the forward and the return run have been completed on one wheelpath, the post data-collection check and quality control check shall be completed before taking measurements on the other wheelpath.

11.5.1. *Post Data-Collection Check*—To ensure the accuracy of the collected data, the operator must conduct the zero and calibration checks outlined in Sections 8.4, 8.5, and 8.6 after completing measurements on a wheelpath. If the dipstick fails either of these checks, the data shall be considered as suspect. If the dipstick fails the zero check, repeat the profile measurements after adjusting the dipstick as noted in Section 8.4 or 8.5. If the dipstick fails the calibration test, follow the procedure under Section 8.6. If the dipstick satisfies these checks, proceed with the quality control checks.

11.6. *Quality Control Check*—Various forms of error may be introduced into the dipstick measurements, including operator bias, footpad slippage, low battery power, and recording errors. A closed-loop survey is used to establish the total accumulated error in the profile measurements acquired with the dipstick. A closed-loop survey is accomplished by completing an initial run along one wheelpath and a return run along the exact same wheelpath (1 closed loop = 2 runs). The final value of the running sum of the two runs should theoretically result in a zero elevation difference. Any difference in elevation that is obtained is assumed to be due to operator error. By dividing the accumulated error by the length of the loop survey, the error per reading can be obtained. The maximum error allowed is 0.076 mm (0.003 in.) per reading. If the allowable elevation difference is exceeded during a dipstick measurement of a section, the section shall be retested until acceptable results are obtained.

12. TRANSVERSE PROFILE TEST PROCEDURE

12.1. Dipstick transverse profile measurements shall be collected at preestablished intervals. Elevations for each transverse profile location will be measured from the outside edge of the pavement and shall extend over the full lane width with the actual distance depending on lane width and pavement striping. The starting point shall be the junction of the transverse measurement line and the inside edge of the white paint stripe along the outside edge of the lane. If no outside edge stripe is present, then the beginning point shall be either the shoulder-lane joint or a point approximately 0.9 m (3 ft) from the center of the outside wheelpath. A comment shall be recorded noting how the starting point was determined. The initial elevation is arbitrarily established as zero and the subsequent readings are recorded relative to this benchmark. The combination of these measurements provides a measure of the pavement cross slope.

12.2. To begin the transverse profile measurements, the dipstick is placed at the outside edge of the pavement starting with the start arrow pointing toward the pavement centerline.

12.2.1. If the manual dipstick is being used, the measurements shall be recorded on a data form or in a field book. If the auto-read dipstick is used, it shall be triggered to record the readings.

12.3. The dipstick operator shall complete two runs per transverse profile of each section; one run up the transverse line and a return run back along the transverse profile to complete the closed-loop survey.

12.4. After the forward and the return run have been completed, the post data-collection check and quality control check need to be completed before finishing.

12.4.1. *Post Data-Collection Check*—To ensure the accuracy of the collected data, the operator must conduct the zero and calibration checks outlined in Sections 8.4, 8.5, and 8.6 after completing the transverse measurements. If the dipstick fails either of these checks, the data shall be considered as suspect. If the dipstick fails the zero check, repeat the transverse profile measurements after adjusting the dipstick as noted in Section 8.4 or 8.5. If the dipstick fails the calibration check, follow the procedure in Section 8.6. If the dipstick satisfies these checks, proceed with the quality control checks.

12.5. *Quality Control*—The total accumulated error in the transverse profile measurement shall be established by a closed-loop survey. The forward and return runs along a transverse section are utilized to compute this error. The maximum allowable error for the transverse profile measurements is 0.076 mm (0.003 in.) per reading, or 1.8 mm (0.072 in.) total for a 3.6-m (12-ft) lane width.

13. REPORT

13.1. *The report shall contain the following information*:

13.1.1. Serial number of the dipstick used;

13.1.2. Date information was collected;

13.1.3. Dipstick operator and data recorder;

13.1.4. Roadway identification;

13.1.5. Results of preoperational checks (zero and calibration checks);

13.1.6. Location of the wheelpaths (for longitudinal profiles);

13.1.7. Dipstick readings as collected at each point;

13.1.8. Post data-collection checks (zero and calibration checks); and

13.1.9. Quality control summary information.

14. PRECISION AND BIAS

14.1. No precision or bias statements are available at this time.

15. KEYWORDS

15.1. Dipstick; pavement profile.

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Standard Practice for

Quantifying Roughness of Pavements

AASHTO Designation: R 43M/R 43-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Practice for

Quantifying Roughness of Pavements

AASHTO Designation: R 43M/R 43-07

1. SCOPE

1.1. This standard practice describes a method for estimating roughness for a pavement section. An international roughness index (IRI) statistic is calculated from a single longitudinal profile measured with a road profiler in both the inside and outside wheel paths of the pavement. The average of these two IRI statistics is reported as the roughness of the pavement section.

1.2. This standard practice recognizes the need for a quality assurance (QA) plan and proposes guidelines for the development of a QA plan.

1.3. Measurements of profile are made in accordance with ASTM E 950. If any part of this standard practice is in conflict with its referenced documents, such as ASTM standards, this standard practice takes precedence for its purpose.

1.4. The values in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in parentheses. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.5. *This standard practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- E 867, Standard Terminology Relating to Vehicle-Pavement Systems
- E 950, Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference
- E 1166, Standard Guide for Network Level Pavement Management

2.2. *Other Documents*:

- Sayers, Michael W. On the Calculation of IRI from Longitudinal Road Profile. University of Michigan, Transportation Research Institute, Preprint TRB, 74th Annual Meeting, Washington, DC, January 1995.
- Sayers, Michael W., T. D. Gillespie, and W. D. O. Paterson. Guidelines for Conducting and Calibrating Road Roughness Measurements. *The World Bank Technical Paper*, Number 46. The World Bank, 1986.

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *roughness*—according to ASTM E 867, the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality. In this standard practice, the term "roughness" is the average of two IRI statistics calculated from longitudinal profile measurements, one in each pavement wheel path.

3.1.2. *longitudinal profile*—the set of perpendicular deviations of the pavement surface from an established horizontal reference plane to the lane direction.

3.1.3. *international roughness index* (IRI)—a statistic used to estimate the amount of roughness in a measured longitudinal profile. The IRI is computed from a single longitudinal profile using a quarter-car simulation as described in the report "On the Calculation of IRI from Longitudinal Road Profile" (Sayers 1995). Computer programs to calculate the IRI statistic from a longitudinal profile are referenced in Appendix X1 of this procedure.

4. SIGNIFICANCE AND USE

4.1. This standard practice outlines standard procedures for measuring longitudinal profile and calculating the IRI for highway pavement surfaces to help produce consistent estimations of IRI for network-level pavement management.

5. QUALITY ASSURANCE

5.1. Agencies using this standard practice are required to develop a satisfactory quality assurance (QA) plan. At a minimum, the plan shall include the requirements listed in the following sections:

5.1.1. Qualification and training records of individuals conducting the survey;

5.1.2. Accuracy and calibration records of equipment used in the survey; and

5.1.3. Periodic and ongoing quality control program and the content of the program.

Note 1—The estimate of roughness of pavements can be used both at network- and project-level pavement management. Guidelines for network level are included in ASTM E 1166, which can be used as a source for the development of a QA plan.

Note 2—The guidelines that can be used for the development of a quality assurance plan are given in Appendix X2.

6. DATA COLLECTION

6.1. Agencies using this standard practice are expected to designate the lane(s) and direction(s) of travel to be surveyed based on sound engineering principles and management needs within the agency.

6.2. Locate (place) the two sensors, separated approximately 1.6 to 1.8 m (58 to 71 in.) in the wheel paths. The longitudinal profile points used for calculating the IRI shall have a longitudinal spacing not greater than 150 mm (6 in.). Long wavelength filters are used to remove all wavelengths exceeding 90 m (300 ft).

Note 3—The use of anti-aliasing filters and averaging to remove small wavelength content from the profile is left to the discretion of the agency and equipment manufacturers.

7. CALCULATIONS

7.1. Calculate IRI values for each 0.1 km (0.1 mi) for both wheel paths. Compute an average of the two IRI values to determine roughness.

Note 4—The tenth of a kilometer (tenth of a mile) values are needed to calculate average values for each data collection section.

8. REPORT

8.1. *Report the following information*:

8.1.1. Roughness calculated in Section 7.1 to the nearest 0.01 m/km (one inch per mile);

8.1.2. Length of the data summary interval of 0.1 km;

8.2. *Report the following minimum data recorded and stored for each section*:

8.2.1. *Section Identification*—List all available information necessary to locate the section using agency's current referencing system;

8.3. IRI for each of the two wheel paths (m/km) [in./mi];

8.3.1. Average of both IRIs calculated for the section (m/km) [in./mi];

8.3.2. Date of data collection (month/day/year);

8.3.3. Length of section in meters for which the data are collected;

8.3.4. Profile sampling interval;

8.3.5. Long wavelength filter setting; and

8.3.6. *Optional*—Pavement surface temperature.

9. KEYWORDS

9.1. Inertial profiler; International Roughness Index; longitudinal pavement profile; pavement; pavement ride quality; pavement smoothness; roughness.

APPENDIXES

(Nonmandatory Information)

X1. FORTRAN PROGRAM TO CALCULATE IRI FROM PROFILE

X1.1. A program that complies with the requirements of R 43M/R 43 was developed by Sayers in 1995 at the University of Michigan.

Note X1—This standard practice requires IRI to be reported in units of meters per kilometer (m/km), the profile elevations (Variable PROF in subroutine IRI) are measured in millimeters, and the input distance between elevation points (variable *dx* in subroutine IRI) is measured in meters. Consequently, the UNITSC value in the program should be set to one (1.0).

Note X2—Another software program is available from the University of Michigan Transportation Research Institute (UMTRI), named RoadRuf. This Microsoft Windows based software contains procedures for calculating IRI and many other profile analysis capabilities. The software can be made to comply with the requirements of this protocol. It is public domain and can be downloaded from the Internet at http://www.umtri.umich.edu/erd/roughness/rr.html. Setup options are discussed in the accompanying documentation.

X2. GUIDELINES—QUALITY ASSURANCE PLAN

X2.1. *Quality Assurance (QA) Plan*—Each agency shall develop a QA plan. The plan shall include survey personnel certification training records, accuracy of equipment, daily quality control (QC) procedures, and periodic and ongoing QC activities. The following guidelines can be used for developing such a plan.

X2.2. *Certification and Training*—Agencies are individually responsible for training and/or certifying their data collection personnel and contractors for proficiency in using the profile measuring equipment according to this standard practice and other applicable agency procedures.

X2.3. *Equipment Calibration*—Equipment calibration (accelerometers and noncontact sensors) is done in accordance with specific manufacturer recommendations. The equipment must operate within the manufacturer's specifications. A regular maintenance and testing program is established for the equipment in accordance with the manufacturer's recommendations.

X2.4. *Verifications Sections*—Verifications sections are selected with known IRI statistics for both wheel paths. These sections are measured by equipment operators on a regular basis. Evaluations of these measurements can provide information about the accuracy of field measurements and give insight into needed equipment calibration. Verification sections are rotated on a regular basis in order to assure that the operators are not repeating previously known IRI statistics during the verification. An alternate to verification sections is to remeasure and compare up to 5 percent of the data as a daily or weekly quality check to ensure system stability and repeatability.

X2.5. *Quality Checks*—Additional quality checks can be made by comparing the most recent IRI statistics with current measurements. At locations where large changes occur, the pavement manager may require additional checks of the data.

Standard Practice for

Determining Rut Depth in Pavements

AASHTO Designation: R 48-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Determining Rut Depth in Pavements

AASHTO Designation: R 48-10

1. SCOPE

1.1. This practice describes a method for determining rut depth in pavement surfaces from transverse profile measurements. Five transverse profile points are the minimum number of points required to determine rut depth. While this practice is based on a five-measurement transverse profile, more than five measurements greatly improve the accuracy and enhance the likelihood of identifying the maximum and average rut depth given survey vehicle wander and various rut configurations.

1.2. Procedures are defined for measuring a transverse profile and deriving a rut depth, but detailed specifications are not included for equipment, instruments, or software used to make the measurements. Any equipment and/or procedure that can measure as specified, with the accuracy stipulated herein, and that can be adequately calibrated is acceptable for this method.

1.3. *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this protocol to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENT

2.1. *FHWA Document*:

- FHWA-RD-01-024, *Characterization of Transverse Profiles*, Federal Highway Administration, 2001

3. TERMINOLOGY

3.1. *rut*—a longitudinal depression in a wheelpath consisting of consecutive rut depth determinations that measure a depression and extend for more than 50 m (150 ft).

3.2. *summary interval*—a longitudinal portion of a pavement lane over which the data are summarized as defined by the agency. This distance is generally 0.1 km (0.1 mi).

4. SIGNIFICANCE AND USE

4.1. This practice outlines standard procedures for measuring a transverse profile of the pavement from which a rut depth may be derived and summarizing the rut depth over a designated interval. Its purpose is to produce consistent estimations of rut depth for network-level pavement management. The intention is to measure rut depth in a vehicle traveling in the designated lane at highway speeds.

5. RUT MEASUREMENT

5.1. Each agency designates the lane(s) and direction(s) of travel to be surveyed based on sound engineering principles and management needs within the agency.

5.2. Transverse profiles should be measured at a maximum spacing of 10 m (33 ft) in the longitudinal direction for the purpose of determining rut depth.

5.3. Transverse profiles are measured across both wheelpaths of the survey lane. The goal of this practice is to obtain a transverse profile from which the depth of both ruts in a traffic lane can be derived. The reported summary statistics are the deepest rut found in each wheelpath and the average rut depth within the longitudinal summary interval.

5.3.1. The transverse locations for the five-measurement procedure are shown in Figure 1.

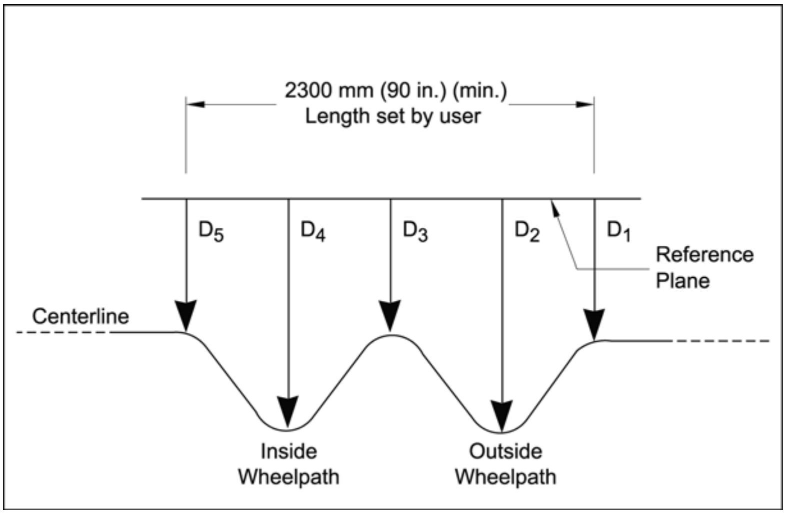

Figure 1—Rut Depth Measurements

5.3.1.1. Spacing between measurement points depend on pavement geometry and typically are not even.

5.3.1.2. For best rut values, the span between D_1 and D_5 measurements should be no less than 500 mm (20 in.) smaller than the lane width. Depending on equipment, safe operation often dictates a shorter span, which compromises the rut value.

5.3.2. Each height measurement, *Di*, shall be made in a manner to minimize variability of measurement due to the pavement surface not being a true planar surface.

5.3.3. The depth measurements shall be made to a resolution of 3 mm (0.12 in.) and an accuracy of ±3 mm (±0.12 in.) with a 95 percent confidence.

5.3.4. *The Basic Five-Point Rut Depth Calculations*:

$$R_o = D_2 - \frac{D_1 + M}{2} \qquad (1)$$

$$R_i = D_4 - \frac{M + D_5}{2} \qquad (2)$$

where:

$$M = \frac{D_1 + D_5}{2} \text{ or } D_3, \text{ whichever, is less} \qquad (3)$$

R_o = rut depth outside wheelpath estimate, mm;

R_i = rut depth inside wheelpath estimate, mm; and

D_1, D_2 ... D_5 = height measured as shown in Figure 1 (mm).

Note 1—This calculation allows for a negative rut depth. The negative rut can come from unusual cross sections, lateral offset of the measurement location, or atypical rut configurations.

5.3.5. The transverse profile is determined on the basis of the vertical distance between an imaginary string line run across the traffic lane from the shoulder to the lane line. The string line may bend at the hump between the wheelpaths where the hump is higher than the outside and inside edges of the lane. For manual measurements, the use of a string line will require D_1 and D_5 to be zero.

Note 2—This procedure is defined with knowledge of FHWA-RD-01-024 *Characterization of Transverse Profiles,* which compared ruts calculated from three- and five-point measurements to significantly denser systems. Users of this standard are advised to review this reference when making transverse measurement collection system decisions.

5.3.6. The five-point system has limited accuracy due to variances in rut configuration and vehicle wander during the collection process. These limitations are further complicated by keeping the sensor systems within a safe envelope while traveling the road.

Note 3—The addition of two sensors at each primary measurement location (D_1, D_2, D_3, D_4, D_5) spaced 150 mm (6 in.) apart and the application of appropriate algorithms dramatically improve the reliability of the derived rut values. For maximum effectiveness, both of the outside sensors need to target beyond the 2300-mm (90-in.) dimension at each end to extend the simulated string to within 250 mm (10 in.) of the lane width.

5.3.7. Technology is available to provide more than 1000 data points across the entire lane width. With such a transverse profile measurement, algorithms can be applied that remove texture effects, compensate for vehicle wander, and resolve a string-line rut value for each wheelpath. *This is the preferred methodology for rut data collection.*

6. OBTAINING THE DATA

6.1. Obtain and store the maximum and average rut depth determined from each wheelpath within the selected data summary interval.

7. REPORT

7.1. *At a minimum, record the following data*:

7.1.1. *Section Identification*—Record agency's information available to locate the section using its current referencing system;

7.1.2. Date of collection;

7.1.3. Length of data collection section (km (mi));

7.1.4. Maximum rut depth in each wheelpath for each summary interval;

7.1.5. Average rut depth in each wheelpath for each summary interval;

7.1.6. Sampling interval (m (ft));

7.1.7. Summary interval (km (mi));

7.1.8. Method agency utilizes to calculate maximum rut depth and average rut depth when negative rut depths are measured.

8. KEYWORDS

8.1. Pavement; pavement distortion; pavement distress; pavement evaluation; pavement management; pavement monitoring; rut; transverse profile; wheelpath; five-point rut estimate.

9. REFERENCES

9.1. AASHTO. *Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, DC, 1993.

9.2. ASTM Standard E 1703/E 1703M, 1995 (2005). "Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge." ASTM International, West Conshohocken, PA.

9.3. SHRP. *Distress Identification Manual for the Long-Term Pavement Performance Project*. Strategic Highway Research Program, SHRP-P-338, Washington, DC, 1993.

APPENDIX

(Nonmandatory Information)

X1. GUIDELINES—QUALITY ASSURANCE PLAN

X1.1. *Quality Assurance Plan*—Each agency shall develop a quality assurance plan. The plan shall include survey personnel certification training records, accuracy of the equipment, daily quality control procedures, and periodic and ongoing quality control. The following guidelines can be used for developing such a plan.

X1.2. *Certification and Training*—Agencies are individually responsible for training and/or certifying their data collection personnel and contractors for proficiency in using the profile measuring equipment according to this practice and other applicable agency procedures.

X1.3. *Equipment Calibration*—Equipment calibration (accelerometers and noncontact sensors) is done in accordance with specific manufacturer recommendations. The equipment must operate within the manufacturer's specifications. A regular maintenance and testing program is established for the equipment in accordance with the manufacturer's recommendations.

X1.4. *Verification Sections*—Verification sections are selected with known rut depths. These sections are measured by equipment operators on a regular basis. Evaluations of these measurements can provide information about the accuracy of field measurements and give insight into needed equipment calibration. Verification sections are rotated on a regular basis in order to assure that the operators are not repeating previously known rut depth values during the verification. An alternate to verification sections is to remeasure and compare up to 5 percent of the data as a daily or weekly quality check.

X1.5. *Quality Checks*—Additional quality checks can be made by comparing the most recent rut depth statistics with current measurements. At locations where large changes occur, the pavement manager may require additional checks of the data.

Standard Practice for

Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems

AASHTO Designation: R 54-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems

AASHTO Designation: R 54-10[1]

1. SCOPE

1.1 This practice provides guidance and example specification language intended for use by Owner-Agencies in development of specific contract language when requiring the measurement and evaluation of ride quality and compliance using inertial profiling systems (IPS) and IRI as the quality measure.

1.2 If any part of this practice is in conflict with references made, such as ASTM or AASHTO Standards, this practice takes precedence for its purposes.

1.3 The values stated are in U.S. Customary units and are to be regarded as the standard.

1.4 *This specification does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this specification to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 328, Inertial Profiler
- R 56, Certification of Inertial Profiling Systems
- R 57, Operating Inertial Profiling Systems

2.2 ASTM Standard:

- E 1926, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *International Roughness Index (IRI)*—a statistic used to determine the amount of roughness in a measured longitudinal profile. The IRI is computed from a single longitudinal profile using a quarter-car simulation as described in the paper "On the Calculation of International Roughness

Index from Longitudinal Road Profile" (Sayers 1995). The IRI is reported as described in ASTM E 1926.

3.1.2 *localized roughness*—any 25-foot segment of roadway that contributes disproportionately to the overall roughness index value. Areas of localized roughness are identified using a report of continuous IRI with a base length of 25 feet. This yields the IRI of every possible 25-foot segment. Any segment for which the continuous report exceeds a threshold IRI value is considered a defective segment requiring correction.

Note 1—The threshold IRI value in inches per mile should be determined by each Owner-Agency. A typical range of values for various highway types is shown below:

Table 1—Typical Threshold Values for Localized Roughness

Roadway Type	IRI (in. per mile)
Interstate	140 to 160
State primary	150 to 170
State secondary	160 to 190

3.1.3 *longitudinal elevation profile*—a longitudinal profile containing a series of relative pavement surface elevation measurements referenced to a common horizontal datum.

3.1.4 *report interval*—the longitudinal distance between the outputs of a profile index value.

3.1.5 *roughness*—the deviation of a surface from a true planar surface with characteristic dimensions that affects vehicle dynamics and ride quality.

3.1.6 *Type A Roughness Measurement*—a test procedure to measure the surface profile index known as the International Roughness Index (IRI) using an inertial profiler.

3.1.7 *Type B Roughness Measurement*—a test procedure to measure surface profile deviations using a straightedge.

4. SIGNIFICANCE AND USE

4.1 This example provides specification language for measuring and accepting ride quality on newly constructed paving projects using an IPS and the IRI quality measure. If an Owner-Agency elects to use some other ride quality index, the fundamental methodology described herein remains valid, but not the individual settings.

Note 2—The IPS should be verified on the same pavement surface type and texture as that being measured. When profiling pavements with rough macro texture, a height sensor with a large footprint is needed. The consequence of not using a large footprint sensor may be an upward bias in the IRI as measured by an IPS with a conventional point laser.

5. EQUIPMENT AND OPERATOR

5.1 Provide an approved 10-ft straightedge.

5.2 Provide an inertial profiler meeting all requirements and specifications found in M 328 and currently certified in accordance with R 56. Operate the equipment in accordance with R 57.

5.3 Provide the Owner-Agency a copy of the equipment certification. Display a current decal on the equipment indicating the expiration date of certification.

Note 3—An equipment certification or decal would be required only if the Owner-Agency had a certification program that issued them, or where it recognizes another agency's certification program in which certifications, decals, or both are issued.

5.4 Provide a qualified profiler operator. Provide the Owner-Agency a copy of the operator's qualifications or current certification.

6. WORK METHODS

6.1 *Quality Control (QC) Testing (nondirected)*—Perform QC tests on a daily basis throughout the duration of the project. Use an approved straightedge, inertial profiler, profilograph, or any other appropriate means.

6.2 *Quality Control Testing (directed)*—Use Type A Roughness Measurement. Use Type B Roughness Measurement only when Type A Roughness Measurement cannot be used or when specified by the Owner-Agency. Measure the finished surface of the completed project or at the completion of a major stage of construction as approved by the Owner-Agency. Coordinate with and receive authorization from the Owner-Agency before starting testing. Obtain roughness measurements within 7 days after receiving authorization and submit results to the Owner-Agency within 24 hours of data collection.

6.2.1 Operate the profiler in accordance with R 57 and provide the Owner-Agency the results of the Daily Measurement Control on a daily basis. The Owner-Agency may require QC testing be performed at off-peak times for traffic flow. Operate the inertial profiler in a manner that does not unduly disrupt traffic flow as determined by the Owner-Agency. Use an approved traffic control plan. Traffic control for QC and verification testing by the Owner-Agency is at the expense of the contractor. Provide all profile measurements to the Owner-Agency in electronic data files of the format specified in R 57.

6.3 *Verification Testing*—Within 10 working days after the contractor's QC testing under Section 6.2 is completed, the Owner-Agency may perform verification testing using an inertial profiler meeting the requirements of R 56. If the verification testing produces an IRI obtained over the same section of roadway that differs from that obtained using the contractor's profiler by more than the percentages shown in Table 2, then the Owner-Agency and contractor shall attempt to resolve the differences to their mutual satisfaction.

Table 2—Typical Allowable IRI Differences

Mean of Agency and Contractor's IRI (in./mi)	Max. Allowable Difference[a]
Fewer than 50	8.5% of mean IRI
50 to 150	6.0% of mean IRI
Greater than 150	7.0% of mean IRI

[a] Actual values should be set by the Owner-Agency.

6.3.1 If the differences cannot be resolved, then referee testing will be conducted. The Owner-Agency will conduct the referee testing and the results will be final and will be used to establish pay adjustments. Referee testing will be conducted using an inertial profiler that recently has been certified in accordance with R 56. The certification should not be more than 90 days old unless both parties agree otherwise.

6.3.2 If the testing confirms the Owner-Agency profiler and fails to confirm the contractor's profiler, then the contractor's profiler shall be taken out of service until it has been recertified in accordance with R 56. A similar requirement will apply if the testing confirms the contractor equipment but fails to confirm the Owner-Agency. If the referee testing fails to confirm either the Owner-Agency or contractor equipment, then both profilers shall be removed from service until recertified.

6.4 *Evaluation of Profiles*—The contractor shall evaluate profiles for acceptance, incentive payments, disincentive payments, or corrective action using the current version of ProVAL and provide the results to the Owner-Agency within 24 hours of completing testing under Section 6.2. Analyze the entire profile. Exclude any areas specifically identified in the contract. Exclude from the analysis for localized roughness the first 12.5 ft after the start of the paving operations and last 12.5 ft prior to the end of the paving operation. Also exclude the first 12.5 ft on either side of bridge structures, manhole covers, utility covers, and approach slabs. Determine pay adjustments in accordance with Sections 6.4.3 and 6.4.4. The Owner-Agency will verify the analysis.

Note 4—The Profile Viewer and Analysis (ProVAL) software program developed for the Federal Highway Administration, which can be used to import, display, and analyze the characteristics of pavement profiles from many different sources, is available at http://www.roadprofile.com.

6.4.1 *Type A Roughness Measurement*—The Owner-Agency may use the QC test results obtained under Section 6.2 to determine pay adjustments for ride quality provided it is able to verify the contractor's profile data. Areas excluded from measurement under Type A Roughness Measurement shall be measured in accordance with Section 6.4.2.

6.4.2 *Type B Roughness Measurement*—Typically used where an IPS cannot be effectively operated. There are no pay adjustments when Type B Roughness Measurement is used. In a manner approved by the Owner-Agency, correct surface areas that have more than $^1/_4$-in. variation between any two contacts on the straightedge. There is no payment for correcting deficient areas. Following correction, retest the area to verify compliance.

6.4.3 *Pay Adjustment Schedule*—The pay adjustment factors from Table 3 will be used in conjunction with the histogram printout from ProVAL's Smoothness Assurance Module based on a report of continuous IRI with a base length of 528 ft, to compute a final pay factor (incentive or disincentive). The final pay factor (PF) computed to three decimals is equal to the sum of the products of the individual pay adjustment factors shown in Table 3 times ProVAL's corresponding histogram percentages all divided by 100. In addition to the final pay factor determined from Table 3, disincentives for localized roughness may apply as described in Section 6.4.4.

Table 3—Pay Adjustment Factors and Computation of Final Pay Factor

IRI range, in./mi[a] (1)	Pay Adjustment Factors (2)	Percent of Pavement within IRI Range taken from ProVAL's Smoothness Assurance Module (SAM) (3)	Pay Adjustment (4)
> ##.0	0.##	#.# or ##.#	#.# or ##.#
##.1 – ##.0	0.##	#.# or ##.#	#.# or ##.#
##.1 – ##.0	0.##	#.# or ##.#	#.# or ##.#
##.1 – ##.0	0.##	#.# or ##.#	#.# or ##.#
##.1 – ##.0	1.00	#.# or ##.#	#.# or ##.#
##.1 – ##.0	1.##	#.# or ##.#	#.# or ##.#
##.1 – ##.0	1.##	#.# or ##.#	#.# or ##.#
##.1 – ##.0	1.##	#.# or ##.#	#.# or ##.#
< ##.0	1.##	#.# or ##.#	#.# or ##.#
	Final Pay Factor (PF) = (Sum/100) =		#.### or 0.###

[a] The number of steps in the table as well as the IRI Ranges and pay adjustment factors should be set by the Owner-Agency.

Note 5—A different set of pay adjustment factors may be used for different project requirements. This pay adjustment table is just one style of many possible pay tables and was designed to utilize quality assurance features within ProVAL. For this table, the final pay factor is determined by taking the values in column (2) and multiplying them by column (3). The results are shown in column (4). The results in column (4) are then summed and divided by 100 to obtain the Final Pay Factor (incentive or disincentive).

6.4.4 *Localized Roughness*—The adjustment factors from Table 4 will be used in conjunction with the histogram printout from ProVAL's Smoothness Assurance Module based on a report of continuous IRI with a base length of 25 feet, to compute the percent disincentive for localized roughness. The amount of the disincentive computed to three decimals is equal to 100 minus the sum of the products of the individual adjustment factors shown in Table 4 times ProVAL's corresponding histogram percentages. The Owner-Agency will either assess the disincentive per Table 4, or require that corrective action be taken. If corrective action is required, re-profile the corrected area and provide the Owner-Agency the results. If the corrective action is not successful, the Owner-Agency will assess the disincentive or require continued corrective action.

Table 4—Disincentives for Localized Roughness

IRI range, in./mi[a] (1)	Pay Adjustment Factors (2)	Percent of Pavement within IRI Range taken from ProVAL's Smoothness Assurance Module (SAM) (3)	Pay Adjustment (4)
> ###.0	0.##	#.# or ##.#	#.### or ##.###
###.1 – ###.0	0.##	#.# or ##.#	#.### or ##.###
###.1 – ###.0	0.##	#.# or ##.#	#.### or ##.###
###.1 – ###.0	0.##	#.# or ##.#	#.### or ##.###
< ###.0	1.00	#.# or ##.#	#.### or ##.###
		Final Percent Disincentive = (100 – Sum) =	#.### or ##.###

[a] The number of steps in the table as well as the IRI Ranges and pay adjustment factors should be set by the Owner-Agency.

Note 6—A different set of pay adjustment factors may be used for different project requirements. This pay adjustment table is just one style of many possible pay tables and was designed to utilize quality assurance features within ProVAL. For this table the final percent disincentive is determined by taking the values in column (2) and multiplying them by column (3). The results are shown in column (4). The results in column (4) are then summed and subtracted from 100 to obtain the final percent disincentive.

6.4.5 *Deficiencies and Corrective Work*—All corrective work will be at the Contractor's expense.

- A defective segment is any area of localized roughness as determined in Section 6.4.4.
- Propose a plan and methodology to correct deficiencies and receive approval from the Owner-Agency before beginning any corrective work. This must be done with the purpose of correcting the minimum area needed to decrease the roughness to acceptable limits. ProVAL's Smoothness Assurance Module is an example of a computer program than can be used to assist in developing a plan.
- The Owner-Agency will determine the final disposition of defective segments, which may include corrective actions, assessment of a penalty, or some combination thereof.
- After making corrections, reprofile the corrected pavement section to verify that the corrections have produced the required improvements. If the corrective action does not produce the required improvement, the Owner-Agency may assess the penalty, or require or allow continued corrective action.
- Corrective actions will not be allowed on nondeficient sections to obtain incentive payments.

7. MEASUREMENT AND PAYMENT

7.1 *Measurement and Payment*—The work performed, materials furnished, equipment, labor, tools, and incidentals will not be measured or paid for directly, but will be subsidiary to bid items of the contract. The final pay factor as determined in Section 6.4.3 and the percent disincentive for localized roughness as determined in 6.4.4 will be applied to the unit bid price for the quantity of pavement placed and accepted. The appropriate incentive or disincentives will be applied separately.

8. REFERENCES

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[1] Formerly MP 17. First published as full standard in 2010.

Standard Practice for

Quantifying Cracks in Asphalt Pavement Surfaces

AASHTO Designation: R 55-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street NW, Suite 249
Washington, DC 20001

Standard Practice for

Quantifying Cracks in Asphalt Pavement Surfaces

AASHTO Designation: R 55-10[1]

1. SCOPE

1.1. This practice covers the procedures for quantifying cracking in asphalt pavement surfaces, both in wheelpath and non-wheelpath areas. Detailed specifications are not included for equipment or instruments used to make the measurements. According to this standard, any process that can quantify, with the accuracy stipulated herein, and that can be adequately validated, is considered acceptable.

Note 1—Standardization will produce consistent pavement condition estimates for network-level pavement management. As an option, the user may define and collect other data, such as edge cracking, centerline cracks, and transverse cracks. This standard is designed for use primarily with automated data collection equipment. However, accommodations have been made for manual methods.

1.2. Either automated or manual data collection surveys as defined below are acceptable.

1.2.1. *Automated Data Collection*—Use a vehicle traveling at near highway speeds and collect data on the entire length of roadway (100 percent sample).

1.2.2. *Manual Data Collection*—Observe distresses and record data on a statistically reliable sample of the lane surveyed. The confidence level in the results for each section should exceed 85 percent. Rating continuous film or tape in an office setting is considered a manual survey.

1.3. *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. TERMINOLOGY

2.1. *crack*—a discontinuity in the pavement surface with minimum dimensions of 1-mm ($^1/_{25}$-in.) width and 25-mm (1-in.) length.

3. SIGNIFICANCE AND USE

3.1. This practice covers the procedures for quantifying cracking in asphalt pavement surfaces both in wheelpath and non-wheelpath areas for network-level pavement management applications. The intent of this practice is to quantify and differentiate between load-associated (fatigue) and nonload-associated (environmental, reflective, etc.) pavement cracking and joints.

Note 2—At the time this standard was drafted, it was already identified in the *Highway Performance Monitoring System Reassessment 2010+* as the collection and reporting standard for pavement cracking. However, this standard was not written specifically for that use and makes no assertion about the fitness of that or any other application beyond use in network-level pavement management.

4. PROCEDURE

4.1. *General Guidelines*—Each agency shall designate the lane(s) and direction(s) of travel to be surveyed or rated based on sound engineering principles and management needs within the agency. The following guidelines are recommended as minimums to provide long-term uniformity:

4.1.1. Survey a 2.5-m (8-ft) strip in the outside lane as shown in Figure 1. As another option, survey the 3.6-m (12-ft) full lane width.

4.1.2. For undivided highways, survey one direction.

4.1.3. For divided highways, survey the outside lane in both directions.

4.1.4. For each survey cycle, it is desirable to use the same direction(s) of travel and survey lane(s).

4.2. *Cracking Types*—Cracks may include longitudinal cracks, transverse cracks, and interconnected cracks. The intent of this practice is to quantify and differentiate between load-associated (fatigue) and nonload-associated (environmental, reflective, etc.) pavement cracking and joints.

4.2.1. For this practice, increased cracking intensity in the wheelpath as compared with the non-wheelpath areas is assumed to quantify load-associated cracking.

4.2.2. Nonload-associated cracking is quantified by the cracking measured in the non-wheelpath areas.

4.2.3. Sealed cracks will not be quantified by manual surveys. Automated data collection equipment will not quantify any discontinuity greater than 25-mm (1-in.) width.

4.3. *Cracking Estimates by Type*:

4.3.1. *Rating Wheelpath Cracks*—Wheelpath cracking is determined in both the inside and outside wheelpath as shown in Figure 1.

4.3.2. *Rating between Wheelpath Cracks*—Non-wheelpath cracking is determined in the area between the wheelpaths as shown in Figure 1.

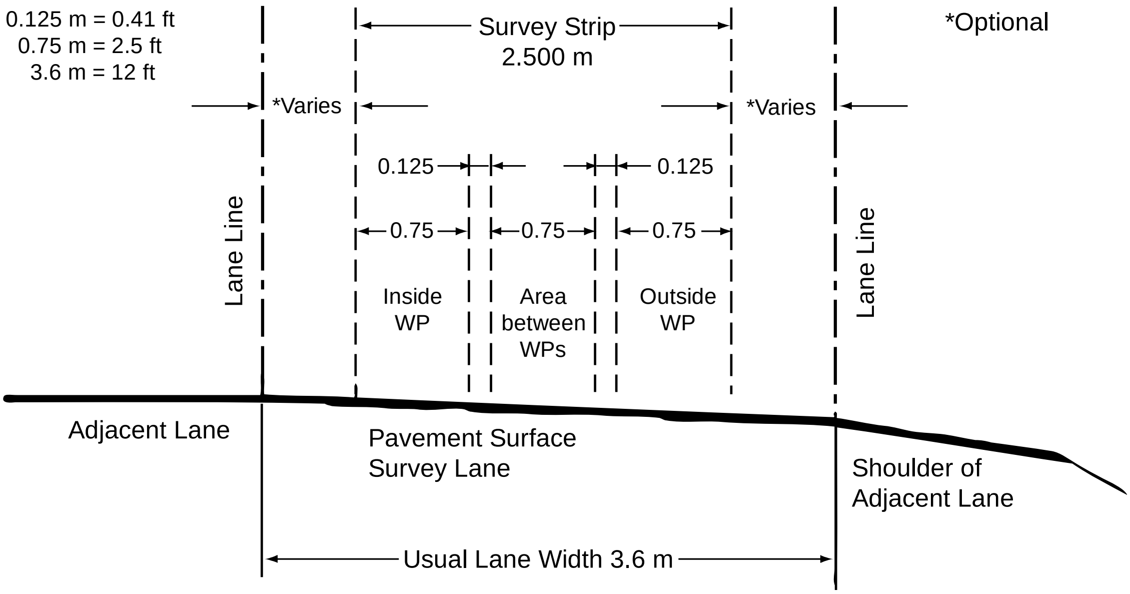

Figure 1—Cross Section of Survey Lane Showing Wheelpaths and Defined Survey Area between Wheelpaths

4.3.3. Determining any additional non-wheelpath cracking for the remainder of the lane width is optional and will be defined by the agency.

4.3.4. Classify cracking by severity and intensity as indicated below.

4.3.4.1. *Severity Level 1*—Cracks ≤3 mm (≤$^1/_8$ in.).

4.3.4.2. *Severity Level 2*—Cracks with dimensions >3 mm (>$^1/_8$ in.) and ≤6 mm (≤$^1/_4$ in.) width.

4.3.4.3. *Severity Level 3*—Cracks with dimensions >6 mm (>$^1/_4$ in.) width.

4.3.5. Quantify intensity of cracking at each level as the total length of cracking per unit area (m/m^2 or ft/ft^2) for each defined survey strip as shown in Figure 1.

Note 3—The sample area is a function of the sample length the agency has chosen in Section 5.

5. RECORDING OF DATA

5.1. *Automated Data Collection*—The entire length of the pavement shall be surveyed (100 percent sample). The data summary interval shall be 0.1 km (0.062 mi).

5.2. *Manual Data Collection*—The number of samples for a given homogeneous section of pavement is determined by the desired confidence level and the variance in the samples. The minimum 85 percent confidence interval of the mean should be no greater than 10 percent of its value. Each section shall have at least four samples. For the purpose of establishing the confidence level, the total crack length for all severity levels within a survey strip may be added together. Table 1 shows the confidence interval for example sample counts and confidence levels as a function of the standard deviation of the samples. It is understood that the samples should be distributed throughout the section.

Table 1—Confidence Interval for Sample Counts

CONFIDENCE INTERVAL		
Number of Samples	85 Percent Confidence	95 Percent Confidence
5	1.034*s*	1.802*s*
10	0.691*s*	1.204*s*
20	0.476*s*	0.829*s*

Note: Where *s* is the standard deviation of the samples

5.2.1. *Data Collection Section*—This section should be a relatively homogenous section of pavement based on visible construction and general condition. Section length may be determined from historical data sources or by delineators inserted during data collection. The more homogeneous the section, the fewer samples required to achieve the required confidence.

5.2.2. *Data Collection Sample*—The exact length of each data collection sample is determined by the agency and shall be between 0.03 km (0.02 mi) and 1.0 km (0.62 mi). Larger samples tend to have less variation.

Note 4—Agencies should experiment with sample size, number, and section definition to minimize the data collection effort necessary to achieve the required confidence.

6. REPORT

6.1. An example of a report is given in Table 2.

Table 2—Example of Data Reporting

Severity Level	Outside Wheelpath, m/m^2	Inside Wheelpath, m/m^2	Between Wheelpath, m/m^2	Optional Areas and Distress		
				Edge Cracking	Joints	Transverse Cracking
1	12	19	5	User defined	User defined	User defined
2	25	10	2	User defined	User defined	User defined
3	10	12	4	User defined	User defined	User defined

6.2. *At a minimum, report the following data*:

Note 5—For reporting requirements, “sample” in the manual data collection mode is equivalent to “interval” for the automated data collection mode.

6.2.1. *Section Identification*—For each data collection section, the agency shall list all information necessary to locate the section using their current referencing system;

6.2.2. Length of the data collection section (km (mi));

6.2.3. Sample length (m (ft)) if not 100 percent;

6.2.4. *Sample Location*—The beginning location of the sample;

6.2.5. Length within the sample for each severity level of wheelpath cracking (m (ft));

6.2.6. Length within the sample for each severity level of non-wheelpath cracking (m (ft)); and

6.2.7. The date of collection (month/day/year).

7. KEYWORDS

7.1. Asphalt pavement; between wheelpath; crack; edge cracking; inside wheelpath; outside wheelpath; pavement management; survey strip; transverse crack.

8. REFERENCES

8.1. FHWA, Highway Performance Monitoring System Reassessment 2010+, available at http://www.fhwa.dot.gov/policy/ohpi/hpms/2010/ch2.cfm.

8.2. SHRP. *Distress Identification Manual for the Long-Term Pavement Performance Project*. Strategic Highway Research Program, SHRP-P-338, Washington, DC, 1993.

APPENDIX

(Nonmandatory Information)

X1. QUALITY ASSURANCE

X1.1. *Quality Assurance Plan*—Each agency shall develop an adequate quality assurance plan. Quality assurance includes survey personnel certification training, accuracy of equipment, daily quality control procedures, and periodic and ongoing control activities. The following guidelines are suggested for developing such a plan.

X1.2. *Qualification and Training*—Agencies are individually responsible for training and qualifying their survey personnel and/or qualifying contractors for proficiency in pavement rating or in operating equipment that must be used as a part of quality assurance.

X1.3. *Equipment*—The basic output of any equipment used shall be checked or calibrated according to the equipment manufacturer's recommendations. The equipment must operate within the manufacturer's specifications. A regular maintenance and testing program must be established for the equipment in accordance with the manufacturer's recommendations.

X1.4. *Validation Sections*—Sections shall be located with established cracking types and levels. These sections shall be surveyed on a monthly basis during data collection season. Comparison of these surveys can provide information about the accuracy of results and give insight into which raters or operators need additional training. Validation sections shall be rotated or replaced on a regular basis in order to ensure that raters or operators are not repeating known numbers from prior surveys. As an alternate to this procedure, up to 5 percent of the data may be audited and compared as a basis for a quality check.

X1.5. *Additional Checks*—Additional checks can be made by comparing the previous year's survey summaries with current surveys. At locations where large changes occur, the data shall be further evaluated for reasonableness and consistency of trends.

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Standard Practice for

Certification of Inertial Profiling Systems

AASHTO Designation: R 56-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Certification of Inertial Profiling Systems

AASHTO Designation: R 56-10[1]

1. SCOPE

1.1 This practice describes a certification procedure for test equipment used to measure a longitudinal surface elevation profile of highways based on an inertial reference system that is mounted on a host vehicle. The minimum requirements stipulated herein are intended to focus on the need for accurate and repeatable profile measurements during construction. It is also applicable to certifying the performance of profiler systems utilized in network data collection.

1.2 This practice describes minimum performance requirements for inertial profiling systems to be used for quality control/quality assurance (QC/QA) of surface roughness on Owner-Agency paving projects where a profile-based roughness construction specification is applicable. The same approach should be utilized for network data collection systems; however, different performance criteria may be employed.

1.3 The filtering methods and threshold values recommended in this document were established to ensure adequate determination of the International Roughness Index (IRI) and the profile features that affect it. An Owner-Agency planning to use an index other than the IRI should filter the profile and set thresholds accordingly. In particular, replace the preprocessor filter in Step 3, Appendix X.1 with a filter that corresponds to the relevant waveband for the alternative index.

1.4 If any part of this practice is in conflict with referenced documents, such as ASTM Standards, this practice takes precedence for its purposes.

1.5 *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 328, Inertial Profiler
- R 57, Operating Inertial Profiling Systems
- R 40, Measuring Pavement Profile Using a Rod and Level

2.2 *ASTM Standards*:

- E 867, Standard Terminology Relating to Vehicle-Pavement Systems
- E 1926, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements

2.3 *Other*:

- Karamihas, S. M. Development of Cross Correlation for Objective Comparison of Profiles. *International Journal of Vehicle Design*, Vol. 36, Nos. 2/3 (2004), pp. 173–193.

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *high-pass filtering*—reduces the effect of long wavelengths that are associated with gradual elevation changes such as hills.

3.1.2 *International Roughness Index (IRI)*—a statistic used to determine the amount of roughness in a measured longitudinal profile. The IRI is computed from a single longitudinal profile using a quarter-car simulation as described in the paper "On the Calculation of International Roughness Index from Longitudinal Road Profile" (Sayers 1995). Computer programs to calculate the IRI statistic from a longitudinal profile are referenced in ASTM E 1926.

3.1.3 *longitudinal profile*—a two-dimensional slice of the roadway surface taken along the travel direction, such as along the wheel path. It represents the perpendicular deviations of the pavement surface from an established reference parallel to the horizontal.

3.1.4 *report interval*—the longitudinal distance between the outputs of a profile index value.

3.1.5 *sample interval*—the longitudinal distance between data capture points. The data include location, height, and accelerometer values. These data points are combined to create one profile data point. These points, in turn, may be combined to create a final value in the reported profile.

4. SIGNIFICANCE AND USE

4.1 This practice outlines standard procedures for certifying and verifying the operational accuracy and repeatability of inertial profiling equipment. It also provides guidance for qualifying the equipment operators.

5. EQUIPMENT

5.1 *Minimum Requirements*—The inertial profiling system must meet all requirements and specifications found in M 328.

5.2 *Operating Parameters*—The inertial profiler must be capable of providing relative elevation measurements that meet the following requirements:

5.2.1 *Report Interval*—The interval at which relative profile elevations are reported must be less than or equal to 2 in.

5.2.2 *High-Pass Filter*—The algorithm for high-pass filtering the profile data shall have an undistorted response (profile amplitude and location error of less than 5 percent) for all wavelengths shorter than 150 ft when operated between 20 and 70 mph for high-speed profilers and 15 and 25 mph for low-speed profilers. It shall also have a minimum of a 30 percent reduction in profile amplitude for wavelengths longer than 300 ft. The filter will have a minimum of a 70 percent reduction for wavelengths longer than 450 ft.

5.3 The profiler software must also be able to calculate and report the IRI (in inches per mile and appropriate SI units) from the corresponding measured true profile and permit the operator to:

- Automatically trigger the start of data collection at the designated location;
- Provide the measured true profiles in electronic text files following the formats prescribed by R 57, in addition to any binary data file storage provided. These profile data are necessary to evaluate profiler accuracy and repeatability and to verify the height and distance measurements as described herein.

6. EQUIPMENT CALIBRATION VERIFICATION

6.1 *General*—This section refers to two important calibration and verification procedures: the block test and the bounce test. It is highly recommended that operators perform these procedures and calibrate their distance measurement instrument (DMI) immediately prior to certification and on a regular basis during normal operation as recommended by the manufacturer. Operators should adhere to the procedures specified in R 57 for calibrating and checking their equipment. The certifying agency shall provide adequate opportunity and facilities to perform these procedures, but it is the responsibility of the profiler operator to provide the needed equipment (e.g., calibration blocks, etc.).

6.1.1 *Calibration Verification Log*—Maintain a log that is to be kept with the inertial profiler to provide a verification of calibration history. The results of the routine bounce tests and verification runs should also be included in this log. The log should contain a record any repairs, replacement of components, and changes in native software versions. If the log is electronic, a backup copy should be kept in a secure location.

7. OPERATOR CERTIFICATION

7.1 Operators of inertial profilers used for QA testing of pavement ride quality must pass a proficiency test and be certified to operate an inertial profiler. Applicants for certification will be tested on the following:

- Owner-Agency ride smoothness specification,
- Operating inertial profilers,
- Collection of profile data, and
- Evaluating the quality of the data collected and the IRI value calculated.

Applicants for certification shall undergo both written and practical examinations. They must pass both portions of the test to be certified. Prior to taking the proficiency test, applicants should have completed a profile training course such as NHI Course 131100 and must have undergone training on the use of the specific inertial profiler they will be operating in the field. Applicants must know how to perform vertical and horizontal calibrations and collect profile data with the inertial profiler. Applicants must bring the inertial profiler with them at the time of testing.

Upon passing the proficiency test, successful applicants will be given documentation that will verify that they are certified to operate the inertial profiler for QA testing on paving projects. The documentation shall identify the specific type or brand of inertial profiler the operator is certified to operate. The initial duration and requirements for renewal of this certification shall be set by the Owner-Agency. Renewal should be required at least every 3 years.

8. EQUIPMENT CERTIFICATION

8.1 Certification frequency shall be as specified by the Owner-Agency. The inertial profiler must successfully perform and pass certification tests to establish compliance with the minimum requirements for accuracy and repeatability set forth in this procedure. An inertial profiler shall be recertified after any major component repairs or replacements as identified in R 57.

8.2 *Dynamic Certification Testing*—Certification tests shall be conducted at a site approved by the Owner-Agency, and involve test sections, reference profiles, and devices used to establish reference profiles as described in the following:

8.2.1 *Test Sections*—Perform dynamic certification testing on sections over a range of roughness. The reference profiles on the smooth section shall have an average IRI within the range of 30 to 75 inch per mile while the corresponding reference profiles on the medium-smooth section shall have an IRI within the range of 95 to 135 inch per mile. If pavements with considerable distress are to be measured, as in network data collection, a third, medium-rough, site should be selected with roughness up to 200 inch per mile.

The surface macro-texture of the test sections should reflect common Owner-Agency specifications for the pavement surfaces to be evaluated. It is imperative that all the surface types on which the profiler will be expected to collect data be included in this process since current height sensors remain sensitive to some surface features.

Each test section will be at least 528 ft in length, with proper lead-in distance and a safe stopping distance available. For complete evaluation, the test section length should approach four times the length of the longest wavelengths being considered.

Test sections should not include significant grade or grade change. Also, significant horizontal curvature or super-elevation should be avoided. If any lateral "g" forces or vehicle roll are sensed during testing at the highest speed employed, the course has too much curvature or single wheel-path elevation changes.

Note 1—Coarse surface textures, such as those found on open-graded surface mixes, chip-sealed, tined (transverse or longitudinal), or grooved pavement, for example, are very challenging to inertial profilers with dot, single point height sensors. Coarse texture is likely to adversely affect the repeatability and accuracy of the profile and the calculated index. Adherence to the requirements of this standard on smooth-textured surfaces does not guarantee acceptable performance of inertial profilers on coarse-textured surfaces. Certification testing on surfaces with the same texture type expected in the final application is required.

8.2.2 *Reference Profiles*—The reference profile for each test section shall be measured in accordance with R 40 except that the maximum horizontal measurement interval and reporting interval shall not be greater than 2.75 in. and the minimum vertical resolution shall not exceed 0.01 in. Other Owner-Agency approved survey techniques that produce third order or better survey accuracy may be used.

Devices that measure and integrate differential elevations, such as the Dipstick® and Walking Profiler, may be used to establish the reference profiles using multiple staggered runs as required to meet the interval requirement. However, the measurements from these devices must be checked with the rod and level at distances along the test profile trace that are multiples of the reporting interval for these devices. The rod and level measurement locations shall be no more than 100 ft apart. Reference profile measurements shall be made on the designated profile trace of each test section as well as on the lead-in to the section. The measured lead-in distance shall be at least equal to the longest wavelength of interest (150 ft for the profiles used to collect IRI). The total lead-in should be at least two times the longest wavelength of interest, with four times being very desirable.

8.2.3 Ten repeat runs of the candidate inertial profiler shall be made on the designated profile trace of each test section in the prescribed direction of measurement. For high-speed profilers, make five runs at the maximum desired certification speed and five runs at the minimum certification speed. Data collection shall be automatically triggered at the starting location of each run of the section, and reported so that a longitudinal position of "zero" occurs at the starting location. An automatically detected mark at the end of the section may be used to verify the DMI repeatability and accuracy.

8.3 *Test Data*—Profile data shall be reported in a format specified by the Owner-Agency.

8.3.1 During the certification tests, the same trace(s) is measured for all runs on a given test section. There will be twice as much data collected and analyzed when dual-path inertial profilers are tested. To facilitate the analysis of the data, the files from the tests described herein shall be named according to the following convention:

- The first three characters of the file name are reserved for identifying the profiler tested. This identification will be established by the testing agency and given to the operator of the profiler on or before the day of testing.
- The fourth character shall be "S" for runs made on the smooth section or "M" for runs on the medium-smooth section and "R" for runs made on the medium-rough section.
- The fifth character shall be "L" or "H" for low- or high-speed runs. "G" is used for governed runs on lightweight profilers.
- The sixth character shall designate the trace or wheel path tested. For dual-sensor profilers, the letter "B" shall be used to indicate that both wheel paths were profiled in the same run. For single-sensor profilers, the designation for the test trace will be given by the testing agency to the operator of the profiler on or before the day of testing.
- The seventh and eighth characters shall designate the run number (01 to 10).
- The file extension shall be the one appropriate for the data type being transmitted and will be specified by the agency.

8.3.1.1 The performance of the profiler is evaluated by analyzing the test data using cross correlation as described in the following sections to establish the repeatability and accuracy for the application of the device. The profiles are filtered to focus the evaluation on the profile features critical to the index being subsequently applied to the collected data. The available free software ProVAL can perform the calculations specified below. The method employed is described in the "Development of Cross Correlation for Objective Comparison of Profiles" by S. M. Karamihas, published in the *International Journal of Vehicle Design*, Vol. 36, Nos. 2/3 (2004), pp. 173–193.

8.3.1.2 *Equipment Repeatability*—Evaluate repeatability using cross correlation of the filtered output as described in Section 8.3.1.4. Calculate the repeatability agreement score of each trace. For single-sensor set profilers, one score for each path will be determined: one for the path in the smooth section, one for the medium-smooth section, and one for the medium-rough section as defined in Section 8.2.1. For dual-path profilers, twice as many scores will be determined, two for each test section.

When the IRI is applied to the profile, the IRI filter should be used. On each trace, cross correlate each of the ten profiles to each of the remaining nine. (Since all of the profiles have the same reporting interval, 45 comparisons will be needed rather than 90 because the process has reciprocity.) The repeatability agreement score for each trace is the average of all 45 values. For IRI, experience has shown that on pavements with IRI values less than 150 inch per mile, an agreement score of 0.92 or greater is required on all traces to provide IRI values within 5 percent with a 95 percent confidence level. A lower agreement score may be acceptable for other applications such as network-level collection given the higher distress levels encountered.

If an alternate index is applied, a filter appropriate to that index should be applied and suitable thresholds established based on independent analysis.

8.3.1.3 *Equipment Accuracy*—Evaluate accuracy using cross correlation of the appropriate filtered output as described in Section 8.3.1.4. On each trace, cross correlate each of the ten profiles to the reference profile. The accuracy agreement score for each trace is the average of the ten individual cross correlation values. Based on the same rationale as in Section 8.3.1.2, a score of 0.90 or greater for applications using IRI should be required for passing for new construction quality control.

A different value may be acceptable in applications utilizing other indexes.

8.3.1.4 *Cross Correlation*—Cross correlate profiles as described in Appendix X1. When cross correlating two profiles, the following processing steps are required:

- If the reference profile contains grade information, it should first be removed by application of a high-pass filter set at least three times the longest wavelength of interest.
- Apply the filter associated with the application to both traces before cross correlating them. For profiles used to determine the IRI, the IRI filter should be applied.
- When comparing a profile from a candidate device to a reference profile, interpolate the candidate profile to the recording interval of the reference profile. (It is important that this step is performed *after* the filter is applied.)
- Cross correlate the two profiles several times by shifting one profile over every possible offset up to 3 ft in either direction. When comparing a profile from a candidate device to the reference device, shift the candidate profile.
- The cross correlation of the two profiles is the maximum (best) value found over the 6-ft range.

8.3.2 *Verification of Computed Ride Statistics (IRI)*—The test equipment software must be capable of computing and reporting the IRI of each profile trace tested. The performance of the calculation software is verified by comparing the calculated values with the values determined by a program of known accuracy. An example of such a program is ProVal. Each IRI value should be comparable to the value from the reference program with an error not greater than 2 percent. Other ride indexes may be verified in a similar fashion.

8.4 *Distance Measurement Index Test*—Test the accuracy of the DMI on one test section.

8.4.1 *Distance Measurement Index Test Section*—Provide a section for DMI testing. The test section will be at least 1000 ft in length, with proper lead-in distance and a safe stopping distance available. This test section may incorporate the test sections that are used for accuracy and repeatability testing. Clearly mark the starting and ending points of the test section. Measure the distance between the starting and ending points with a temperature-compensated steel tape, pulled taut but still following the pavement contour.

Note 2—The same runs may be used for verification of DMI accuracy as are used for testing accuracy and repeatability of the collected profile. The ideal test of DMI accuracy would be performed over a known but undisclosed length of pavement.

8.4.2 At least three auto-triggered runs at the lowest and highest test speeds of the candidate inertial profiler shall be made on the designated length of pavement in the prescribed direction of measurement. At the end of each run, record the reading from the profiler's DMI. For high-speed profilers, this results in at least six values. Collection speed governed devices should make at least five runs.

8.4.3 *Distance Measurement Index Accuracy*—Compute the absolute difference between the DMI readings and the known distance of the path tested for each run. The average of the absolute differences for both the high-speed and low-speed runs, if applicable, must be less than 0.15 percent to pass the test.

8.5 *Test Results*—The results of the certification tests shall be documented by the testing agency. The distribution of the results of the certification shall be determined by the testing agency. Results of certification shall include the following information:

- Identification of the profiler tested (i.e., make, model serial number, software version, Owner, etc.);
- Date of last certification;
- Operator of the profiler;
- Name of the individual from the testing agency who conducted the test;
- Date of test;
- Number of paths the profiler can measure in the same run;
- Filter type, name of the filter program, and the applicable program version number used to evaluate the profiler accuracy;
- Overall determination from the test: Pass or Fail;
- Known longitudinal distance of the DMI test section; and
- Average absolute difference between the DMI readings and the known distance, expressed in distance unit and as a percentage of the known longitudinal distance.

The following information is to be provided for each trace:

- Overall repeatability score;
- Overall accuracy score;
- The average percent difference of the IRIs computed from the profiles and those from the reference software.

8.6 The report will also label each test result with a Pass or Fail depending on whether the given test value meets or fails to meet the prescribed criterion. The profiler must pass all tests to be certified. A decal or other approved marking shall be placed on the profiler as evidence of certification. This decal shall show the expiration date (month and year) of the certification.

9. KEYWORDS

9.1 Inertial profiler; IRI; International Roughness Index; pavement ride quality; profiler certification.

10. REFERENCES

10.1 NHI Training Course 131100. *Pavement Smoothness: Use of Inertial Profiler Measurements for Construction Quality Control*. March 2002.

10.2 Sayers, M. W. On the Calculation of International Roughness Index from Longitudinal Road Profile. In *Transportation Research Record 1501*. Transportation Research Board, National Research Council, Washington, DC, 1995, *pp*. 1–12.

10.3 Sayers, M. W., T. D. Gillespie, and W. D. O. Paterson. Guidelines for Conducting and Calibrating Road Roughness Measurements. *The World Bank Technical Paper, Number 46*. The World Bank, Washington, DC, 1996.

10.4 Sayers, M. W., and S. M. Karamihas. *The Little Book of Profiling*. University of Michigan Transportation Institute, Ann Arbor, Michigan, 1998.

APPENDIX

(Nonmandatory Information)

X1. CROSS CORRELATION

X1.1. Cross correlate any pair of profiles using the following steps. When cross correlation is performed for repeatability analysis, either profile may be selected as the "reference."

Step 1: Identify a reference profile (*Q*). It will also be considered the location reference. As such, the start of the section of interest shall occur at a longitudinal location of "zero," with at least 150 ft of profile upstream of the section start and 5 ft of profile after the section end. The profile will have a recording interval Δx.

Step 2: Identify a segment of the correlated (or candidate) profile (*p*). Using auto-triggering, the profiler should place the section starting point at a longitudinal location of "zero," with at least 150 ft of profile upstream of the section start.

Step 3: Preprocess the reference profile and the candidate profile by applying the IRI filter to them. This includes the 9.84-in. moving average, the conversion to slope, and the quarter-car simulation.[2]

Step 4: Crop the preprocessed reference profile to include only the section of interest. For a section length of L_q, a number of samples within the section of interest is $N_q + (L_q/\Delta x + 1)$. Offset the cropped profile to have a mean of zero. Calculate the standard deviation of the preprocessed, cropped, and shifted reference profile (*q*), and the result is σ_q.

Step 5: Rewrite the preprocessed candidate profile (*p*) to the recording interval of the reference profile (*q*). Calculate the value at each location using linear interpolation of the surrounding points. Offset the resulting profile to have a mean of zero. The preprocessed, interpolated profile (*p*) will be cross correlated to the reference profile.

Step 6: Cross correlate the reference profile (*q*) to the candidate profile (*p*) several times, over a range of longitudinal offsets from a lead of 3 ft to a lag of 3 ft. For a sample interval of Δx, cross correlation will be performed $2M + 1$ times, where $M = \text{int}(3/\Delta x)$, where Δx is in feet.[3] This produces a correlation function, ρ_m, where *m* is an integer subscript that ranges from $-M$ to M:

$$\rho_m = \frac{1}{\max\left(\sigma_{\hat{p}}, \sigma_q\right)^2} \sum_{i=1}^{N_q} \left(\hat{p}_{i+m} q_m\right)$$

Each increment of the subscript m represents a unique longitudinal offset of the candidate profile of $m\Delta x$. At each step (i.e., each increment of the subscript *m*), the candidate profile (*p*) must be conditioned by removing the mean to produce a vertically shifted profile $\left(\hat{p}\right)$. Note also that the standard deviation of the candidate profile $\left(\sigma_{\hat{p}}\right)$ must be recalculated at each step.

Step 7: Search the function ρ_m for its maximum cross correlation value $\rho_{\max}$.

Step 8: Calculate the adjustment factor for overall roughness as follows:

$f = \min(\sigma_p, \sigma_q)/\max(\sigma_p, \sigma_q)$

Step 9: Calculate the "agreement score" for the two profiles: $f \bullet \rho_{\max}$.

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[1] Formerly PP 49. First published as a full standard in 2010.

[2] Application of the IRI filter is described in "On the Calculation of International Roughness Index from Longitudinal Road Profile" (Sayers 1995). Do NOT rectify the signal (i.e., do not take the absolute value of every point in the signal).

[3] The "int()" function truncates the argument at the decimal point.

Standard Practice for

Operating Inertial Profiling Systems

AASHTO Designation: R 57-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Operating Inertial Profiling Systems

AASHTO Designation: R 57-10[1]

1. SCOPE

1.1. This practice describes the procedure for operating and verifying the calibration of an inertial profiling system. This practice is meant to be performed as a Quality Control/Quality Assurance (QC/QA) test for use with the appropriate smoothness specification for paving operations. It is not meant to be required as a QA procedure to monitor daily paving operations; however, this method is recommended when inertial profiling systems are used for QC testing and for network-level data collection.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 328, Inertial Profiler
- R 56, Certification of Inertial Profiling Systems

2.2. *ASTM Standards*:

- E 1926, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements
- E 2560, Standard Specification for Data Format for Pavement Profile

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *International Roughness Index (IRI)*—a statistic used to determine the amount of roughness in a measured longitudinal elevation profile. The IRI is computed from a single longitudinal elevation profile using a quarter-car simulation as described in the paper “On the Calculation of International Roughness Index from Longitudinal Road Profile” (Sayers 1995). Computer programs to calculate the IRI statistic from a longitudinal elevation profile are referenced in ASTM E 1926.

3.1.2. *longitudinal elevation profile*—a series of relative pavement surface elevation measurements taken along a longitudinal path and referenced to a common horizontal datum.

3.1.3. *roughness*—the deviation of a surface from a true planar surface with characteristic dimensions that affects vehicle dynamics and ride quality.

4. SIGNIFICANCE AND USE

4.1. This practice outlines standard procedures for operating inertial profiling systems for project level QC/QA determinations. These procedures can also be used for network-level data collection and analyses and are recommended for project-level QC determinations.

5. EQUIPMENT

5.1. *Minimum Requirements*—The inertial profiling system must meet all requirements and specifications found in M 328 and must be currently certified in accordance with R 56.

Note 1—For consistent pavement profile determination, maintain air pressure on the wheels of the host vehicle according to the manufacturer's specification. The host vehicle and all system components will be in good repair and proven to be within the manufacturer's specifications. The operator of the inertial profiler shall have all tools and components necessary to adjust and operate the inertial profiler according to the manufacturer's instructions.

5.2. *Repair, Adjustment, and Upgrade of Inertial Profilers*:

5.2.1. Major component repairs or replacement to an inertial profiler that would require the recertification of the equipment include, but are not limited to, the following:

- the accelerometer and its associated hardware;
- the noncontact height sensor and its associated hardware;
- any printed circuit board necessary for the collection of raw sensor data or the processing of the inertial profiles;
- change of host vehicle in the case of permanently mounted equipment; or
- major repairs to host vehicle.

5.2.2. The operator of the inertial profiler will be allowed to make minor adjustments to the equipment without having to complete the recertification process as long as the adjustments allow the equipment to fulfill the verification of calibration process in Section 5.3. Minor adjustments to the system include, but are not limited to, the following:

- inspecting, resoldering, or replacing connectors;
- cleaning components, normal adjustments to power supply voltage levels as required by the manufacturer;
- setting software parameters and/or scale factors as required by the manufacturer in a routine calibration procedure; or
- mounting on different suitable host vehicle(s) in the case of portable equipment.

5.3. *Verifying Calibration*—The following verification procedure is required for QA testing and is recommended when an inertial profiler is to be used as a QC instrument on a daily basis.

5.3.1. *Standards*:

5.3.1.1. *Longitudinal*:

5.3.1.1.1. The longitudinal verification standard shall be a straight and level roadway test section of at least 528 ft in length in addition to lead-in equal to 1.5 times the longest wavelength of interest.

5.3.1.1.2. Measure this length accurately to within 0.05 percent using a temperature-compensated steel survey measurement tape since the distance to be measured is the travel length the wheels encounter.

5.3.1.2. *Vertical*:

5.3.1.2.1. The vertical measurement standard shall be flat plates or blocks of known thickness and low thermal expansion.

5.3.1.2.2. Mark the blocks with the known thickness. Certify the block thickness accurate to within 0.001 in. As a minimum, test a smooth base plate and both a 1-in. and a 2-in. gauge block.

5.3.2. *Procedure*:

5.3.2.1. *Frequency of Verifying Calibration*:

5.3.2.1.1. Perform the longitudinal and vertical verification of calibration of the inertial profiler prior to use on each paving project in accordance with the manufacturer's recommendation and at such times as the Owner-Agency determines that verification is necessary.

5.3.2.1.2. Check the cold tire air pressure on the wheels of the host vehicle at least daily and maintain according to the manufacturer's recommendations.

5.3.2.1.3. Maintain a log with the inertial profiler in accordance with R 56.

5.3.2.2. *Longitudinal Verification of Calibration*:

5.3.2.2.1. Perform the longitudinal verification of calibration by navigating the inertial profiler over a measured test section of at least 528 ft in length in addition to lead-in equal to 1.5 times the longest wavelength of interest.

5.3.2.2.2. The inertial profiler's distance measuring subsystem, after tire and electronic warm-up in accordance with the manufacturer's recommendations, must measure the length of the test section to within 0.15 percent of its actual length.

5.3.2.2.3. Adjust the inertial profiler's distance measurement subsystem according to the manufacturer's guidelines as needed.

5.3.2.2.4. Failure to meet the specified tolerance, after attempts to adjust have been performed, will require recalibration and reverification as described under Verifying Calibration.

5.3.2.3. *Vertical Verification of Calibration*:

Block Test—Vertical height sensor check tests shall be performed in accordance with the manufacturer's recommended procedures. In the absence of manufacturer's procedures, perform the block test as described in Section 5.3.2.3.1.

5.3.2.3.1. *Block Test*—Vertical height sensor check tests are run after the profiler has reached operational stability as specified by the manufacturer. This test will be conducted with the inertial profiler on a relatively flat and level area. Its purpose is to check the height measurements (in inches or millimeters) from the height sensor(s) of the test vehicle using blocks of known heights. During the test, do not lean on the profiler or cause it to move in any way. Under windy conditions, it may be necessary to perform this test indoors. The test procedure consists of the following steps:

- Position a smooth base plate under the height sensor of the profiler and allow the system to take height measurements.
- Position a 0.25-in. block underneath the height sensor on top of the base plate and allow the system to take height measurements.
- Carefully remove the 0.25-in. block from the base plate and replace it with a 0.50-in. block. Make another set of height measurements.
- Carefully replace the 0.50-in. block with a 1.00-in. block and take another set of height measurements.
- Finally, carefully replace the 1.00-in. block with a 2.00-in. block and take the last set of height measurements.

As a minimum, test a base plate and both the 1-in. and 2-in. measurement blocks. If the equipment fails the minimum test, then perform the full range of check tests to determine system linearity problems, stand-off problems, or complete system failure.

The owners of the profiler must furnish their own base plate and gauge blocks. Measure the thickness of the gauge blocks at three different positions on each side of the plate or block with a device capable of measuring to the nearest 0.001 inch. For each block, an average thickness shall be determined from the measurements made which shall be used in checking the height sensors as described in this test. The average thickness shall be marked on each gauge block.

The operator of the profiler should tabulate the measurements and record them in a calibration log.

Determine the difference between each measurement on a gauge block and the average of the ten measurements on the base plate to get the thickness of the gauge block as measured by the height sensor. Repeat this calculation for each gauge block. Determine the absolute values of the differences between the computed thickness and the known average block thickness. The average of the absolute differences should be less than or equal to 0.01 in. for each gauge block.

5.3.2.3.2. *Bounce Test*—To perform the bounce test, position the host vehicle on a surface as flat and level as possible. Power the system and ensure the profiler has reached operational stability as specified by the manufacturer. Center a thin, smooth, flat, non-glossy material plate under each sensor. Using the equipment's normal data collection software, initiate a data collection run using a simulated travel speed at the midpoint of the manufacture's recommended data collection speed range. (The only difference between a bounce test and a normal data collection run is that there is an artificial longitudinal travel signal supplied and the vehicle is not actually traveling along the road. The bounce test utilizes the same data collection software and routines used during normal data collection.)

The bounce test will require a profile collection run with a minimum simulated travel distance of 2,184 ft. Allow the profiler to collect a minimum of 828 ft of static profile with the host vehicle as motionless as possible. Next, the sensor(s) should be moved vertically for a total displacement of approximately 1 to 2 in. (a yardstick may be helpful until the operator gets used to the procedure) keeping the sensors as close to perpendicular to the surface as possible during this movement. This movement must continue until a minimum of 528 ft of simulated longitudinal distance has been covered.

The typical method for full-size high-speed host vehicles is to push the mounting system (bumper) down an inch or so and let the vehicle suspension rebound to create the total vertical travel of 1 to 2 in. The typical method for lightweight slow-speed host vehicles is to stand toward the center of the vehicle platform and hop up and down such that all four corners of the vehicle suspension travel approximately 1 to 2 in. vertically. After a minimum of 528 ft of bounce profile is collected, allow the profiler to collect an additional minimum of 828 ft of static profile. The profiles shall then be saved and analyzed in ProVAL using the Ride Statistics Continuous analysis with a 528 ft base length for each profile collected.

When reviewing the analysis results, ignore the first and last 300 ft of the profile as it is lead-in and lead-out distance. Ensure the remaining static portions result in an IRI of less than 3 in. per mile and the bounce portion is less than 8 in. per mile. The two static IRI portions should be about the same. See Appendix X1 for further details concerning the bounce test.

5.3.2.4. *Daily Measurement Control*—The operator should select a reasonable method to verify daily that the inertial profiling system utilized can produce consistent results under normal operating conditions on pavements typically encountered during data collection. Options include using a Test Section as described in R 56; Control Sections, or Checks using previous day's data. The surface texture of the section used for daily verification should be similar to that on which measurements are to be obtained for QC/QA purposes.

5.3.2.4.1. Control sections can be established by selecting one or more 0.1-mile sections with a maximum IRI of 120 in. per mile that will maintain a consistent ride profile over the time period when daily checks are needed. A profiler certified within the past 90 days should determine the IRI of the section by making a series of at least five profile measurements. The average IRI of the measurements shall be used to establish the IRI of the control section; provided that the cross correlation of the measurements as determined using the latest version of ProVAL is at least 88 percent (value is dependent on the filters used, spectral content of the measured surface, operator, etc.). Once established, this control section can be used to validate on a daily basis that an inertial profiler is operating properly. A control chart should be established and maintained by plotting daily runs to determine profile drift as the section ages. Typically, no single IRI determination should vary more than 5 percent from the original control section IRI.

5.3.2.4.2. Checks using the previous day's data can be used when data is being collected on a fairly continuous basis such as on a construction project or during annual network-level analyses. Under these circumstances, it is possible to rerun short sections of pavement that were measured on the previous day for comparison purposes. The current day's IRI value should not differ by more than 6 percent from the previous day's IRI value.

5.3.2.4.3. *Calibration Verification Log*—Maintain a log to be kept with the inertial profiler in accordance with R 56.

6. TEST PROCEDURE

6.1. Table 1 outlines the steps for measuring the pavement profile using an inertial profiler.

Table 1—Measuring Pavement Profile for QA Purposes

Step	Action
1	Clean the roadway path to be measured of all debris and other loose material.
2	When measuring the pavement profile, operate the inertial profiler at a constant speed within the certified range.
	All data collected above or below the certified speed range are not acceptable.[a]
	Remeasure any pavement segment where the travel speed of the profiler is less than or exceeds the manufacture's recommended operational speed at any point during data collection.
3	A pre-section length of roadway of up to 450 ft may be required to stabilize the inertial profiler's filters and achieve the same accuracy in the first 0.1 mile that is achieved through the rest of the job. The pre-section length is dependent on the filter type, the grade change on entering the test segment, and the accuracy required of the first 0.1 mile of measured pavement. Typically, this pre-section shall be at least 300 ft in length and located immediately before the section of pavement to be tested. Shorter sections have been used when the physical constraints of the project required it and the other project conditions made it acceptable.
	Take the inertial profiler measurements on one or more longitudinal lines as specified by the Owner-Agency.
	If two longitudinal traces are specified, set the sensor path spacing to the values specified by the Owner-Agency. If such is not specified, sensor path spacing shall be between 65 and 71 in.
	If two longitudinal traces are specified, but the profiling system collects profile data only in one longitudinal path at a time, the longitudinal traces shall be taken in each wheel path of the lane independently.
4	Collect measurements in the direction of traffic. Multiple runs provide the opportunity to reject runs with known operator and/or equipment errors. When using an inertial profiler that collects a single trace per pass, take care to ensure that the measurements from each trace in a travel lane start and stop at the same longitudinal locations.
5	Data Collection (QA data collection is meant to be performed at the end of the paving operation or staged as prescribed by the Owner-Agency).
	Submit a table to the Owner-Agency that identifies the lane(s), trace(s), and distance location(s) tested for each file created during the QA testing.
6	Present the profile elevation data to the Owner-Agency in an approved electronic file format. The format must be readable by ProVAL.[b]
7	Compute a summary roughness statistic. The recommended index to compute is the continuous IRI reported as a histogram that presents the percentage of the job that falls within IRI categories selected by the agency.

[a] Failure to maintain the minimum certified speed will cause the inertial referencing subsystem to "droop" and the pavement profile elevations will not be usable.

[b] The Owner-Agency will calculate the IRI values and any associated pay factors.

Note 2—ProVAL is a computer software program developed under the auspices of FHWA and is available for use to calculate and compare profiles and their indices. The software also has the ability to calculate the continuous IRI histogram.

6.2. In order to ensure collection of quality profiles, the host vehicle may need to be operated at the lower end of the certified speed range when profiling on vertical and horizontal curves and super-elevations. Higher speeds may cause excessive pitch and roll in the host vehicle, which will adversely affect the integrity of the measurements. In addition, rapid longitudinal accelerations and decelerations (for example, speed changes such as heavy braking) may adversely affect the profile measurements.

6.3. *Test Data Description and Format*—In addition to proprietary file formats, provision shall be made for export of profile data in the format as per ASTM E 2560 or other ProVAL compatible formats.

7. KEYWORDS

7.1. Inertial profiler; International Roughness Index; ride quality; road profile; roughness; smoothness.

8. REFERENCES

8.1. NHI Training Course 131100. *Pavement Smoothness: Use of Inertial Profiler Measurements for Construction Quality Control*.

8.2. Sayers, M. W. On the Calculation of International Roughness Index from Longitudinal Road Profile. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1501,* Transportation Research Board of the National Academies, Washington, D.C., 1995, pp. 1–12.

8.3. Sayers, M. W., and S. M. Karamihas. *The Little Book of Profiling.* University of Michigan Transportation Institute, Ann Arbor, Michigan, 1998.

APPENDIX

(Nonmandatory Information)

X1. BOUNCE TEST PURPOSE, REASONING, AND ERROR

X1.1. A bounce test is a sanity check on the profiler to ensure that the data from the height sensor and accelerometer are legitimate and being properly combined to compute the longitudinal elevation profile. While the host vehicle is stationary, an artificial signal is supplied to the profiler to simulate a travel speed within the manufacturer's recommended range for collecting road profile data. A routine data collection run is initiated, after which the suspension on the host vehicle is excited to cause the sensor(s) to move vertically. Since the sensor footprint is hovering over the same location, the end result, in theory, should be a perfectly flat and level road profile the IRI of which would equal zero if all is working correctly. In practice, a perfectly flat profile with a zero IRI is not possible. Sources of error in a bounce test include:

- Signal noise of the height sensor, accelerometer, and respective circuitry;
- Inability to position the host vehicle in such a manner that the sensors are perfectly perpendicular to a known flat and level surface;
- Inability to bounce the host vehicle such that sensors maintain a perpendicular orientation to the flat and level surface (sensor footprint moves laterally or fore and aft due to pitch and roll of the host vehicle while bouncing);
- Equipment malfunction; and
- Error in signal and data processing.

X1.2. There are two levels of acceptable error in both static (non-bounce) and bounce profiles in which a minimum of 528 ft of simulated longitudinal distance is traveled. The limits of IRI of those profiles are in 3 in. per mile and 8 in. per mile, respectively.

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[1] Formerly PP 50. First published as full standard in 2010.

Standard Practice for

Statistical Procedures

AASHTO Designation: R 4-97 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Statistical Procedures

AASHTO Designation: R 4-97 (2009)

1. SCOPE

1.1. This standard practice is to provide guidance in the use and application of statistical procedures in the precision analysis of sampling, testing, and acceptance of construction materials.

2. GENERAL PROVISIONS

2.1. It is recommended that AASHTO specifications for materials and for sampling and testing incorporate accepted statistical standard procedures. The following ASTM designations provide guidance in this area and their latest published revisions are adopted as a standard practice for the development of AASHTO standards.

- ASTM C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- ASTM C 802, Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials
- ASTM D 2915, Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber
- ASTM D 3665, Standard Practice for Random Sampling of Construction Materials
- ASTM D 4460, Standard Practice for Calculating Precision Limits Where Values are Calculated from Other Test Methods
- ASTM E 105, Standard Practice for Probability Sampling of Materials
- ASTM E 122, Standard Practice for Calculating Sample Size to Estimate, with Specified Precision, the Average for a Characteristic of a Lot or Process
- ASTM E 141, Standard Practice for Acceptance of Evidence Based on the Results of Probability Sampling
- ASTM E 177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods
- ASTM E 178, Standard Practice for Dealing With Outlying Observations
- ASTM E 456, Standard Terminology Relating to Quality and Statistics
- ASTM E 1488, Standard Guide for Statistical Procedures to Use in Developing and Applying Test Methods
- ASTM G 16, Standard Guide for Applying Statistics to Analysis of Corrosion Data

Standard Practice for

Acceptance Sampling Plans for Highway Construction

AASHTO Designation: R 9-05 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Practice for

Acceptance Sampling Plans for Highway Construction

AASHTO Designation: R 9-05 (2009)

1. SCOPE

1.1 *Definition of Acceptance Plan*—An agreed upon method of taking samples and making measurements or observations on these samples for the purpose of evaluating the acceptability of a lot of material or construction (*Transportation Research Circular Number E-C037*, 2002).

1.2 *Purpose of Acceptance Plan*—This standard practice provides guidelines in the preparation of statistically based acceptance plans using statistical and quality assurance (QA) principles. The acceptance plans must be realistic, fair to both the contractor and agency, and must be statistically accurate. This standard practice includes the basic criteria for the most common AASHTO applications. It uses the broad definition of acceptance plan to include the separate functions of both quality control (QC) and acceptance. Other aspects are provided where deemed important, but should not be interpreted to define a complete QA program. References are given for more advanced criteria and special applications.

1.3 *Target Audience*—It is assumed that the user is a mid-level materials engineer and has an understanding of statistics, including the calculation of the mean and standard deviation, the development of histograms, and the use of continuous probability density functions or distributions.

1.4 *Background Sources*—Preparatory knowledge of acceptance plans is included in the course entitled *Materials Control and Acceptance—Quality Assurance* (2000); in the manual *Optimal Procedures for Quality Assurance Specifications* (2003); and in most basic statistics textbooks.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 4, Statistical Procedures
- R 10, Definition of Terms Related to Quality and Statistics As Used in Highway Construction
- R 25, Technician Training and Qualification Programs
- R 38, Quality Assurance of Standard Manufactured Materials

2.2 *ASTM Standards*:

- D 3665, Standard Practice for Random Sampling of Construction Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 178, Standard Practice for Dealing With Outlying Observations
- MNL 7A, *Manual on Presentation of Data and Control Chart Analysis*, Committee E-11 on Quality and Statistics

2.3 *FHWA Standard*:

- FHWA/RD-02/095, *Optimal Procedures for Quality Assurance Specifications*, 2003.

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3. DEFINITIONS

3.1 *The following definitions are provided in this standard practice to help the reader become acclimated to general QA terms*:

3.1.1 *population (lot)*—a specific quantity of similar material, construction, or units of product subject to either an acceptance or process control decision. This can range from all of the history of a material to a single lot (*Transportation Research Circular Number E-C037*, 2002).

3.1.2 *sample*—a small part of a population (lot) that represents the whole (R 10). This implies a statistical sample. Thus, the use of the term sample size, n, denotes the number of test values used to make a decision. (This should not be confused with size of sample that indicates a quantity of material).

3.1.3 *sampling and testing*—sampling, testing, and the assessment of test results done to determine whether or not the quality of produced material or construction is acceptable in terms of the specifications (R 10). The results are best used to estimate a population. This is true for both QC and acceptance functions. To estimate a population, two measures are needed, one is the center of the estimated population and the other is a measure of its variability.

3.1.4 *types of acceptance plans*—a statistical acceptance plan is one based on either an analysis of variables or attributes. This standard practice focuses on analysis of variables for acceptance. Analysis by attributes is based on noting the presence or absence of some characteristic or attribute. Attribute analysis is most often used in visual inspections or when an item can only be classified as either acceptable or not acceptable or pass/fail. Attribute plans are sometimes used with "screening tests" in which the material is tested before it is incorporated in the construction. Variables analysis is applicable to materials and construction in which quality is evaluated by measuring the numerical magnitude of a quality characteristic. A quality characteristic is a characteristic of a unit or product that is actually measured for acceptance purposes (*Transportation Research Circular Number E-C037*, 2002).

3.1.5 *variability known acceptance plans*—acceptance plans that assume a known and constant variability. These types of acceptance plans measure only the average and are not appropriate for highway materials and construction.

3.1.6 *variability unknown acceptance plans*—acceptance plans that measure both the product average and variability as estimates of a population. This is the type of acceptance plan discussed in this standard practice.

3.2 *For those definitions that are not described within, two useful reference sources are*:

3.2.1 Definition of Terms for Specifications and Procedures (R 10).

3.2.2 Glossary of Highway Quality Assurance Terms (*Transportation Research Circular Number E-C037*, 2002).

4. DEVELOPMENT AND REVISION OF ACCEPTANCE PLANS

4.1 The development and the revision of acceptance plans is a design process that should continuously evolve and improve as new processes, test methods, etc., are found. The development steps outlined below provide a rational development procedure and will be useful to those embarking on an initial statistical acceptance plan. The procedure assumes that some users may want to know how to initiate, proceed through the development, and eventually implement the plan. For those revising an existing plan, some steps may not be needed. However, in both cases it is important that the plan be analyzed to ensure it produces the desired results. The user may enter the steps at any point of interest.

- Initiation and Planning
- Acceptance Plan Development Steps
- Develop QC Procedures
- Develop Acceptance Procedures
- Risks and Risk Analysis
- Pay Factors
- Implementation Steps

5. INITIATION AND PLANNING

5.1 It is important to identify and establish the needs for a new or modified acceptance plan. Some possible reasons for doing this are:

- The present quality levels are substandard.
- Premature failures have occurred that are related to the current acceptance plan.
- A new or different quality measure, e.g., standard deviation, percent within limits, etc., is needed.
- A new quality characteristic, e.g., permeability, resilient modulus, thickness, smoothness, etc., upon which to base acceptance has been identified.
- The risks between contractor and agency are not properly balanced or are too high for one or both.
- A more rigorous acceptance procedure is needed.

5.2 Define the goals and expectations of the acceptance plan. The primary goal is to identify potential benefits to the agency and to the industry. To achieve this goal, determine the criteria to be used to judge success. Examples of these criteria may be improved quality, a more knowledgeable industry, shared responsibility with industry, and/or faster completion times.

5.3 At this point, seek industry acceptance of and participation in the development of the acceptance plan. This is necessary to aid in industry cooperation and eventual positive reception.

6. ACCEPTANCE PLAN DEVELOPMENT STEPS

6.1 Develop the initial acceptance plan for one material and/or construction area, as opposed to several simultaneously. This is recommended to simplify the development process.

6.2 Determine if outside expertise is required. The agency may not have sufficient knowledge in such areas as statistical analysis or new areas such as nondestructive testing.

6.3 Look for other agencies or sources that have developed practices to provide guidance on how to proceed with selection of quality characteristics, the use of pay equations, composite pay factors, etc. Contact and interview those agencies and keep in mind industry associations that may have practices that can be used. Learning from the mistakes that others have made can save time and effort. Conduct a thorough literature search to identify current practices. Recent Transportation Research Board and National Cooperative Highway Research Program publications can provide guidance.

6.4 Develop an outline for the acceptance plan. This includes such items as:

6.4.1 QC requirements,

6.4.2 Acceptance requirements,

6.4.3 Independent assurance (IA) requirements,

6.4.4 Agency validation (if contractor's tests are used in the acceptance decision),

6.4.5 Conflict resolution, and

6.4.6 Determination of pay factors, both individual and combined.

6.5 Develop the acceptance plan introductory information. A fundamental concept in statistical acceptance plans is the separation of the QC and acceptance functions. The contractor is *always* responsible for QC and the agency is responsible for acceptance. Maintaining the separation of the functions for QC and acceptance is very important. Additionally, address the needs and requirements for both technician and laboratory qualification in the introductory information (R 25).

6.6 A very important point that must be understood is the relationship between sample statistics and population parameters for both QC and acceptance procedures. The sample result is always an estimate of the population. The larger the sample size, the better the estimate of the population.

6.7 *Random Sampling*—Random sampling is a sampling procedure whereby any individual measurement in the population is as likely to be included as any other (*Materials Control and Acceptance-Quality Assurance*, 2000).

6.8 A basic assumption in a sampling plan is the necessity of taking samples in a random manner (*Materials Control and Acceptance-Quality Assurance*, 2000). Random sampling is achieved most commonly through the use of random number tables or random number generators on calculators or computers (ASTM D 3665). Random sampling always removes the selection of the sample tonnage, location, time, etc. from the decision of the sampler. Intuitively selecting a "random" sample is not random. Random sampling is a necessary requirement for all acceptance and IA sampling. Under some circumstances it is required for QC sampling.

6.9 Describe and discuss the need for the IA function and how it will be implemented in the acceptance plan. Independent assurance is a management tool that requires a third party, not directly responsible for QC or acceptance, to provide an independent evaluation of the testing process.

6.9.1 The IA program is an independent evaluation of testing procedures and equipment and inspection procedures and is designed to provide continuity to the acceptance plan. It may involve a separate and distinct schedule of sampling, testing, and observation.

6.9.2 It is very important that an IA program compare results and detect deficiencies, when they exist, in a timely manner. This improves the reliability of testing results. The timely comparison of data may be restricted by agency resources, including personnel, facilities, and geographical constraints. These resource needs must be considered in the IA program.

6.9.3 It is very important that qualified personnel conduct IA tests and use different sampling and testing equipment than the equipment used for QC or acceptance.

7. DEVELOP QUALITY CONTROL (QC) PROCEDURES

7.1 *Quality Control (QC)*—Also called process control. Those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality of the end product (*Transportation Research Circular Number E-C037*, 2002).

7.2 *Purpose of QC*—The purpose of a QC plan is to measure quality characteristics and inspect activities that impact production at a time when corrective action can be taken to prevent nonconforming material from being incorporated in the project. (See *AASHTO Implementation Manual for Quality Assurance* (*1995)* for examples of QC plans for hot mix asphalt (HMA) concrete and both structural and paving portland cement concrete (PCC)).

7.3 A QC plan can be either contractor-specific or generic. Ideally, the plan should be contractor- and operation-specific. However, some agencies choose to develop a generic plan to be used by all contractors or suppliers. In either case, the contractor should develop control limits based on the production capabilities of the specific operation.

7.4 A very important part of a QC plan is the requirement that those persons performing the tests be qualified. This can be accomplished several ways, but some agencies require certification to determine qualification. (See R 25 and R 38 for more detailed information.)

7.5 The QC function is the responsibility of the contractor and is a separate function from acceptance. This means that control limits used for QC control charts must be developed separately from the specification limits.

7.6 Measure the quality characteristics chosen for QC early in the production activity to assess the quality as quickly as practical. Therefore, the QC tests should be relatively rapid tests.

7.7 Examples of QC tests for hot mix asphalt (HMA) are aggregate quality tests, binder physical properties, gradation of critical sieves, degree of aggregate coating, plant and discharge temperatures, moisture content of the fine aggregate and of the finished mix, and the use of a density gauge for field compaction control.

7.8 Examples of QC tests for portland cement concrete (PCC) are aggregate quality tests, gradation of critical sieves, air content, water–cement content, mix temperature, and slump.

7.9 The use of control charts is an important part of the QC function. Statistical control charts are the most effective control charts to use. This tool provides, in real time, the contractor and agency a visual estimate of the population of the quality characteristic being produced.

7.10 Since estimating the population being produced is the purpose of QC, the use of the most appropriate procedures is recommended. The most effective and simplest pair of statistical control charts is the joint use of:

7.10.1 An average chart ($\overline{X}$ chart) to measure the center.

7.10.2 A range chart (R chart) to measure the variability. The range is recommended because of the simplicity to measure it.

7.11 An example of an average and range control chart is shown in Figure 1.

7.11.1 The mean of the $\overline{X}$ chart is the center of production. This may or may not be the center of the specification limits. In fact, there may not be a specification requirement for this QC measure.

7.11.2 Control limits, also called action limits, are boundaries established by statistical analysis for material production control using the control chart technique. When values of the process fall within these limits, the process is "under control" (R 10). The limits are set at the equivalent of $\pm 3\sigma_{\overline{X}}$ from the mean of the $\overline{X}$ chart. Both an upper control limit (UCL) and a lower control limit (LCL) are used.

7.11.3 Since an estimate of variability is desired, the sample size used to plot statistical control charts must be at least two, i.e., $n \geq 2$.

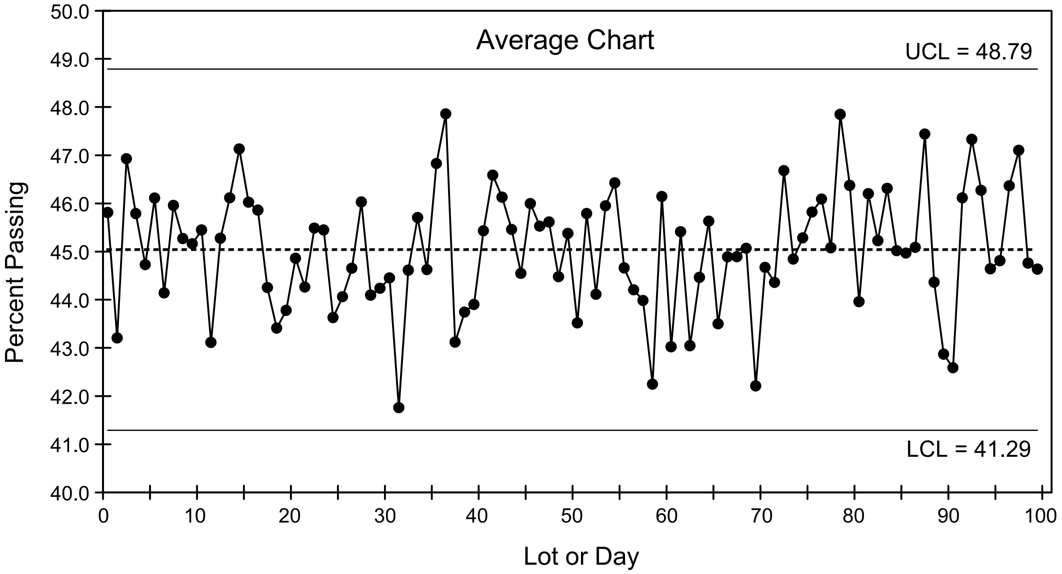
7.11.4 Warning limits are boundaries established on control charts within the UCL and LCL to warn the producer of possible problems in the production process that may lead to the process going out-of-control (R 10). These limits are often set at $\pm 2\sigma_{\overline{X}}$. When values fall outside these limits, there is approximately a 5 percent chance the process is out-of-control. (For the purpose of clarity, these are not shown on Figure 1.)

7.11.5 The center of the R chart is the mean range and the control limits are typically set at $\pm 3\sigma R$. In this case, σR is the standard deviation of the ranges. However, the LCL for the R chart is zero for most practical sample sizes.

7.12 Control limits are intended to show when a process is out-of-control. The chance of a point being more than $\pm 3\sigma_{\overline{X}}$ away from the average is only 0.3 percent. So, a value outside the action limit is an indication that the process has changed.

7.12.1 In the case that a point is more than $\pm 3\sigma_{\overline{X}}$ from the average, the contractor may decide to quickly take another test in an attempt to confirm that the process has, in fact, changed before altering production. If the second test result is close to the first, this provides an indication that the process may have changed. (If a check test is made, include both test results in the QC documentation.) Although the check sample would not have been obtained in a random manner, it is a permissible course of action. This is one good example of why QC and acceptance must be maintained as separate functions.

7.13 The calculation and use of control chart limits are beyond the scope of this standard practice. (See ASTM MNL 7A for more information on control charts.)



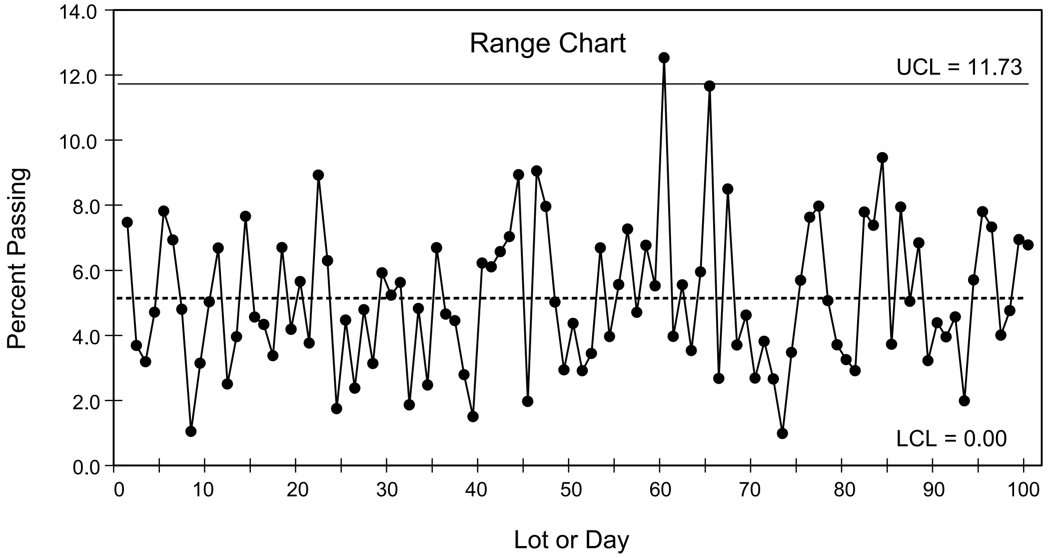


Figure 1—Examples of Average and Range Charts for the 2.36-mm Sieve

8. DEVELOP ACCEPTANCE PROCEDURES

8.1 *Acceptance*—Sampling and testing, or inspection, to determine the degree of compliance with contract requirements *(Transportation Research Circular Number E-C037,* 2002*)*.

8.2 *Purpose of Acceptance Procedures*—These procedures are intended to accept adequate quality level product and reject inadequate quality level product as often as feasible.

8.3 Most previous work in acceptance plans has been in terms of percent within limits (PWL) and some work has been done using percent defective (PD). Percent within limits and PD are complementary and add up to 100 percent. One can be converted to the other by Equation 1:

$$PD + PWL = 100\% \qquad (1)$$

This relationship is shown graphically in Figure 2. The PWL is sometimes called the percent conforming; also, the percent nonconforming may be a more appropriate term than percent defective. The PWL approach is preferred by some agencies over PD because it is a positive expression. Also, in terms of the theory of acceptance sampling plans, the material outside of the limits may not be strictly defective but of lesser quality than material within the limits.

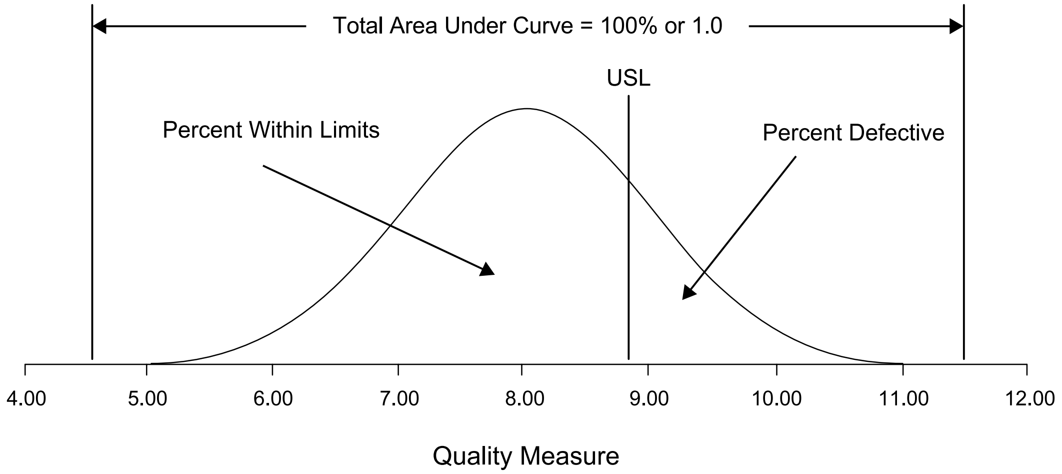


Figure 2—Complementary Relationship between Percent within Limits and Percent Defective

8.4 The PWL procedure produces an estimate of the population. Conceptually, as the sample size, *n*, increases, the estimate of the population improves. The PWL concept is one of small sample sizes and the distribution used is the noncentral *t* distribution. This distribution converges with the normal distribution when *n* approaches infinity. Since PWL is an estimate of a population, it must use an estimate of both the central tendency and the variability.

8.5 *Specification and Acceptance Limits*—In the development of an acceptance plan, specification and acceptance limits must be determined, and the acceptable quality level (AQL) and rejectable quality level (RQL) must be selected. The AQL, RQL, specification limits, and acceptance limits are intimately related, and the decisions regarding these are typically made concurrently.

8.6 *Specification Limits*—The limiting value(s) placed on a quality characteristic, established preferably by statistical analysis, for evaluating material or construction within the specification requirements. The term can refer to either an individual upper specification limit (USL) or lower specification limit (LSL), called a single specification limit; or to USL and LSL together, called double specification limits (*Transportation Research Circular Number E-C037,* 2002). As discussed below, specification and acceptance limits are different and serve different purposes.

8.7 Specification limits are based on engineering requirements and are expressed in the same units as those used for the quality characteristic of concern (e.g., percent, millimeters, kilograms per square millimeter, etc.). The acceptance limits are the limiting values placed on a quality measure that will permit acceptance of the lot. In PWL acceptance plans they are expressed in statistical units (PWL).

8.8 *Establishing the Specification Limits*—Establishing specification limits requires determining what constitutes acceptable (AQL) and unacceptable (RQL) material. The determination of both AQL and RQL are engineering decisions. The AQL decision defines acceptable material or construction, and addresses the product that will provide satisfactory service at an affordable cost when used for the intended purpose. Acceptable material is often determined based on what has performed well in the past. However, if performance data are available, it is preferable to quantify performance. Statistics has been a valuable tool in defining the parameters (mean and standard deviation) for acceptable material. Caution should be exercised if a lower variability is chosen for the specification than has been shown to be readily achievable. Arbitrarily "tightening the specs" can increase the cost of the product above what is considered cost-effective.

8.8.1 *Acceptable Quality Level (AQL)*—That minimum level of actual quality at which the material or construction can be considered fully acceptable (for that quality characteristic). For example, when quality is based on PWL, the AQL is that actual (not estimated) PWL at which the quality characteristic can just be considered fully acceptable (*Transportation Research Circular Number E-C037*, 2002). Acceptance plans should be designed so that AQL material will receive an average pay over the long run of 100 percent.

8.8.2 *Rejectable Quality Level (RQL)*—That maximum level of actual quality at which the material or construction can be considered unacceptable (rejectable) (*Transportation Research Circular Number E-C037*, 2002). For example, when quality is based on PWL, the RQL is that actual (not estimated) PWL at which the quality characteristic can just be considered fully rejectable. [It is desired to require removal and replacement, corrective action, or the assignment of a relatively low pay factor when RQL work is detected.]

8.8.3 Setting specification limits is slightly more complicated for double specification limits as compared to a single specification limit. For a quality characteristic with a single specification limit, the limit can be set at the appropriate number of standard deviations (process variability) above the minimum desired value to obtain the necessary PWL. But for a specification with double limits, there may be concern that in addition to the number of standard deviations (process variability) used to set the limits, a "target miss" may be warranted.

8.8.4 *Target Miss*—The failure of a contractor to center the process exactly on the target value. (For more detailed information on target miss, see *Optimal Procedures for Quality Assurance Specifications*, 2003.)

8.8.5 The proper way to address the issue of "target miss," is to determine how variable the actual process means are about the target value. This variability regarding where the process will be centered, called "target miss variability," can then be combined with the typical process variability to obtain the correct standard deviation value for use in establishing specification limits. The "target miss variability" and the "process variability" can be combined simply by adding their associated variances, *not* their standard deviations (see Equations 2 and 3). This assumes that the amount of process variability is independent of where the process is centered. (The example in Appendix X1 includes a calculation of "target miss" variability).

$$\hat{\sigma}^2_{\text{combined}} = \hat{\sigma}^2_{\text{target - miss}} + \hat{\sigma}^2_{\text{process}} \tag{2}$$

$$\hat{\sigma}_{\text{combined}} = \sqrt{\hat{\sigma}^2_{\text{combined}}} \tag{3}$$

where:

$\hat{\sigma}^2_{\text{combined}}$ = estimated combined target miss and process variance,

$\hat{\sigma}^2_{\text{target - miss}}$ = estimated target miss variance,

$\hat{\sigma}^2_{\text{process}}$ = estimated process variance, and

$\hat{\sigma}_{\text{combined}}$ = estimated combined standard deviation.

8.9 Select the specification limit(s) in concert with the quality measure, i.e., the measure that is used to quantify quality and the AQL and RQL. For instance, the AQL might be set at 90 PWL. This means that when the population has 90 percent of the product within specification limits, the product is completely acceptable. However, the same product could be defined by an AQL of 85 PWL with more restrictive specification limits or by many other possible combinations of AQL and specification limits. Selecting lower values of AQL may give the perception that lower quality levels are acceptable. It is recommended that AQL values be set at 90 or 95 PWL unless there is an overriding reason to select another value.

8.9.1 It is important to distinguish between a population (e.g., $N = 4$) and a sample (e.g., $n = 4$), because different equations are used to determine a population's variability than are used to estimate a sample's variability. When working with a population, it is desirable to have a large number of data points. However, sample sizes upon which to base acceptance or process control decisions are typically small, e.g., from four to ten, depending on the lot size. Larger lot and sample sizes are suggested to offer the advantage of lowering the risks of making a wrong acceptance or rejection decision.

8.10 *Acceptance Limit*—In variables acceptance plans, the limiting upper or lower value, placed on a quality measure, which will permit acceptance of a lot. (Unlike specification limits placed on a quality characteristic, an acceptance limit is placed on a quality measure. For example, in PWL acceptance plans, PWL refers to specification limits placed on the quality characteristic, and the minimum allowable PWL identifies the acceptance limit for the PWL quality measure.) (*Transportation Research Circular Number E-C037,* 2002)

8.11 *Acceptance Limits with Pay Adjustments*—For acceptance plans with pay adjustment provisions, additional acceptance limits, often expressed in the form of an equation or equations, are used to distinguish among the various possible pay levels.

8.12 *An Example of Specification and Acceptance Limits, AQL and RQL.*

8.12.1 An agency has decided, based on a large number of project data that it collected and analyzed, that a "typical" standard deviation for a lot defined in the acceptance plan for asphalt content for HMA is 0.18 percent. It has further been decided that PWL will be used as the quality measure. (See the example in Appendix X1 on how to properly select the "typical" standard deviation.)

8.12.2 *Determine AQL Material*—Since asphalt content has a stipulated target value, i.e., the job mix formula (JMF) asphalt content, the agency may choose to determine AQL material as a lot for which the average asphalt content is equal to the JMF target value and for which the standard deviation is equal to or less than the "typical" value of 0.18 percent. This defines AQL material in terms of the desired population mean and standard deviation, but the AQL definition must also be related to the required quality measure, which in this case is PWL.

8.12.3 *Set Specification Limits*—Since the specification limits and the AQL are related, the agency might decide to set the AQL as a value of 90 PWL. This selection of 90 PWL for the AQL is arbitrary, but is a commonly used value and one suggested in the AASHTO *Quality Assurance Guide Specification* (1995). The AQL population defined from past projects in terms of mean and standard deviation should just meet this PWL definition for AQL. So, in this case, the specification limits would be set such that a population with a mean at the JMF and a standard deviation of 0.18 percent would have 90 percent of its area within the specification limits. These limits can be determined by finding the *Z*-value from a standard normal table that corresponds to an area of 0.90 within the mean ± *Z* standard deviations (i.e., $\mu \pm Z\sigma$). (This example assumes the contractor can hit the JMF consistently, and no target miss is necessary. See the example in Appendix X1 on the addition of a target miss value).

8.12.4 Table 1 presents some typical ± *Z* regions within which selected areas of the normal distribution fall. From this table, it is seen that 0.90 (or 90 percent) of the normal distribution falls within ±1.645 standard deviations from the population mean.

Table 1—$\mu \pm Z\sigma$ Regions for Selected Areas under the Normal Distribution

Area	0.99	0.95	0.90	0.85	0.80
± *Z*	2.576	1.960	1.645	1.439	1.282

8.12.5 Figure 3 shows the specifications set at the JMF asphalt content ±1.645 times the typical standard deviation value, or JMF ± 1.645 (0.18 percent) = JMF ± 0.30 percent. In this case, the AQL is 90 PWL and the specification limits are JMF ± 0.30 percent.

8.12.6 Alternatively, using the same AQL population, the agency could decide to establish the AQL as 85 PWL. In this case, the specification limits would be set at the JMF ± 1.439 times the typical standard deviation value (see Table 1), or JMF ± 1.439 (0.18 percent) = JMF ± 0.26 percent. The specification limits are different in this case because the definition for AQL in terms of PWL is different. However, although the same population is desired in both cases, the perception is that quality is not as important with an AQL of 85 compared to an AQL of 90.

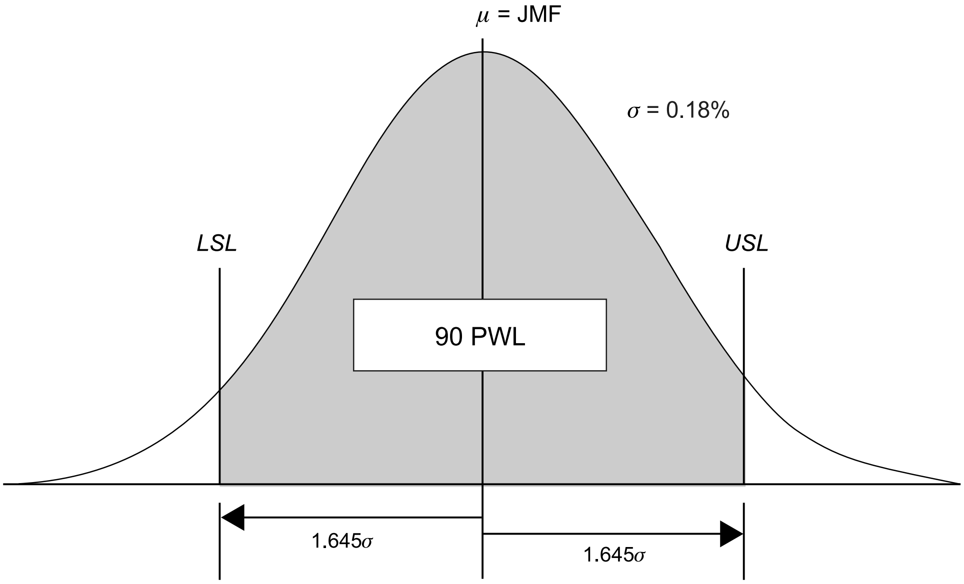


Figure 3—AQL Material for Example 8.12

8.12.7 *Determine RQL Material*—There is no single correct way to establish either the AQL or the RQL. Once the AQL and specification limits are established, the RQL can be determined in a number of ways. One way is to decide that the material should be rejected once a "large" percentage of material is outside the specification limits. Determining what constitutes a "large" percentage then needs to be decided. The agency may decide that the material is unacceptable once half of it is outside of the specification limits. In this case, the RQL would be established as a PWL value of 50. Any lot with an estimated PWL value of 50 or less would then be required to be removed and replaced or other penalty applied. Typical values for RQL are between 70 and 30 PWL.

8.12.8 Alternately, the agency might base the definition of RQL on the analysis of past project data. The agency might decide that past projects had performed inadequately when the average asphalt content was 0.25 percent above or below the JMF target value. In this case, the agency might decide to set the RQL based upon the PWL value for a population with a mean 0.25 percent above or below the JMF target and with a standard deviation equal to the "typical" value of 0.18 percent. Figure 4 illustrates the case of the RQL population when the specification limits are JMF ± 0.30 percent. In this case, it can be seen that the PWL for the RQL population corresponds to the area of the population that lies within the specification limits. In this case, the RQL might be defined as a lot with a PWL value of 60 (rounded from 61) as shown in Figure 4.

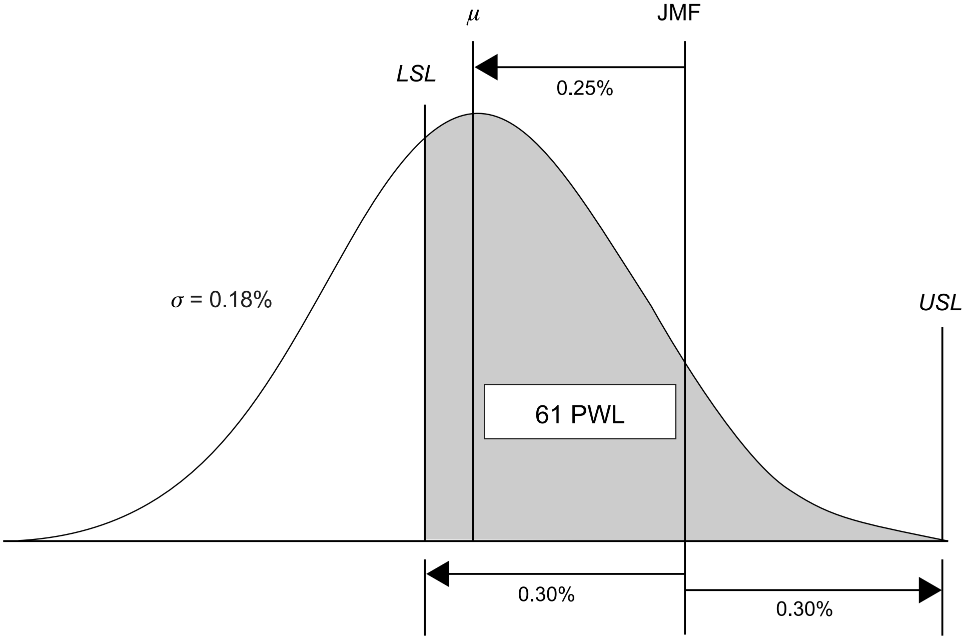


Figure 4—RQL Material for Example 8.12

8.12.9 The above approach to defining RQL material contains a number of simplifying assumptions. It looks only at how far the population mean departs from the target value and does not consider the population standard deviation. This assumes that the typical standard deviation value of 0.18 percent will be achieved on all projects. This approach also does not consider the interaction and effect of other quality characteristics, such as density, thickness, etc., on the performance of past projects.

8.13 *Application of PWL*—Determining the PWL is similar in concept to determining the area under the normal curve. The theory in the use of the PWL (or PD) method assumes that the population being sampled is normally distributed. In practice, it has been found that statistical estimates of quality are reasonably accurate provided the sampled population is at least approximately normal; i.e., reasonably bell shaped and not bimodal or highly skewed. This has been found to be true for most material and construction measures not associated with a physical constraint; e.g., since gradation cannot exceed 100 percent passing a top size sieve, a measure of this characteristic is often skewed and therefore not normally distributed.

8.13.1 When the average and standard deviation are known (or assumed known), the area under the normal curve can be calculated to determine the percentage of the population that is within certain limits. However, when the average and standard deviation are unknown—as in the case of determining the acceptance for a lot—the percentage of the lot that is within the specification limits can be estimated. In this latter case, instead of using the *Z*-value and the standard normal curve, the quality index, *Q*, is used to estimate PWL. The *Q*-value is used with a PWL table to determine the estimated PWL for the lot.

8.13.2 A sample table relating *Q* values with the appropriate PWL estimate is shown in Table 2 for a sample size of $n = 5$. A more complete set of PWL tables in this format, for sample sizes from $n = 3$ to $n = 30$, is available (*Quality Assurance Software for the Personal Computer*, 1996).

Table 2—A PWL Estimation Table for Sample Size *n* = 5

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.36	50.71	51.07	51.42	51.78	52.13	52.49	52.85	53.20
0.1	53.56	53.91	54.27	54.62	54.98	55.33	55.69	56.04	56.39	56.75
0.2	57.10	57.46	57.81	58.16	58.52	58.87	59.22	59.57	59.92	60.28
0.3	60.63	60.98	61.33	61.68	62.03	62.38	62.72	63.07	63.42	63.77
0.4	64.12	64.46	64.81	65.15	65.50	65.84	66.19	66.53	66.87	67.22
0.5	67.56	67.90	68.24	68.58	68.92	69.26	69.60	69.94	70.27	70.61
0.6	70.95	71.28	71.61	71.95	72.28	72.61	72.94	73.27	73.60	73.93
0.7	74.26	74.59	74.91	75.24	75.56	75.89	76.21	76.53	76.85	77.17
0.8	77.49	77.81	78.13	78.44	78.76	79.07	79.38	79.69	80.00	80.31
0.9	80.62	80.93	81.23	81.54	81.84	82.14	82.45	82.74	83.04	83.34
1.0	83.64	83.93	84.22	84.52	84.81	85.09	85.38	85.67	85.95	86.24
1.1	86.52	86.80	87.07	87.35	87.63	87.90	88.17	88.44	88.71	88.98
1.2	89.24	89.50	89.77	90.03	90.28	90.54	90.79	91.04	91.29	91.54
1.3	91.79	92.03	92.27	92.51	92.75	92.98	93.21	93.44	93.67	93.90
1.4	94.12	94.34	94.56	94.77	94.98	95.19	95.40	95.61	95.81	96.01
1.5	96.20	96.39	96.58	96.77	96.95	97.13	97.31	97.48	97.65	97.81
1.6	97.97	98.13	98.28	98.43	98.58	98.72	98.85	98.98	99.11	99.23
1.7	99.34	99.45	99.55	99.64	99.73	99.81	99.88	99.94	99.98	100.00

Note: Values in the body of the table are estimates of PWL corresponding to specific values of $Q_L = (\overline{X} - LSL) / s$ or $Q_U = (USL - \overline{X}) / s$
For negative *Q* values, the table values must be subtracted from 100.

8.13.3 *Calculation and Rounding Procedures*—The calculation procedures and rounding rules can influence the estimated PWL value that is obtained. This can become a point of contention, particularly if the pay determination is based on the estimated PWL value. It is, therefore, important that the agency specify the exact calculation process, including number of decimal places to be carried in the calculations, as well as the exact manner in which the PWL table is to be used.

8.13.4 Conceptually, the *Q*-value performs identically the same function as the *Z*-value does for a normal distribution. Except now the reference points are the individual sample mean ($\overline{X}$) and standard deviation (*s*) instead of the population mean (μ) and standard deviation (σ) and the points of interest with regard to areas under the curve are the specification limits.

$$Q_L = \frac{\overline{X} - LSL}{s} \tag{4}$$

and

$$Q_U = \frac{USL - \overline{X}}{s} \tag{5}$$

where:

Q_L = quality index relative to the lower specification limit,

Q_U = quality index relative to the upper specification limit,

LSL = lower specification limit,

USL = upper specification limit,

$\overline{X}$ = sample mean for the lot, and

s = sample standard deviation for the lot.

8.13.5 The *Q*-value, therefore, represents the distance in sample standard deviation units that the sample mean is offset from the specification limit. A positive *Q*-value represents the number of sample standard deviation units that the sample mean falls inside the specification limit. Conversely, a negative *Q*-value represents the number of sample standard deviation units that the sample mean falls outside the specification limit. These cases are illustrated in Figure 5. *QL* is used when there is a one-sided lower specification limit, while *QU* is used when there is a one-sided USL. For two-sided specification limits, the PWL value is estimated as:

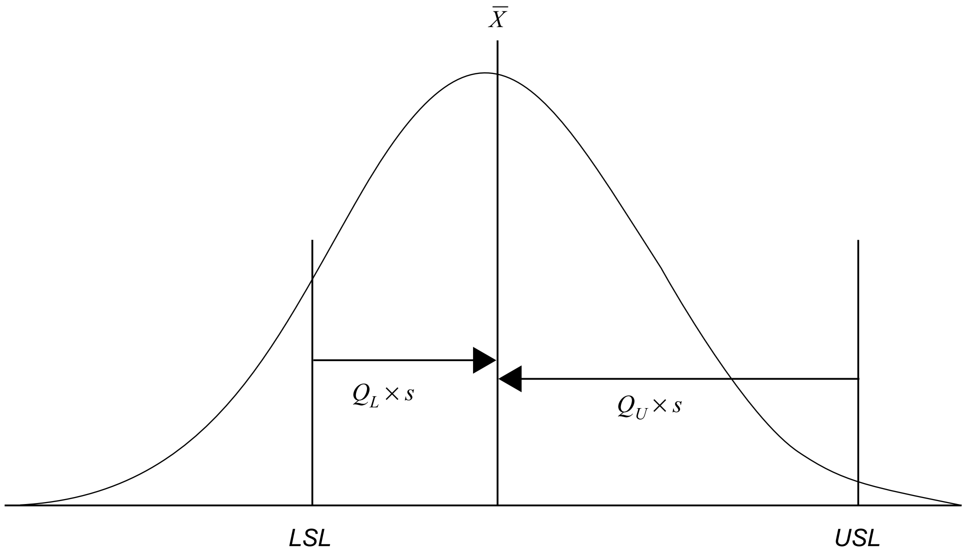
$$PWL_T = PWL_U + PWL_L - 100 \tag{6}$$

where:

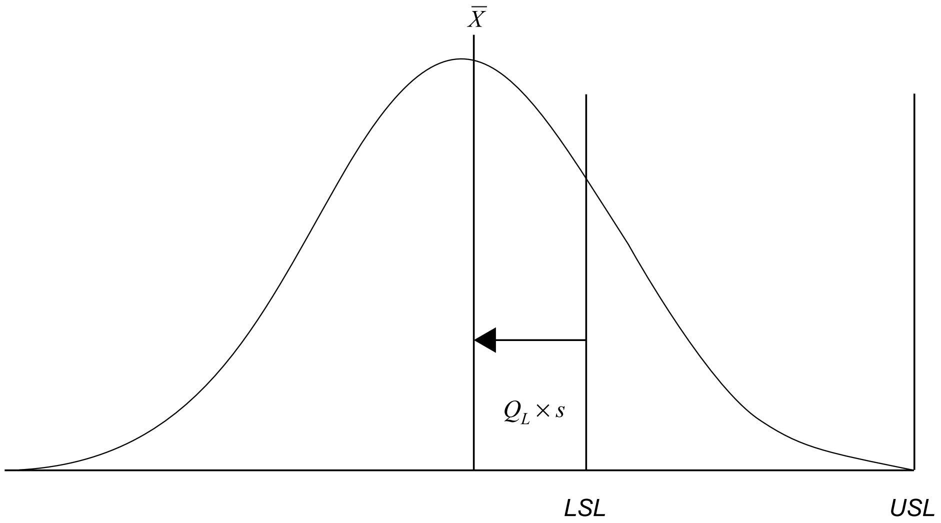
PWL_T = percent within the upper and lower specification limits.

PWL_U = percent below the upper specification limit (based on Q_U).

PWL_L = percent above the lower specification limit (based on Q_L).



(a) Illustration of Positive Quality Index Values



(b) Illustration of a Negative Quality Index Value

Figure 5—Illustration of the Quality Index, *Q*

8.13.6 Intuitively, PWL is a good measure of quality since it is reasonable to assume that the more of the product that is within the specification limits, the better the quality of the product should be. (A detailed discussion and analysis of the PWL measure of quality is presented in *Optimal Procedures for Quality Assurance Specifications*, 2003.)

8.14 If the agency conducts the acceptance tests, sampling and testing must be performed in qualified laboratories and by qualified sampling and testing personnel. There are no additional requirements for verification other than the typical IA requirement.

8.15 However, if the contractor/third party conducts tests used in the acceptance decision, a validation procedure is necessary as required in FHWA 23 CFR 637 (1995). The requirements are:

8.15.1 The sampling and testing must be performed in qualified laboratories and by qualified sampling and testing personnel.

8.15.2 The quality of the material must be validated by verification sampling and testing. The verification sampling and testing is to be performed on samples that are taken independently from those used in the acceptance decision.

8.16 Statistically sound verification procedures must be developed and used. There are several forms of verification procedures, and some forms are more efficient than others. It is in the best interest of both parties to make the verification process as effective and efficient as practicable.

8.17 FHWA 23 CFR 637 states that the verification samples shall be taken independently. This requirement does not allow the direct comparison of split samples for validation. However, this does not prohibit the use of split sample test results. For instance, the contractor may test 100 samples and the agency select the split portion of all one hundred samples but test only 20 of the samples. Then the agency can compare their 20 tests results to the 80 contractor test results that are not paired with those of the agency, using the *F*-test and independent *t*-test.

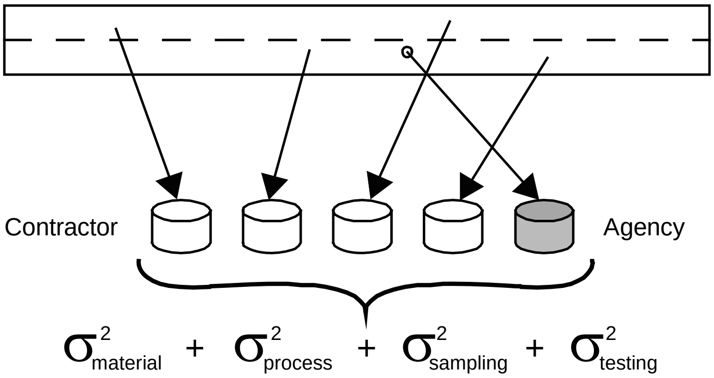
8.17.1 There is a difference in the information provided by split and independent sampling procedures, and the difference is related to the concept of components of variability.

8.17.2 *Split Sample*—A sample that has been divided into two or more portions representing the same material. (Split samples are sometimes taken to verify the acceptability of an operator's test equipment and procedure. This is possible because the variability calculated from differences in split test results is comprised solely of testing variability.) (*Transportation Research Circular Number E-C037*, 2002)

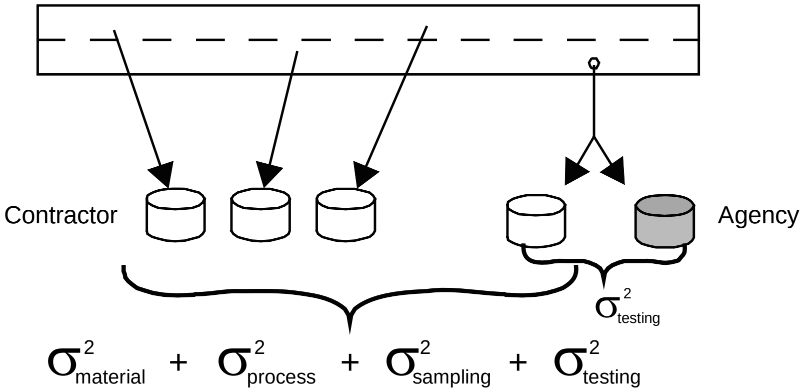
8.17.3 *Independent Sample*—A sample taken without regard to any other sample that may also have been taken to represent the material in question. [An independent sample is sometimes taken to verify an acceptance decision. This is possible because the data sets from independent samples, unlike those from split samples, each contain independent information reflecting all sources of variability, i.e., materials (which often includes both the material and the process variabilities), sampling, and testing.] (*Transportation Research Circular Number E-C037*, 2002)

8.17.4 The five specimens shown in Figure 6(a) have been taken independently. The variability represented by them includes all sources of variability; i.e., material, process, sampling, and testing. Thus, if the total variability is to be evaluated, independent samples must be taken.

8.17.5 In Figure 6(b), four of the five specimens have been taken independently; however, the two on the far right are split samples from the same batch, i.e., they are two results that represent the same material. The variability represented by these two specimens includes only the component of testing variability. However, either of the two specimens on the far right can be combined with the other three to measure all sources of variability; but both cannot be used with the other three in an analysis. Specimens tested by different laboratories may be combined, from a statistical standpoint, if found not to be statistically different. However, a higher variability is likely to result and, thus, this is not recommended.



(a) Independent Samples



(b) Split Samples

Figure 6—Components of Variance for: (a) Independent Samples and (b) Split Samples

8.17.6 The analysis of the variability for split samples will be a smaller value, $\sigma^2_{\text{testing}}$, than the variability for independent samples, $\sigma^2_{\text{overall}}$, because the latter includes all components of variability. But the decision of whether to use split or independent samples should not be made based on the magnitude of the variability but, instead, on the component(s) of variability that is (are) desired to be measured. So, the choice of whether to use split or independent samples is not an arbitrary decision.

8.18 *Definition of Verification*—The process of determining or testing the truth or accuracy of test results by examining the data and/or providing objective evidence. (Verification sampling and testing may be part of an IA program (to verify contractor QC testing or agency acceptance) or part of an acceptance program (to verify contractor testing used in the agency's acceptance decision)) (*Transportation Research Circular Number E-C037*, 2002).

8.19 *Verification Procedures*—The ability of the comparison procedure to identify differences between two sets of test results depends on the number of tests from each set that are being compared. The greater the number of test results from each set, the greater the ability of the procedure to identify statistically valid differences. A rule of thumb is a minimum agency rate of 10 percent of the contractor's testing rate. It is preferred to conduct a risk analysis to determine whether a higher rate is warranted. It also must be decided whether the test method or the process is to be verified. This relates to the use of split or independent samples.

8.20 *Hypothesis and Level of Significance*—An hypothesis is a statement of an assumption about a set of data. The null hypothesis, H_o, defines an assumed set of conditions. (The null hypothesis cannot be proved true. It can be shown, with specified risks, to be untrue). The alternative hypothesis, H_a, is the hypothesis that is accepted when the null hypothesis is disproved (i.e., rejected). The level of significance, α, is the probability of rejecting a null hypothesis when it is, in fact, true (*Transportation Research Circular Number E-C037*, 2002). Typical levels of significance are 0.10, 0.05, and 0.01. If, for example, $\alpha = 0.01$ is used and the null hypothesis is rejected, then there is only one chance in 100 that H_o is true and was rejected in error.

8.21 *Test Method Verification Procedures*—These procedures compare results of split samples. The two procedures used most often for test method verification are the d2s limits and the paired *t*-test.

8.21.1 *d2s Limits*—This is the simplest procedure that can be used for verification. It is also the least powerful. Because the procedure uses only two test results, it cannot detect real differences unless the results are far apart. The value provided by this procedure is contained in many AASHTO test methods. The d2s limit indicates the maximum acceptable difference between two results obtained on test portions of the same material (and thus, applies only to split samples), and is provided for single and multi-laboratory situations. It represents the difference between two individual test results that has approximately a 5 percent chance of being exceeded if the tests are actually from the same population.

8.21.2 When this procedure is used for test method verification, a sample is split into two portions and the contractor tests one split sample portion while the agency tests the other split sample portion. The difference between the contractor and agency test results is then compared to the d2s limits. If the test difference is less than the d2s limit, the two tests are considered verified, i.e., they are assumed to have come from the same population. If the test difference exceeds the d2s limit, then the contractor's test result is not verified, and the source of the difference is investigated.

8.21.3 *Paired t-test*—For the case in which it is desirable to compare more than one pair of split sample test results, the *t*-test for paired measurements can be used. This test uses the differences between pairs of tests and determines whether the average difference is statistically different from 0. Thus, it is the difference within pairs, not between pairs, that is being tested. The *t*-statistic for the *t*-test for paired measurements is:

$$t = \frac{\left|\overline{X}_d\right|}{\dfrac{s_d}{\sqrt{n}}} \qquad (7)$$

where:

$\overline{X}_d$ = average of the differences between the split sample test results,

s_d = standard deviation of the differences between split sample test results, and

n = number of split sample pairs.

8.21.4 The calculated *t*-value is then compared to the critical value, t_{crit}, obtained from a table of *t*-values at a level of $\alpha/2$ and with $n - 1$ degrees of freedom. (A table of critical *t* values can be found in *Materials Control and Acceptance-Quality Assurance*, 2000; *Optimal Procedures for Quality Assurance Specifications*, 2003; and most basic statistics textbooks. Computer spreadsheet programs contain statistical test procedures for the paired *t*-test.)

8.21.5 Since the use of d2s limits is not very powerful, it is recommended that each individual split sample be compared using the d2s limits, but that the paired *t*-test also be used on the accumulated split samples to provide for a comparison with more discerning power.

8.21.6 The above recommendation also applies to the IA component of the acceptance plan because it also uses split samples.

8.22 *Process Verification Procedures*—Just as there are statistical tests for verification of split sample test results, there are also tests for verification of independently obtained test results. The tests most often used are the *F*-test and *t*-test, which are usually used together.

8.22.1 *F-test and t-test*—This procedure involves two statistical tests, where the null hypothesis for each test is that the contractor's test results and the agency's test results are from the same population. Specifically, the null hypotheses are that (1) the variability of the two data sets are equal for the *F*-test, and (2) the means of the two data sets are equal for the *t*-test. It is important to compare both the means and the variances when comparing two sets of data. A different test is used for each comparison. The *F*-test provides a method for comparing the variances of the two sets of data. Differences in means are assessed by the *t*-test.

8.22.2 The procedures involved with the *F*-test and *t*-test may, at first, seem complicated and involved. Some of the complexity of the *F*-test and *t*-test comparisons can be eliminated by the use of computer programs. Many spreadsheet programs have the ability to conduct these tests. (An example of the *F*-test and *t*-test is shown in Appendix X2).

8.23 *Dispute Resolution*—Also called conflict resolution. For QA programs permitting contractor acceptance testing, procedures to resolve conflicts resulting from discrepancies between the agency's and contractor's results of sufficient magnitude to impact pay. (The procedure may, as an initial step, include the testing of independent samples and, as a final step, third-party arbitration.) (*Transportation Research Circular Number E-C037*, 2002). Dispute resolution procedures to identify testing errors are considered an important part of any QA program.

8.24 *Dispute Resolution Procedure*—It is intended to provide a means to minimize adversarial relationships and claims. The use of appropriate procedures should help avoid disputes and claims. Establish a formal monitoring program that will provide both the contractor and the agency assurances that all data are reliable, unbiased, and truly indicate quality. There are many aspects of dispute resolution addressed in detail in *AASHTO Implementation Manual for Quality Assurance* (1995). Two are briefly discussed here.

8.24.1 *Identifying Outlying Observations*—An outlying observation, or "outlier," is one that appears to deviate markedly from other sample test values from which it was taken (ASTM E 178). When considering outliers, two conditions exist:

1. The value may be an extreme value of the population or excessive variability of the population. In either case the value should be retained and used in further evaluations or computations.
2. It may be the result of gross deviation from prescribed sampling and or test procedures, or in calculating or recording the numerical value, in which case it should be discarded.

Use a procedure to determine which decision to make; i.e., the value is not an outlier and should be retained or the value is an outlier and should be discarded. (See ASTM E 178 for further discussion of outliers). It should be remembered that because of the way specification limits are set, some results of AQL material may be outside of the specification limits. Thus, to arbitrarily discard values is not a valid procedure.

8.24.2 *The Proper Policy for Resampling and Retesting*—If resampling and/or retesting is allowed, establish specific procedures stating when and how it should be done. An example of when retesting may be warranted is the requirement of a "remove and replace" provision when the quality is estimated to be at or below the RQL. It may be decided that the quality estimate should be improved by testing another set of samples because the economic consequences of "remove and replace" are severe. This is an acceptable practice if all the test results—the original and retests—are used and none of the results are discarded.

9. RISKS AND RISK ANALYSIS

9.1 Establishing the acceptance limits is an important step. Making the limits too restrictive deprives the contractor of a reasonable opportunity to meet the specification. If the limits are not sufficiently restrictive they will be ineffective in controlling quality. Both engineering requirements and economical process capabilities should be considered when establishing acceptance limits. Selection of the limits relates to the determination of risks. The concept of risks for acceptance is similar to that discussed in Section 8 for verification testing to evaluate whether test results came from the same population. A well-written QA plan takes these risks into consideration in a manner that is fair to both the contractor and the agency. Too large a risk for either party undermines credibility. Thus, the risks should be balanced and should be reasonably small. For most highway products, if this is not possible because of the sample size selected, the risks to the contractor should be less than that to the agency except for potential catastrophic failures.

9.1.1 *Risks: Definitions and Levels*

9.1.1.1 *Seller's Risk* (*α*)—Also called contractor's risk or risk of a Type I error. The probability that an acceptance plan will erroneously reject AQL material or construction with respect to a single acceptance quality characteristic. It is the risk the contractor or producer takes in having AQL material or construction rejected (*Transportation Research Circular Number E-C037,* 2002).

9.1.1.2 *Buyer's Risk* (*β*)—Also called agency's risk or risk of a Type II error. The probability that an acceptance plan will erroneously fully accept (100 percent or greater) RQL material or construction with respect to a single acceptance quality characteristic. It is the risk the highway agency takes in having RQL material or construction fully accepted. [The probability of having RQL material or construction accepted (at any pay) may be considerably greater than the buyer's risk.] (*Transportation Research Circular Number E-C037*, 2002).

9.1.1.3 The α and β risk levels that might be appropriate vary depending upon the material or construction process that is involved. The appropriate risk level is a subjective decision that can vary from agency-to-agency. However, as an economic decision, typical practice limits risks to no more than five percent.

9.1.1.4 The more critical the application, the lower should be the buyer's risk. But only under rare circumstances should the buyer's risk be lower than the seller's risk.

9.2 *Risks Concepts*—As noted in the section on verification testing in Section 8, the concept of α and β risks derives from statistical hypothesis testing in which there is either a right or wrong decision. As such, when α and β risks are applied to materials or construction, they are only truly appropriate for the case of a pass/fail or accept/reject decision and, in fact, may lead to considerable confusion if an attempt is made to apply them to the pay adjustment case. When materials not only can be accepted or rejected, but can also be accepted at an adjusted pay, then additional interpretations or clarifications must be applied to the definitions of risks.

9.2.1 For example, in the definition for buyer's risk above, it states that β is the probability that RQL material will be accepted at 100 percent pay or greater. The definition must then go on to point out that there may be a much greater probability that the RQL material will receive some reduced pay. While it is not stated as directly, the same reasoning is true for the seller's risk. The definition indicates that α is the probability that AQL material will be rejected. Although not stated in the definition, it is also true that there may be a much greater probability that the AQL material will be accepted at a reduced pay.

9.3 *Operating Characteristic (OC) Curves*—α and β are very narrowly defined to occur at only two specific quality levels. β is the probability of accepting, at full pay or more, material that is exactly at the RQL, while α is the probability of rejecting material that is exactly at the AQL. These definitions do not therefore provide an indication of the risks over a wide range of possible quality levels. To evaluate how the acceptance plan will actually perform in practice, it is necessary to construct an operating characteristic (OC) curve.

9.3.1 *OC Curve*—A graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either (1) the probability of its acceptance (for accept/reject acceptance plans) or (2) the probability of its acceptance at various pay levels (for acceptance plans that include pay adjustment provisions) (*Transportation Research Circular Number E-C037*, 2002).

9.3.2 An example of an OC curve for a pass/fail or accept/reject acceptance plan, case (1) in the above definition, is shown in Figure 7. Probability of acceptance is shown on the vertical axis for the range of quality levels indicated on the horizontal axis. An example of an OC curve for an acceptance plan with pay adjustment provisions, case (2) in the above definition, is shown in Figure 8. The axes are the same as for Figure 7, but there are multiple curves, one for each of several selected pay levels.

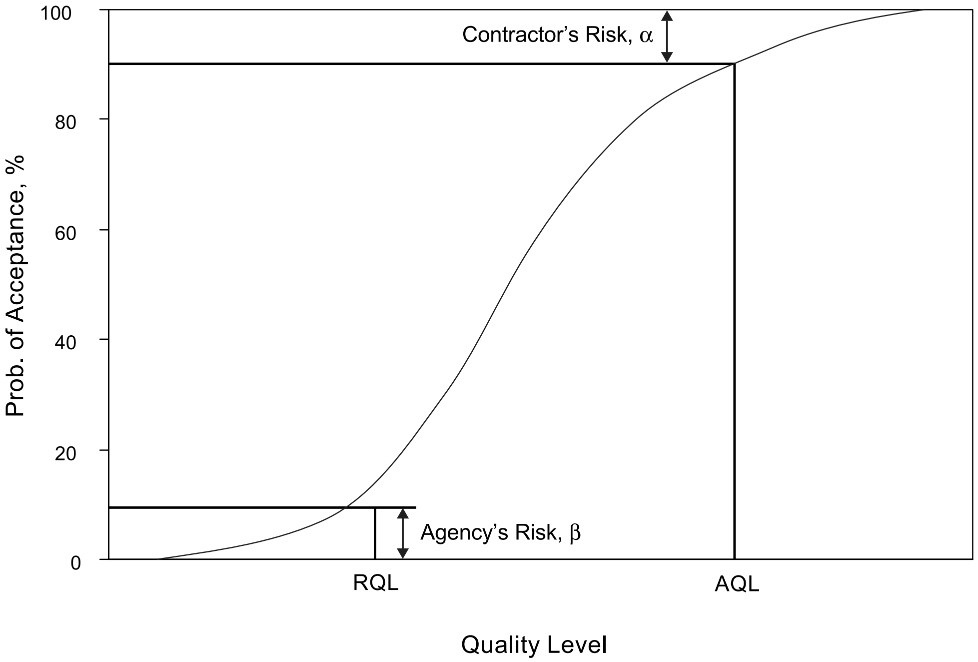


Figure 7—Typical OC Curve for an Accept/Reject Acceptance Plan

9.3.3 Each curve plotted in Figure 8 represents the probability of receiving a pay factor equal to or greater than the one indicated for the line. For example, for the OC curves in Figure 8, material that is of exactly AQL quality has approximately a 45 percent chance of receiving a pay factor of 1.04 (104 percent) or greater. This same AQL material has approximately a 60 percent chance of receiving full pay (100 percent) or greater, which also means that it has approximately a 40 percent chance of receiving less than 100 percent pay. This AQL material has essentially a 100 percent chance of receiving a pay factor of 0.80 (80 percent) or greater.

9.3.4 On the other hand, for the OC curves in Figure 8, material that is of exactly RQL quality has approximately a 50 percent chance of receiving a pay factor of 0.80 (80 percent) or greater, and approximately an 80 percent chance of receiving a pay factor of 0.70 (70 percent) or greater. Similar pay probabilities can be determined for any level of actual quality, and additional curves could be developed for any specific pay factor.

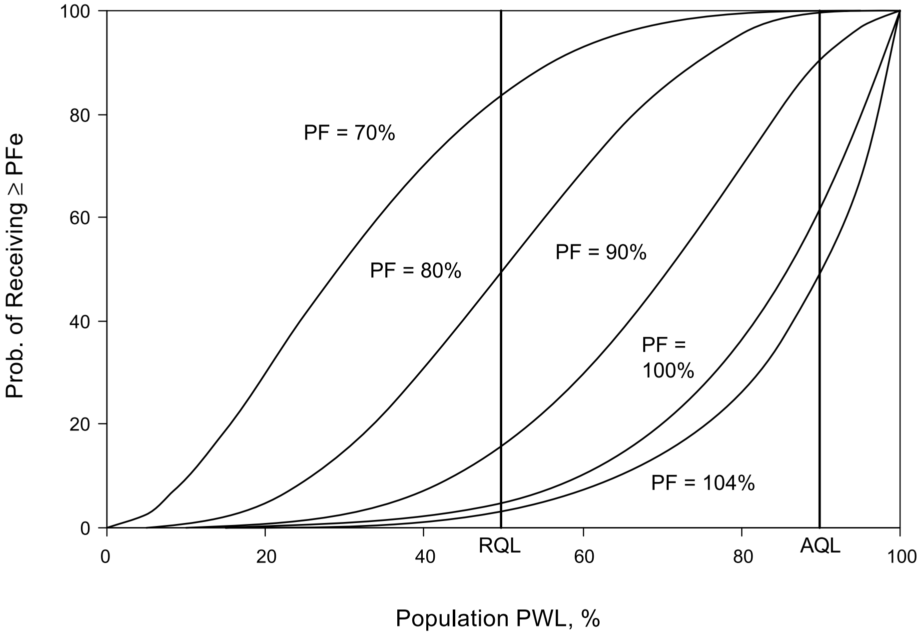


Figure 8—Typical OC Curves for an Acceptance Plan with Pay Adjustments

9.4 *Pay Adjustment System Plans*—As discussed above and shown in Figure 8, the consideration of only α and β risks is not sufficient when pay adjustments are used. From Figure 8 it can also be seen that using multiple OC curves is not an easy way to evaluate an acceptance plan.

9.5 *Expected Pay (EP) Curves*—Thus, another way to present the pay performance for an acceptance plan is with what is called an expected pay (EP) curve.

9.5.1 *Definition of EP Curve*—A graphic representation of an acceptance plan that shows the relation between the actual quality of a lot and its EP, i.e., mathematical pay expectation, or the average pay the contractor can expect to receive over the long run for submitted lots of a given quality (*Transportation Research Circular Number E-C037*, 2002). Both OC and EP curves should be used to evaluate how well a pay adjustment acceptance plan is theoretically expected to work.

9.5.2 An example of an EP curve is shown in Figure 9. Quality levels are indicated on the horizontal axis in the usual manner, but instead of probability of acceptance, the vertical axis gives the expected (long-term average) pay factor as a percent of the contract price.

9.5.3 Although the risks have a different interpretation when associated with EP curves than with OC curves, the same type of information is provided. It is a generally accepted tenet that the average pay for material that is just fully acceptable should be approximately 100 percent of the contract price. For the example in Figure 9, AQL work receives an expected pay of 100 percent, as desired, while truly superior work that is better than the AQL receives an expected pay of 102 percent. At the other extreme, RQL work corresponds to an expected pay of 70 percent. For still lower levels of quality, the curve levels off at a minimum expected pay of 50 percent.

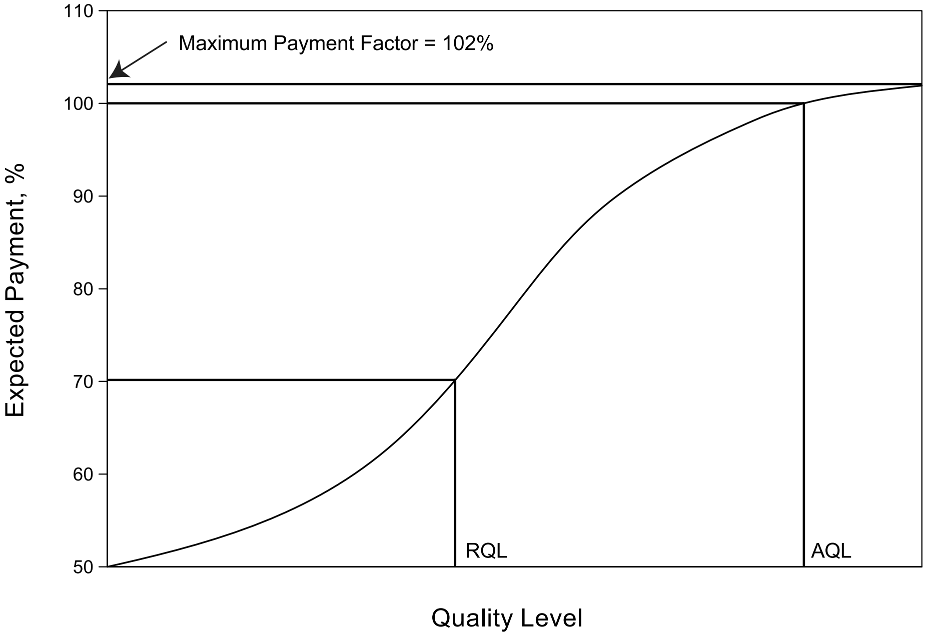


Figure 9—Typical EP Curve

9.6 *Evaluating Risks*—The way potential risks are evaluated depends upon the type of acceptance plan that is used. The factors to be considered are: α, β, n, AQL, and RQL.

9.7 *Accept/Reject Plans*—The evaluation of risks is straightforward for accept/reject (pass/fail) acceptance plans. As noted above, α and β risks and OC curves were developed specifically for this type of situation. Therefore, they can be directly used to assess the risks to both parties.

9.7.1 To reiterate, the α risk is the probability that AQL material will be rejected; while the β risk is the probability that RQL material will be accepted. However, since contractors will not operate at only these two quality levels, to fully consider risks the OC curve, which illustrates probability of acceptance for any quality level, must be developed for the acceptance plan under consideration. An example is used to illustrate how this can be done.

9.7.2 *Example of Accept/Reject Acceptance Plans-OC Curves*—Two computer programs are available to assist in developing OC curves. Program NONCENTT uses an analytical approach based on the noncentral *t* distribution and the symmetrical Beta distribution to estimate PWL and can also determine the α and β risks and develop the OC curve for one-sided acceptance plans (Barros, 1982). Program OCPLOT, found and discussed in Weed (1996), uses simulation methods to determine the α and β risks and to plot the OC curve for both one-sided or two-sided acceptance plans. In this example, the agency has:

- Decided to use asphalt content as an accept/reject property for an HMA pavement (note, this is *not* recommended, but is used here solely for the purpose of illustrating the use of an OC curve for an accept/reject situation).
- Established a lower specification limit of 5.60 percent and an upper specification limit of 6.40 percent for asphalt content.
- Decided to use the PWL, based on a sample size of four, as the quality measure.
- Selected 90 PWL for the AQL and 50 PWL for the RQL.
- Decided that the lot will be accepted if the estimated PWL is greater than or equal to 70, i.e., the acceptance limit is 70 PWL.
- Decided to use program OCPLOT to evaluate the risks associated with the acceptance plan.

Table 3 and Figure 10 show the results of the OCPLOT analysis of this proposed acceptance plan. For comparison purposes, Table 3 also includes the probability of acceptance values calculated using program NONCENTT. The OCPLOT values are approximations due to the fact that they were derived by simulation. The NONCENTT values are also approximations because the procedure was developed for one-sided acceptance limits. Table 3 shows that there is little difference between the results of the two programs. Since OCPLOT is generally more available, better documented, and easier to use, it is used for all example problems in this standard practice.

9.7.3 From the OCPLOT values in Table 3, it can be seen that the seller's risk is $\alpha = 1.000 - 0.905 = 0.095$ (or 9.5 percent) and the buyer's risk is $\beta = 0.144$ (or 14.4 percent). Further, both Table 3 and Figure 10 show the probability of acceptance over the total range of possible lot quality levels, as defined by the actual PWL for the lot. The agency must now decide whether or not it considers these levels of risk to be appropriate. If the risks are determined to be too high, consider changing the acceptance limit and/or the sample size.

Table 3—OC Table from OCPLOT for the Example Problem

Population PWL	Probability of Acceptance (OCPLOT)	Probability of Acceptance (NONCENTT)
100	1.000	1.000
95	0.976	0.975
90 (AQL)	0.905 ($\alpha = 0.095$)	0.906
85	0.810	0.810
80	0.696	0.701
75	0.579	0.589
70	0.466	0.482
65	0.363	0.382
60	0.288	0.295
55	0.200	0.220
50 (RQL)	0.144 ($\beta = 0.144$)	0.158
45	0.093	0.109
40	0.066	0.071
35	0.038	0.043
30	0.021	0.024
25	0.013	0.012
20	0.000	0.000

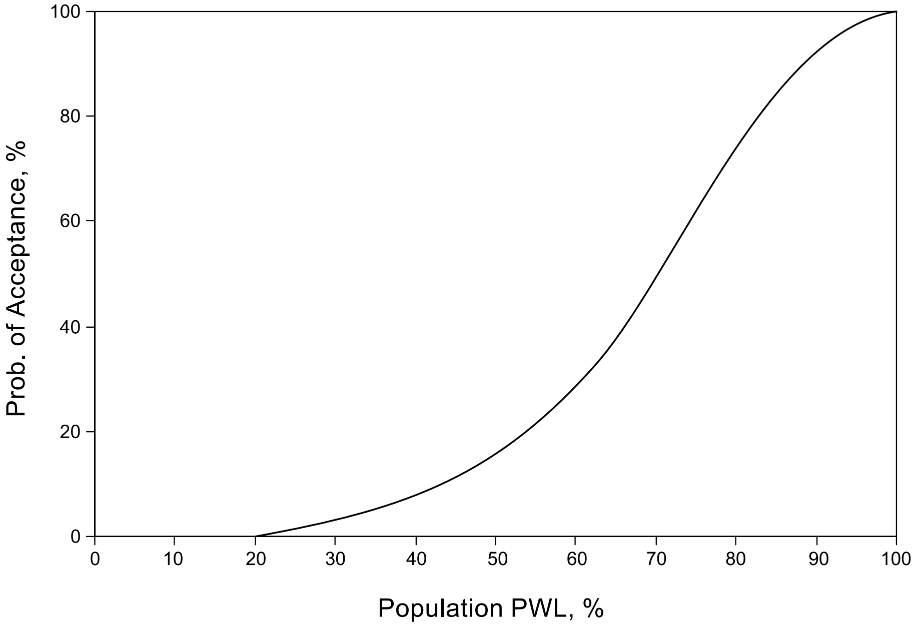


Figure 10—OC Curve for the Accept/Reject Acceptance Plan Example

9.8 *Pay Adjustment System Plans*—The evaluation of risks becomes more complicated when the acceptance plan includes pay adjustment provisions. As discussed above, α and β risks, which were developed from hypothesis testing, where there is a decision to accept or reject the null hypothesis, are not sufficient when the decision involves not only accept or reject, but also accept at an adjusted pay level.

9.8.1 The *Transportation Research Circular Number E-C037* (2002) definitions for seller's and buyer's risks do not attempt to incorporate the concept of pay adjustments. Whether or not a lot received 105 percent, 100 percent, 75 percent, or 50 percent pay would have no impact with regard to the seller's risk based on this definition. Obviously, however, these different pay levels would have quite an impact on how the contractor perceived its risks.

9.8.2 Similarly, the buyer's risk definition disregards the impact of partial pays when determining the buyer's risk. However, when considering its risks, the agency will certainly be interested in the probability of accepting RQL material at reduced pay levels as well as at 100 percent pay or greater.

9.8.3 Since the use of α and β risks to evaluate pay adjustment system plans is not sufficient, an additional method is necessary to properly evaluate the risks when pay adjustments are added to the acceptance decision. The EP curve (see Figure 9) is another method for considering the pay adjustment aspects of the acceptance plan. However, EP alone is also not sufficient to fully evaluate the risks that are involved. Multiple OC curves for various pay levels (see Figure 8) should also be developed when evaluating acceptance plans with pay adjustment provisions. An example will help to illustrate the evaluation of risks for pay adjustment acceptance plans.

9.8.4 *Example of Pay Adjustment System Plans-EP Curves*—Consider the previous asphalt content example where the sample size was four, the allowable specification range was 5.60 percent to 6.40 percent, and the AQL and RQL were defined as 90 PWL and 50 PWL, respectively. Instead of a simple accept/reject acceptance plan, the agency chooses to use the AASHTO equation (Equation 8) to establish the pay factor for a lot:

$$PF = 55 + (0.50 \times PWL) \tag{8}$$

where:

PF = pay factor for the lot, as a percent of contract price; and

PWL = estimated PWL value for the lot.

9.8.4.1 Throughout this standard, the AASHTO equation has been used as an example to develop concepts that are applicable to all acceptance plans. However, for the reasons stated in Sections 9.1.3, 9.1.4, 9.8.8, and 10.3, its use is not generally recommended.

9.8.5 From the above equation, it can be seen that the maximum pay factor is 105 percent at 100 PWL, while the pay factor at the AQL (i.e., 90 PWL) is 100 percent and the pay factor at the RQL (i.e., 50 PWL) is 80 percent. The intent of the acceptance plan is that the average pay for AQL material be 100 percent, as in this example.

9.8.6 With the above information, the OCPLOT program can be used to develop the EP curve shown in Figure 11. It can be seen in this figure that, as desired, the EP for AQL material is 100 percent. This means that a contractor that consistently produces AQL material will receive an average pay factor of 100 percent in the long-run. Similarly, the EP for RQL material is 80 percent as desired from the pay equation.

9.8.7 The EP curve has the advantage of combining all of the possible pay levels into a single expected, or long-term average, pay for each given quality level. While it is an improvement over only considering α and β risks, the use of the EP alone still has some deficiencies. The primary deficiency is that, while it considers the average long-term pay factor, it fails to consider for a given quality level the variability of the individual lot pay factors that comprise this long-term average. This variability is directly related to the sample size; i.e., the variability about the average pay factor decreases as the size of the individual samples increases. To fully evaluate the risks, it is necessary to also consider this variability about the expected pay values.

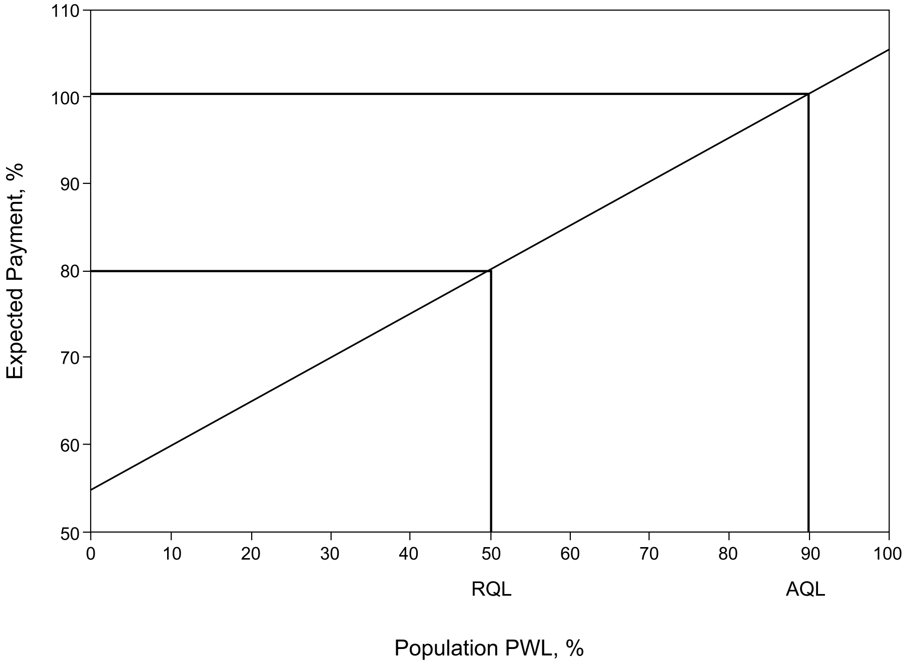


Figure 11—EP Curve from OCPLOT for the Pay Adjustment System Plan Example

9.8.8 The OCPLOT program output can be used to demonstrate this variability of the individual lot pay factors. Figure 12 shows for an AQL population a histogram that displays the individual lot PWL estimates along with their corresponding pay values for 1,000 simulated lots using a sample size of four for each individual lot. Figure 13 shows similar information for an RQL population. The high degree of variability of the individual lot pay factors is obvious from these histograms. For example, for AQL material, in Figure 12 at least one lot has an estimated PWL = 44 with a pay factor of 77 percent. Over a large number of lots, the high and low estimates for lot PWL will tend to balance out to give the correct average pay factor. If, however, there are only a small number of lots on a project, then it is possible that a significantly low estimated PWL value could negatively impact the pay that the contractor would receive. Similarly, higher PWL estimates could be obtained that would provide a larger pay than is deserved. But from a contractor's perspective, the potential negative pay likely outweighs the positive pay.

9.8.9 The variability associated with the estimate of the lot PWL can be reduced by increasing the size of the sample obtained from each lot. Figure 14 shows a histogram that displays for an AQL population the individual lot PWL estimates along with their corresponding pay values for 1,000 simulated lots using a sample size of 20 for each individual lot. Figure 15 shows similar information for an RQL population. When these figures are compared with Figures 12 and 13, for sample sizes of four, the smaller spread of the individual PWL and pay factor estimates is apparent.

9.8.10 While Figures 12 through 15 illustrate the relative variabilities of the individual PWL and pay factor estimates associated with different sample sizes, they do not provide any quantitative measure for the variabilities. One way to quantify these variabilities is to calculate the standard deviation of the individual PWL or pay estimates. (More information on how to do this can be found in *Optimal Procedures for Quality Assurance Specifications*, 2003.)

9.8.11 *Example: Pay Adjustment System Plans—Multiple OC Curves.* Another step that is necessary to evaluate fully the risks for a pay adjustment system plan is to plot OC curves, such as those shown in Figures 8 and 16, associated with receiving various pay factors.

9.8.12 Using the OCPLOT program to develop multiple OC curves for the asphalt content acceptance plan from the previous example, Figure 16 shows OC curves for the probability of receiving greater than or equal to various levels of pay factor for a sample size of four using the pay relationship shown in Equation 9. These OC curves would be considered along with the EP curve from the previous example to evaluate the risks associated with the acceptance plan.

9.8.13 While the EP curve in Figure 11 shows that the average long-term pay is 100 percent for AQL material, the OC curves in Figure 16 show that the probability is about 60 percent that any individual lot of AQL material will receive 100 percent pay or greater. This means that there is about a 40 percent chance that a contractor would receive less than full pay for a lot that was of AQL quality. This risk seems high, however, it is somewhat offset by the fact that the OC curves also indicate that there is nearly a 50 percent chance of receiving a pay of 104 percent or greater. The risk is further mitigated by the fact that contractors intent on obtaining the maximum allowable incentive payment will often try to operate at quality levels higher than the AQL.

9.8.14 OCPLOT works by simulating a large number of estimated individual lot PWL values, determining the corresponding payment factors from the payment equation, and then averaging all of the individual estimated pay factors to determine the expected pay. Figure 16 indicates that the probability is approximately 40 percent that any individual lot of AQL material will receive less than 100 percent payment. Projects, however, consist of multiple lots. Although the analysis goes beyond the scope of this standard practice, the probability that a project operating at the AQL will receive less than 100 percent payment remains constant regardless of the number of lots on the project. However, also regardless of the number of lots per project, the expected, or average, payment over a number of projects will be 100 percent. Once again, however, this seemingly high percentage of AQL projects that would receive a relatively small reduction from full payment is mitigated by the fact that about 60 percent of AQL projects would receive greater than 100 percent payment, and by the fact that many contractors will try to operate at quality levels that are higher than the AQL.

9.9 *Reducing Risks*—As discussed above, for small sample sizes, the risks of not receiving appropriate average pay factor can be calculated and balanced for any combination of quality levels, such as the AQL and RQL. But the risk of a small number of lots, even at the AQL, having a negative price adjustment can be large. There are at least two potential solutions.

9.9.1 *Lot Size vs. Sample Size*—Use larger sample sizes. By increasing the sample size, both the contractor's risk (α) and the agency's risk (β) can be reduced. For this to be practical, larger lot sizes are usually necessary. Some agencies designate the total project as a lot. This naturally allows larger sample sizes. If the total project is selected as the lot this will impact how the typical process variability is determined. (See Appendix X1 and *Optimal Procedures for Quality Assurance Specifications*, 2003.) This means that larger quantities of material will be subjected to negative and positive pay. However, if the normal distribution assumption has not been violated, the PWL estimates will improve, so the pay will more nearly reflect the quality produced. Using sample sizes in the neighborhood of $n = 8$ to $n = 10$ can have a significant impact on reducing the risks to acceptable levels.

9.9.2 *Multiple Pay Equations*—If the use of larger sample sizes is not an option and if the agency considers the risks to be too large for the small sample sizes used, changing the pay determination procedure is an option. Depending upon the initial expected payment values, the payment equation could be modified to allow for higher or lower pay factors for various PWL values. The AASHTO pay relationship in Equation 8 is simple because it is a straight line. However, it may not be true that all materials have a straight-line relationship between quality, as measured by PWL, and value, as represented by the pay factor. It may be decided that the disincentives should not be as great for PWL values near the AQL as they are for PWL values further from the AQL. This could be represented by two or more straight line pay equations, or by a single curvilinear pay equation. Another option might be to use multiple pay factor equations for different sample sizes. To accomplish this, the procedure discussed in Sections 9.8.8 through 9.8.12 can be used iteratively.

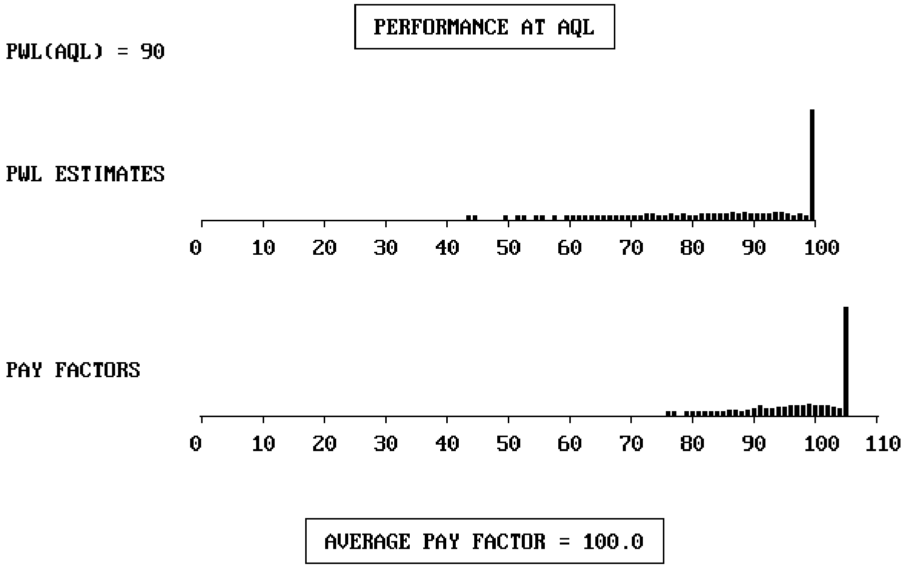


Figure 12—Histogram for an AQL Population Showing Variability of Individual PWL and Pay Factor Estimates for a Sample Size of 4

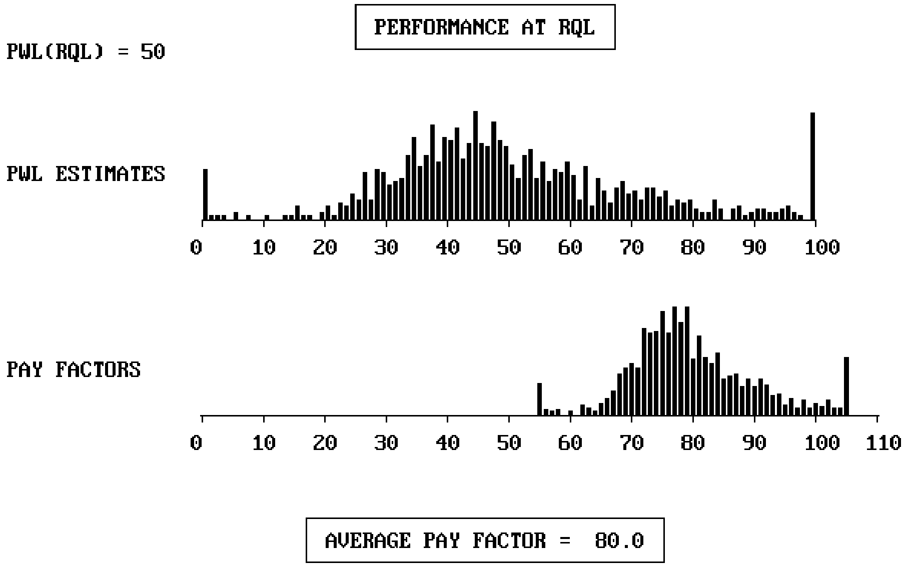


Figure 13—Histogram for an RQL Population Showing Variability of Individual PWL and Pay Factor Estimates for a Sample Size of 4

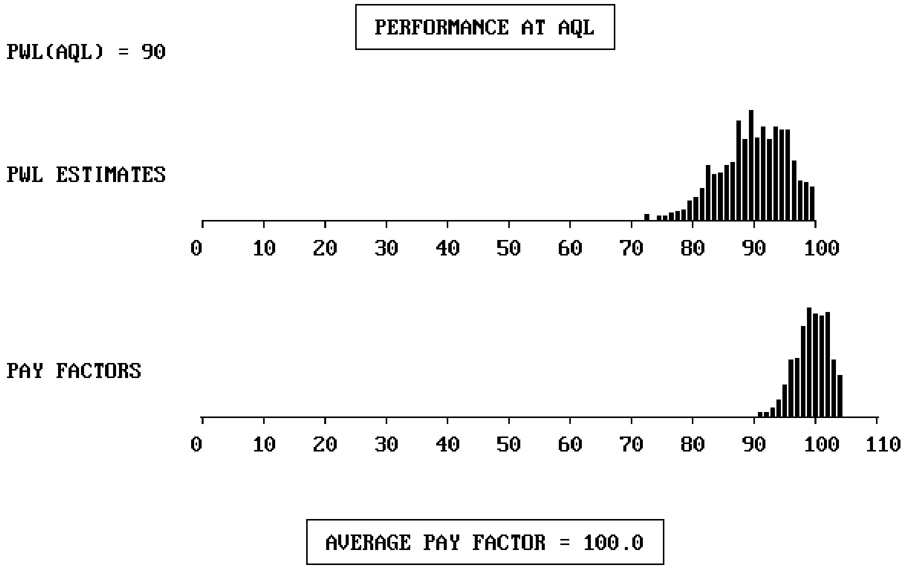


Figure 14—Histogram for an AQL Population Showing Variability of Individual PWL and Pay Factor Estimates for a Sample Size of 20

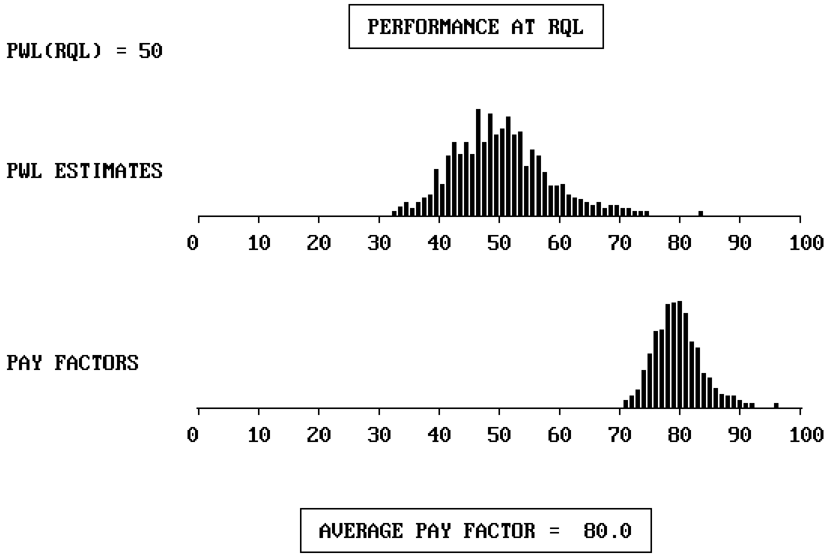


Figure 15—Histogram for an RQL Population Showing Variability of Individual PWL and Pay Factor Estimates for a Sample Size of 20

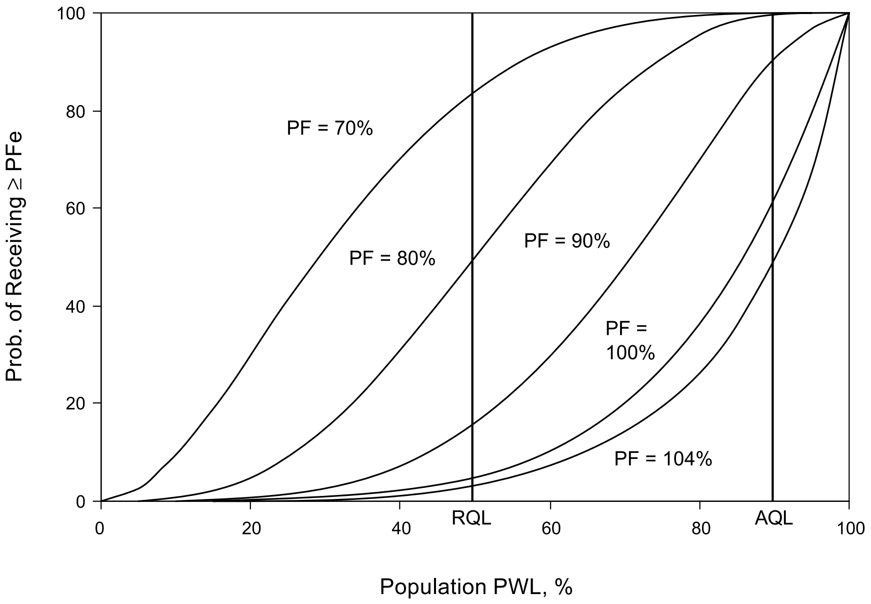


Figure 16—OC Curves for a Sample Size of 4 Using the Pay Relationship in Equation 8

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10. PAY FACTORS

10.1 Several decisions must be made concerning pay relationships. These are extremely important. From a contractor's perspective, the pay factor schedule is one of the most important parts of the acceptance plan. Relating quality and performance to pay is the most desirable form of pay relationship because the relationship supports and defends the decision. This is true because negative pay adjustments are typically viewed with skepticism by the contracting industry. However, when the pay schedule can be shown to be related to quality and, preferably, to performance, it is viewed to be more credible than when it is established arbitrarily.

10.1.1 *Pay Factor Rationale*—The primary purpose of a pay schedule is to provide sufficient incentive to produce the desired quality level at the time of initial construction. A secondary purpose of the pay schedule is to recoup part of the anticipated future costs that are likely to occur when poor quality is received.

10.1.2 *Pay Factor Equations (for Individual Quality Characteristics)*—There are two types of pay factor schedules, "stepped" and "continuous." An example of a stepped pay factor schedule is shown in Table 4 and Figure 17.

Table 4—Typical Stepped Pay Schedule Based on PWL

Estimated PWL	Pay Factor, %
95.0–100.0	102
85.0–94.9	100
50.0–84.9	90
0.0–49.9	70

10.1.3 The use of a continuous (equation-type) pay schedule is becoming more commonplace. The AASHTO equation shown in Equation 9 is one such equation. It is also plotted in Figure 17 (AASHTO *Quality Assurance Guide Specification*, 1995).

$$PF = 55 + (0.50 \times PWL) \qquad (9)$$

where:

PF = pay factor as a percent of contract price, and

PWL = estimated percent within limits.

As noted above, although Equation 9 is simple to use, it may not be likely that there is a straight-line relationship between quality, as measured by *PWL*, and value, as indicated by pay factor. It is best if the pay equation can be related to performance.

10.1.4 Although risk analysis would show these two types of pay schedules to have very nearly the same long-term pay performance, there is a distinct advantage associated with the continuous form. Small changes in the quality estimate can cause large differences in the pay when the quality measure is near a boundary in a stepped pay schedule. A continuous pay schedule avoids this problem.

10.1.5 The AASHTO equation is only one of many possible equations. (When used, consideration should be given to the effects of few lots when small sample sizes are used, as discussed in Section 9.9.) However, the concepts incorporated in the AASHTO equation are important (see Section 9.8.4.1). These concepts, which apply to any pay equation, are:

- The pay is 1.00 (100 percent) when the PWL is at the AQL. Assuming an AQL of 90 PWL, the equation meets this requirement.
- The average pay is 1.00 (100 percent) when at the AQL. For the average pay to be 1.00, clearly, there must be an incentive that allows pay above 1.00 to compensate for lower pay factors from estimated quality levels below the AQL.

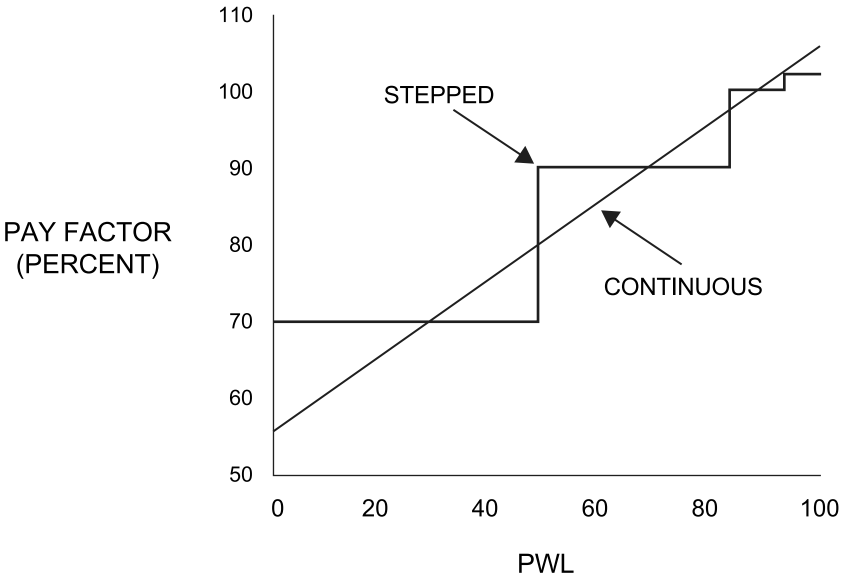

Figure 17—Example of Stepped and Continuous Pay Schedules

10.1.6 *Pay Factors for Composite Quality Characteristics*—Most acceptance plans will contain multiple quality characteristics. In absence of a model to relate these, several methods are currently in use to combine them:

10.1.6.1 The approach that uses the minimum individual pay factor for the composite is based on the "weak link" approach. The least pay factor indicates the value of the combined quality characteristics.

10.1.6.2 The approaches that average or multiply the individual pay factors are based on the concept that all factors contribute equally to the total. However, the outcome of the two can be quite different depending on the individual pay factors.

10.1.6.3 *Pay Factor Examples*—The results based on either the minimum, the average, or multiplying for three quality characteristics in Table 5 demonstrate the differences in the resulting combined pay for various individual pay factor values. In this example, the average approach is the most stable and the approach using multiplication has the greatest differences in values.

Table 5—Results of Different Methods for Combining Individual Pay Factors

Strength	Permeability	Thickness	Minimum	Average	Multiply
1.00	1.00	1.00	1.00	1.00	1.00
1.05	1.05	1.05	1.05	1.05	1.16
0.80	0.80	0.80	0.80	0.80	0.51
1.00	0.80	1.05	0.80	0.95	0.84

10.1.7 *Weighted Pay Factors*—Several agencies use a weighting system to combine individual pay factors based on the concept that some characteristics are more important than others. An example of a weighted pay factor equation is shown in Equation 10.

$$CPF = W_1(PF_1) + W_2(PF_2) + W_3(PF_3) + \ldots \qquad (10)$$

where:

CPF = Composite pay factor,

W_1 = Weighting factor one,

PF_1 = Pay Factor for quality characteristic one,

W_2 = Weighting factor two,

PF_2 = Pay Factor for quality characteristic two,

W_3 = Weighting factor three, and

PF_3 = Pay Factor for quality characteristic three.

10.1.8 *Risks Associated with Composite Pay Factors*—Using more quality characteristics than needed to define product quality is unnecessary and is an encumbrance upon both the agency and the contractor. The risks discussed in Section 9 apply to each pay factor. When using composite quality characteristics, the calculation of risks is more complicated. It is important that the quality characteristics not be highly interrelated. If the quality characteristics are interrelated, care must be taken to either not use both or to minimize the joint effect of them. While there is no minimum number of quality characteristics that should be used, the intent is to use those that are most indicative of quality. (For more discussion on composite pay factors see *Optimal Procedures for Quality Assurance Specifications*, 2003.)

10.1.9 *Composite Quality Measures*—Another approach is to base the pay equation on a single quality measure that is a composite of the individual quality measures. This approach combines the various decision-making steps into a single performance indicator and perhaps simplifies the procedure. (This topic is discussed in detail in *Optimal Procedures for Quality Assurance Specifications*, 2003 and Weed, 2003.)

10.1.9.1 An example of this approach is shown in Equation 11 for HMA air voids and thickness:

$$CPWL = 100 - 0.331PWL_{AV} - 0.193PWL_{\mathrm{THICK}} - 0.00476PWL_{AV}PWL_{\mathrm{THICK}} \qquad (11)$$

where:

$CPWL$ = composite PWL quality measure,

PWL_{AV} = PWL air voids, and

PWL_{THICK} = PWL thickness.

11. IMPLEMENTATION STEPS

11.1 *Simulate Acceptance Plan*—Data can be used from existing projects to analyze how the acceptance plan will work and what the pay would have been if the acceptance plan had been used. But it must be remembered that the contractor will not have bid under, nor will react to, the proposed acceptance plan.

11.2 *Technician Qualification Training*—There are two important parts of training to emphasize during and beyond implementation of the acceptance plan.

11.2.1 Emphasize the importance of having qualified, trained technicians. This effort must be an ongoing program to not only initially train and qualify technicians but to stress the need for continuous training.

11.2.2 Provide combined agency/industry training where both parties to the contract hear the same information and get to express their viewpoints in a constructive training atmosphere.

11.3 *Pilot Projects*—Pilot projects are intended as one way to ease into the acceptance plan on a limited basis. This allows the contractors to develop bidding strategies, to see how the acceptance plan works in a limited manner, and allows the agency to examine the outcome and, if desired, to fine-tune the acceptance plan. Clearly specify the contractor's risk in the specification so that contractors will know their risk and how to bid.

11.4 *Reevaluate the Acceptance Plan*—Based on the outcome of the pilot projects, it may be desirable to change certain aspects of the acceptance plan. If so, this is a good opportunity to do it. If problems are found, look at potential reasons for the problems. For example, if one quality characteristic is a consistent source of a large pay adjustment, examine the test procedures used to evaluate that quality characteristic. Are the procedures being used correctly? Is the variability of the results within expected limits?

11.5 *Phase-In Acceptance Plan*—Consider applying percentages of incentive/disincentive over a short time period to encourage contractor participation. A schedule of 25 percent, 50 percent, and 100 percent over 3 years is one strategy that has been successful. Do not rush into full implementation. A 5-year timetable for full implementation is realistic.

11.6 *Monitor Performance of Acceptance Plan*—An annual review of the acceptance plan is desirable.

11.6.1 Analyze project data for each quality characteristic to determine how well the process standard deviations that are being attained compare with the "typical" values used when developing the acceptance plan. The desired AQL not being consistently achieved may indicate that the technology is not sufficient to allow the contractors to achieve the AQL.

11.6.2 *Look for Administrative Problems*—Is the definition for a lot creating any problems? Are lots open for long periods before the pay factor can be determined?

11.6.3 *Consider Contractor Concerns*—Does the industry think the plan is working as intended? Do they have constructive suggestions as to how it can be improved? Listen to industry's concerns.

11.6.4 *Identify Technology Changes*—Consider including significant technology changes as they occur. As stated previously, the acceptance plan should be dynamic.

11.6.5 *Tie Results of the Acceptance Plan into the Pavement Management System (PMS)*—For the acceptance plan to be a true measure of quality, closing the loop relating quality to performance requires the integration of the quality levels and/or pay factors with the agency's pavement management system. This may be a source of performance information for future modifications of the specifications.

11.6.6 *Compare the Quality Levels Achieved with the Criteria Established for Success*—Close the loop with the goals and expectations that were set in the initiation and planning stage. Is the plan performing the way it was anticipated? If not, why not? Are further revisions needed?

12. KEYWORDS

12.1 Acceptance sampling plans; buyer's risk; control charts; expected pay curve; operating characteristic curve; percent within limits; quality control; seller's risk; stepped and continuous pay schedules; variability known; variability unknown.

13. REFERENCES

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APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE ACCEPTANCE PLAN DEVELOPMENT

X1.1. ***Step 1:*** *Decide on the Quality Characteristic to be Measured, the Lot Size, Sublot Size, and Sample Size*—The agency wants to establish a variables type acceptance plan for asphalt content. The agency will perform the acceptance tests and *Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Oven Test* (T 308) has been chosen as the method of test. The sample will be taken from the paving site and brought to the field lab for testing. The preliminary decision for lot size has been established as 4,000 tons and sublots will be 500 tons. This sets the sample size, $n = 8$. After the risks have been analyzed, these decisions of lot, sublot, and sample size may have to be adjusted.

X1.2. ***Step 2:*** *Collect Project Data*—A random sampling plan is used to collect data from projects, under the conditions and with the lot and sublot definitions decided upon in Step 1. Ten typical projects throughout the agency jurisdiction are sampled over the period of 30 paving days to provide the data. This allows the agency and contractor an opportunity to assess the viability of the proposed sampling and testing program.

X1.3. ***Step 3:*** *Analyze the Data*—The analysis determines several properties. One is the appropriate probability distribution to use to represent the product. This includes estimates for population parameters—mean, standard deviation, variance, bias, and skewness—on a lot-by-lot basis. "Typical" values, particularly for process standard deviation, are also developed. Using computerized statistical programs, which include histograms and calculation of statistical measures, asphalt content was found to be approximately normally distributed (see FHWA-RD-98-077, 1998).

X1.3.1. ***Step 3a:*** Next, develop a value for the "process" variability that is consistent with Step 1. Conceptually, the *individual* standard deviation, s, values for each lot are pooled to get a typical "within-lot" standard deviation for each project. It is *not* appropriate to combine all test results from a project and then to calculate a standard deviation for these combined data. To estimate the "within-lot" standard deviation, the lot variances, rather than standard deviations, are used. The sample variance is an *unbiased* estimator of the population variance, whereas the sample standard deviation is a *biased* estimate of the population standard deviation. The square root of the pooled lot variance is an unbiased estimate of the within-lot standard deviation. The pooled variance is a weighted average based on the sample sizes associated with the individual lot variances. The formula for this estimate is shown in Equation X1.1, if there are k individual lots,

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \cdots + (n_i - 1)s_i^2}{n_1 + n_2 + \cdots n_i - k} \qquad (X1.1)$$

where:

s_p^2 = pooled estimate for the within-lot variance;

s_i^2 = variance for lot i, where $i = 1, 2, \ldots k$;

n_i = number of values for lot i; and

k = number of lots in the project.

The pooled standard deviation is then the square root of the pooled variance.

Example of Within-Lot Pooled Standard Deviation—The test results for 12 lots from one project are shown in Table X1.1. The "within-lot" standard deviation, as determined from the pooled lot variance, is $\sqrt{0.0229}$ = 0.151. This is not the same as the average standard deviation of 0.148.

Table X1.1—Example Summary of Test Results for a Project

Lot	Test Results	n	JMF	Lot Mean	Lot Std Dev	Lot Variance
1	4.8, 5.0, 5.1, 4.8, 4.9, 5.1, 5.2, 4.8	8	5.0	4.96	0.160	0.0255
2	4.7, 5.1, 5.1, 5.0, 4.9, 4.8, 5.0, 4.8	8		4.92	0.149	0.0221
3	5.2, 5.3, 4.7, 4.9, 5.0, 4.9, 4.8, 5.0	8		4.98	0.198	0.0393
4	5.3, 5.1, 4.9, 5.0, 5.1, 4.8, 4.9, 5.0	8		5.01	0.155	0.0241
5	5.2, 5.0, 4.6, 4.8, 4.7, 4.9, 5.0, 4.8	8		4.88	0.191	0.0364
6	4.8, 4.9, 4.9, 4.8, 5.0, 4.9, 4.8, 4.8	8		4.86	0.074	0.0055
7	4.9, 4.7, 4.9, 4.6, 4.7, 5.0, 4.9, 4.8	8		4.81	0.136	0.0184
8	4.9, 5.1, 5.2, 4.7, 4.7, 4.8, 4.9, 4.8	8		4.89	0.181	0.0327
9	4.9, 4.7, 5.1, 5.0, 4.8, 4.9, 4.9, 4.8	8		4.89	0.125	0.0155
10	4.9, 4.6, 5.0, 4.8, 4.9, 4.7, 5.0, 4.9	8		4.85	0.141	0.0200
11	5.0, 4.9, 4.8, 5.1, 4.8, 5.1, 4.9, 5.0	8		4.95	0.120	0.0143
12	5.0, 5.2, 4.9, 4.8, 5.0, 5.1, 5.2, 4.9	8		5.01	0.146	0.0210
	Average	96		4.92	0.148	0.0229
	Pooled for 12 Lots	12			0.151	0.0229

Note: In the above example, the pooled variance is equal to the average of the individual lot variances. This is true only because the sample size, n, was the same for each lot. If the sample size were not constant for each lot, as may happen with historical data, then the pooled variance and the average of the individual variances would typically not be the same.

X1.3.2. ***Step 3b:*** *Select a "Typical" Process Variability*—After determining typical within-lot variabilities for the ten projects, it can then be determined whether the data from different contractors are reasonably consistent, or whether some have appreciably lower or higher variabilities than others.

The typical process variability should not be set for the most or least consistent contractor. Once the project variability data are available, a decision must be made regarding what variability to use as the “typical” process variability. This typical variability will then be used to establish specification limits. There is no single “correct” way to decide upon the typical variability to use.

Example of Process Variability—Data from the ten projects are shown in Table X1.2.

Table X1.2—Example Process Variability Results

Project	Project “Within-Lot” Standard Deviation	Project	Project “Within-Lot” Standard Deviation
1	0.151	6	0.169
2	0.205	7	0.178
3	0.166	8	0.225
4	0.154	9	0.199
5	0.113	10	0.181

The typical within-lot process variability value is based on consideration of all of the ten project data rather than just a single best or worst project. When the standard deviation values are ordered from smallest to largest, this yields: 0.113, 0.151, 0.154, 0.166, 0.169, 0.178, 0.181, 0.199, 0.205, and 0.225. A subjective decision is then made to choose a mid-value (0.18) as the “typical” value. The three projects with higher standard deviations would have to reduce their variability to meet the specifications, but the other seven should have little trouble.

X1.3.3. ***Step 3c:** Determine if a “Target Miss” Is Appropriate*—In addition to the typical “process” variability, another factor that needs to be considered is the capability of contractors to center their processes on the target value. The “target miss” data from the ten projects are shown in Table X1.3.

Example of Determining the “Target Miss” and Combined Standard Deviation

Table X1.3—Example Project “Target Miss” Results

Project	Project “Target Miss” Averages	Project	Project “Target Miss” Averages
1	–0.08	6	–0.11
2	–0.20	7	+0.04
3	–0.10	8	+0.05
4	–0.04	9	+0.11
5	+0.06	10	–0.07

The mean for these ten project “target misses” is –0.034. This indicates that, on the average, the test results are only slightly lower than the JMF. It is decided that the contractors are able to hit the JMF reasonably well. However, the standard deviation for these ten “target misses” is 0.096, with a corresponding variance of 0.00922. Using these data with the previously selected typical process variability of a standard deviation of 0.18, producing a corresponding variance of 0.0324, the combined standard deviation for establishing specification limits is then calculated using Equations X1.2 and X1.3.

$$\hat{\sigma}^2_{\text{combined}} = \hat{\sigma}^2_{\text{center}} + \hat{\sigma}^2_{\text{process}} \qquad (X1.2)$$

$$\hat{\sigma}_{\text{combined}} = \sqrt{\hat{\sigma}^2_{\text{combined}}} \qquad (X1.3)$$

where:

$\hat{\sigma}^2_{\text{combined}}$ = estimated combined “target miss” and “process” variance,

$\hat{\sigma}^2_{\text{center}}$ = estimated “target miss” variance,

$\hat{\sigma}^2_{\text{process}}$ = estimated “process” variance, and

$\hat{\sigma}_{\text{combined}}$ = estimated combined standard deviation.

Using the project data, the above equations result in:

$$\hat{\sigma}^2_{\text{combined}} = 0.00922 + 0.0324 = 0.04162 \qquad \textit{(X1.4)}$$

$$\hat{\sigma} = \sqrt{0.04162} = 0.204 \qquad \textit{(X1.5)}$$

The combined standard deviation is determined to be approximately 0.20 percent asphalt content.

X1.4. ***Step 4:** Determine the Specification Limits, Acceptance Limits, AQL, and RQL—t* has been decided that the AQL will be 90 PWL.

X1.4.1. ***Step 4a:*** Using the AQL with the combined estimated standard deviation of 0.20 percent that was found in Step 3, defines AQL material as shown in Figure X1.1. The specification limits are: JMF ± (1.645 × 0.20) = JMF ± 0.33, rounded to ±0.35 (See Table 1). If a “target miss” value had been found to be significant, this value would have been added to the tolerance.

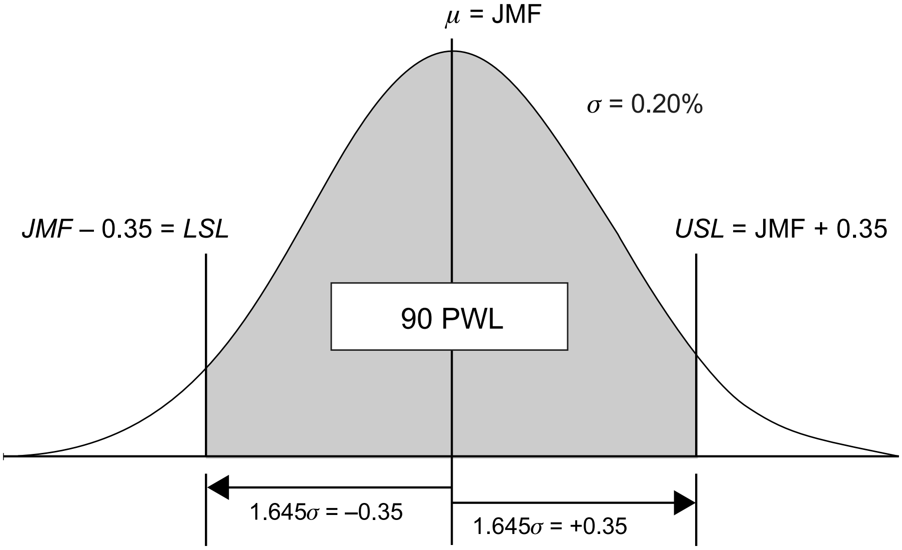


Figure X1.1—AQL Material for the Asphalt Content Example

X1.4.2. ***Step 4b:*** For this example, the analysis of performance data indicates that the RQL should be set at PWL = 50. Figure X1.2 shows two possible populations that represent RQL material. When the average value is ±0.35 from the JMF, the population is centered at either the LSL or USL and 50 percent of the population is estimated to be outside the specifications.

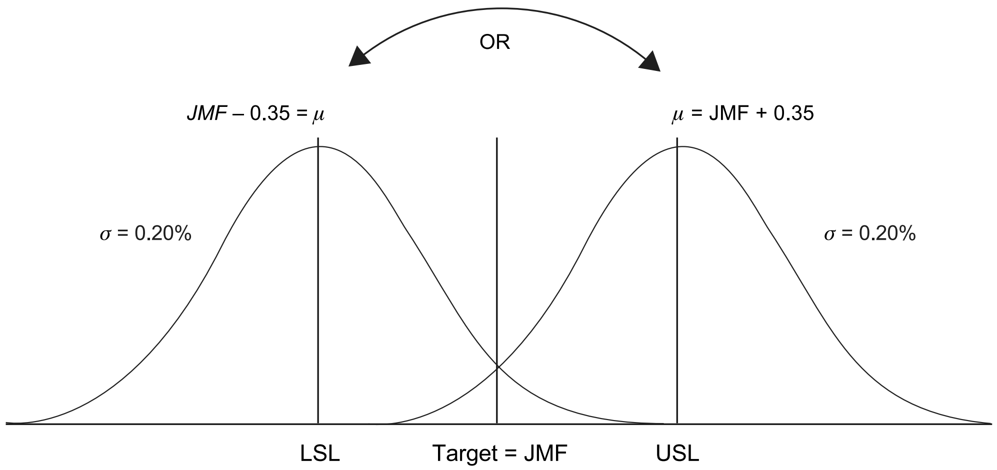


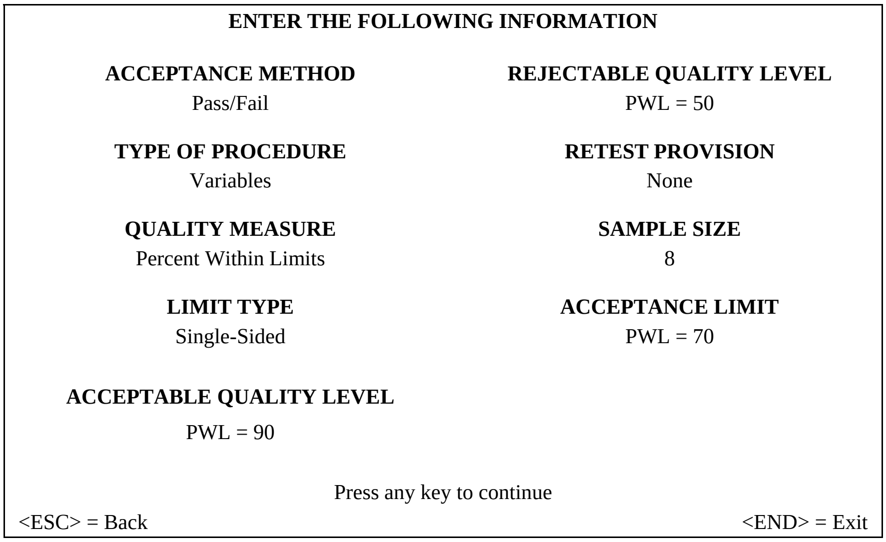
Figure X1.2—RQL Material for the Asphalt Content Example

X1.5. ***Step 5:** Determine Risks*—If the quality characteristic will be evaluated on an accept or reject basis, calculate the buyer's and seller's risks and skip Step 6. If the quality characteristic will be evaluated on a pay factor basis, skip Step 5 and proceed to Step 6.

As a first try, the acceptance limit is set at 70 PWL, i.e., any lot with a PWL of 70 or greater is accepted, while any lot with a PWL less than 70 is rejected. Using OCPLOT and the pass/fail option, calculate the OC table, OC Curve, and determine α and β. At its highest precision level, OCPLOT simulates 5000 lots. An example of the completed input screen from OCPLOT for this example problem is shown in Figure X1.3.

Since OCPLOT uses simulation, the probability of acceptance values will change slightly each time the program is run. For this example, OCPLOT was run five times, with each trial simulating 5000 lots. The five values were then averaged to obtain the probability of acceptance for various population PWL values. These average values are shown in Table X1.4 and Figure X1.4. The $\alpha = 0.021$ (2.1 percent) and $\beta = 0.067$ (6.7 percent) values are determined to be reasonable.

Note X1—If these values were not considered reasonable, then either the sample size or the acceptance limit could be changed and OCPLOT could be run again. This iterative process would continue until the risks were considered reasonable.



ENTER THE FOLLOWING INFORMATION

ACCEPTANCE METHOD
Pass/Fail

REJECTABLE QUALITY LEVEL
PWL = 50

TYPE OF PROCEDURE
Variables

RETEST PROVISION
None

QUALITY MEASURE
Percent Within Limits

SAMPLE SIZE
8

LIMIT TYPE
Single-Sided

ACCEPTANCE LIMIT
PWL = 70

ACCEPTABLE QUALITY LEVEL
PWL = 90

Press any key to continue

<ESC> = Back

<END> = Exit

Figure X1.3—Completed Input Screen for the Pass/Fail (Accept/Reject) Variables Acceptance Plan Example

Table X1.4—OC Table from OCPLOT for the Asphalt Content Example

Population PWL	Probability of Acceptance
100	1.000
95	0.999
90 (AQL)	0.979 ($\alpha = 0.021$)
85	0.909
80	0.793
75	0.637
70	0.481
65	0.332
60	0.218
55	0.125
50 (RQL)	0.067 ($\beta = 0.067$)
45	0.034
40	0.015
35	0.000

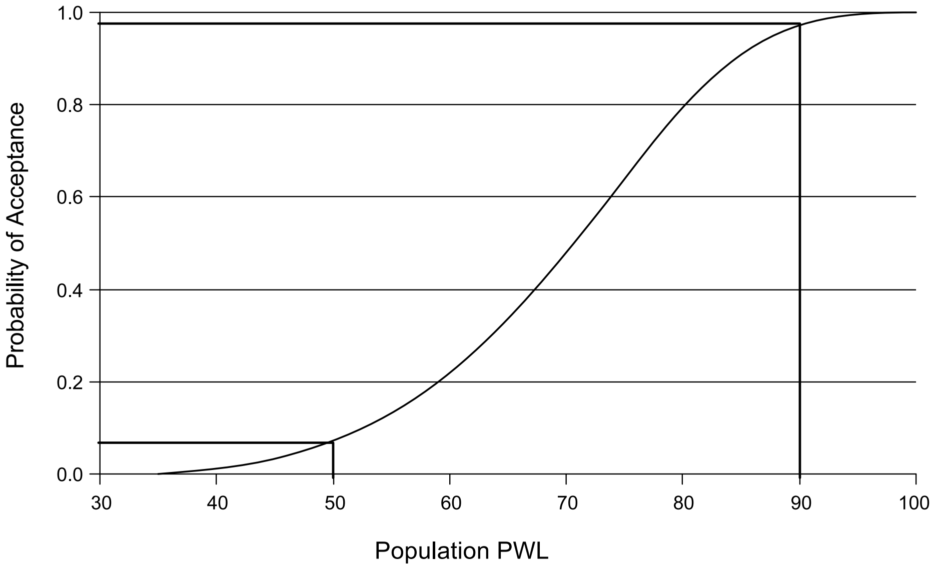
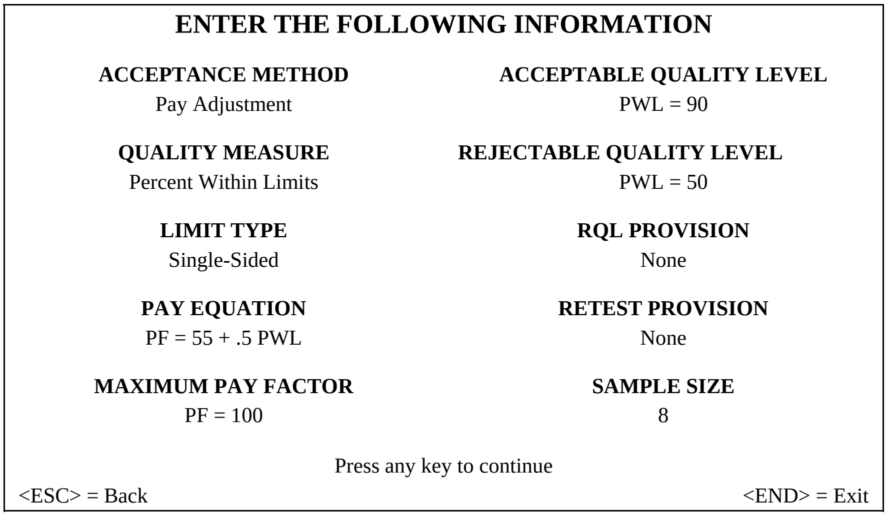


Figure X1.4—OC Curve for the Accept/Reject Asphalt Content Decision

X1.6. ***Step 6:*** If the quality characteristic will be evaluated on a pay factor basis, an appropriate pay equation with reasonable risks must be identified.

X1.6.1. ***Step 6a:*** Use OCPLOT with the Pay Adjustment option to decide on the pay equation and to calculate the EP Curve. An example of the completed input screen from OCPLOT for this example problem is shown in Figure X1.5.

Once again, five runs of OCPLOT, each with 5000 lots, were performed and the average EP values were calculated. These are shown in Table X1.5 and Figure X1.6. The AASHTO pay equation, $PF = 55 + (0.50 \times PWL)$, is used as a first try. The EP curve duplicates the pay equation. The average pay at the AQL is 100 percent, as desired, while the average pay at the RQL is 80.0 percent, as indicated by the pay equation chosen.



ENTER THE FOLLOWING INFORMATION

ACCEPTANCE METHOD
Pay Adjustment

ACCEPTABLE QUALITY LEVEL
PWL = 90

QUALITY MEASURE
Percent Within Limits

REJECTABLE QUALITY LEVEL
PWL = 50

LIMIT TYPE
Single-Sided

RQL PROVISION
None

PAY EQUATION
PF = 55 + .5 PWL

RETEST PROVISION
None

MAXIMUM PAY FACTOR
PF = 100

SAMPLE SIZE
8

Press any key to continue

<ESC> = Back

<END> = Exit

Figure X1.5—Completed Input Screen for the Pay Adjustment Variables Acceptance Plan Example

Table X1.5—EP Table from OCPLOT for the Asphalt Content Example

Population PWL	Expected Pay Factor
100	105.0
95	102.5
90 (AQL)	100.0
85	97.5
80	95.1
75	92.5
70	90.0
65	87.6
60	85.1
55	82.5
50 (RQL)	80.0
45	77.5
40	75.1
35	72.5
30	70.0
25	67.5
20	65.0
15	62.5
10	60.0
5	57.5
0	55.0

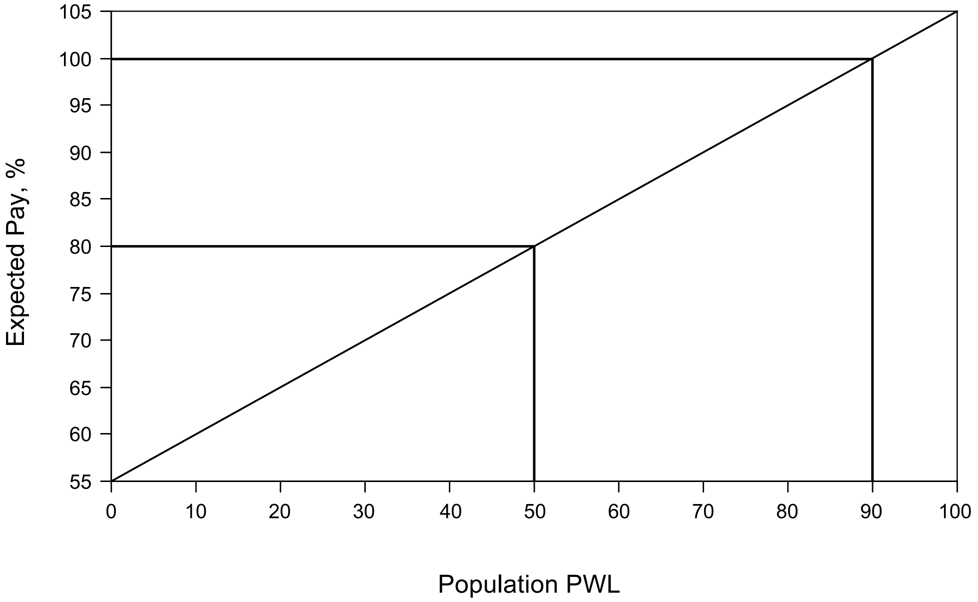


Figure X1.6—EP Curve for the Asphalt Content Example

X1.6.2. ***Step 6b:*** Next, the performance at the AQL is examined. As shown in Figure X1.7, when at the AQL, some lots would be estimated to have a PWL between 60 and 70, resulting in pay factors of 90 percent and less. However, several would be estimated to be at a PWL of more than 95, resulting in pay factors of more than 102 percent. So while there is about a 40 percent chance that a contractor would receive less than full pay for a lot that was of AQL quality, this risk is somewhat offset by the fact that the histograms also indicate that there is about a 60 percent chance of receiving a pay of 100 percent or greater.

Figure X1.7 shows that AQL material may be paid up to 5 percent too much and up to about 15 percent too little. If the agency decides that this pay factor equation results in reasonable risks, then this evaluation of risks must be explained to the contracting community. If it is decided that too much variability exists, one solution is to increase the sample size with a commensurate lot size increase; another solution is to choose a different pay factor equation. Choosing a larger sample size will not affect the expected pay values, but it will decrease the spread of the estimated PWL values, thereby decreasing the maximum underpayment, and possibly overpayment, at the AQL. Similarly, a payment equation with a shallower slope, or a series of straight line equations that have shallower slopes near the AQL and steeper slopes further away from the AQL, will tend to reduce the amounts of the over or underpayments at the AQL. If the pay factor equation is changed, this will also change the EP values.

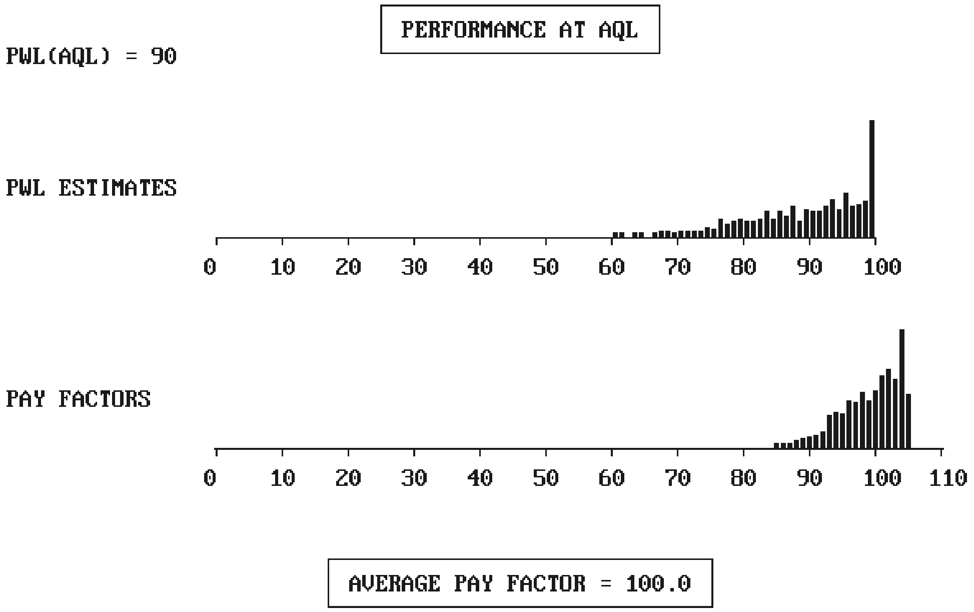


Figure X1.7—Histogram for an AQL Population Showing Variability of Individual PWL and Pay Factor Estimates for a Sample Size of 8

X1.6.3. ***Step 6c:*** Next, the performance at the RQL is examined. This is shown in Figure X1.8. Although not as critical as the performance at the AQL, the agency is interested in the PWL estimates when the material is at the RQL. Figure X1.8 shows that when at the RQL some lots would be estimated to be at a PWL of above 80, resulting in pay factors as high as about 95 percent. As in Step 6b, if the agency decides that this pay factor equation results in reasonable risks at the RQL it can select this pay factor equation. If it is decided that too much variability exists, one solution is to increase the sample size with a commensurate lot size increase; another solution is to choose a different pay factor equation.

Note X2—Step 6 may require a number of iterations to arrive at an acceptable pay factor relationship. The pay equation should not be selected arbitrarily or just for the sake of simplicity. Ideally, the pay factor equation should relate the quality of the material or construction, as represented by the quality measure, PWL in this example, to the value of the material or construction, as represented by the pay factor. This relationship may be more complex than a simple linear relationship. A number of different performance models are available to assist in establishing this performance to pay factor relationship. Some of these approaches are discussed in *Optimal Procedures for Quality Assurance Specifications* (2003).

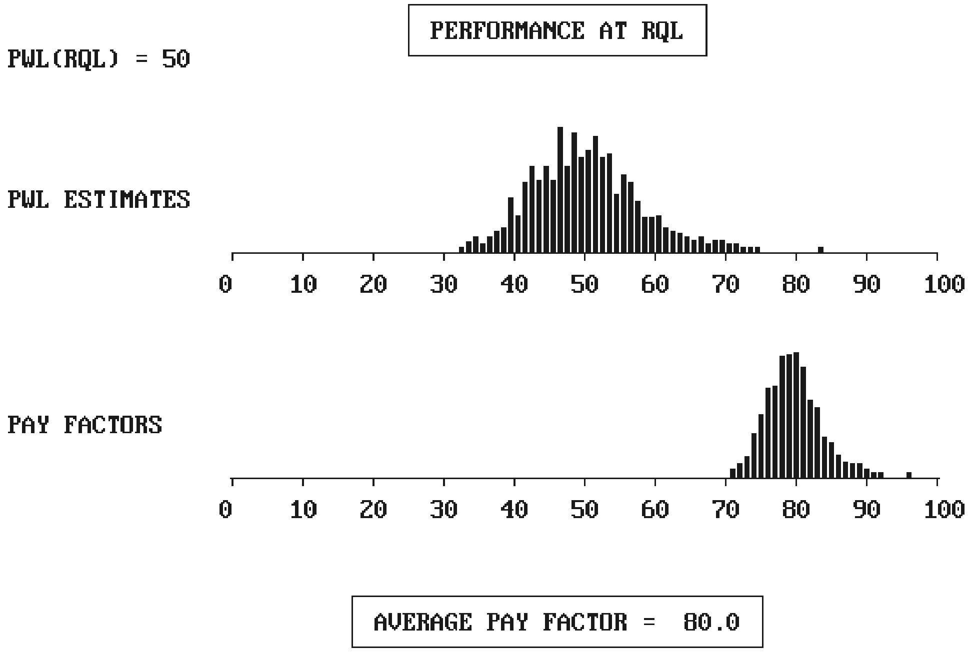


Figure X1.8—Histogram for an RQL Population Showing Variability of Individual PWL and Pay Factor Estimates for a Sample Size of 8

X2. EXAMPLE OF *F*-TEST AND *T*-TEST METHOD FOR COMPARING TWO SETS OF DATA

X2.1. *Purpose*:

X2.1.1. The purpose of this procedure is to provide a method for comparing two sets of data, such as contractor and agency test results. The statistical tests used to make the comparisons are called hypothesis tests, where the assumption (null hypothesis, H_o) for each test is that the data sets are from the same population. In other words, the null hypotheses are that the variabilities of the two data sets are equal for the *F*-test, and that the means of the two data sets are equal for the *t*-test.

X2.2. *Analysis*:

X2.2.1. When comparing two data sets, it is important to compare both the means and the variances. A different test is used for each of these comparisons. The *F*-test provides a method for comparing the variances (standard deviation squared) of the two sets of data. Differences in means are assessed by the *t*-test. Test results generated from construction processes and material properties usually follow a normal distribution. For normal distributions, the ratios of variances follow an *F*-distribution, while the means of relatively small samples follow a *t*-distribution. Hypothesis tests for equal variances and means can therefore be conducted using these distributions.

For samples from the same normal population, the statistic *F*, which is the ratio of the two sample variances, has a sampling distribution called the *F*-distribution. Tables are available for the *F*-distribution just like they are for the normal distribution. For process verification testing, the *F*-test is based on the ratio of the sample variance of the contractor's test results, s_c^2, and the sample variance of the agency's test results, s_a^2.

Similarly, the *t*-statistic and the *t*-test can be used to test whether the sample mean of the contractor's test results, $\overline{X}_c$, and that of the agency's test results $\overline{X}_a$, came from populations with the same mean.

The equations and solutions for the *F*-test and *t*-test are presented in the following sections, but it is recommended that a computer program be used in practice to perform the calculations. Spreadsheet programs, such as Microsoft® Excel, have both *F*-tests and *t*-tests. Some agencies have chosen to develop their own computer packages.

When comparing contractor and agency samples, it is important that random sampling was used when obtaining the samples. Also, because sources of variability influence the population parameters, the two sets of test results must have been sampled over the same time period, and the same sampling and testing procedures must have been used. If it is determined that a significant difference is likely between either the variances or the means, the source of the difference should be identified. The identification of a difference is just that; i.e., it detects that a difference exists. The reason for the difference must still be determined.

Before comparing contractor and agency samples, a level of significance, α, must be selected. While α values of 0.10, 0.05, and 0.01 are common, many agencies select a value of 0.01 to minimize the likelihood of incorrectly concluding that the results are different when they actually came from the same population. However, it should be recognized that selecting a low α value reduces the chance of detecting a real difference when one actually exists.

X2.3. *Procedure*:

X2.3.1. *F-test for Sample Variances*

Since the values used for the *t*-test are dependent upon whether or not the variances are assumed equal for the two data sets, it is necessary to test the variances before the means. The intent is to determine whether the difference in the variability of the contractor's tests and the agency's tests is larger than might be expected by chance if they came from the same population. It does not matter which variance is larger. After comparing the *F*-test results, one of the following will be concluded:

- The two sets of data have different variances because the difference between the two sets of test results is greater than is likely to occur from chance if their variances are actually equal.
- There is no reason to believe the variances are different because the difference is not so great as to be unlikely to have occurred from chance if the variances are actually equal.

X2.3.2. *Steps Involved in the F-test*

The first step is to choose α, the level of significance for the test. For this discussion, $\alpha = 0.01$ is used. Next, compute the variance for the contractor's tests, s_c^2, and the agency's tests, s_a^2. Then use the simple ratio equation to compute *F*, where $F = s_c^2 / s_a^2$ or $F = s_a^2 / s_c^2$. *Always use the larger of the variances in the numerator so the ratio will be greater than 1.*

The next step is to determine the critical *F* value, F_{crit}, from the *F*-table (see Table X2.1 at the end of this appendix) for the α level of significance chosen, and using the degrees of freedom ($n - 1$) associated with each set of test results. Thus, the degrees of freedom associated with the contractor's variance, s_c^2, is ($n_c - 1$) and the degrees of freedom associated with the agency's variance, s_a^2, is ($n_a - 1$). The values in this *F*-table are tabulated to test if there is a difference (either larger or smaller) between the two variance estimates. This is known as a two-tailed test. Care must be taken when using other tables of the *F*-distribution, since they are usually based on a one-tailed test, i.e., testing whether one variance is larger than another. This means that the F_{crit} values in Table11 are the same values that would be listed at the 99.5 percentile (even though the 99.0 percentile would normally be associated with $\alpha = 0.01$) for a one-tailed test.

Once the value for F_{crit} is determined from the table (making sure the appropriate degrees of freedom for the numerator and denominator are used), if $F \geq F_{crit}$, then decide that the two sets of tests have significantly different variabilities. If $F < F_{crit}$, then decide that there is no reason to believe that the variabilities are significantly different.

X2.3.3. *F-test Example Problem 1*

A contractor has run 12 asphalt content tests and the agency has run 6 tests over the same period of time using the same sampling and testing procedure. The results are shown below. Based on their variability, is it likely that the tests came from the same population?

Contractor Tests	Agency Tests
6.41	5.42
6.23	5.78
6.08	6.23
6.55	5.38
6.11	5.62
5.97	5.79
6.28	
6.07	
5.92	
5.76	
6.06	
5.71	
$\bar{X}_c = 6.10$	$\bar{X}_a = 5.70$
$s_c^2 = 0.061$	$s_a^2 = 0.097$

Use the *F*-test to determine whether or not to assume the variance of the contractor's tests differs from the variance of the agency's tests.

Step 1: Compute the variance, s^2, for each set of tests.

$s_c^2 = 0.061 \qquad s_a^2 = 0.097$

Step 2: Compute *F*:

$$F = \frac{s_a^2}{s_c^2} = \frac{0.097}{0.061} = 1.59$$

Step 3: Determine F_{crit} from the *F*-distribution table making sure to use the correct degrees of freedom for the numerator ($n_a - 1 = 6 - 1 = 5$) and the denominator ($n_c - 1 = 12 - 1 = 11$). From Table X2.1, $F_{crit} = 6.42$.

Conclusion: Since $F < F_{crit}$ (i.e., $1.59 < 6.42$), there is no reason to believe that the two sets of data have different variabilities. That is, they could have come from the same population.

Note X3—To simplify the example, the means were rounded to two decimal points and the variances to three. This can result in a significant difference in the computed result. In practice, several more decimal points should be used (see Section X2.15.3).

X2.3.4. *F-test Example Problem 2*

A contractor has run ten air void tests from cores and the agency has run five air void tests over the same period of time using the same sampling and testing procedure. The results are shown below. Based on their variability, is it likely that the tests came from the same population?

Contractor Tests	Agency Tests
6.42	7.52
7.18	11.38
5.04	9.20
4.56	5.32
7.12	3.18
7.98	
6.32	
6.08	
5.92	
5.78	
$\overline{X}_c = 6.24$	$\overline{X}_a = 7.32$
$s_c^2 = 1.036$	$s_a^2 = 10.299$

Step 1: Compute the variance, s^2, for each set of tests.

$s_c^2 = 1.036$ $\quad$ $s_a^2 = 10.299$

Step 2: Compute F: $\quad F = \frac{s_a^2}{s_c^2} = \frac{10.299}{1.036} = 9.94$

Step 3: Determine F_{crit} from the F-distribution table making sure to use the correct degrees of freedom for the numerator ($n_a - 1 = 5 - 1 = 4$) and the denominator ($n_c - 1 = 10 - 1 = 9$). From Table X2.1, $F_{crit} = 7.96$.

Conclusion: Since $F > F_{crit}$ (i.e., $9.94 > 7.96$), it is unlikely that the two data sets came from the same population. Therefore, conclude that the contractor and agency results came from different populations. Since the results are different the agency should investigate the cause of the difference.

Note X4—To simplify the example the means were rounded to two decimal points and the variances to three. This can result in a significant difference in the computed result. In practice, several more decimal points should be used.

X2.3.5. *t-Test for Sample Means*

Once the variances have been tested and assumed to be either equal or not equal, the means of the test results can be tested to determine whether they differ from one another or can be assumed to be equal. The desire is to determine whether it is reasonable to assume that the contractor's tests came from the same population as the agency's tests. A *t*-test is used to compare the sample means. Two approaches for the *t*-test are necessary. If the sample variances are assumed equal (*F*-test Example Problem 1 above), then the *t*-test is conducted based on the two samples using a pooled estimate for the variance and the pooled degrees of freedom. This approach is *t*-test example 1 described below. If the sample variances are assumed to be different (*F*-test Example Problem 2 above), then the *t*-test is conducted using the individual sample variances, the individual sample sizes, and the effective degrees of freedom (estimated from the sample variances and sample sizes). This approach is *t*-test Example 2 below.

In either of the two cases discussed in the previous paragraph, one of the following decisions is made:

- The two sets of data have different means because the difference in the sample means is greater than is likely to occur from chance if their means are actually equal.

- There is no reason to believe that the means are different because the difference in the sample means is not so great as to be unlikely to have occurred from chance if the means are actually equal.

Conceptually, for the *t*-test in which the sample variances are equal, the equation used to calculate the *t*-value divides the difference between two means by the pooled standard deviation. The pooled standard deviation is the square root of the pooled variance, which is the weighted average of the two variances using the degrees of freedom for each sample as the weighting factor. (Again, conceptually, this is similar to the *Z*-equation in which the difference between the mean and a point of interest is expressed in standard deviation units. But because small sample sizes are used, the *t*-distribution is used.)

To determine the critical t value, t_{crit}, against which the computed *t*-value is compared, it is necessary to select the level of significance, α. Again, a value of $\alpha = 0.01$ is common. Next, the critical *t*-value, t_{crit}, is obtained from the *t*-table (see Table X2.2 at the end of this appendix) for the pooled degrees of freedom. The pooled degrees of freedom for the case where the sample variances are assumed equal are $(n_c + n_a - 2)$. If $t \geq t_{crit}$, then decide that the two sets of tests have significantly different means. If $t < t_{crit}$, then decide that there is no reason to believe the means are significantly different.

X2.3.6. *t-test Example Problem 1: Sample Variances Assumed to Be Equal*

Use *F*-test Example Problem 1 above (see Section X2.3.3) in which a contractor has run 12 asphalt content tests and the agency has run six tests over the same period of time using the same sampling and testing procedures. Based on their means, is it likely that the tests came from the same population?

Use the *t*-test for the case of equal variances (determined above in *F*-test Example Problem 1) to determine whether or not to assume the mean of the contractor's tests differs from the mean of the agency's tests.

In *F*-test Example Problem 1, it was determined that $s_c^2 = 0.061$ and $s_a^2 = 0.097$.

Step 1: Compute the sample mean, $\bar{X}$, for each set of tests (see Section X2.3.3).

$\bar{X}_c = 6.10$ $\bar{X}_a = 5.70$

Step 2: Compute the pooled variance, s_p^2, using the sample variances from above.

$$s_p^2 = \frac{s_c^2(n_c - 1) + s_a^2(n_a - 1)}{n_c + n_a - 2}$$

$$s_p^2 = \frac{0.061(12-1) + 0.097(6-1)}{12+6-2} = 0.072$$

Step 3: Compute the *t*-statistic, t, using the equation for equal variances.

$$t = \frac{\left|\bar{X}_c - \bar{X}_a\right|}{\sqrt{\frac{s_p^2}{n_c} + \frac{s_p^2}{n_a}}}$$

$$t = \frac{\left|6.10 - 5.70\right|}{\sqrt{\frac{0.072}{12} + \frac{0.072}{6}}} = 2.981$$

Step 4: Determine the critical t value, t_{crit}, for the pooled degrees of freedom.

Degrees of freedom = $(n_c + n_a - 2) = (12 + 6 - 2) = 16$.

From Table X2.2, for $\alpha = 0.01$ and 16 degrees of freedom, $t_{crit} = 2.921$.

Conclusion: Since 2.981 > 2.921, we reject the null hypothesis, and assume that the sample means are not equal. We therefore assume that they came from different populations. We therefore conclude that it is unlikely (but not impossible) that the contractor and agency test results represent the same process. In other words, the agency tests do not verify the contractor tests. Therefore, the agency should investigate the cause for the difference in means.

Note X5—To simplify the example, the means were rounded to two decimal points and the variances to three. This can result in a significant difference in the computed result. In practice several more decimal points should be used.

X2.3.7. *t-Test Example Problem 2: Sample Variances Assumed to Be Different*

The *F*-test Example Problem 2 above, in which a contractor ran ten air void tests from cores and the agency ran five tests over the same period of time, concluded that based on the variances the contractor and agency results came from different populations. Based on their means, is it likely that the tests came from the same population?

In *F*-test Example Problem 2, it was determined that $s_c^2 = 1.036$ and $s_a^2 = 10.299$.

Step 1: Compute the mean, $\bar{X}$, for each set of tests (see Section X2.3.4).

$\bar{X}_c = 6.24$ $\quad\quad$ $\bar{X}_a = 7.32$

Step 2: Compute the *t*-statistic, *t*, using the equation for unequal variances.

$$t = \frac{\left|\bar{X}_c - \bar{X}_a\right|}{\sqrt{\dfrac{s_c^2}{n_c} + \dfrac{s_a^2}{n_a}}}$$

$$t = \frac{\left|6.24 - 7.32\right|}{\sqrt{\dfrac{1.036}{10} + \dfrac{10.299}{5}}} = 0.734$$

Step 3: Determine the critical *t* value, t_{crit}, for the effective degrees of freedom, f'.

$$f' = \frac{\left(\dfrac{s_c^2}{n_c} + \dfrac{s_a^2}{n_a}\right)^2}{\left[\dfrac{\left(\dfrac{s_c^2}{n_c}\right)^2}{n_c + 1} + \dfrac{\left(\dfrac{s_a^2}{n_a}\right)^2}{n_a + 1}\right]} - 2$$

$$f' = \frac{\left(\dfrac{1.036}{10} + \dfrac{10.299}{5}\right)^2}{\left[\dfrac{\left(\dfrac{1.036}{10}\right)^2}{10 + 1} + \dfrac{\left(\dfrac{10.299}{5}\right)^2}{5 + 1}\right]} - 2 = 4.61 \rightarrow 4$$

The calculated value for effective degrees of freedom is truncated to the lower integer in this example. Truncating the calculated value for effective degrees of freedom is the most common approach. In general, rounding to a smaller value for degrees of freedom gives a larger critical value, thereby making it less likely to reject the null hypothesis of equal means.

An even more simplified approach is to use the degrees of freedom for the data set with the fewest values. In this example, that would be $n_a - 1 = 4$, which yields the same result as the effective degrees of freedom calculation. This, however, will not always be the case, and the use of the effective degrees of freedom is the preferred approach.

Note that the value for effective degrees of freedom is less than would have been used if the variances had been assumed to be equal.

From Table X2.2 for $\alpha = 0.01$ and 4 degrees of freedom, $t_{crit} = 4.604$.

Conclusion: Since 0.734 < 4.604, there is no reason to reject the assumption that the means are equal. Therefore, we assume that it is possible (but not certain) that they came from the same population. However, since the results of the *F*-test were different the agency should investigate the cause for the difference in variances.

Note X6—The difference in sample means is much greater in this example (7.32 – 6.24 = 1.08) than in the previous example (6.10 – 5.70 = 0.40). However, in the previous example it was concluded that the means were different, while in this example it was not concluded that the means were different. The larger ratio of variance values in this example is the reason that it was not possible to conclude that the means were different.

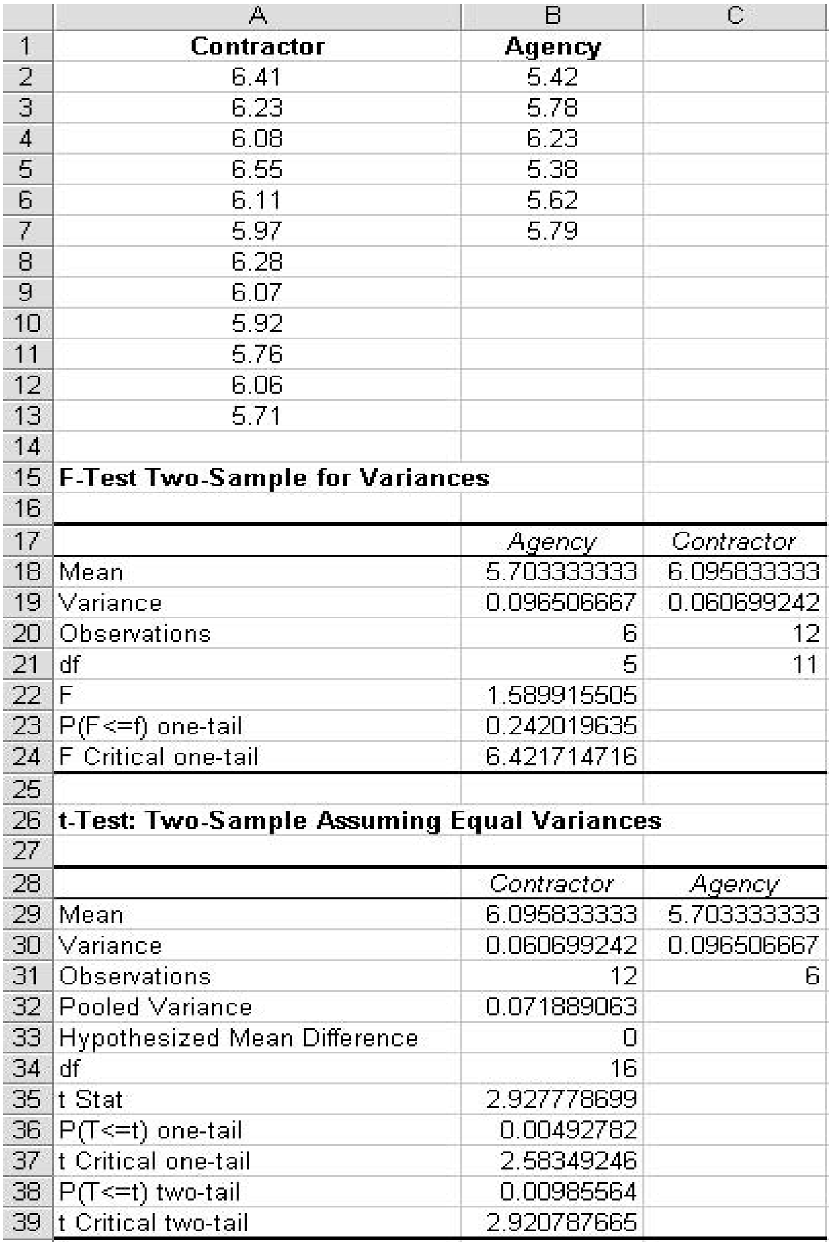
Note X7—To simplify the example the means were rounded to two decimal points and the variances to three. This can result in a significant difference in the computed result. In practice several more decimal points should be used (see Section X2.4).

X2.4. *Computer Programs for the F-Test and t-Test Calculations*

As can be seen from the example problems, the required computations can be quite complex and time consuming. This introduces the possibility of human error.

Spreadsheet programs often have built-in functions for conducting both *F*-tests and *t*-tests. These tests can be performed by anyone with a basic knowledge of how to use spreadsheet functions. A spreadsheet program that can conduct *F*-tests as well as paired *t*-tests, and two-sample *t*-tests for the cases of both equal and unequal variances can perform all necessary analyses of verification test results.

The use of spreadsheets for conducting *F*-tests and *t*-tests can be illustrated by comparing the data sets used in Example Problem 1 above. Figure X2.1 shows a spreadsheet with the contractor and agency test results as well as the results of the *F*-test and *t*-test performed by the spreadsheet program. Due to the number of decimals used in the hand calculations vs. the spreadsheet, some differences in the values exist.



	A	B	C
1	**Contractor**	**Agency**	
2	6.41	5.42	
3	6.23	5.78	
4	6.08	6.23	
5	6.55	5.38	
6	6.11	5.62	
7	5.97	5.79	
8	6.28		
9	6.07		
10	5.92		
11	5.76		
12	6.06		
13	5.71		
14			
15	**F-Test Two-Sample for Variances**		
16			
17		*Agency*	*Contractor*
18	Mean	5.703333333	6.095833333
19	Variance	0.096506667	0.060699242
20	Observations	6	12
21	df	5	11
22	F	1.589915505	
23	P(F<=f) one-tail	0.242019635	
24	F Critical one-tail	6.421714716	
25			
26	**t-Test: Two-Sample Assuming Equal Variances**		
27			
28		*Contractor*	*Agency*
29	Mean	6.095833333	5.703333333
30	Variance	0.060699242	0.096506667
31	Observations	12	6
32	Pooled Variance	0.071889063	
33	Hypothesized Mean Difference	0	
34	df	16	
35	t Stat	2.927778699	
36	P(T<=t) one-tail	0.00492782	
37	t Critical one-tail	2.58349246	
38	P(T<=t) two-tail	0.00985564	
39	t Critical two-tail	2.920787665	

Figure X2.1—Spreadsheet Results for Data from Example Problem 1

As shown in cell A24 in Figure X2.1, the spreadsheet program conducts a one-tailed *F*-test. The spreadsheet results for this program show the *F*-statistic calculated from the data, in cell B22, as well as the value for F_{crit}, in cell B24. The two data sets would be considered to likely have different variances when the calculated *F*-statistic is greater than the value of F_{crit}.

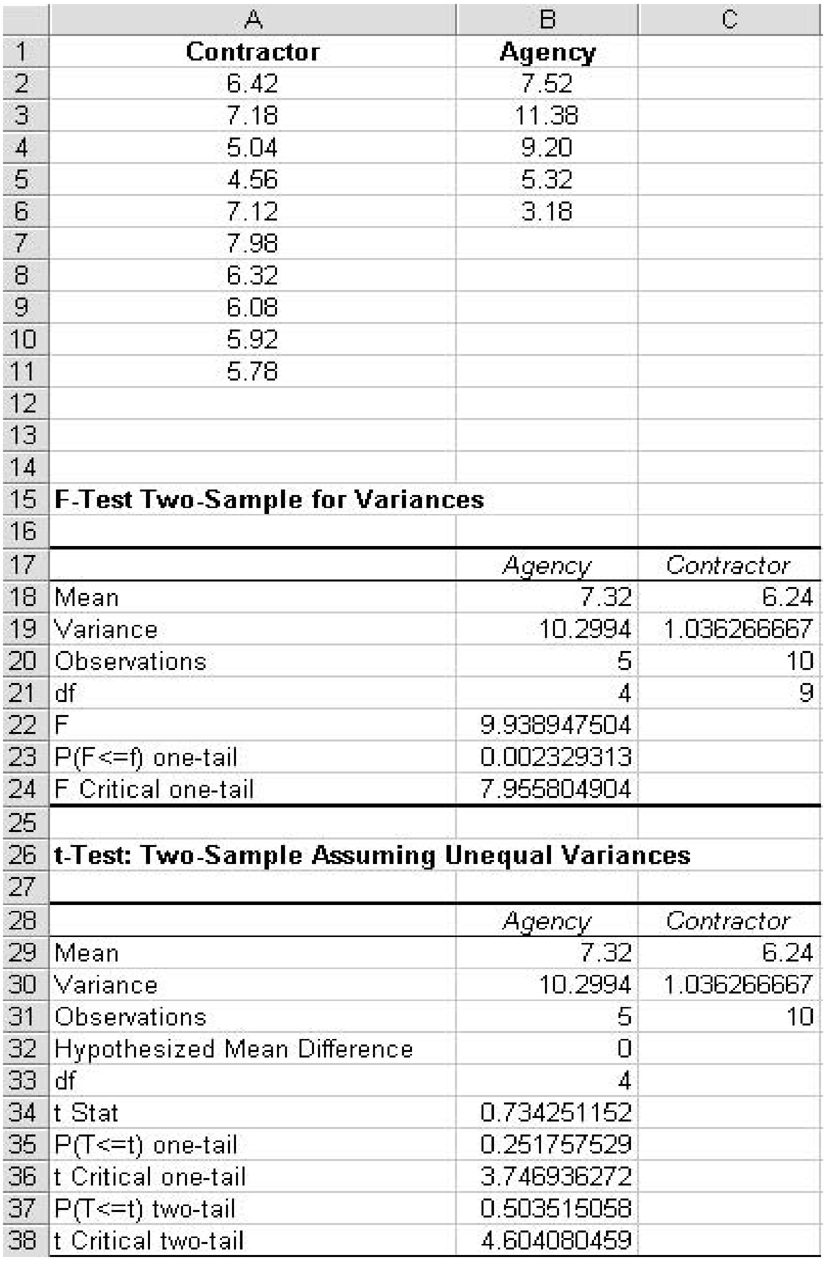
The value that is displayed in cell B23 is the probability of getting an *F*-value as large as the one for these data sets if the two data sets actually have the same variance. In other words, the lower the probability value returned by this function, the less likely it is that the two sets of data have the same variance.

The level of significance, α, is one of the input values in the spreadsheet program that calculated the results shown in Figure X2.1. To arrive for a one-sided *F*-test at the same critical values that are shown in Table X2.1, which is based on a two-sided *F*-test, the one-sided level of significance that is used must be half that for an equivalent two-sided level of significance. Specifically, since Table X2.1 is based on a two-sided α value of 0.01, the input level of significance to the spreadsheet program must be $\alpha/2 = (0.01/2) = 0.005$ to match the Table X2.1 values.

Once the results of the *F*-test are known, the *t*-test can then be conducted using the spreadsheet's *t*-test capability. As shown in Figure X2.1, this spreadsheet program presents the result for both one-tailed, cell B37, and two-tailed, cell B39, *t*-tests. The values in Table X2.2 are for two-tailed *t*-tests, and therefore compare directly with the two-tailed spreadsheet results. The two data sets would be considered to likely have different means when the calculated *t*-statistic is greater than the value of t_{crit}.

Similarly, a spreadsheet program can be used to perform the *F*-test and *t*-test on the data sets from Example Problem 2 above. This is illustrated in Figure X2.2.

The results in Figure X2.2 indicate that the variances are assumed to be not equal ($F = 9.939$, which is greater than the F_{crit} value of 7.956). This means that the unequal variance *t*-test should be used. The results in Figure X2.2 indicate that the means are assumed to be equal ($t = 0.734$, which is less than the t_{crit} value of 4.604). Due to the number of decimals used in the hand calculations vs. the spreadsheet, some differences in the values exist.



	A	B	C
1	**Contractor**	**Agency**	
2	6.42	7.52	
3	7.18	11.38	
4	5.04	9.20	
5	4.56	5.32	
6	7.12	3.18	
7	7.98		
8	6.32		
9	6.08		
10	5.92		
11	5.78		
12			
13			
14			
15	**F-Test Two-Sample for Variances**		
16			
17		*Agency*	*Contractor*
18	Mean	7.32	6.24
19	Variance	10.2994	1.036266667
20	Observations	5	10
21	df	4	9
22	F	9.938947504	
23	P(F<=f) one-tail	0.002329313	
24	F Critical one-tail	7.955804904	
25			
26	**t-Test: Two-Sample Assuming Unequal Variances**		
27			
28		*Agency*	*Contractor*
29	Mean	7.32	6.24
30	Variance	10.2994	1.036266667
31	Observations	5	10
32	Hypothesized Mean Difference	0	
33	df	4	
34	t Stat	0.734251152	
35	P(T<=t) one-tail	0.251757529	
36	t Critical one-tail	3.746936272	
37	P(T<=t) two-tail	0.503515058	
38	t Critical two-tail	4.604080459	

Figure X2.2—Spreadsheet Results for Data from Example Problem 2

Table X2.1—Critical Values, F_{crit}, for the F-test for a Level of Significance, $\alpha = 0.011$

DEGREES OF FREEDOM FOR NUMERATOR

DEGREES OF FREEDOM FOR DENOMINATOR

	1	2	3	4	5	6	7	8	9	10	11	12
1	16200	20000	21600	22500	23100	23400	23700	23900	24100	24200	24300	24400
2	198	199	199	199	199	199	199	199	199	199	199	199
3	55.6	49.8	47.5	46.2	45.4	44.8	44.4	44.1	43.9	43.7	43.5	43.4
4	31.3	26.3	24.3	23.2	22.5	22.0	21.6	21.4	21.1	21.0	20.8	20.7
5	22.8	18.3	16.5	15.6	14.9	14.5	14.2	14.0	13.8	13.6	13.5	13.4
6	18.6	14.5	12.9	12.0	11.5	11.1	10.8	10.6	10.4	10.2	10.1	10.0
7	16.2	12.4	10.9	10.0	9.52	9.16	8.89	8.68	8.51	8.38	8.27	8.18
8	14.7	11.0	9.60	8.81	8.30	7.95	7.69	7.50	7.34	7.21	7.10	7.01
9	13.6	10.1	8.72	7.96	7.47	7.13	6.88	6.69	6.54	6.42	6.31	6.23
10	12.8	9.43	8.08	7.34	6.87	6.54	6.3	6.12	5.97	5.85	5.75	5.66
11	12.2	8.91	7.60	6.88	6.42	6.10	5.86	5.68	5.54	5.42	5.32	5.24
12	11.8	8.51	7.23	6.52	6.07	5.76	5.52	5.35	5.20	5.09	4.99	4.91
15	10.8	7.70	6.48	5.80	5.37	5.07	4.85	4.67	4.54	4.42	4.33	4.25
20	9.94	6.99	5.82	5.17	4.76	4.47	4.26	4.09	3.96	3.85	3.76	3.68
24	9.55	6.66	5.52	4.89	4.49	4.20	3.99	3.83	3.69	3.59	3.50	3.42
30	9.18	6.35	5.24	4.62	4.23	3.95	3.74	3.58	3.45	3.34	3.25	3.18
40	8.83	6.07	4.98	4.37	3.99	3.71	3.51	3.35	3.22	3.12	3.03	2.95
60	8.49	5.80	4.73	4.14	3.76	3.49	3.29	3.13	3.01	2.90	2.82	2.74
120	8.18	5.54	4.50	3.92	3.55	3.28	3.09	2.93	2.81	2.71	2.62	2.54
∞	7.88	5.30	4.28	3.72	3.35	3.09	2.90	2.74	2.62	2.52	2.43	2.36

Note: This is for a two-tailed test with the null and alternate hypotheses: H_0: $s_c^2 = s_a^2$ H_a: $s_c^2 \neq s_a^2$

Table X2.1—Critical Values, F_{crit}, for the F-test for a Level of Significance, α = 0.011 (*continued*)

DEGREES OF FREEDOM FOR NUMERATOR

DEGREES OF FREEDOM FOR DENOMINATOR

	15	20	24	30	40	50	60	100	120	200	500	∞
1	24600	24800	24900	25000	25100	25200	25300	25300	25400	25400	25400	25500
2	199	199	199	199	199	199	199	199	199	199	199	200
3	43.1	42.8	42.6	42.5	42.3	42.2	42.1	42.0	42.0	41.9	41.9	41.8
4	20.4	20.2	20.0	19.9	19.8	19.7	19.6	19.5	19.5	19.4	19.4	19.3
5	13.1	12.9	12.8	12.7	12.5	12.5	12.4	12.3	12.3	12.2	12.2	12.1
6	9.81	9.59	9.47	9.36	9.24	9.17	9.12	9.03	9.00	8.95	8.91	8.88
7	7.97	7.75	7.65	7.53	7.42	7.35	7.31	7.22	7.19	7.15	7.10	7.08
8	6.81	6.61	6.50	6.40	6.29	6.22	6.18	6.09	6.06	6.02	5.98	5.95
9	6.03	5.83	5.73	5.62	5.52	5.45	5.41	5.32	5.30	5.26	5.21	5.19
10	5.47	5.27	5.17	5.07	4.97	4.90	4.86	4.77	4.75	4.71	4.67	4.64
11	5.05	4.86	4.76	4.65	4.55	4.49	4.45	4.36	4.34	4.29	4.25	4.23
12	4.72	4.53	4.43	4.33	4.23	4.17	4.12	4.04	4.01	3.97	3.93	3.90
15	4.07	3.88	3.79	3.69	3.59	3.52	3.48	3.39	3.37	3.33	3.29	3.26
20	3.50	3.32	3.22	3.12	3.02	2.96	2.92	2.83	2.81	2.76	2.72	2.69
24	3.25	3.06	2.97	2.87	2.77	2.70	2.66	2.57	2.55	2.5	2.46	2.43
30	3.01	2.82	2.73	2.63	2.52	2.46	2.42	2.32	2.30	2.25	2.21	2.18
40	2.78	2.60	2.50	2.40	2.30	2.23	2.18	2.09	2.06	2.01	1.96	1.93
60	2.57	2.39	2.29	2.19	2.08	2.01	1.96	1.86	1.83	1.78	1.73	1.69
120	2.37	2.19	2.09	1.98	1.87	1.80	1.75	1.64	1.61	1.54	1.48	1.43
∞	2.19	2.00	1.90	1.79	1.67	1.59	1.53	1.40	1.36	1.28	1.17	1.00

Note: This is for a two-tailed test with the null and alternate hypotheses: H_0: $s_c^2 = s_a^2$ H_a: $s_c^2 \neq s_a^2$

Table X2.2—Critical Values, t_{crit}, for the *t*-test[a]

Degrees of Freedom	$\alpha = 0.01$	$\alpha = 0.05$	$\alpha = 0.10$
1	63.657	12.706	6.314
2	9.925	4.303	2.920
3	5.841	3.182	2.353
4	4.604	2.776	2.132
5	4.032	2.571	2.015
6	3.707	2.447	1.943
7	3.499	2.365	1.895
8	3.355	2.306	1.860
9	3.250	2.262	1.833
10	3.169	2.228	1.812
11	3.106	2.201	1.796
12	3.055	2.179	1.782
13	3.012	2.160	1.771
14	2.977	2.145	1.761
15	2.947	2.131	1.753
16	2.921	2.120	1.746
17	2.898	2.110	1.740
18	2.878	2.101	1.734
19	2.861	2.093	1.729
20	2.845	2.086	1.725
21	2.831	2.080	1.721
22	2.819	2.074	1.717
23	2.807	2.069	1.714
24	2.797	2.064	1.711
25	2.787	2.060	1.708
26	2.779	2.056	1.706
27	2.771	2.052	1.703
28	2.763	2.048	1.701
29	2.756	2.045	1.699
30	2.750	2.042	1.697
40	2.704	2.021	1.684
60	2.660	2.000	1.671
120	2.617	1.980	1.658
∞	2.576	1.960	1.645

[a] This is for a two-tailed test with the null and alternate hypotheses:
H_0: $\overline{X}_c = \overline{X}_a$ H_a: $\overline{X}_c \neq \overline{X}_a$

Standard Recommended Practice for

Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories

AASHTO Designation: R 18-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Recommended Practice for

Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories

AASHTO Designation: R 18-10[1]

1. SCOPE

1.1. This document contains criteria and guidelines for establishing and implementing a quality management system (QMS) for use by a construction materials laboratory (CML). These criteria may also be used by laboratory-evaluating agencies.

1.2. The criteria in this document only apply to the following testing areas: soil, aggregate, asphalt binder, cutback asphalt, emulsified asphalt, asphalt mixtures, hydraulic cement, portland cement concrete, unit masonry, metals, plastic pipe, and sprayed fire-resistive material.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 152, Flow Table for Use in Tests of Hydraulic Cement
- PP 57, Establishing Requirements for and Performing Equipment Calibrations, Standardizations, and Checks
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 32, Sampling and Testing Brick
- T 48, Flash and Fire Points by Cleveland Open Cup
- T 49, Penetration of Bituminous Materials
- T 50, Float Test for Bituminous Materials
- T 51, Ductility of Asphalt Materials
- T 53, Softening Point of Bitumen (Ring-and-Ball Apparatus)
- T 59, Emulsified Asphalts
- T 72, Saybolt Viscosity
- T 79, Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93.3°C (200°F)
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

- T 98, Fineness of Portland Cement by the Turbidimeter
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 100, Specific Gravity of Soils
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 119, Slump of Hydraulic Cement Concrete
- T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 129, Normal Consistency of Hydraulic Cement
- T 131, Time of Setting of Hydraulic Cement by Vicat Needle
- T 134, Moisture-Density Relations of Soil-Cement Mixtures
- T 135, Wetting-and-Drying Test of Compacted Soil-Cement Mixtures
- T 136, Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures
- T 137, Air Content of Hydraulic Cement Mortar
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 153, Fineness of Hydraulic Cement by Air Permeability Apparatus
- T 154, Time of Setting of Hydraulic Cement Paste by Gillmore Needles
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
- T 167, Compressive Strength of Hot Mix Asphalt
- T 170, Recovery of Asphalt from Solution by Abson Method
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 179, Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 186, Early Stiffening of Hydraulic Cement (Paste Method)
- T 190, Resistance R-Value and Expansion Pressure of Compacted Soils
- T 192, Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve
- T 193, The California Bearing Ratio
- T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
- T 201, Kinematic Viscosity of Asphalts (Bitumens)
- T 202, Viscosity of Asphalts by Vacuum Capillary Viscometer
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 228, Specific Gravity of Semi-Solid Asphalt Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- T 246, Resistance to Deformation and Cohesion of Hot Mix Asphalt (HMA) by Means of Hveem Apparatus
- T 247, Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor
- T 300, Force Ductility Test of Asphalt Materials
- T 301, Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.2. *ASTM Standards*:

- C 29, Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate
- C 31, Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
- C 67, Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile
- C 88, Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
- C 91, Standard Specification for Masonry Cement
- C 109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
- C 115, Standard Test Method for Fineness of Portland Cement by the Turbidimeter
- C 128, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate
- C 131, Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- C 138, Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- C 143, Standard Test Method for Slump of Hydraulic-Cement Concrete
- C 173, Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
- C 185, Standard Test Method for Air Content of Hydraulic Cement Mortar
- C 187, Standard Test Method for Normal Consistency of Hydraulic Cement
- C 191, Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle
- C 204, Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus
- C 230, Standard Specification for Flow Table for Use in Tests of Hydraulic Cement
- C 231, Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
- C 266, Standard Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles
- C 305, Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
- C 430, Standard Test Method for Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve
- C 451, Standard Test Method for Early Stiffening of Hydraulic Cement (Paste Method)
- C 778, Standard Specification for Standard Sand
- D 5, Standard Test Method for Penetration of Bituminous Materials
- D 36, Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)

- D 70, Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method)
- D 88, Standard Test Method for Saybolt Viscosity
- D 92, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester
- D 113, Standard Test Method for Ductility of Bituminous Materials
- D 139, Standard Test Method for Float Test for Bituminous Materials
- D 244, Standard Test Methods and Practices for Emulsified Asphalts
- D 422, Standard Test Method for Particle-Size Analysis of Soils
- D 558, Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures
- D 559, Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures
- D 560, Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures
- D 698, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))
- D 854, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
- D 1074, Standard Test Method for Compressive Strength of Bituminous Mixtures
- D 1557, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
- D 1560, Standard Test Methods for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus
- D 1561, Standard Practice for Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor
- D 1754, Standard Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)
- D 1856, Standard Test Method for Recovery of Asphalt from Solution by Abson Method
- D 1883, Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
- D 2041, Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
- D 2168, Standard Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors
- D 2170, Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)
- D 2171, Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer
- D 2419, Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate
- D 2844, Standard Test Method for Resistance R-Value and Expansion Pressure of Compacted Soils
- D 2850, Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils
- D 2872, Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)
- D 3143, Standard Test Method for Flash Point of Cutback Asphalt with Tag Open-Cup Apparatus
- D 4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- D 4402, Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer
- D 4753, Standard Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
- D 4829, Standard Test Method for Expansion Index of Soils

- D 6084, Standard Test Method for Elastic Recovery of Bituminous Materials by Ductilometer
- D 6307, Standard Test Method for Asphalt Content of Hot-Mix Asphalt by Ignition Method
- D 6521, Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- D 6648, Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- D 6723, Standard Test Method for Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- D 6925, Standard Test Method for Preparation and Determination of the Relative Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- D 6926, Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus
- D 6927, Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures
- D 7000, Standard Test Method for Sweep Test of Bituminous Emulsion Surface Treatment Samples
- D 7175, Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer
- E 11, Standard Specification for Wire Cloth and Sieves for Testing Purposes
- E 77, Standard Test Method for Inspection and Verification of Thermometers

3. TERMINOLOGY

3.1. *calibration*— a process that, under specified conditions, establishes metrological traceability by determining: (1) the relation between the quantity values provided by measurement standards and the corresponding indications from a measuring instrument or system, and (2) the resulting measurement uncertainty (Note 1).

Note 1—This definition for calibration and the following definitions for check, standardization, traceability, uncertainty, and verification of calibration are based on the definitions in PP 57.

3.1.1. *Examples*—balances (measurement instrument), dynamic shear rheometer (measurement system), pycnometer (material measure).

3.1.2. *Discussion*—The purpose of calibration is to establish the traceability of a measurement. Uncertainty estimates obtained during calibration are used to judge if an instrument is suitable for its intended purpose. There is a need to re-establish traceability or recalibrate only when instrument measurements drift out of control (as determined through verification of calibration).

3.2. *check*—a specific type of inspection and/or measurement performed on equipment and materials to indicate compliance or otherwise with stated criteria.

3.2.1. *Example*—specimen molds.

3.2.2. *Discussion*—Stated criteria can be dimensional tolerances.

3.3. *maintenance*—a regularly scheduled preventive measure taken to preserve the effective working condition of test equipment.

3.4. *measurement standard*—The embodiment of the definition of a given quantity, with a stated value and measurement uncertainty, used as a reference.[2] This term is often called “reference standard.”

3.5. *metrological traceability*—the property of a result of a measurement whereby it can be related to stated references, usually national or international standards, through a documented, unbroken chain of calibrations, each contributing to the measurement uncertainty.

3.5.1. *Discussion*—There is a need for traceable measurements. Measurements, not the instrument, can be traceable. Measurement traceability is established through calibration. Measurement traceability is maintained through verification of calibration (a regular check of instrument output using a control standard).

3.6. *quality management system (QMS) (for a CML)*—the organizational structure, staff responsibilities, policies, standard operating procedures, processes, and records which assist the laboratory in achieving its quality objectives.

3.7. *standardization*—a process that determines (1) the correction to be applied to the result of a measuring instrument, measuring system, material measure, or measurement standard when its values are compared to the values realized by standards, or (2) the adjustment to be applied to a piece of equipment when its performance is compared with that of an accepted standard or process.

3.7.1. *Discussion*—Standardization in case (1) is a simplified form of calibration that estimates systematic error but does not identify random error. Standardization, therefore, does not address all of the elements of uncertainty of measurement and does not lead to traceable measurements. An example of case (2) standardization is adjusting the number of blows of a mechanically operated hammer so it applies the energy equivalent to that of a manually operated hammer.

3.8. *uncertainty*—a parameter associated with the result of a measurement that defines the range of the values that could be attributed to the measured quantity.

3.8.1. *Discussion*—The uncertainty of a measurement is required in order to establish its traceability. The uncertainty estimates obtained during calibration are used to judge if an instrument is suitable for its intended purpose.

3.9. *verification of calibration*—a process that establishes whether the results of a previously calibrated measurement instrument, measurement system, or material measure are stable.

3.9.1. *Discussion*—Verification of calibration is used to maintain the traceability of a measurement and to determine when to recalibrate. Control charts are often used to plot the results and determine whether instrument measurements have drifted out of control.

4. SIGNIFICANCE AND USE

4.1. This document provides guidance to laboratories in the establishment and implementation of a quality management system. By use of the concepts in this document, a laboratory may prepare policies, procedures, and records that describe the elements and functions of its quality management system.

4.2. This document is not intended to prescribe the methods by which a laboratory achieves the desired level of quality, but does provide acceptable approaches.

4.3. The user is cautioned that a QMS prepared by following this document can only serve a useful purpose if it describes or references procedures that are practiced on a routine basis by the laboratory. A QMS only describes the elements of the system and how they are intended to be implemented. It is not the existence but the implementation of an effective quality management system that is important.

5. MANAGEMENT REQUIREMENTS

5.1. *Quality Management System (QMS)*:

5.1.1. The laboratory shall establish, implement, and maintain a quality management system (QMS) appropriate to the scope of its activities. The QMS shall be available for use and understood by laboratory staff.

Note 2—A QMS may be documented and distributed in hard copy or electronic format.

Note 3—Examples of some QMS documents are provided in the Appendix. The laboratory may establish methods other than those shown in the Appendix to meet QMS requirements.

5.2. *Document Control*:

5.2.1. Each QMS document shall indicate its preparation date. When a document is revised, the date of revision shall be indicated on the document.

5.2.2. *Test Methods, Practices, Procedures, and Specifications*—The laboratory shall maintain copies of standards for the testing performed and shall ensure that the procedures are the most current and are readily accessible to the employees performing the testing.

5.3. *Organization*:

5.3.1. The legal name and address of the laboratory—and that of the main office or company, if different—and any other information needed to identify the organization, shall be documented.

5.3.2. The ownership and management structure of the laboratory shall be documented. Names, affiliations, and positions of principal officers and directors shall be listed.

5.3.3. The laboratory shall maintain an organization chart showing relevant internal organizational components, including positions and names, that are part of the organization. The organization chart shall clearly define relationships with other partner organizations where applicable.

5.4. *Staff*:

5.4.1. The laboratory shall maintain a position description for each technical operational position shown on the laboratory’s organization chart. Position descriptions shall identify the position and include a description of the duties, required skills, and education and experience associated with the position.

5.4.2. The laboratory shall maintain a brief biographical sketch, noting the education, work experience, licensure, certifications, and current position for each supervisory technical staff.

5.4.3. *Technical Manager*—The laboratory shall have a technical manager (however named) who has overall responsibility for the technical operations of the laboratory. In addition, the laboratory shall nominate an individual to serve in the technical manager’s absence.

5.4.4. *QMS Management*—The laboratory shall designate a person(s) having responsibility for determining whether quality management system activities are being implemented by laboratory staff. This individual(s) shall have direct access to top management (Note 4).

Note 4—This individual(s) may have other responsibilities (e.g., laboratory manager).

5.5. *Technician Training and Evaluation*:

5.5.1. The laboratory shall maintain a procedure which describes the method used to ensure that new laboratory personnel are trained to perform tests in accordance with standard procedures. In addition to the description of training methods, the document shall indicate what position or employee is responsible for the laboratory training program and the maintenance of training records (see Figure X1.1).

Note 5—There may be several different methods employed for differing levels of staff experience including (1) on-the-job apprentice training (one-on-one) for new employees with little or no experience in laboratory or inspection work; (2) formal in-house training sessions for certification, rating, or competency evaluation; and (3) training by external organizations. An individual with prior experience performing a specific test need only have competency confirmed by the laboratory (see Section 5.5.2).

5.5.2. The laboratory shall maintain a procedure describing the method used to evaluate staff competency to ensure that each test covered by the scope of this standard is performed in accordance with standard procedures. This description shall include the frequency of competency evaluations for each technician and indicate what position or employee is responsible for evaluating staff competency and maintaining records. The procedure shall ensure that each technician receives a performance evaluation for each test that technician performs (see Figure X1.2).

Note 6—Proficiency sample testing may be useful in evaluating staff competency; however, it should be used in conjunction with observation of actual testing performed.

5.5.3. The laboratory shall maintain records of technician training and competency evaluation activities. The records shall include the test method for which the technician was evaluated, the date on which competence was determined or confirmed, the name of the individual who evaluated the technician’s competency, and comments about the training or competency evaluation activity.

5.6. *Internal Audits*:

5.6.1. The laboratory shall maintain a document describing the scope of internal audits. Internal audits shall verify that the laboratory’s operations continue to comply with its policies and procedures and the requirements of this standard.

5.6.2. The document shall include the frequency of the reviews and identification of the individual(s) responsible for the review. The internal audit program shall address all elements of the quality management system and shall be conducted at least every 12 months by trained personnel independent of the activity being audited, where possible.

5.6.3. Findings from internal audits shall be recorded (see Figures X1.3 and X1.4).

5.7. *Corrective Action*:

5.7.1. The laboratory shall maintain a procedure for implementing corrective action when nonconforming work or departures from policies and procedures have been discovered (Note 7). The procedure shall identify the individual responsible for implementing corrective action and shall begin with an investigation to determine the root cause of the problem. Records of corrective action shall be maintained (see Figure X1.5).

Note 7—The corrective action procedure should be implemented for nonconformities in the following areas: internal audits; customer complaints; equipment calibrations;, standardizations; checks and maintenance; external assessments; and proficiency sample testing.

5.7.2. The laboratory shall document the method used in responding to customer complaints (see Figure X1.6). Records of customer complaints and the resulting actions shall be maintained.

5.8. *Records Retention*:

5.8.1. *Quality Management System Records*—Records pertaining to external assessments, internal audits, proficiency sample testing, technician training and evaluation, and personnel shall be retained by the laboratory for a minimum of 5 years.

5.8.2. *Technical Records*—The laboratory shall retain records of test data, test reports, equipment calibration, standardization, check, and maintenance activities for a minimum of 5 years.

Note 8—Although a 5-year retention schedule is adequate in some instances, there are many circumstances when a longer retention period may be advantageous to the laboratory. Records concerning the calibrations, standardizations, checks, and maintenance of equipment are an example. Retention schedules of this type usually require such records to be held throughout the useful life of the equipment.

6. TECHNICAL REQUIREMENTS

6.1. *Equipment*:

6.1.1. *Inventory*—The laboratory shall maintain an inventory of major sampling, testing, calibration, standardization and check equipment, and measurement standards. The list shall include, where available, the name, date placed in service, manufacturer, and model and serial number.

Note 9—An identification number assigned by the laboratory or other unique identifying information may be substituted for the model and serial number if this is the practice normally followed by the laboratory.

Note 10—Major equipment includes all equipment that is normally amortized by a laboratory, such as shakers, physical or chemical testing machines, balances, baths, ovens, microscopes, and computing equipment dedicated to testing. Equipment such as chairs, desks, and file cabinets may be excluded. Major equipment does not usually include expendable items such as miscellaneous glassware, sieves, molds, and viscometers.

6.1.2. *Equipment Calibrations, Standardizations, and Checks*:

6.1.2.1. The laboratory shall maintain a list giving a general description of equipment which requires calibration, standardization, and checks. For each item the list shall include the interval of calibration, standardization, or checks and a reference to the procedure used (Note 11) (see Figure X1.7).

Note 11—When standard procedures are used, the standard should be referenced (e.g., unit weight bucket, T 19; compression machine, T 67). When the procedure used has been prepared by the laboratory, the in-house designation should be referenced. It should be indicated if the work is performed by an outside agency.

6.1.2.2. The laboratory shall have a procedure which describes the method for ensuring that the calibration, standardization, and checks are performed for all required equipment at the specified intervals. This procedure shall include the name of the individual(s) or position(s) responsible for ensuring that these activities are performed, and procedures for handling equipment which is newly acquired, removed from service, or defective (see Figure X1.8).

6.1.2.3. The laboratory shall have detailed written procedures for all in-house calibration, standardization, and check activities not addressed in standards or operating instructions (Note 11). These procedures shall indicate the equipment required to perform the calibration, standardization, or check (see Figures X1.9 to X1.14). If a piece of laboratory testing equipment is used over a range of measurements (e.g. thermometer, dial indicator, etc.), the calibration or standardization shall include several measurements over that range.

6.1.2.4. The laboratory shall calibrate, standardize, and check all significant equipment associated with tests which the laboratory performs (Note 12). As a minimum, the applicable equipment listed in Tables A1.1 through A1.8 shall be included.

Note 12—Refer to PP 57 for guidance on performing equipment calibrations, standardizations, and checks.

6.1.2.5. *Calibration, Standardization, and Check Frequencies*—Applicable measurement equipment shall be calibrated, standardized, or checked at the intervals specified in the laboratory's QMS. The laboratory shall establish intervals according to the following guidelines:

6.1.2.5.1. The intervals specified by the laboratory shall be no greater than those indicated in Tables A1.1 through A1.8 unless such equipment is calibrated, standardized, or checked before each use or the laboratory has documented evidence to show that the conformance of the equipment to the specification requirements is stable (Notes 13, 14, and 15).

Note 13—The intervals for the calibration of measurement equipment may be extended provided that verification of calibration data obtained with frequent measurement checks using control standards indicate that equipment measurement results are stable over time. Process-control charts are commonly used to display the data.

Note 14—Equipment check intervals may be extended provided that equipment check data indicate that equipment wear is predictable over time.

Note 15—Analysis of the verification of calibration data and check data for some equipment may indicate that intervals should be decreased to ensure that the equipment consistently meets the specification requirements or is removed from service when appropriate.

6.1.2.5.2. When a maximum interval for a specific piece of measurement equipment is specified in a standard, the interval specified by the laboratory shall not exceed this interval unless the equipment is calibrated, standardized, or checked before each use.

6.1.2.6. Equipment that has been removed from service and newly acquired equipment without a manufacturer's certification shall be calibrated, standardized, or checked before being placed in service.

6.1.3. *Measurement Standards*:

6.1.3.1. The laboratory shall maintain calibration certificates that establish the traceability of measurement standards or in-house equipment used for calibrations, standardizations, and checks. The calibration certificates shall include estimates of measurement uncertainty. The QMS shall include a procedure that describes how the laboratory ensures the calibration of its measurement standards.

6.1.4. *Equipment Maintenance*:

6.1.4.1. The laboratory shall have a system in place for performing regular maintenance on any equipment or test system in which repeated use could degrade the equipment's or test system's ability to produce repeatable results.

6.1.4.2. The laboratory shall maintain a list giving a general description of equipment which requires maintenance. For each item, the list shall include the interval of maintenance and a reference to the procedure used (Note 16) (see Table A1.9 for requirements and Figure X1.17 for an example of a maintenance table).

Note 16—In most cases, the laboratory should refer to the manufacturers' instructions to determine the recommended maintenance interval and procedures. In some cases, the laboratory will need to create its own maintenance intervals and procedures based on the frequency of use and risk of equipment failure.

6.1.4.3. The laboratory shall have detailed written procedures for all in-house maintenance activities. These procedures shall indicate the equipment required to perform the maintenance and a general explanation of the work performed. If manufacturer's instructions for maintenance are available, they shall be referenced on the in-house procedure (see Figure X1.18).

6.1.4.4. The maintenance records shall contain the name of the individual that performed the maintenance, the date that the work was completed, and any comments.

6.1.4.5. The laboratory shall maintain the manufacturers' instructions for operating and maintaining equipment, where applicable.

6.1.5. *Equipment Records*—The laboratory shall maintain calibration, standardization, check, and maintenance records for all equipment specified in the QMS. Such records shall include:

6.1.5.1. Detailed results of the work performed (dimensions, mass, force, frequency, temperature, time, etc.);

6.1.5.2. Description of the equipment calibrated, standardized, checked, or maintained, including model and serial number or other acceptable identification (Note 9);

6.1.5.3. Date the work was done;

6.1.5.4. Identification of the individual who performed the work;

6.1.5.5. Identification of the calibration, standardization, check, or maintenance procedure used; and

6.1.5.6. Identification of any device used for in-house calibration, standardization, check, or maintenance, including serial numbers, laboratory numbers, or other identification.

6.2. *Sample Management*:

6.2.1. The laboratory shall have a procedure for the storage, retention, and disposal of test samples (see Figure X1.15).

Note 17—In this context, the term "storage" refers to sample placement and handling before testing. The term "retention" refers to sample placement and handling after testing.

6.2.2. The laboratory shall have a procedure for identifying test samples. The identification shall be retained throughout the life of the sample in the laboratory.

6.3. *Test Records and Reports*:

6.3.1. The laboratory shall have a document which describes methods used by the laboratory to produce test records and to prepare, check, and amend test reports. The document shall identify the individual(s) responsible for maintaining test records and reports and shall describe the distribution of test reports (see Figure X1.16).

6.3.2. *Test Records*—The laboratory shall maintain test records which contain sufficient information to permit verification of any test reports. Records pertaining to testing shall include original observations, calculations, derived data, and an identification of personnel involved in sampling and testing.

6.3.2.1. The laboratory shall prepare test reports which clearly, accurately, and unambiguously present the information specified in Table 1.

Table 1—Test Report Requirements

Identification of the report and the date issued
Description, identification, and condition of the test sample
Identification of the standard test method used
Test results and other pertinent data required by the standard test method
Identification of any test results obtained from tests performed by a subcontractor
Name of the person(s) accepting technical responsibility for the test report (if applicable)

6.3.2.2. In addition to the requirements listed in Section 6.3.2.1, the information listed in Table 2 shall be available and traceable to the test reports.

Table 2—Test Report Information

Name and address of the testing laboratory
Name and address of the client or identification of the project
Date of receipt of the test sample
Date(s) of test performance
Deviations from, additions to, or exclusions from the test method

6.3.2.3. The procedure for amending reports shall require that the previously existing report be clearly referenced when an amendment is made. The references shall establish a clear audit trail from the latest issuance or deletion to the original report and its supporting data.

6.4. *Subcontracting*—The laboratory shall maintain a document describing the policies that the laboratory follows relative to subcontracting, if it engages in such activities. These policies shall include procedures followed by the laboratory in selecting competent subcontractors and reporting the results of testing performed by subcontractors.

6.5. *Assuring the Quality of Results:*

6.6. The laboratory shall have procedures for monitoring the validity of test results. The monitoring shall be planned and may include one or more of the following:

6.6.1.1. Participation in external assessment programs (Note 17);

6.6.1.2. Participation in proficiency sample or interlaboratory comparison testing (Note 17); and

6.6.1.3. Retesting of retained items.

Note 18—The AASHTO Materials Reference Laboratory (AMRL) and the Cement and Concrete Reference Laboratory (CCRL), located in Gaithersburg, Maryland, conduct on-site assessment and proficiency sample programs which the laboratory may use.

6.6.2. *Records*—The laboratory shall retain results of the monitoring activities, including the steps taken to determine the root cause of any nonconformities and the corrective actions taken.

7. KEYWORDS

7.1. Calibration; check; construction materials testing; equipment maintenance; internal audit; quality management system; standardization.

ANNEX A1

(Mandatory Information)

Table A1.1—General Testing Equipment

Equipment	Requirement	Max. Interval (months)
Mechanical Shakers	Check Sieving Thoroughness	12
Ovens	Standardize Thermometric Device	12
Coarse Sieves (Openings ≥4.75 mm)	Check Physical Condition and Dimensions of Openings	12
Fine Sieves (Openings <4.75 mm)	Check Physical Condition	12
Specimen Molds	Check Critical Dimensions	12
General Purpose Balances and Masses	Standardize	12
Thermometer	Standardize	12
Analytical Balances and Masses	Calibrate	12
Calipers	Standardize	12
Vacuum/Pressure Measurement Devices: (Bourdon Gauges, Pressure Manometers, and Electronic Pressure Transducers)	Standardize	12
Length Measurement Devices: (Dial Indicators, LDTs, LVDTs, and Extensometers)	Standardize	12
Compression, Loading, or Tensile Testing Devices	Standardize	12

Table A1.2—Aggregate Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Unit Weight Measures	T 19/C 29	Standardize	12
Sulfate Oven	T 104/C 88	Check Rate of Evaporation	12
Sulfate Soundness Sample Containers	T 104/C 88	Check Physical Condition	12
L.A. Machine	T 96/C 131	Check RPM and Critical Dimensions	24
Steel Balls	T 96/C 131	Check Individual Weight and Charge Weight	24
Conical Mold, Tamper	T 84/C 128	Check Critical Dimensions	24

Table A1.3—Asphalt Binder/Cutback Asphalt/Emulsified Asphalt Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Saybolt Viscometers	T 59/D 244	Standardize	36
Brush Holder and Brush	D 7000	Check Critical Dimensions	12
Nylon Strip	D 7000	Check	6
Timing Devices	T 49, T 201, T 202/ D 5, D 2170, D 2171	Standardize	12
Penetrometer Needle	T 49/D 5	Check Condition and Critical Dimensions	12
Penetrometer	T 49/D 5	Standardize for Pen. Depth	12
Ductility Machine	T 51, T 300, T 301/ D 113, D 6084	Check Speed of Travel	12
TFO Shelf and RTFO Carriage	T 179, T 240/ D 1754, D 2872	Check Rotation Speed	12
Brass Rings and Assemblies	T 53/D 36	Check Critical Dimensions	12
Pycnometers	T 228/D 70	Check Physical Condition	12
Pycnometers	T 228/D 70	Standardize Volume	12
Collars and Floats	T 50/D 139	Check Critical Dimensions	12
Flow Meters	T 170, T 240/ D 1856, D 2872	Standardize	12
Flash Cups	T 48, T 79/D 92, D 3143	Check Critical Dimensions	12
Pressurized Aging Vessel	R 28/D 6521	Standardize Temperature and Pressure	6
Rotational Viscometer	T 316/D 4402	Standardize with Reference Fluid	6
Dynamic Shear Rheometer	T 315/D 7175	Standardize with Reference Fluid	6
Bending Beam Rheometer	T 313/D 6648	Calibrate Masses	12

Table A1.4—Asphalt Mixtures Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Mechanical Compactor	T 245	Standardize	36
CA Kneading Compactor	T 247/D 1561	Standardize	24
Follower, Calibration Cylinder	T 246, T 247/ D 1560, D 1561	Check Critical Dimensions	12
Manual Compaction Hammers, Breaking Heads	T 245/D 6926, D 6927	Check Critical Dimensions, Check Mass of Hammer	12
Plungers	T 167/D 1074	Check Critical Dimensions	12
Gyratory Compactor	T 312/D 6925	Standardize Ram Pressure, Frequency of Gyration, LVDT	12
Gyratory Compactor	T 312	Standardize Internal Angle of Gyration	12
Gyratory Compactor	D 6925	Standardize External or Internal Angle of Gyration	12
Ram Face, Base Plate Face	T 312/D 7115	Check Critical Dimensions	12
Ignition Oven Internal Balance	T 308/D 6307	Standardize	12

Table A1.5—Soil Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Mechanical Compactor	T 99, T 180/D 698, D 1557	Standardize	12
CA Kneading Compactor	T 190/D 2844	Standardize	24
Manual Hammer	T 99, T 180/D 698, D 1557, D 4829	Check Mass and Critical Dimensions	12
Liquid Limit Device	T 89/D 4318	Check Wear and Critical Dimensions	12
Grooving Tool	T 89/D 4318	Check Critical Dimensions	12
Hydrometers	T 88/D 422	Check Critical Dimensions	24
Straightedge	T 99, T 134, T 135, T 136, T 180/D 558, D 559, D 560, D 698, D 1557	Check Planeness of Edge	12
Weighted Foot Assembly	T 176/D 2419	Check Mass	12
CBR Annular and Slotted Weights	T 193/D 1883	Check Mass	12
CBR Penetration Piston	T 193/D 1883	Check Diameter and Length	12
Standard Metal Specimen	T 190/D 2844	Check Outside Diameter	12
Metal Follower	T 190/D 2844	Check Diameter	12
Vertical Load	D 4829	Standardize	12

Table A1.6—Portland Cement Concrete Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Unit Weight Measures	T 121/C 138	Standardize	12
Air Meters (pressure type)	T 152/C 231	Standardize	3[a]
Air Meters (volumetric type)	C 173	Standardize	12[a]
Air Meters (volumetric type)	T 196	Standardize	36[a]
Capping Material		Check Strength	3
Slump Cones	T 119/C 143	Check Critical Dimensions	12
Metallic Reusable Molds	T 22, T 23/C 31, C 39	Check Critical Dimensions	12
Single Use Molds	T 22, T 23/C 31, C 39	Check Dimensions of Each Shipment	—
Recording Thermometer	C 31, C 39	Standardize	6

[a] The individual test methods specify conditions that require restandardization, such as changes in elevation and rough handling.

Table A1.7—Hydraulic Cement Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Moist Cabinet/Water Tank Recording Thermometer(s)	T 106/C 109	Standardize	6
Storage Water	T 106/C 109	Check for Lime Saturation	6
No. 325 Sieves	T 192/C 430	Clean after 5 Determinations, Standardize after 100 Determinations	—
No. 325 Nozzle	T 192/C 430	Check Flow Rate	6
Bearing Blocks	T 106/C 109	Check Planeness	12
Wagner Turbidimeter	T 98/C 115	Standardize	6
Standard Sand		Check Each New Shipment for Conformance to C 778	—
Air-Permeability Apparatus	T 153/C 204	Standardize Using NIST 114	30
Flow Tables	M 152/C 230	Standardize Flow Results[a]	30
Air Content Measures	T 137/C 185	Standardize[a]	30
Cube Molds and Tampers	T 106/C 109	Check Critical Dimensions and Physical Condition[a]	30
Vicat Apparatus and Vicat Ring	T 129, T 131, T 186/ C 187, C 191, C 451	Check Physical Condition, Critical Dimensions, and Mass[a]	30
Gillmore Test Apparatus	T 154/C 266	Check Physical Condition, Critical Dimensions, and Mass[a]	30
Mechanical Mixing Apparatus	T 162/C 305	Check Critical Clearances and Speeds[a]	30
Water-Retention Apparatus	C 91	Check Critical Dimensions[a]	30

[a] The equipment evaluation provided by CCRL during their routine inspection satisfies this requirement.

Table A1.8—Masonry Testing Equipment

Equipment	Test Method (AASHTO/ASTM)	Requirement	Max. Interval (months)
Micrometer	T 32/C 67	Standardize	12
Air Content Measures	T 137/C 185	Standardize[a]	30
Flow Tables	M 152/C 230	Standardize Flow Results[a]	30
Water-Retention Apparatus	C 91	Check Critical Dimensions[a]	30
Water Retention	C 91	Standardize vacuum	12
Cube Molds and Tampers	T 106/C 109	Check Physical Condition and Critical Dimensions[c]	12
Flexural Bond Apparatus		Standardize	12
Mixers		Check paddle to bowl clearance	24

[a] The equipment evaluation provided by CCRL during their routine inspection satisfies this requirement.

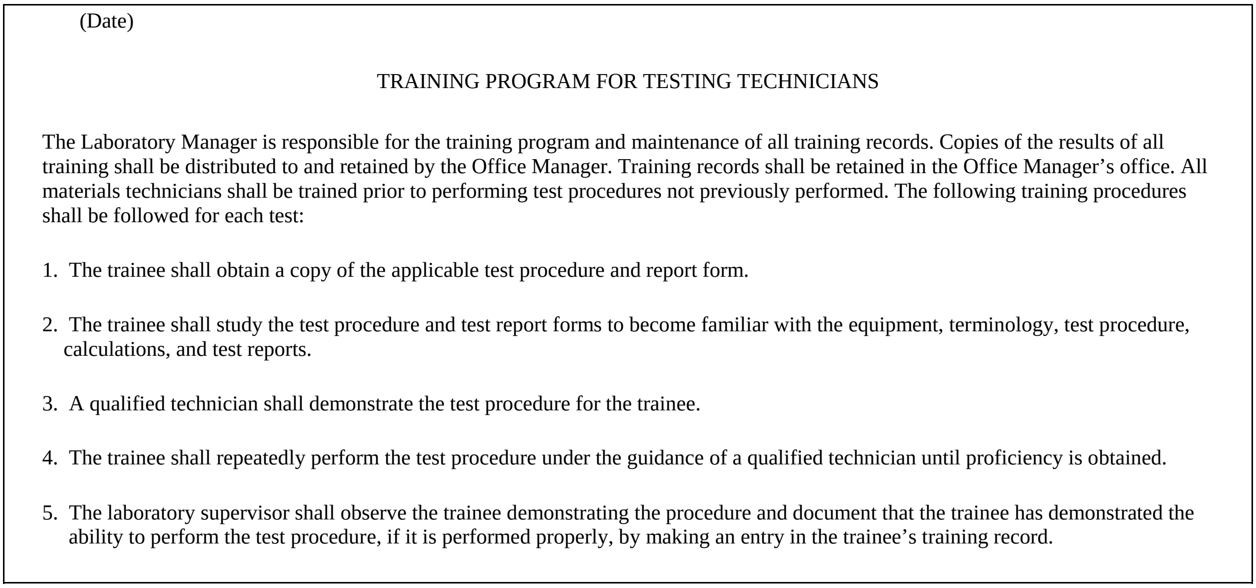
Table A1.9—Equipment Maintenance

Equipment	Test Method (AASHTO/ASTM)	Max. Interval (months)
Performance-graded binder equipment	R 28, T 240, T 313, T 314, T 315/D 2872, D 6521, D 6648, D 6723, D 7175	12
Ductilometers	T 51, T 300, T 301/D 113, D 6084	12
Mechanical Marshall compactors	T 245	12
California kneading compactors	T 190, T 247/D 1561, D 2844	12
Gyratory compactors	T 312/D 6925	12
Mechanical compactors	T 99, T 180/D 698, D 1557	12
Compression machines	Where applicable	12
Mechanical shakers	Where applicable	12

Note A1—There may be more items added to the laboratory's list of equipment that require maintenance. Maintenance activities will typically involve lubricating, tightening fittings, cleaning, replacing fluids, checking and replacing damaged or worn parts, etc. These activities will vary based on the type of equipment, how often the equipment is used, the manufacturer's recommendations, etc.

APPENDIX X1[3]

(Nonmandatory Information)



(Date)

TRAINING PROGRAM FOR TESTING TECHNICIANS

The Laboratory Manager is responsible for the training program and maintenance of all training records. Copies of the results of all training shall be distributed to and retained by the Office Manager. Training records shall be retained in the Office Manager's office. All materials technicians shall be trained prior to performing test procedures not previously performed. The following training procedures shall be followed for each test:

1. The trainee shall obtain a copy of the applicable test procedure and report form.

2. The trainee shall study the test procedure and test report forms to become familiar with the equipment, terminology, test procedure, calculations, and test reports.

3. A qualified technician shall demonstrate the test procedure for the trainee.

4. The trainee shall repeatedly perform the test procedure under the guidance of a qualified technician until proficiency is obtained.

5. The laboratory supervisor shall observe the trainee demonstrating the procedure and document that the trainee has demonstrated the ability to perform the test procedure, if it is performed properly, by making an entry in the trainee's training record.

Figure X1.1—Description of Testing Technician Training Program

(Date)

METHOD FOR REVIEWING TECHNICIAN'S COMPETENCY

Each laboratory supervisor is responsible for evaluating their test technician's competency at least once every 12 months by requiring each technician to demonstrate the AASHTO and/or ASTM test procedures for which he/she has been trained to perform. [If a technician does not routinely perform a test, it may not be necessary to evaluate his or her competency to perform the test every 12 months. However, the technician's competency shall be evaluated prior to performing the test.] Copies of the results of all competency evaluations shall be maintained by the Office Manager. Competency evaluation records shall be retained in the Office Manager's office.

For each testing technician, the supervisor shall record the test demonstrated, the date of the demonstration, and the results of the evaluation (satisfactory or unsatisfactory). In addition, the supervisor shall sign each entry on the evaluation record.

If an unsatisfactory result is recorded for a specific test, the supervisor shall review all observed deviations from the standard AASHTO or ASTM procedure with the testing technician, observe the technician re-demonstrate the test procedure and record the results as indicated above.

Figure X1.2—Method for Reviewing Test Technician's Competency

(Date)

INTERNAL AUDIT PROCEDURE

1. The Quality Manager shall review the following records, reports, and associated documentation every 12 months to ensure that established quality procedures are being followed:

a) Proficiency Sample Reports
b) On-Site Assessment Reports
c) Previous Internal Audit Findings and Corrective Actions
d) Equipment Calibration, Standardization, Check, and Maintenance Records
e) Technician Training Records
f) Technician Evaluation Records
g) Customer Feedback Records
h) Test Records and Reports
i) Quality Management System

2. After each 12-month review the Quality Manager shall discuss any deficiencies noted with appropriate staff, ensure corrective action is taken, and prepare a memorandum to the Laboratory Manager describing the items reviewed, the deficiencies identified, and the corrective action taken.

3. The Office Manager shall maintain a file containing all documents relating to quality management system review in his office.

Figure X1.3—Internal Audit Procedure

	All records adequate and/or deficiencies corrected?					
	Binder Lab	Hot Mix Lab	Soil Lab	Agg. Lab	Conc. Lab	Date Checked
Equipment Records						
Personnel Training/Competency Records						
Test Records and Reports						
Proficiency Sample Reports						
On-Site Assessment Corrective Actions						
Internal Audit Records and Corrective Actions						
Customer Feedback Records						

Have there been any changes made or updates required in the following sections of the QMS? Describe any actions taken below.

	Changes made?	QMS updated?
a) Organizational charts...		
b) Staff position descriptions...		
c) Staff biographical sketches..		
d) Staff training methods...		
e) Staff evaluation methods...		
f) Equipment inventory list..		
g) Equipment calibration/check list..		
h) Procedure describing in-house calibrations/checks...		
i) In-house equipment calibration/check procedures		
j) Equipment calibration certificates		
k) Procedures followed to produce test records		
l) Procedures followed to prepare, check, and amend test reports		
m) Procedures for sample identification, storage, retention, and disposal		
n) Policies relative to customer complaints		
o) Policies relative to internal audits		
p) Policies relative to subcontracting		

Actions taken:

____

____

Reviewed by: ____ Date: ___________________ Next Review Date: __________________

Figure X1.4—Internal Audit Check Sheet

(Date)

PROCEDURES RELATED TO PROFICIENCY SAMPLE TESTING AND ON-SITE ASSESSMENTS

GENERAL:

It is the responsibility of the Quality Manager to review all reports pertaining to proficiency sample testing, on-site assessment, and quality management system evaluations and to bring poor results or differences to the attention of the appropriate unit supervisor. It is the responsibility of the unit supervisor to ensure that corrective action is taken and documented. (In some cases it may be necessary for the Quality Manager to take corrective action and prepare documentation relative to specific differences.)

Reports covering the results of proficiency sample testing and on-site assessment and quality management system evaluations, and memorandums summarizing investigations and any corrective action taken shall be maintained by the Quality Manager in the Quality Manager's office.

PROFICIENCY SAMPLE TESTING:
Participation:
AMRL Soil Proficiency Sample Program
AMRL Aggregate Proficiency Sample Program
CCRL Concrete Proficiency Sample Program

Identifying poor results:
Any result that is beyond 2 standard deviations from the average value.

Procedures to follow when poor results occur:
1. Determine if the Agency conducting the program correctly entered the data reported.
2. Determine if the test result obtained was properly transferred to the data sheet submitted.
3. Determine if all calculations leading to the test results obtained were correct.
4. Determine if the equipment used to perform the test meets specification requirements.
5. Determine if the procedures followed when performing the test conformed to specification requirements.
6. Take corrective action to repair or take steps to replace defective equipment or instruct the technician of the correct procedure to follow.
7. Prepare a memorandum of record summarizing the results of the investigation, identifying the cause of the poor results if determined, and describing any corrective action taken.

ON-SITE ASSESSMENTS:
Participation:
AMRL Soils Inspection
AMRL Aggregate Inspection
CCRL Portland Cement Concrete Inspection

Procedures to follow when findings are reported:
(Apparatus Deficiencies)
1. Determine if the equipment meets specification requirements.
2. If the equipment is found to be defective, take necessary steps to repair or replace it.
3. Prepare a memorandum of record summarizing the results of the investigation and any corrective action taken.

(Procedural Deficiencies)
1. Discuss each procedural deficiency with the testing technician and review the proper procedure.
2. Observe the technician perform the test properly.
3. Prepare a memorandum of record summarizing the action taken.

(Quality Management System Deficiencies)
1. The Quality Manager shall review each deficiency cited by the evaluator with the responsible employee.
2. Take appropriate action.
3. Prepare a memorandum of record summarizing the action taken.

Figure X1.5—Procedures Related to Proficiency Sample Testing and On-Site Assessments

(Date)

HANDLING CUSTOMER FEEDBACK

Upon receipt of a customer complaint, the following actions shall be taken:

1. The Director of the laboratory shall be notified.
2. Complaint is brought to the attention of the Supervisor of the department or section in question.
3. Supervisor contacts the customer to verify all aspects of the complaint and establish resolution date (if necessary).
4. All reports, records, and pertinent data shall be reviewed; and all calculations are to be checked for accuracy.
5. The technician(s) performing the test is consulted by the Supervisor to determine any unusual problems or circumstances involved.
6. Supervisor reports all information gathered to the Director.
7. The Director shall formulate an appropriate reply and issue same to the complainee.

Figure X1.6—Procedure for Responding to Customer Feedback

(Date)

EQUIPMENT CALIBRATION, STANDARDIZATION, AND CHECK INFORMATION

Item(s)	Interval	Requirement	Procedure
Balances	12 Month	Standardization	ASTM D 4753
Analytical Balances and Masses	12 Month	Calibrate	Outside Contractor
Mechanical Compactors	12 Mo.	Standardization	ASTM D 2168
LA Abrasion Equipment	12 Mo.	Check	In-House Procedure A-2
Proctor Hammer	12 Mo.	Check	In-House Procedure S-1
Compression Machines	12 Mo.	Standardization	Outside Contractor
Proctor Molds	4 Mo.	Check	In-House Procedure S-2
Marshall Molds	4 Mo.	Check	In-House Procedure B-2
Unit Weight Buckets	6 Mo.	Standardization	AASHTO T 19
Thermometers	6 Month	Standardization	ASTM E 77

Figure X1.7—List Showing Equipment Calibration, Standardization, and Check Information

(Date)

EQUIPMENT CALIBRATION, STANDARDIZATION, CHECK, AND MAINTENANCE POLICIES AND PROCEDURES

General Policies:

1. Required equipment shall be calibrated, standardized, checked, or maintained at specified intervals following the general procedures indicated below.

2. Newly acquired equipment without a manufacturer's certification and equipment that has not been calibrated, standardized, or checked because it has been removed from service shall be calibrated or checked before being returned to service.

3. When any of the Unit's test equipment is overloaded, mishandled, giving results that are suspect, or is not meeting specification tolerances, the Unit Supervisor shall remove it from service and clearly mark it by attaching a red ribbon or tape. The equipment shall be returned to service only after appropriate repairs are made and calibration, standardization, or checks confirm the equipment functions satisfactorily or meets specification tolerances.

General Procedures:

1. The Supervisor in each Testing Unit is responsible for ensuring that calibration, standardization, checks, and maintenance activities are performed. He shall maintain a file for each piece of equipment in his unit requiring calibration, standardization, check, or maintenance. The file for each piece of equipment shall contain detailed records of calibration, standardization, check, or maintenance work performed in chronological order and shall be kept in the Supervisor's office.

2. The Supervisor in each Testing Unit shall maintain a set of 12 labeled folders in his office—one for each month of the year. Each month's folder shall contain a partially completed calibration, standardization, check, or maintenance record form for each piece of equipment requiring calibration, standardization, checks, or maintenance during the month indicated on the folder's label.

3. During the first week in each month, the Supervisor in each Testing Unit shall remove the partially completed record forms from the current month's folder and instruct the appropriate staff to perform the necessary calibration, standardization, check, or maintenance work within the next week and return the completed record forms.

4. The Supervisor shall prepare partially filled out record forms for each piece of equipment calibrated, standardized, checked, or maintained that month—identifying the equipment and the next date that calibration, standardization, check, or maintenance work is required (month and year)—and file each partially filled out form in the appropriate monthly folder.

5. The Supervisor shall file each of the completed record forms in the appropriate equipment record file in chronological order.

Figure X1.8—Policies and Procedures for Conducting Equipment Calibration, Standardization, Checks, and Maintenance

(Date) Procedure: G-2

Equipment Checked: SIEVES

Purpose:
This method provides instructions for checking the physical condition of laboratory tests sieves ranging in size from 75 mm (3 in.) to 0.075 mm (No. 200) and for measuring the openings of coarse sieves having openings greater than or equal to 4.75 mm (No. 4).

Equipment Required:

1. A caliper readable to 0.01 mm (use for 4.75-mm sieve and coarser).
2. An eye comparator with a 0.1-mm scale or a magnifier (for use with sieves finer than 4.75 mm).

Tolerance:
Sieves shall meet the physical requirements specified in AASHTO M 92 (ASTM E 11).

Procedure:

1. For sieves having openings equal to or greater than 4.75 mm, select and measure, using the calipers, the dimensions of at least four or five sieve openings in each sieve to ensure that the openings in the wire cloth conform to the requirements in Table 1 of AASHTO M 92 (ASTM E 11). Be sure to include, in the selection, any openings that appear distorted or unusual in size. Measure each of the openings as the distance between parallel wires measured at the center of each opening. Measure each opening in both the x (horizontal) and y (vertical) directions. Record the measurements for each of the selected openings. If a sieve has less than five full openings, measure all full openings.
2. For sieves smaller than 4.75 mm, inspect the sieve cloth against a uniformly illuminated background. Use the eye comparator or magnifier to examine any suspicious areas of the cloth. If obvious deviations, such as weaving defects, creases, wrinkles, or excessive foreign matter in the cloth are found, the wire cloth is unacceptable.
3. Inspect the general condition of the sieve. Check the frame and solder joints for cracks or holes. (Check for pin holes in the finer sieves.)
4. Ensure that the sieve has an appropriate label.
5. Check for tightness of the wires on each individual sieve.

Figure X1.9—Procedure for Checking Sieves

(Date) Procedure: S-1

Equipment Checked: MANUAL HAMMER (AASHTO T 99, T 180) (ASTM D 698, D 1557)

Purpose:
This method provides instructions for checking the critical dimensions of the proctor hammers.

Equipment Required:

1. Calipers readable to 0.01 mm.
2. Tape measure readable to 1 mm.
3. Balance, capacity 5 kg, readable to 1 g.

Tolerance:
Equipment shall meet the dimensional tolerances specified in the applicable test method.

Procedure:

1. Measure and record the diameter of the rammer face determined by taking two readings 90° apart using the calipers.
2. Pull up the handle, measure, and record the drop height of the hammer. Determine this height inside the guide-sleeve using the tape measure.
3. Remove the hammer from the guide-sleeve. Determine and record its mass to the nearest 1 g.
4. Measure and record the diameters of the vent holes near the end of the hammer.

Figure X1.10—Procedure for Checking Manual Compaction Hammers

(Date) Procedure: A-1

Equipment Checked: CONICAL MOLD, TAMPER (AASHTO T 84) (ASTM C 128)

Purpose:
This method provides instructions for checking the critical dimensions of the sand cone and tamper used in the above test method.

Equipment Required:

1. Calipers readable to 0.1 mm.
2. Balance, 500 g capacity, readable to 0.1 g.
3. Ruler readable to 1 mm.

Tolerance:
Equipment shall meet the dimensional tolerances specified in the test method.

Procedure:
(Cone)

1. Measure the inside diameter at the top of the cone to the nearest 1 mm by taking two readings 90° apart using the ruler and record the results.
2. Invert the cone and repeat step 1.
3. Place the cone on a flat glass surface. Measure and record the depth of the cone.
4. Using the calipers, measure the thickness of the cone to the nearest 0.1 mm by taking two readings 90° apart at the top of the cone and two readings 90° apart at the bottom of the cone and record the results.

(Tamper)

1. Measure and record the diameter of the tamping face to the nearest 1 mm by taking two readings 90° apart using the ruler.
2. Determine and record the mass of the tamper to the nearest 0.1 g.

Figure X1.11—Procedure for Checking Conical Molds and Tampers

(Date) Procedure: A-2

Equipment Checked: L. A. ABRASION MACHINE (AASHTO T 96) (ASTM C 131)

Purpose:
This method provides instructions for checking the critical dimensions and general operating condition of the L. A. abrasion machine and the mass of the spheres used as test charges.

Equipment Required:
1. Steel rule readable to 1 mm.
2. Stopwatch readable to 0.1 s.
3. Balance with a 5 kg capacity, readable to 1 g.

Tolerance:
The L. A. machine shall meet the dimensional tolerances specified in the applicable test method listed above and shall be in good operating condition. The steel spheres used to charge the L. A. machine shall meet the mass tolerances specified in the applicable test method listed above.

Procedure:
(L.A. Machine)
1. Measure and record the inside diameter of the drum at the left and right edges to the nearest 1 mm.
2. Measure and record the width and height of the opening to the nearest 1 mm.
3. Measure and record the wall thickness at the left and right edge to the nearest 1 mm.
4. Determine if the cylinder is horizontal using a steel ball to check left-to-right roll.
5. Measure and record the shelf width inside the drum to the nearest 1 mm.
6. Measure and record the distance from the shelf to the opening in the direction of rotation.
7. Using the stopwatch, determine the r/min to the nearest whole number over a 5-minute period. Record the r/min.
8. Check that the number of revolutions is 500 by looking at the counter on the machine.

(Steel Spheres)
1. Determine and record the mass of each individual sphere to the nearest 1 g.
2. Determine and record the mass of the collective charge(s) to the nearest 1 g.

Figure X1.12—Procedure for Checking L.A. Abrasion Machines

(Date) Procedure: B-3

Equipment Checked: TIMERS (AASHTO T 72, T 201, T 202) (ASTM D 88, D 2170, D 2171)

Purpose:
This procedure provides instructions for checking the accuracy of timing devices.

Inspection Equipment Required:
1. Timer, readable to 0.1 s., having a verified accuracy within the tolerance listed in above test methods.

Tolerance:
Timers shall meet the accuracy requirements specified in the applicable test methods listed above.

Procedure:
1. Hold the calibrated timer in one hand and the timer to be checked in the opposite hand.
2. Start the timers simultaneously by pressing the “start” buttons at the same time.
3. Allow the timers to run for at least 15 min. Then stop the timers simultaneously. Record the time indicated by both timers.
4. Record the difference between the two timers. Calculate and record the percent accuracy.

$$\%\ \text{accuracy} = \frac{\left(A = B\right)}{B} \times 100$$

A = Reading on lab timer (s)
B = Reading on standard timer (s)

Figure X1.13—Procedure for Checking Timing Devices

(Date) Procedure: B-4

Equipment Checked: PENETRATION APPARATUS (AASHTO T 49) (ASTM D 5)

Purpose:
This procedure provides instructions for checking the equipment used to perform the penetration test.

Equipment Required:
1. Balance, readable to 0.01 g.
2. Microscope or eyepiece, 10×.
3. Metal block, 10.0 mm high. Metal block, 25.4 mm (1 in.) high.
4. Support block, 75–87.5 mm high.
5. Ruler, readable to 1 mm.
6. Calibrated stopwatch, readable to 0.1 s.

Tolerance:
The equipment shall meet the tolerances specified in test methods AASHTO T 49 and ASTM D 5.

Procedure:
1. Remove the spindle, 50- and 100-g weights from the penetrometer. Record the weight of each to the nearest 0.01 g.
2. Weigh each needle to the nearest 0.01 g. Visually examine each needle with a microscope or eyepiece. Each needle should be straight and free of burrs. The base of each needle should be flat.
3. If an automatic timing mechanism is used on the penetrometer start the calibrated stopwatch when the plunger is released and stop the calibrated stopwatch when the plunger stops. Record the time indicated on the calibrated stopwatch to the nearest 0.1 s. If a manual device is used to release the plunger, check the accuracy of the timing device used over a 60-s interval. Record the elapsed time to the nearest 0.1 s.
4. Place the support block on the base of the penetrometer. Place the 10-mm block on the support block. Adjust the needle height so that its tip just touches the top of the 10-mm block. Remove the 10-mm block and release the needle to the support block. Adjust the instrument to measure the distance moved. Repeat step 4 using the 25.4-mm (1-in.) block. Determine dial accuracy by comparing readings with the height of the blocks.
5. Measure and record the distance from the perforated shelf to the bottom of the water bath. Measure and record the distance from the perforated shelf to the surface of the water. Measure and record the distance the thermometer is immersed in the water.
6. Observe and record the temperature of the water in the bath to the nearest 0.1°C (0.2°F).

Figure X1.14—Procedure for Checking Penetration Test Apparatus

______(Date)______

PROCESSING OF SAMPLES

IDENTIFICATION:
Each sample shall be accompanied by a sample tag indicating the sample number. This identifies the material in terms of the project, the location of use within the project, the quantity of material represented by the sample, and the material's intended use. The sample tag is kept with the sample as long as it remains in the materials laboratory.

STORAGE:
After being logged in, samples are stored in the area of the laboratory in which testing is to be done. During storage, care is taken to avoid disturbance or contamination. Any AASHTO requirements for storage (e.g., the moist storage of portland cement concrete cylinders) are followed.

RETENTION:
Samples with acceptable test results are generally discarded when testing is completed. Those with failing results are retained until review of those results is completed. At that time, the decision is made whether to discard, retest, or continue to retain the sample.

DISPOSAL:
Discarded non-hazardous materials are transported daily by materials section personnel to an appropriate area. Hazardous materials (e.g., bituminous concrete extraction solution) are stored in proper containers in an isolated area of the laboratory. Disposal by an approved disposal contractor is arranged periodically by the hazardous waste disposal officer.

Figure X1.15—Procedure for Sample Management

(Date)

TEST RECORDS

PREPARING SAMPLE LOG:

Each sample brought to the materials laboratory for testing is recorded in a log book maintained by the Laboratory Manager. The following information is recorded for each sample:

1. Sample number (this is assigned sequentially to each line of the log book).
2. Project name or contract number.
3. Description of the material.
4. Supplier of the material.
5. Location from which the sample was taken.
6. Name of person(s) who sampled the material.
7. Date of sampling.
8. Date the sample was received in the materials laboratory.
9. The word "RESAMPLE" in red ink (when applicable).
10. The date testing was completed.
11. The initials of the tester.

PREPARING AND CHECKING TEST REPORTS:

Test results are recorded on standard materials section worksheets, which are submitted to the materials lab supervisor who reviews them prior to preparing a test report. An original and two copies of the test report are prepared for review by the laboratory manager. The original test report is filed in the project folder. One copy of the test report is kept on file with the worksheets in the materials laboratory, and the other copy is sent to the project engineer for review. Test records and reports are maintained by the Office Manager.

AMENDING REPORTS:

When a report must be amended, a report form shall be filled out indicating the amended test results; the report status field "amended" on the report form shall be checked; the comment section on the report form shall state the reason for the amended report; the amended report shall be attached to the original report and processed in the normal manner; and the amended report shall be filed with the original report.

Figure X1.16—Procedures for Producing Test Records and Preparing, Checking, and Amending Test Reports

Date:_____________

MAINTENANCE INTERVALS

Equipment	Activity	Interval (months)
Compression machine	Clean, lubricate	1
Moist room	Ensure spray nozzles unclogged Check for leaks Check position of temperature recorder probe	3
Mechanical shakers	Lubricate, check for wear	3
LA abrasion machine	Lubricate	6

Figure X1.17—List of Maintenance Activities and Intervals

Date:_________ Maintenance Procedure: M-2

MECHANICAL SHAKER MAINTENANCE PROCEDURE

Equipment Needed: wrench, grease, brush

Procedure:

1. Clean all loose dust and particles from all exposed surfaces of machine
2. Check each paddle for looseness – tighten where necessary
3. Replace any paddles that are in poor condition
4. Clean and grease rotating base
5. Operate shaker without sieves in place to determine how shaker is working
6. Explore any other possible issues and resolve them

MECHANICAL SHAKER MAINTENANCE RECORD

Date	Name	Comments
1/5/08	Technician A	Replaced 2 paddles
4/3/08	Technician A	Done
7/7/08	Technician A	Screws were loose on rotating base
10/2/08	Technician B	Done
1/3/09	Technician B	Installed sound dampener on door

Figure X1.18—Mechanical Shaker Maintenance Procedure and Record

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[1] This document is under the jurisdiction of the American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Materials and is the direct responsibility of the Administrative Task Group.

[2] The definition is from the International Vocabulary of Metrology (abbreviated VIM), 3rd edition, 2008, published by the International Organization for Standardization (ISO), in the name of the eight organizations that supported its development and nominated the experts who prepared it: the Bureau International des Poids et Mesures (BIPM), the International Electrotechnical Commission (IEC), the International Federation of Clinical Chemistry (IFCC), International Laboratory Accreditation Cooperation (ILAC), ISO, the International Union of Pure and Applied Chemistry (IUPAC), the International Union of Pure and Applied Physics (IUPAP), and the International Organization of Legal Metrology (OIML). The VIM should be the first source consulted for the definitions of terms not included in this practice.

[3] The figures in this Appendix illustrate typical examples of documents, forms, and standard operating procedures that address the requirements of this practice. A laboratory may employ other methods that satisfy the intent of this practice. The figures are intended as examples of documents in a laboratory's Quality Management System. They are not intended to include all possible laboratory organizational structures or capabilities.

Standard Practice for

Procedures for Measuring Highway Noise

AASHTO Designation: R 20-99 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Procedures for Measuring Highway Noise

AASHTO Designation: R 20-99 (2008)

1. SCOPE

1.1. This standard practice is to provide guidance in acceptable procedures for measuring highway noise levels.

2. GENERAL PROVISIONS

2.1. It is recommended that the following Federal Highway Administration Report be used for field measurement of highway noise levels.

2.1.1. FHWA-PD-96-046, DOT-VNTSC-FHWA-96-5, "Measurement of Highway-Related Noise," May 1996.[1]

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[1] This document is available from the National Technical Information Service (NTIS) at NTIS, 5285 Port Royal Road, Springfield, VA, 22161. Request NTIS Publication No. PB-83-152561.

Standard Practice for

Quality Assurance of Standard Manufactured Materials

AASHTO Designation: R 38-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Quality Assurance of Standard Manufactured Materials

AASHTO Designation: R 38-10

1. SCOPE

1.1 This standard practice contains minimum criteria and guidelines for establishing and implementing quality assurance (QA) procedures for *standard manufactured materials* used in highway construction. The purpose of this document is to establish minimum quality control (QC) requirements for manufacturers and to provide guidelines for acceptance of standard manufactured materials by transportation agencies.

1.2 *Standard Manufactured Materials*—Materials used in transportation construction are broadly categorized according to their source and corresponding methods of production. The three principal materials categories are as follows:

- Project-produced materials,
- Fabricated structural materials, and
- Standard manufactured materials.

1.3 In order to explain the difference between these materials categories and provide a basic understanding of how QA is applied to them, each of the three primary material categories is defined below (see Section 3). Although QA procedures should be addressed for each of these material categories, the scope of this standard practice is the application of QA to standard manufactured materials.

1.4 Standard manufactured materials are standard items that are produced routinely (i.e., not for a specific project) by a manufacturer. They are generally characterized by one or more of the following conditions:

1.4.1 The materials are normally mass-produced under highly controlled and largely automated manufacturing conditions.

1.4.2 The material properties are stable and have no potential for alteration under proper transportation from the manufacturer to the project site.

1.4.3 The materials arrive at the project site in a solid, finished state and require only installation.

1.5 *Relevant Items*—This standard practice addresses those items used in transportation construction which meet the above description of standard manufactured materials. Some examples of standard manufactured materials used in transportation construction are presented in Table 1 below. The list of items in Table 1 is not all-inclusive but is intended to provide examples of typical items within each of the three principal materials categories.

Table 1—Typical Items by Materials Category

Materials Category	Example Items
Project -Produced Materials	Earthwork Subbase and Base Courses Geotechnical Items* Hot Mix Asphalt (HMA)* Portland Cement Concrete (PCC)* Field Applied Structural Coatings* Pavement Markings*
Fabricated Structural Materials	Fabricated Structural Steel and Coatings* Precast/Prestressed Concrete Structural Elements* (e.g., Precast Box Culverts, Prestressed Bridge Beams)
Standard Manufactured Materials	Binders and Cements (e.g., PG Binder, Portland Cement) Drainage or Water Systems (e.g., Ductile Iron Pipe, Corrugated Metal Pipe, PVC Pipe, Hydrants, Gates and Valves, etc.) Geotextile Fabrics Landscaping Items (e.g., Lime, Fertilizer, Seed, Mulch, Chain Link Fence, etc.) Paints and Coatings (e.g., Traffic Paints, Glass Beads, Preformed Markings, Epoxy, Zinc Galvanizing, etc.) Roadside Safety Devices (e.g., Impact Attenuators, Steel Beam Guardrail, Wood Posts, etc.) Standard Precast Concrete Items (e.g., Concrete Pipe, Concrete Manholes and Junction Boxes, Concrete Barrier, Concrete MSE Wall Panels, etc.) Standard Steel Shapes or Products (e.g., Anchor Bolts, Frames and Grates, Rebar, Stay-in-Place Forms, Sheeting and Piles, etc.) Traffic Control Devices (e.g., Electrical Conduit, Signal Heads, Signal Poles, Controllers, Signs, etc.)

* Some constituent materials incorporated are evaluated as standard manufactured materials.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories

2.2 *ASTM Standards*:

- D 3665, Standard Practice for Random Sampling of Construction Materials
- E 4, Standard Practices for Force Verification of Testing Machines
- E 105, Standard Practice for Probability Sampling Of Materials

2.3 *Other Documents*:

- ISO 10013, Guidelines for Quality Management System Documentation

3. TERMINOLOGY

3.1 *Relevant Terms and Definitions*—The terms and definitions included below are provided to ensure standard application of terminology relevant to the QA of transportation construction materials, including standard manufactured materials. Where terms or definitions in this standard practice differ from the above-referenced documents, the terms included herein shall replace those contained in the above referenced documents.

3.1.1 *acceptance*—all factors used by the agency (i.e., sampling, testing, and inspection) to evaluate the degree of compliance with contract requirements and to determine the corresponding value for a given product.

3.1.2 *accredited laboratories*—laboratories that are recognized by a formal accrediting body as meeting quality system requirements, including demonstrated competence to perform standard test procedures.

3.1.3 *agency*—any organization, constituted under Federal, state, or municipal laws, that is responsible for administering contracts for highway or transportation construction.

3.1.4 *calibration*—a systematic process used to standardize measurement instruments or test equipment by determining any deviation from an established reference or standard. A correction or adjustment of the instrument or equipment may be required based on the amount of deviation from the standard.

3.1.5 *certified personnel*—personnel who are recognized by a formal certifying body as qualified to perform sampling, testing, inspection, or related procedures.

3.1.6 *control chart*—also called "statistical control chart." A graphical plot of QC measurements or test values used to identify variation in a production or placement process due to either chance causes or assignable causes.

3.1.7 *control chart limits*—also called "action limits." Statistically derived boundaries applied to a control chart for controlling material production or placement. [Control chart limits are expressed as the upper control limit (UCL) and the lower control limit (LCL). When values of the material characteristics fall within these limits, the process is "under control." When values fall outside the limits, there is an indication that some assignable cause is present causing the process to be "out of control."]

3.1.8 *dispute resolution*—the procedure used to resolve conflicts resulting from discrepancies between the agency's and contractor's results of sufficient magnitude to impact payment.

3.1.9 *engineering limits*—the absolute limiting value(s) placed on a quality characteristic beyond which the test result for an individual sample is considered to be unacceptable. [Engineering limits are established to identify material that does not provide the minimum required engineering properties. They usually have an upper engineering limit (UEL), a lower engineering limit (LEL), or both. The engineering limits may be the same as the specification limits.]

3.1.10 *fabricated structural materials*—major structural items produced specifically for an individual construction project by a material fabricator. [They are generally characterized by one or more of the following conditions: (a) The production process for the material occurs under controlled conditions at an established fabricator plant typically located within state or in another state; (b) The material properties are stable and have no potential for alteration under proper transportation from the fabricator to the project site; (c) The materials arrive at the project site in a solid state and require little or no additional work after installation.]

3.1.11 *fabricator*—a company that produces fabricated structural materials (e.g., precast/prestressed concrete structural elements, fabricated structural steel) for either the prime contractor or a subcontractor.

3.1.12 *lot*—a specific quantity of material from a single source that is assumed to be produced or placed by the same controlled process.

3.1.13 *manufacturer*—a company that manufactures and supplies standard manufactured materials for either the prime contractor, a subcontractor, or a fabricator.

3.1.14 *population*—a collection of all possible individuals, objects, or items that possess some common specified characteristic(s) that can be measured.

3.1.15 *prime (general) contractor*—the company which has the primary construction contract for an agency project and which assumes overall responsibility for completing the work.

3.1.16 *producer*—a company that produces and supplies project-produced materials (e.g., aggregates, HMA, PCC) for either the prime contractor or a subcontractor.

3.1.17 *project-produced materials*—major items produced directly for an individual construction project either by a contractor or by a material producer. [They are generally characterized by one or more of the following conditions: (a) The production process for the material occurs either at the project site or at a production plant located in close proximity to the project site; (b) The material properties are subject to potential contamination or segregation during transportation from the plant to the project site; (c) The materials arrive and are placed at the project site in a nonsolid or loose mixture state requiring subsequent mixing, compaction, finishing, or curing.]

3.1.18 *qualified laboratories*—laboratories that are capable as defined by appropriate programs established or recognized by each agency. [Accredited laboratories are considered "qualified." However, a "qualified laboratory" need not be accredited.]

3.1.19 *qualified personnel*—personnel who are capable as defined by appropriate programs established or recognized by each agency.

3.1.20 *quality*—(1) the degree of excellence of a product or service; (2) the degree to which a product or service satisfies the needs of a specific customer; (3) the degree to which a product or service conforms with a given requirement; or (4) conformance to requirements.

3.1.21 *quality assurance (QA)*—(1) all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service; or (2) ensuring the quality of a product is what it should be. [The two primary elements of a QA program for standard manufactured materials include QC by the manufacturer and acceptance by the agency. Additional elements of a QA program for standard manufactured materials include qualified personnel, qualified laboratories, and dispute resolution procedures.]

3.1.22 *quality characteristics*—a product characteristic that is measured through testing, either for QC purposes or for conformance with acceptance requirements. [Quality characteristics are specific material properties or product requirements which are evaluated by QC and acceptance testing. Quality characteristics are normally selected because they: (a) relate to initial and long-term performance; (b) are quantifiable or measurable; and (c) can be measured with good repeatability.]

3.1.23 *quality control (QC)*—the system used by a contractor party to monitor, assess and adjust their production or placement processes to ensure that the final product will meet the specified level of quality. [QC includes sampling, testing, inspection, evaluation, and corrective action (when required) to maintain continuous control of a production or placement process.]

3.1.24 *quality measure*—any one of several mathematical tools used to quantify the level of quality of an individual quality characteristic. [Application of a quality measure to a set of test data provides an overall numeric representation of quality for a specific quality characteristic. Typical quality measures used in QA are selected because they quantify the average quality, the variability, or both. Examples of quality measures that may be used include: mean, standard deviation, percent defective (PD), percent within limits (PWL), average absolute deviation (AAD), moving average, and conformal index (CI). PWL and PD are the quality measures recommended for use in QA specifications.]

3.1.25 *quality system manual (QSM)*—a written document that describes the overall QC operating procedures of a contractor party (e.g., prime contractor, subcontractor, producer, fabricator, manufacturer). [A manufacturer's QSM documents the internal policies for achieving quality and the assignment of responsibility and accountability for QC within the manufacturer's organization. It may also describe the minimum QC requirements expected of upper- or lower-tier contractor parties who supply constituent materials or who are involved in handling or processing of the manufacturer's products.]

3.1.26 *random sampling*—a sampling procedure whereby each sample obtained from the lot has an equal probability of being selected.

3.1.27 *run chart*—also called "music bar chart." A control chart that presents individual measurements or test values for a specific quality characteristic on a vertical axis and the individual sample numbers (in consecutive order) on a horizontal axis. [Run charts plot individual sample values ($n = 1$) and usually check the measurements or test results against the specification limits or engineering limits.]

3.1.28 *sample*—(1) also called "material sample." A small quantity of material or measurement obtained from a sublot or lot. [A sample can refer to either a point of inspection (i.e., visual examination or physical measurement) or an individual material sample obtained for testing. A sample may be composed of one or more increments of equal size that have been obtained from the sampling location and combined.]; or (2) also called statistical sample. All of the samples obtained from a lot that provide information that may be used to quantify the quality of the entire lot. [The context in which the word "sample" is used determines its meaning. For example, "obtain a sample here" would mean obtain a physical quantity of material from a specific location; while "the sample size equaled nine" means that at total of nine individual material samples were obtained in a random manner and thus comprised the statistical sample of size $n = 9$. Each sample is included in the overall statistical sample for a given lot.]

3.1.29 *specification limits*—the statistically based limiting value(s) placed on a quality characteristic which are applied with a particular quality measure (such as PWL) to evaluate the quality of a lot. [Specification limits are usually composed of an upper specification limit (USL), a lower specification limit (LSL), or both. It is important to recognize that since specification limits are statistical limits, individual sample test results may fall beyond the USL or LSL and still be included in the acceptance determination. The specification limits will ultimately be used for computation of quality levels (e.g., PWL), which will be used in calculating pay factors for a lot.]

3.1.30 *standard manufactured materials*—standard items that are produced routinely (i.e., not for a specific project) by a manufacturer. [They are generally characterized by one or more of the following conditions: (a) the materials are normally mass-produced under highly controlled and largely automated manufacturing conditions; (b) the material properties are stable and have no potential for alteration under proper transportation from the manufacturer to the project site; (c) the materials arrive at the project site in a solid, finished state and require only installation.]

Note 1—Exceptions to this condition include materials such as PG binders, cements, and paints/coatings that are incorporated into either project-produced materials or fabricated structural materials.

3.1.31 *statistical control chart*—see *control chart*.

3.1.32 *statistical sample*—see *sample*.

3.1.33 *stratified random sampling*—a sampling procedure whereby samples are randomly obtained from each sublot.

3.1.34 *subcontractor*—a company which is responsible for field placement or installation of an individual item of work under contract to the prime contractor.

3.1.35 *subgroup*—a set ($n > 1$) of QC sample values from within a lot the mean or range of which are plotted on a control chart.

3.1.36 *sublot*—a subdivision of a lot.

3.1.37 *target value*—the value that is placed on a quality characteristic that represents the mean of the expected distribution of the specified population.

3.1.38 *validation*—the mathematical comparison of two independently obtained sets of data (e.g., agency acceptance data vs. manufacturer QC data) to determine whether it can be assumed they came from the same population.

4. SIGNIFICANCE AND USE

4.1 *Manufacturer Quality Control*—This document outlines minimum requirements that should be followed by manufacturers in implementing an effective QC system. It is not intended to prescribe the methods by which a manufacturer achieves the desired level of quality but instead establishes minimum guidelines and criteria for documenting and implementing QC procedures for standard manufactured materials.

4.2 *Agency Acceptance*—This document outlines recommended approaches for acceptance of standard manufactured materials by transportation agencies. It is not intended to prescribe a singular acceptance procedure for all agencies, but rather provides a uniform framework for acceptance of standard manufactured materials that takes into consideration the quality control requirements established herein.

5. QUALITY CONTROL REQUIREMENTS

5.1 Each manufacturer shall have a QC system in place to ensure the quality of their products. Quality control procedures must provide adequate assurance to agencies that the products purchased will meet relevant AASHTO, ASTM, and industry standards. The following minimum requirements for manufacturer QC shall be satisfied.

5.1.1 *Quality System Manual*—Each manufacturer shall establish and maintain a QSM. The QSM is a general document intended to outline the overall internal QC operating procedures of the manufacturer. A QSM documents the manufacturer’s policies for achieving quality and the assignment of responsibility and accountability for QC within the manufacturer organization. It also describes the minimum QC requirements expected of other manufacturers or material suppliers from whom the manufacturer obtains constituent materials incorporated in each manufactured product.

5.1.1.1 Guidelines for the preparation of QSM may be available from industry organizations that administer manufacturing facility certification programs. In addition, ISO10013 contains guidelines on the development and preparation of QSM. However, each manufacturer QSM shall meet the format and content requirements outlined below.

5.2 *QSM Format*—The manufacturer’s QSM may be maintained in an electronic format. However, one or more copies of the QSM must be maintained by the manufacturer’s QC manager in a printed and bound format (three-ring or other). The QSM shall be available to all of the manufacturer’s employees. Each document in the QSM shall indicate its preparation date, and all pages of the QSM shall be numbered. If a document is revised, the date of the revision shall be indicated on the document and recorded in a table of revisions.

5.2.1 It is the intent of this standard practice that the QSM shall address each of the items outlined below, except as agreed upon by the agency. The QSM shall be formatted to provide numbered sections for each item, in the order listed below, except as otherwise approved by the agency. The standard QSM items are as follows:

5.2.1.1 Manufacturer's quality statement;

- Written policy or mission statement

5.2.1.2 Manufacturing facility and products;

- Facility address and telephone number
- Standard manufactured materials produced

5.2.1.3 Terms and definitions;

5.2.1.4 Applicable specifications (AASHTO, ASTM, other);

5.2.1.5 QC system roles and responsibilities;

- QC organization
- QC manager
- QC technicians
- QC personnel qualification requirements
- Production personnel responsibilities for quality

5.2.1.6 QC laboratories;

- Laboratory addresses and telephone numbers
- Laboratory accreditation or qualification
- Testing equipment

5.2.1.7 Preproduction materials control;

- Constituent material types and sources of supply
- Visual inspection of constituent materials
- Control and testing of constituent materials properties
- Constituent materials storage

5.2.1.8 QC during production of standard manufactured materials;

- Lot and sublot sizes
- QC visual inspection
- Random sampling plan
- Selective sampling
- Sample identification system
- Standard QC sampling and testing methods (AASHTO, ASTM, other)
- Manufacturer-developed test procedures
- QC sample storage and retention procedures
- QC inspection and test result reporting
- Use of control charts
- Statistical analysis of test results
- Resolution of nonconforming inspection or test results

5.2.1.9 Postproduction QC activities; and

- Marking, storage, shipping, and handling of standard manufactured materials

- ■ QC records
- ■ Retention of inspection and test results and product traceability
- ■ Issuance of materials certificate of compliance (COC)

5.2.1.10 Quality audit of the manufacturing facility (as required by agency—see Section 5.13).

5.3 A model QSM outline, which includes each of the standard items above, is contained in Appendix X1 of this standard practice. The information required in each of the above QSM Sections is described below.

5.4 *Manufacturer's Quality Statement*:

5.4.1 *Written Policy or Mission Statement*—A written quality policy or quality mission statement shall be endorsed by the company's chief executive officer and shall also be available to all employees. The quality policy/mission statement shall indicate the support of top management to enforce the QC requirements contained in the QSM. The quality policy/mission statement shall contain a commitment to meeting a minimum standard of quality. A description of the QC system standards to be met shall be included.

5.5 *Manufacturing Facility and Products*:

5.5.1 *Facility Address and Telephone Number*—The QSM shall include the addresses and telephone numbers of all manufacturing facilities addressed by the QSM. The QSM shall include the telephone number and e-mail address for the QC manager and designated contact personnel.

5.5.2 *Standard Manufactured Materials Produced*—A brief listing and description of the specific products being manufactured shall be included in the QSM.

5.6 *Terms and Definitions*—The QSM should present and define any significant terms used throughout the QSM in order to establish a uniform understanding of essential concepts and to avoid potential confusion. Any terms defined in the QSM shall be consistent with the terms and definitions (see Section 3.1) included in this standard practice.

5.7 *Applicable Specifications (AASHTO, ASTM, Other)*—For all standard manufactured materials addressed under the QSM, the applicable AASHTO, ASTM, or agency specifications shall be identified. A list of the specifications should be presented (with relevant section numbers where applicable) in order to facilitate review of pertinent information.

5.8 *QCl System Roles and Responsibilities*—The personnel structure established to implement the manufacturer's quality system shall be outlined in the QSM. The specific roles and responsibilities of all QC personnel shall be documented as described below.

5.8.1 *QC Organization*—An organizational chart for the company shall be provided in the QSM. The organizational chart should indicate a clear separation between the QC personnel and production personnel. (see Figure 1.)

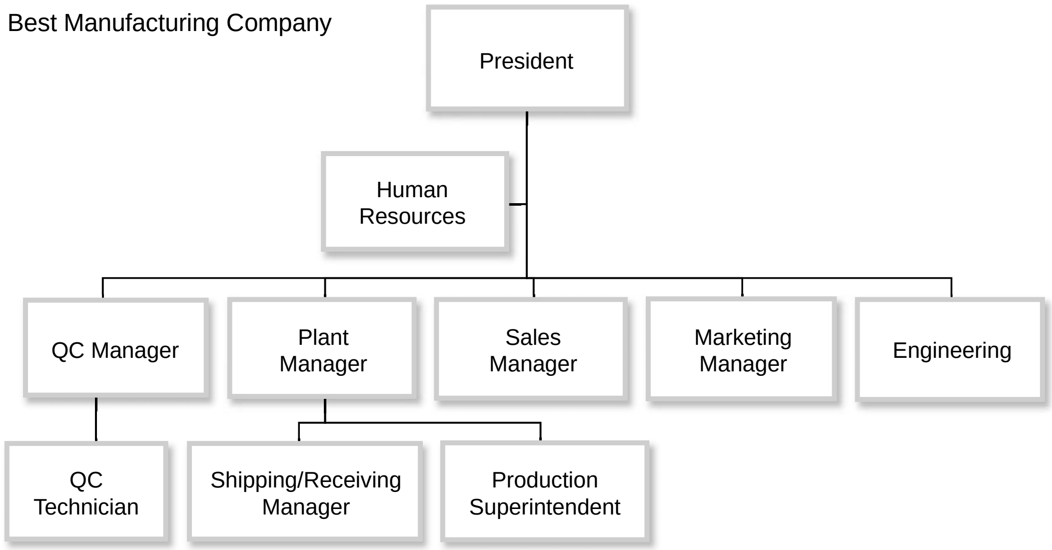

Figure 1—Sample Organization Chart

5.8.1.1 This figure illustrates a typical example of a manufacturing organization's structure and hierarchy. It is not intended to be prescriptive for the purpose of meeting the QSM requirements. Individual companies may vary in their size and arrangement; however, the effectiveness of the QC department may be significantly impacted unless the structure of the organization allows direct access to top management, independent from production responsibilities.

5.8.2 *Q C Manager*—The manufacturer shall have a QC manager who has the overall responsibility for implementing the requirements of the QSM. In addition, the manufacturer shall designate an individual with equivalent experience and qualifications to serve in the QC manager's absence. These individuals must have direct access to top management.

5.8.2.1 The QC manager shall review the QC system established to satisfy the requirements of this practice at least annually, if changes in the manufacturing process(es) occur, or whenever technical or purchaser's complaints describe a trend toward reduced quality.

5.8.3 *QC Technicians*—The manufacturer shall maintain a sufficient number of QC technicians to perform QC sampling, testing, and inspection, independent of production personnel. The technicians performing QC testing must be familiar with the tests they perform and have sufficient authority to assure that corrective actions are carried out when necessary. The quality system manual shall indicate the line of authority of QC technicians, which must demonstrate their authority to require corrective action. The QSM shall designate the qualified QC technicians at each production facility and laboratory involved in the production or testing of a product.

5.8.4 *QC Personnel Qualification Requirements*—The QSM shall contain a description of the specific knowledge, skills, qualifications, and certifications required for all personnel in the QC organization. All manufacturer QC sampling, testing, and inspection personnel shall be qualified through appropriate QC personnel qualification or certification programs. Personnel qualification/certification programs utilized may be either:

5.8.4.1 Personnel qualification/certification programs established by recognized organizations representing a particular manufacturing industry, or

5.8.4.2 Manufacturer in-house personnel qualification/certification programs acceptable to the transportation agency.

5.8.4.3 As a minimum, manufacturer in-house personnel qualification/certification programs shall require relevant experience, training, and demonstrated ability to satisfactorily perform the required inspection, testing, reporting, and documentation for the particular product manufactured.

5.8.4.4 The QSM shall describe in detail the particular qualification/certification program requirements the manufacturer will use to qualify QC personnel. Qualification/certification programs used shall include:

- Training in AASHTO, ASTM, or manufacturer test procedures,
- Demonstration of proficiency in each required test, and
- Demonstration of ability to properly document test results.

5.8.4.5 The program shall also include periodic auditing of each QC technician's ability to satisfactorily perform the required tests. The training shall include the operation of equipment, procedures to be used, calculations required, and reporting. Retraining shall be provided when an applicable method is revised. Technician training will be documented and the records pertaining to qualification/certification will be available for review.

5.8.5 *Production Personnel Responsibilities Concerning Quality*—QC should not be viewed simply as a separate activity or function within the manufacturer's organization but rather must be integrated throughout the organization. In other words, QC is not simply the responsibility of a "QC staff." It is not about relying on QC inspection and testing personnel to "make quality happen." While QC does require sampling, testing, and inspection by qualified QC personnel, quality can only be achieved by skilled workers who are properly trained to produce standard manufactured materials that conform to the specification requirements. The QSM shall describe the specific training provided to production personnel and the operating procedures implemented by these personnel to ensure the required quality of all standard manufactured materials produced.

5.9 *QC Laboratories*—Each manufacturer will maintain its own laboratory to perform QC testing. If required by the agency, the manufacturer will designate an alternate laboratory to serve a backup capacity.

5.9.1 *Laboratory Contact Information*—The QSM shall include the addresses and telephone numbers of all laboratories used by the manufacturer for QC testing. For each laboratory, the QSM shall include a contact person's name, telephone number, and e-mail address.

5.9.2 *Laboratory Accreditation or Qualification*—All manufacturer QC laboratories shall be qualified to perform the specific QC testing required for the manufactured items through an appropriate laboratory accreditation or qualification program. Laboratory accreditation or qualification must be attained through organizations or programs within one of the following three categories:

5.9.2.1 *Category I*—National laboratory accreditation programs,

5.9.2.2 *Category II*—Manufacturing industry organization programs that address laboratory qualification, or

5.9.2.3 *Category III*—Individual manufacturer laboratory qualification programs acceptable to the agency.

5.9.2.4 Examples of national laboratory accreditation programs (Category I) that address some standard manufactured materials include:

- AASHTO Accreditation Program (AAP)
- National Cooperation for Laboratory Accreditation (NACLA)
- American Association for Laboratory Accreditation (A^2LA)
- National Voluntary Laboratory Accreditation Program (NVLAP)

5.9.2.5 Examples of manufacturing industry organization programs that address laboratory qualification (Category II) for specific standard manufactured materials include:

- American Concrete Pipe Association (ACPA) Q-Cast Program
- Concrete Reinforcing Steel Institute (CRSI) Epoxy Certification Program
- National Precast Concrete Association (NPCA) Certification Program

5.9.2.6 Individual manufacturer laboratory qualification programs acceptable to the agency (Category III) must ensure that the following minimum requirements are met:

- A qualified technician shall supervise the laboratory facilities, and only qualified technicians shall perform all tests.
- The laboratory shall maintain current versions of all AASHTO, ASTM, and manufacturer test procedures for all tests performed and a current version of the company's QSM.
- The facility must adequately house and allow proper operation of all required testing equipment.
- The testing equipment shall be calibrated/verified in accordance with R 18. Testing equipment not described in R 18 shall be calibrated/verified in accordance with the manufacturer's recommendations at least once every 12 months by an appropriately qualified person.
- All laboratory equipment shall be properly maintained.
- The laboratory shall maintain records of all agency reviews and actions taken to resolve any noted deficiencies.
- Records of equipment calibration and verification will be maintained and available to the agency upon request.
- Category III laboratory programs will be reviewed and approved by the agency. Qualification will be based on the laboratory's ability to perform the required test procedures in accordance with the applicable standards, use of qualified testing technicians, calibration and verification of all testing equipment, and proper documentation. The agency may require one or more of the following before granting laboratory qualification: a demonstration of the equipment and procedures, split-sample testing with the agency, or round-robin testing.

5.9.3 *Testing Equipment*—The QSM shall contain an inventory of the major sampling, testing, and calibration equipment associated with any tests required to meet the QSM standards (Note 1). The QSM shall assign a unique identification number to each piece of testing equipment. The inventory shall include for each piece of major equipment: the name, date placed in service, manufacturer, model, and serial number (see Appendix X2, Figure X2.1).

Note 1—Major equipment includes all equipment that is normally amortized by a manufacturer, such as physical or chemical testing machines, balances, ovens, microscopes, computing equipment dedicated to testing, etc. Equipment such as chairs, desks, and file cabinets should be excluded. Major equipment does not include expendable items such as miscellaneous glassware, sieves, molds, etc.

5.9.3.1 The QSM shall contain a list giving a general description of testing equipment for performing tests covered by the scope of this standard practice which require calibration or verification. For each item listed, it shall include the interval of calibration or verification, a reference to the calibration or verification procedure used, and the location of calibration and verification records. When standard calibration procedures are used, the standard shall be referenced (e.g., compression machine, ASTM E 4). When the procedure used has been prepared by the manufacturer, the in-house designation shall be referenced. It shall be indicated whether the calibration is performed by an outside organization.

5.9.3.2 A copy of the manufacturer's instructions for use and calibration must be maintained on file. A reference to where the testing equipment inventory is located is acceptable if it is not included in the QSM.

5.9.3.3 The QSM shall describe the methods for ensuring that the calibration and verification procedures are performed for all required equipment at the specified intervals. It shall include the name of individual(s) responsible for ensuring that calibration and verification activities are performed and that procedures for handling new equipment, equipment removed from service, and out-of-calibration or defective equipment are followed. The QSM shall identify the individual(s) responsible for maintaining equipment calibration and verification records, describe the distribution of equipment calibration and verification records to management, and identify the location of resulting records.

5.10 *Pre-Production Materials Control*:

5.10.1 *Constituent Material Types and Sources of Supply*—The QSM shall list the specific types of constituent materials used for production of standard manufactured materials. All sources of supply of constituent materials shall be identified in the QSM.

5.10.2 *Visual Inspection of Constituent Materials*—All constituent materials should be visually inspected, as appropriate, prior to their use in the production of standard manufactured materials. QC procedures for visual inspection of constituent materials shall be included in the QSM.

5.10.3 *Control and Testing of Constituent Materials Properties*—The QSM shall contain a description of the specification requirements for any constituent materials received. The QSM shall contain a description of the certification and test reports delivered by the supplier(s) of the constituent materials and the location of these records. Any constituent materials that are not accepted by the manufacturer on the basis of a COC shall be tested and approved by the manufacturer prior to production of the standard manufactured material.

5.10.3.1 The QSM must include QC testing of the constituent materials used in the manufacturing process and must contain a statement that no raw materials will be used unless they have been tested and meet all AASHTO/ASTM requirements or have been shipped with a COC stating conformance with all requirements. For material having only a COC, at least one random sample must be taken from each lot of constituent materials received for preproduction QC testing to verify conformance with the specified requirements.

5.10.4 *Constituent Materials Storage*—All constituent materials should be properly stored to prevent damage, contamination, or other physical or chemical alteration prior to use in production of standard manufactured materials. QC procedures for adequate storage of constituent materials shall be described in the QSM.

5.11 *QC During Production of Standard Manufactured Materials*:

5.11.1 *Lot and Sublot Sizes*—The QSM shall describe the procedure and frequencies for inspection and selection of material samples during production. All standard manufactured materials shall be identified on a lot basis. Material lot sizes shall be established to ensure adequate QC inspection sampling and testing for the standard manufactured materials they represent. The lot size may be established by the manufacturer based upon production-run quantities or other criteria that ensure the material being evaluated within a lot is from the same material population.

5.11.1.1 QC inspection, sampling, and testing of each lot shall be established using one of the two following approaches:

- Nonstatistical lot system, or
- Statistically based lot and sublot system.
- The agency shall specify which system is to be used by the manufacturer.

5.11.1.2 Under a nonstatistical lot system, the manufacturer must provide a minimum frequency of QC inspection, sampling, and testing as specified by the agency. However, a minimum of one random sample shall be tested per lot. Lot sizes and QC inspection, sampling, and testing frequencies for each lot shall be identified in the manufacturer's QSM.

5.11.1.3 Under a statistically based lot and sublot system, each lot will be divided into a number of equally sized sublots. The use of a statistically valid sampling procedure is recommended to provide meaningful QC sampling and testing (Note 2). When a statistically based system is used, the manufacturer should select a minimum of three to five sublots per lot to ensure that the statistical sample obtained provides a meaningful representation of the lot. One random QC sample is obtained and tested from each sublot. QC inspection should also be provided for each sublot. Lot and sublot sizes shall be identified in the manufacturer's QSM when a statistically based lot and sublot system is used.

Note 2—ASTM E 105 describes procedures for determining statistically valid sample sizes and frequencies.

5.11.2 *QC Visual Inspection*—All standard manufactured materials should be visually inspected during production to ensure that the product meets the established requirements for quality. The QSM shall include QC procedures and documentation for visual inspection of each lot.

5.11.3 *Random Sampling Plan*—All manufacturer QC sampling and testing utilized in issuing a COC representing a given lot shall be performed using stratified random sampling techniques. Random sampling should be performed in accordance with ASTM D 3665. All random QC sample locations shall be properly documented. Procedures for performing and documenting QC random sampling shall be included in the QSM.

5.11.4 *Selective Sampling*—Nonrandom selective sampling may also be performed as necessary by the manufacturer to assist in controlling the production process or to assist in isolating apparent nonconforming material. Procedures for determining and documenting QC selective sampling locations shall be fully described in the QSM.

5.11.5 *Sample Identification System*—Each sample selected for QC inspection and testing (including all random and selective samples) shall be designated with a sample control number for record keeping and traceability. The test report for each sample shall identify the plant, date, shift of manufacture, production line, lot/sublot designation, and sample number. The QSM shall outline the QC sample identification system.

5.11.6 *Standard QC Sampling and Testing Methods (AASHTO, ASTM, Other)*—The QSM shall contain a description of the QC tests and verification processes utilized throughout the manufacturing process to ensure that the end product will meet the required quality level and quality limits (specification limits and engineering limits). Relevant test methods for any QC testing must be defined. Test methods should normally include AASHTO, ASTM, or other recognized industry standards. The specific quality characteristics that the test methods are being used to assess shall also be identified.

5.11.7 *Manufacturer-Developed Test Procedures*—The use of some surrogate test methods may be appropriate as part of the manufacturer's QC system. Manufacturer-developed tests shall only be used if there is no AASHTO or ASTM test method. The QSM shall include all manufacturer developed test procedures used in QC testing. All sampling and testing methods (standard and surrogate) shall be included in the QSM.

5.11.8 *QC Sample Storage and Retention Procedures*—Storage practices prior to testing should ensure that all QC samples are kept in a suitable location that protects them from damage and provides the proper environment for curing the material or maintaining the required material properties. It is recommended practice for all QC samples to be split prior to testing, in accordance with relevant sampling and testing procedures. The split-sample portion of material not used for initial testing should be retained in the original sample storage device with proper identification. The split samples should be stored in an appropriate "sample storage room" at the QC laboratory that performed the initial testing for a reasonable period (e.g., 30 to 60 days) acceptable to the agency. The QSM shall describe the procedures used for proper QC sample storage and retention.

5.11.9 *QC Inspection and Test Result Reporting*—Standard inspection report forms (IRFs) and standard test report forms (TRFs) should be used to record all QC inspection sampling and testing information. The QSM shall contain descriptions and examples of the IRFs and TRFs used by the manufacturer. The QSM shall identify the individual(s) responsible for maintaining inspection and test records and reports, shall describe the distribution of reports, and shall identify the location of resulting records. The QC IRFs and TRFs must be maintained and available for review for a minimum of 3 years.

5.11.10 *Use of Control Charts*—The manufacturer shall use statistical control charts to monitor the manufacturing process. Run charts may be used. However, control charts that plot subgroups of data must also be used. The QSM shall identify target values and ranges of operation used to set control chart limits. Control chart limits should be established for individual quality characteristics using data that define their relationship to specification limits and engineering limits.

5.11.10.1 Statistically valid control chart limits are necessary to describe threshold values reached during production of a lot when changes to the manufacturing process or other corrective action may be required to maintain the production of material within the quality limits. The QSM shall contain standard procedures for preparing and using control charts which depict the performance of the manufacturing process over time (see Appendix X3, Figure X3.1).

5.11.11 *Statistical Analysis of Test Results*—The QSM shall contain a description of the procedures used to statistically evaluate the quality of each lot using the applicable quality measure for each quality characteristic. QC personnel shall monitor QC test results for the purpose of identifying trends and to adjust production as necessary. All random QC test results should be evaluated for conformance with engineering limits and specification limits. The results of the statistical analysis of random QC test results for each lot shall be documented and included on the COC for each lot of standard manufactured materials.

5.11.12 *Resolution of Nonconforming Inspection or Test Results*—The QSM shall contain a description of the procedures used to identify and document products that do not conform to specification requirements. The identification of nonconformances may occur at any level of inspection or testing. Therefore, action at each level shall be based on standard policies described within the QSM. The QSM shall contain provisions for resolving non-conforming products or test results. Materials in a sublot that are identified as visibly deficient or that yield QC test results indicating potentially deficient material should be isolated from the lot. In the latter case, a statistically valid procedure shall be used for sampling and testing the remaining material in the sublot. The material should either be rejected (if determined to be visibly deficient) or further evaluated through selective sampling plus additional random sampling (a minimum of three random samples is recommended) and testing to ensure sufficient data is available to make a final disposition on the affected sublot.

5.11.12.1 Material in the sublot evaluated through this subsequent testing that is determined to be out-of-specification shall be labeled as defective. All nonconforming material shall be segregated in the inventory and corrected, if possible, or discarded. Procedures for marking and subsequent correcting or discarding of nonspecification material identified shall be fully described in the QSM.

5.12 *Post-Production QC Activities*:

5.12.1 *Marking, Storage, Shipping, and Handling of Standard Manufactured Materials*—The QSM shall describe a method for permanently marking the manufactured product in accordance with the requirements of any relevant AASHTO or ASTM standards. The QSM shall describe procedures for product handling, storage, and shipping to ensure that these processes will not adversely affect the material composition, characteristics, or product quality.

5.12.2 *QC Records*—All manufacturer QC inspection, sampling, and testing will be documented on standard forms developed by the manufacturer or as requested by the agency. All inspections will be documented on standard IRFs developed by the manufacturer. TRFs shall indicate the action taken to resolve nonconforming test results. The manufacturer shall maintain a complete list of documentation used to support the QSM and its processes. At a minimum, the following documentation shall be maintained:

5.12.2.1 Records of QC personnel qualifications and related training,

5.12.2.2 QC laboratory accreditation or qualification,

5.12.2.3 Testing equipment identification and verification/calibration records,

5.12.2.4 Incoming constituent material COCs and inspection and testing results,

5.12.2.5 In-process QC inspection and testing results,

5.12.2.6 Nonconforming material identification and disposition, and

5.12.2.7 Physical product dimensions or other characteristics related to agency acceptance.

5.12.3 *Retention of Inspection and Test Results and Product Traceability*—The QSM shall describe in detail the retention of all QC testing and inspection reports. They shall be available to the agency upon request. Certification and test results shall be kept on file for a period of not less than 3 years following shipment and delivery. The QC inspection and testing reports will be identified in such a way that the results for the manufactured product can be traced to the individual sublot and lot they represent.

5.12.4 *Issuance of Materials COC*—Each manufacturer will prepare for each lot of standard manufactured materials a standard COC form that meets the requirements of the agency. The COC shall include all necessary information to properly identify the material (e.g., pay item number, material number, lot number, sublot numbers) represented by the COC. Each COC is to be accompanied by a copy of all manufacturer QC inspection and test results for the corresponding lot of material.

5.13 *Quality Audit of the Manufacturing Facility*—If required by the agency, each manufacturing facility shall be audited by an independent auditing organization. Such quality audits shall be performed on an annual or other periodic basis as established by the agency. When periodic quality audits are required by the agency, the QSM shall include a description of the quality audit of each manufacturing facility producing standard manufactured materials. The quality audit shall assess the manufacturer’s compliance with each of the following QSM requirements, as a minimum:

5.13.1 Manufacturer’s quality statement,

5.13.2 Manufacturing facility and products,

5.13.3 Terms and definitions,

5.13.4 Applicable specifications,

5.13.5 Quality system roles and responsibilities,

5.13.6 QC laboratories,

5.13.7 Pre-production materials control,

5.13.8 QC during production of standard manufactured materials, and

5.13.9 Postproduction QC activities.

5.13.10 The audit findings shall be discussed with the QC manager, production manager, and top management and shall be documented in a quality audit report. Corrective actions will be taken as necessary and documented in a report prepared by the QC manager. The quality audit report shall be available for review by the agency.

6. ACCEPTANCE OF STANDARD MANUFACTURED MATERIALS

6.1 *QSM Approval*—The manufacturer's QSM shall be submitted for review and approval to each agency that is anticipated to purchase the manufacturer's product(s). The agency's approval is intended only to indicate that the QSM is in conformance with the minimum QC requirements set forth in this standard practice.

6.1.1 Once approved, the QSM provisions will remain in effect unless revisions are determined necessary by the QC manager or if revisions are requested by the agency. If any changes are made in the QSM, an updated copy of the QSM must be submitted to the agency for review and approval along with clear identification of the specific changes. Continued approval of the QSM will be based on the manufacturer's satisfactory adherence to all provisions contained in the approved QSM.

6.2 *Agency Access to Manufacturer Facilities*—The manufacturer shall sign a statement that allows state agency inspectors or their designated agents to enter any manufacturing plant or QC laboratory, unannounced, to observe the manufacturing process, review QC inspection, testing, and associated records, obtain samples for acceptance testing, or to inspect QC testing facilities, product storage, handling, and transport.

6.3 *Approach for Acceptance of Standard Manufactured Materials*—The specific procedures for acceptance of standard manufactured materials shall be determined by each agency. However, acceptance will typically be based on a COC that is supported by the QC inspection, sampling, and testing performed for the corresponding lot of standard manufactured materials in accordance with the approved QSM. If required by the agency, a copy of the manufacturer QC inspection and test results for the corresponding lot shall accompany each COC. QC test results will be reviewed by qualified agency personnel and may be used in the acceptance determination for material in a given lot. The agency may also perform acceptance inspection, sampling, and testing of products obtained from the manufacturing facility or after product delivery to the agency construction project site, in order to validate QC data.

6.4 *Acceptance Inspection, Sampling, and Testing*—The specific procedures and frequencies for acceptance inspection, sampling, and testing of standard manufactured materials shall be determined by each agency. However, acceptance inspection, sampling, and testing will typically not be performed by the agency during the manufacturing process for a given lot. As determined by the agency, acceptance sampling and testing may be performed for some quality characteristics of some materials by qualified agency personnel at the agency's laboratory on each lot delivered to the agency construction project site. The frequency of acceptance sampling and testing will typically be performed in the range of 10 to 20 percent of the manufacturer QC testing frequencies for each lot. However, this frequency may be adjusted by the agency as deemed appropriate for the particular material being tested. Field acceptance inspection of standard manufactured materials will be performed by qualified agency personnel at field placement locations on each lot at minimum frequencies determined by the agency.

6.5 *Application of Engineering Limits and Specification Limits*—The specific quality limits (specification limits and engineering limits) to be applied to each standard manufactured material shall be determined by each agency. However, the specification limits and engineering limits used will typically be in accordance with applicable AASHTO or ASTM standards or other relevant industry standards. Specification limits may be used to compute quality levels which may be used in calculating pay factors. Individual sample test results that fall beyond the engineering limits are considered to represent material that may be below an acceptable level and should be further evaluated to support an appropriate acceptance decision.

6.6 *Acceptance Documentation*—The specific procedures for documentation of the acceptance of standard manufactured materials shall be determined by each agency. However, the review by the agency of each manufacturer COC, accompanied by a copy of manufacturer QC inspection and test results, will typically be documented on a standard COC review form (COCRF) developed by the agency. Any acceptance sampling and testing performed on lots of standard manufactured materials delivered to the agency construction project site will be documented on standard TRFs developed by the agency. All agency field inspection of standard manufactured materials delivered to the agency construction project site will be documented on standard IRFs developed by the agency.

APPENDIXES

(Nonmandatory Information)

X1. MODEL QSM OUTLINE

X1.1. Manufacturer’s Quality Statement:

X1.1.1. Written Policy or Mission Statement

X1.2. Manufacturing Facility and Products:

X1.2.1. Facility Address, Telephone Number, and E-mail Contacts

X1.2.2. Standard Manufactured Materials Produced

X1.3. Terms and Definitions

X1.4. Applicable Specifications (AASHTO, ASTM, Other)

X1.5. QC System Roles and Responsibilities:

X1.5.1. QC Organization

X1.5.2. QC Manager

X1.5.3. QC Technicians

X1.5.4. QC Personnel Qualification Requirements

X1.5.5. Production Personnel responsibilities for Quality

X1.6. QC Laboratories:

X1.6.1. Laboratory Addresses, Telephone Numbers, and E-mail Contacts

X1.6.2. Laboratory Accreditation or Qualification

X1.6.3. Testing Equipment

X1.7. Preproduction Materials Control:

X1.7.1. Constituent Material Types and Sources of Supply

X1.7.2. Visual Inspection of Constituent Materials

X1.7.3. Control and Testing of Constituent Materials Properties

X1.7.4. Constituent Materials Storage

X1.8. Quality Control During Production of Standard Manufactured Materials:

X1.8.1. Lot and Sublot Sizes

X1.8.2. QC Visual Inspection

X1.8.3. Random Sampling Plan

X1.8.4. Selective Sampling

X1.8.5. Sample Identification System

X1.9. Standard QC Sampling and Testing Methods (AASHTO, ASTM, Other):

X1.9.1. Manufacturer Developed Test Procedures

X1.9.2. QC Sample Storage and Retention Procedures

X1.9.3. QC Inspection and Test Result Reporting

X1.9.4. Use of Control Charts

X1.9.5. Statistical Analysis of Test Results

X1.9.6. Resolution of Nonconforming Inspection and Test Results

X1.10. Postproduction QC Activities:

X1.10.1. Marking, Storage, Shipping, and Handling of Standard Manufactured Materials

X1.10.2. QC Records

X1.10.3. Retention of Inspection and Test Results and Product Traceability

X1.10.4. Issuance of Materials COC

X1.11. Quality Audit of the Manufacturing Facility

X2. EQUIPMENT INVENTORY AND CALIBRATION/VERIFICATION

Company: XYZ Manufacturing, Anytown, USA		
Manufacturer: A-1 Test Equipment Co.		Type: Compression Machine
Location: Bay 1, QC Test Office		Test: ASTM E 4
Model No: ABC1001	Serial No: 123456	Placed in Service: 2/4/99
Calibration/Verification Interval: Annual		Last Calibrated: 1/23/02

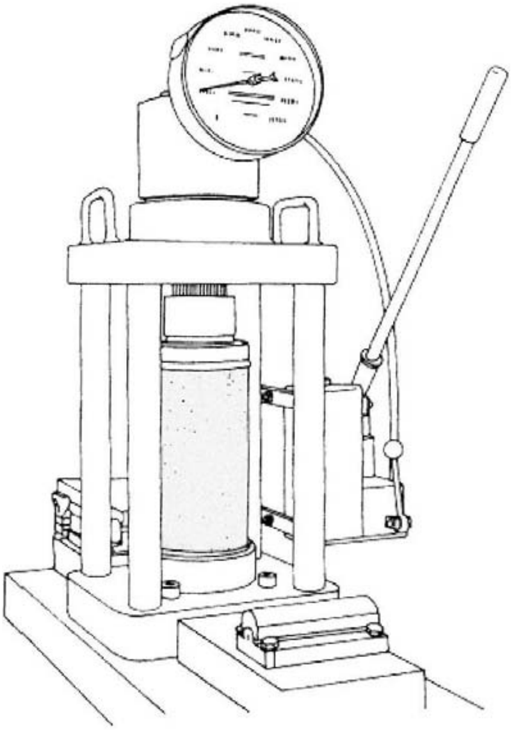

Figure X2.1—Example of Equipment Inventory and Calibration/Verification Document

X3. CONTROL CHART

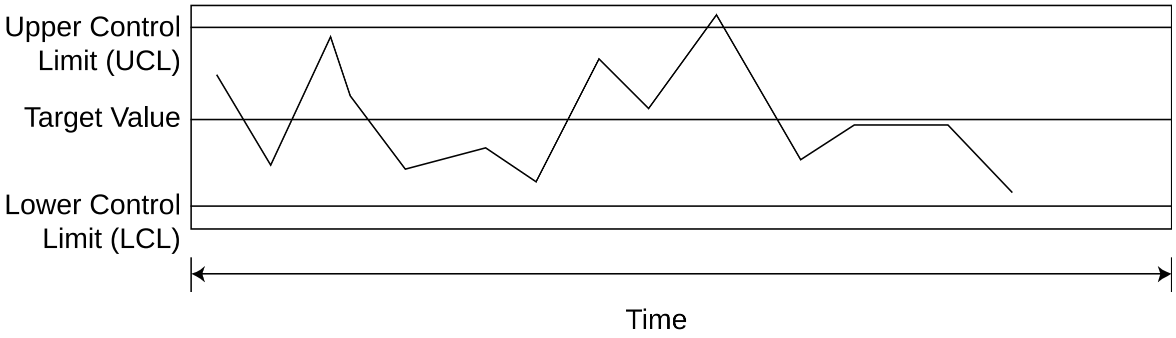

Figure X3.1—Example of Control Chart

Standard Practice for

Developing a Quality Assurance Plan for Hot Mix Asphalt (HMA)

AASHTO Designation: R 42-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Developing a Quality Assurance Plan for Hot Mix Asphalt (HMA)

AASHTO Designation: R 42-06

1. INTRODUCTION

1.1. This standard practice presents specific details necessary to effectively control the production and placement of hot mix asphalt (HMA).

1.2. *This standard practice may involve hazardous materials, operations, and equipment. This standard practice does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard practice to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. SCOPE

2.1. This standard practice provides the necessary quality assurance plan for control, verification, and acceptance of HMA pavement. It contains requirements for both quality control and acceptance.

2.1.1. This standard practice provides framework for a quality control plan that establishes minimum requirements and activities for a contractor's quality control (QC) System related to HMA production, and placement. These requirements include a listing of the inspections and tests necessary to substantiate material and product conformance to the specifications. The primary method of field quality control employs the use of the Superpave gyratory compactor and evaluation of the volumetric properties of the mix.

2.1.2. This standard practice also provides framework for a plan that establishes acceptance requirements for an agency's assessment and acceptance of an HMA project.

2.2. The values stated in SI units are to be regarded as the standard.

3. REFERENCE DOCUMENTS

3.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- R 9, Acceptance Sampling Plans for Highway Construction
- R 10, Definition of Terms Related to Quality and Statistics As Used in Highway Construction
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- R 26, Certifying Suppliers of Performance-Graded Asphalt Binders
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)

- R 35, Superpave Volumetric Design for Hot Mix Asphalt
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 30, Mechanical Analysis of Extracted Aggregate
- T 40, Sampling Bituminous Materials
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 165, Effect of Water on Cohesion of Compacted Bituminous Mixtures (Discontinued)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 283, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
- T 287, Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method
- T 304, Uncompacted Void Content of Fine Aggregate
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

3.2. *ASTM Standards*:

- C 702, Standard Practice for Reducing Samples of Aggregate to Testing Size
- D 8, Standard Terminology Relating to Materials for Roads and Pavements
- D 2950, Standard Test Method for Density of Bituminous Concrete in Place by Nuclear Methods
- D 3665, Standard Practice for Random Sampling of Construction Materials
- D 3666, Standard Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials
- D 4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
- D 5361, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing
- D 5821, Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate.
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 105, Standard Practice for Probability Sampling Of Materials
- E 122, Standard Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
- E 141, Standard Practice for Acceptance of Evidence Based on the Results of Probability Sampling

4. TERMINOLOGY

4.1. The terminology used in this standard is in accordance with R 10 unless otherwise specified.

4.2. *hot mix asphalt (HMA)*—a mixture of aggregate and asphalt binder produced from an HMA plant.

4.3. *design mix formula (DMF)*—the single point target value for percent passing designated sieve sizes and volumetric properties developed in the laboratory before the start of production.

4.4. *job mix formula (JMF)*—the single point target value for percent passing designated sieve sizes and volumetric properties established after the initial production process to be used by the contractor for production quality control.

4.5. *performance-graded asphalt binder (PGAB)*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers graded to temperature regimes and performance.

4.6. *quality assurance (QA)*—planned and systematic actions necessary to provide confidence that a product is in conformance with agency plans and specifications. It contains both QC and acceptance as two separate functions.

4.7. *quality control (QC)*—planned and systematic actions and considerations to control the level of quality being produced.

4.8. *QC plan*—project-specific plan that identifies methods of sampling, testing, calibration, QC monitoring, construction controls, paving plans, process balancing, and overall operations.

4.9. *acceptance*—sampling, testing, and assessment of test results to determine whether produced material and construction operation is in conformance with agency plans and specifications.

4.10. *independent assurance program (IAP)*—program developed by the agency to evaluate personnel and equipment used in the acceptance process on a project or system-wide basis.

4.11. *agency*—state highway agency or owner of the roadway.

4.12. Definitions of many common terms relating to HMA are contained in ASTM D 8.

4.13. Definitions of terms used in reference to other Standards are as defined therein.

4.14. Definitions of terms used in mathematical expressions are as generally used in standard practice. Unique terms are defined in the section containing the first presentation of such terms.

5. SUMMARY

5.1. This standard presents a procedure containing minimum requirements for QC and QA plans applicable to the production, placement, and acceptance of HMA. It incorporates the use of other available standards, which are appropriate to the accomplishment of this task. The requirements allow tailoring to accommodate the needs of an individual agency.

6. SIGNIFICANCE AND USE

6.1. Quality cannot be tested nor inspected into an HMA pavement. It must be built in through the implementation of properly designed QC and acceptance plans. The contractor should have a properly designed quality control plan and the agency should have a properly designed acceptance plan. The design and use of the plans is a critical step toward the successful manufacture, placement, and performance of HMA pavements.

6.2. This standard is used to aid in the completion of tasks noted in Sections 6.2.1 and 6.2.2.

6.2.1. Implementation of a QC plan for a contractor(s).

6.2.2. Implementation of an acceptance plan for an agency.

6.3. QC and acceptance plans conforming to this standard practice are applicable to HMA pavement construction projects. If an inconsistency exists between the contract documents and either plan, the contract documents should govern.

7. APPARATUS

7.1. *Laboratory Requirements*:

7.1.1. Personal safety equipment required by the laboratory or OSHA for work in the HMA design and testing areas.

7.1.2. Apparatus as required by referenced standards for this standard practice.

7.1.3. All other laboratory apparatus needed to control the quality of HMA production and placement in accordance with project specifications.

7.2. *Field Requirements*:

7.2.1. Personal safety equipment required by the field organization or OSHA.

7.2.2. Field apparatus listed in standards referenced as requirements in this standard practice.

7.2.3. All other field apparatus needed to control the quality of HMA production and placement in accordance with project specifications.

7.3. Apparatus required in Sections 7.1 and 7.2 should be furnished in the quantity necessary to assure that the materials and products used can be shown to conform to the HMA specification requirements without undue delay of the production and placement process.

7.4. Additional apparatus required for use by agency representatives for verification and acceptance activities should be provided by the agency unless otherwise specified.

8. STANDARDIZATION

8.1. Agency and contractor laboratories conducting work should satisfactorily participate in the AASHTO Materials Reference Laboratory (AMRL) proficiency sample program and should also be AMRL inspected. Alternately, a non-AASHTO laboratory qualification program that meets the same requirements could be used. Inspections or tests not covered by AMRL should comply with the applicable requirements of R 18 and ASTM D 3666.

8.1.1. All apparatus should be calibrated, and the calibration verified at established intervals, relevant to AASHTO, ASTM, or agency standards.

8.2. Sampling and testing personnel should be qualified through procedures developed by the agency for obtaining samples, processing samples, inspection of work, operation of testing equipment, and test equipment validation.

8.3. Verify the calibration of the nuclear density gauge(s) using ASTM D 2950 or another system approved by the agency.

8.4. Records demonstrating compliance with the equipment, personnel, and QC requirements should be available during construction for agency review.

9. FUNCTIONS AND RESPONSIBILITIES ON HMA PROJECTS

9.1. *Agency*:

9.1.1. The agency should review and approve HMA volumetric mix designs proposed by the contractor and assess the adequacy of the contractor’s QC plans. A reasonable time for review should be specified. The agency or a representative of the agency is responsible for all acceptance testing.

9.2. *Contractor*:

9.2.1. The contractor should be responsible for the development and formulation of the DMF using M 323, R 35, and T 312 which should be submitted to the agency for approval. The contractor should be responsible for the QC of all materials during the handling, blending, mixing, and placing operations. In addition, contractor tests may be used in the acceptance decision when a contractor acceptance program is developed by the agency in accordance with Section 14.5.

10. SAMPLING

10.1. *Initial Production Samples*:

10.1.1. The contractor and the agency should obtain samples of HMA from plant-produced materials in accordance with T 168 and the applicable procedures contained in Section 12.3 and Appendix X1. Samples should be reduced to testing size in accordance with T 248 or ASTM C 702. Procedures for oven conditioning or reheating of samples should be established.

10.1.2. The contractor and the agency should select sample locations on the control strip in accordance with Section 12.3 and Appendix X1. These locations are used for in-place density testing.

10.2. *Mix Production Samples*:

10.2.1. The contractor should obtain samples for QC in accordance with T 168, using a stratified random sampling plan in accordance with Section 13.3 for determining lot sizes and Appendix X1 or ASTM D 3665 for sample location. Samples should be reduced to testing size in accordance with T 248 or ASTM C 702.

10.2.2. The agency should obtain samples for acceptance in accordance with T 168, using a stratified random sampling plan in accordance with Section 13.3 for determining lot sizes and Appendix X1 or ASTM D 3665 for sample location. Samples should be reduced to testing size in accordance with T 248 or ASTM C 702.

10.3. *Sample Locations for In-place Coring or Testing*:

10.3.1. The agency representative should select in-place sample locations in accordance with Section 13.3 for determining lot sizes, Appendix X1 for sample location, and when cores are required, ASTM D 5361 for sampling.

Note 1—In addition to the random number tables in Appendix X1, ASTM D 3665 also contains a table of random numbers, including instructions for use. R 9 and ASTM E 105, E 122, and E 141 contain additional information concerning sampling practices.

11. MATERIAL REQUIREMENTS

11.1. *Performance-Graded Asphalt Binder*:

11.1.1. PGAB should conform to the requirements of M 320.

11.1.2. Quality control of PGAB from all suppliers should be in accordance with R 26 or other programs approved by the agency.

11.2. *Aggregates*:

11.2.1. The agency should develop a testing program to ensure that aggregates meet specification requirements. The contractor’s QC plan should include, as a minimum, discussion on the proposed processing, transportation, stockpiling, and plant charging operations.

12. FIELD ADJUSTMENT OF THE DMF

12.1. *Summary*:

12.1.1. During initial plant start-up adjustments may be made during the initial lot production to assure the plant-produced HMA will meet the design requirements.

12.1.2. The contractor should be responsible for the operation of the HMA plant and the production of the HMA within the DMF limits in Table 1. The limits in Table 1 are also used to control the amount of deviation from the DMF that the contractor may use when declaring a JMF. The declared JMF should meet the requirements of M 323.

Table 1—Allowable DMF Adjustments for Initial Production

HMA Composition Property	Adjustment Limit, %
Asphalt Binder Content (P_b)	±0.4
Gradation Passing 0.150-mm and Larger Sieves	±4.0
Gradation Passing 0.075-mm Sieve	±1.5
Voids in Mineral Aggregate (VMA)	±1.0
Voids Filled with Asphalt (VFA)	±5.0

12.2. *Initial Production Lot*:

12.2.1. At the beginning of production of each mixture required in the contract, an initial production lot should be used to evaluate the DMF. The initial production lot should be divided into four sublots as specified in Table 2 depending on the mixture type. The properties of the sublots will be measured and compared to the DMF. If the deviation in air voids in any sublot exceeds ±2.0 percent or in any two sublots exceeds ±1.5 percent, the production should cease and a new DMF should be developed in accordance with Section 9.2. If the difference from the DMF for asphalt binder content in any sublot exceeds the limit shown in Table 1, the production should cease and a new DMF should be developed in accordance with Section 9.2. If the difference from the DMF for any property other than asphalt binder exceeds two times the limits shown in Table 1 or any two sublots exceed the limits shown in Table 1, the production should cease and a new DMF should be developed in accordance with Section 9.2.

Table 2—Initial Production Lots and Sublots

Nom Max Size, mm	Sublot (Mg or tons)	Lot (Mg or tons)
4.75	300	1200
9.5	400	1600
12.5	500	2000
19.0	500	2000
25.0	500	2000
37.5	500	2000

12.2.2. The last sample in the lot should be within the limits of Table 1. The initial production lot should be closed out and the Contractor should declare a JMF. The lot should be accepted with a pay factor of 1.00. For material produced outside the tolerances of Section 12.2.1 the agency should determine if the material should be left in place. The agency should require that a JMF be declared after the initial production lot. Only one initial production lot should be allowed.

12.3. *Initial Production Lot Samples*:

12.3.1. The Contractor should obtain, using the methods required by Section 10, a sample of plant-produced HMA from each sublot. Samples should be obtained from the mat behind the screed or from the haul trucks at the plant. Since the evaluation criteria are based on in-place measurements, it is recommended that QC testing be completed on road samples.

Note 2—If acceptance testing is performed on road samples, and the QC testing is based on truck samples taken at the HMA plant, the contractor should develop appropriate correlation factors.

12.3.1.1. Determine asphalt binder content and combined aggregate gradation of the HMA samples in accordance with T 164 and T 30, or T 308, or T 287 and T 30 (on cold feed material).

12.3.1.2. Determine maximum theoretical specific gravity of the HMA samples in accordance with T 209.

12.3.1.3. Compact samples of HMA according to T 312.

12.3.1.3.1. Determine bulk specific gravity, G_{mb}, in accordance with T 166, Method A.

12.3.1.3.2. Determine the air void content in accordance with R 35 at N_{ini} and N_{des} gyrations.

12.3.1.4. Determine the VMA and the VFA in accordance with R 35.

12.4. *Control Chart Initiation*:

12.4.1. A process control chart is needed to determine whether the manufacturing process is in control. Individual data points and moving averages are plotted. The individual data points indicate variability and the moving average indicates conformance to the target value. Control charts should comply with the requirements of Appendix X2.

12.4.2. When an HMA initial production lot has been produced, the contractor should establish initial control charts using single point target values from the JMF in accordance with the requirements of Appendix X3.

12.4.3. Control charts are used to graphically represent the continuous control process. They include the target value that is to be achieved for a certain material property and acceptable upper and lower limits. When a measured value is determined and plotted on the control chart, it should fall within the control limits. Mixture adjustment can be made in response to the values plotted on these control charts.

12.4.4. Control limits are established based on statistical concepts that assume the material parameter in question follows a normal distribution. Typically, the upper and lower control limits (UCL and LCL) are based on $\pm 2s$ (warning control limits) and $\pm 3s$ (action control limits), where s is the typical industry standard deviation listed in Table X3.1.

12.5. *HMA Control Strip*:

12.5.1. The Contractor should place and compact the mixture produced during the initial production lot in order to establish that the equipment and the processes planned for placement and compaction are satisfactory.

12.5.2. The final compacted thickness of the HMA control strip should be the thickness required by the pavement cross-section.

12.5.3. The control strip should be a minimum of 150 m (500 ft) long.

12.5.4. After compaction is completed, ten cores should be taken at locations selected in accordance with Appendix X1. Density of the cores will be determined in accordance with T 166.

12.5.5. The control strip will be considered acceptable when the average core density meets or exceeds contract specifications. The Agency should specify limits for the number of control strips to be allowed.

12.5.6. The Agency should determine a minimum density (e.g. 91.0 percent of T 209) above which the HMA in the control strip is allowed to remain in place and paid for with a pay factor of 1.00. For

HMA with a density less than the minimum density, the Agency should determine if the HMA should be left in place.

13. QUALITY CONTROL SYSTEM

13.1. *General Requirements*:

13.1.1. The contractor should provide and maintain a QC system that will provide reasonable assurance that all materials and products conform to the specification requirements whether manufactured or processed by the contractor or procured from suppliers or subcontractors. The contractor should perform or have performed the inspection and tests required to substantiate product conformance to the HMA design requirements, and should also perform or have performed all inspections and tests otherwise required by the project specifications. The contractor's QC procedures, inspections, and proposed testing should be documented in a written QC plan (see Appendix X3). The plan should be approved by the Agency and be available for review through the life of the contract.

13.1.2. The contractor's QC Plan should be based on tests performed to determine compliance of the HMA with the JMF. The tests should be performed on samples obtained using statistically sound, randomized sampling procedures in accordance with Section 10.

13.1.3. Typical QC HMA properties include asphalt binder content, maximum theoretical specific gravity, air voids, VMA, VFA, and percent passing key sieves in the combined gradation. Target values for these HMA properties are those from the JMF. JMF values developed from Section 12.2 are the control values. In some situations the Agency may want to require other properties such as moisture content in the HMA or bulk specific gravity of the aggregate.

13.1.4. QC testing will be based on samples from individual sublots and lots.

13.1.5. In accordance with Agency requirements, the Contractor should record the quantities of asphalt binder, aggregate, mineral filler, and fibers (if required), as well as the quantities of HMA produced, and the production temperature.

13.2. *Quality Control Components*:

13.2.1. The QC plan should be contract-specific and state how the Contractor proposes to control the materials, equipment, and operations of the project. The Agency should specify minimum information for the QC plan such as: personnel, plant operation, HMA transportation, roadway operations, and compaction operations.

13.3. *Lots and Sublots for Quality Control*:

13.3.1. The QC plan should indicate lot and sublot size for initial production and production lots.

13.3.2. Production lots will be based on HMA as delivered to the roadway. Recommended lot will be defined for 19.0-mm nominal maximum aggregate size or larger mixture designs and for 12.5-mm or smaller mixture designs. Lots will be further sub-divided into equal sublots not to exceed 1000 Mg (1000 tons) for 19.0-mm or larger mixture designs or 600 Mg (600 tons) for 12.5-mm or smaller mixture designs. Typically, four or more sublots constitute a lot. Partial sublots of 100 Mg (100 tons) or less can be added to the previous sublot. Partial sublots greater than 100 Mg (100 tons) can constitute a full sublot. Lots that contain a single sublot could be combined with the previous lot for acceptance purposes.

13.4. *Quality Control Laboratory*:

13.4.1. The HMA producer should provide and maintain a laboratory for QC testing. The laboratory should have the necessary space, equipment, and supplies for the tests to be performed. The laboratory testing equipment should meet the requirements of the test methods identified for the required sampling and testing. The agency should have the right to observe all QC testing.

13.5. *Test Equipment Calibration*:

13.5.1. The test equipment furnished by the contractor should be properly calibrated or verified and maintained in accordance with Appendix X3.2 and R 18.

13.6. *Quality Control for Plant Operations*:

13.6.1. The contractor should designate the sampling and sample reduction procedures, sampling locations, and size of samples necessary for testing. Sampling should be performed on each sublot. Sample locations should be selected randomly according to Appendix X1. The contractor may select random numbers independent of agency locations or may match the Agency locations, but samples should not be split. If contractor tests are to be used for acceptance, Section 14.5 should govern the sampling requirements.

13.6.2. The contractor should utilize QC charts that show test results for critical sieves, asphalt binder content, maximum theoretical specific gravity, air voids, VMA and VFA to identify variability in the HMA production. Target values, warning and action limits should be shown on the same charts. Details regarding QC plans and QC charts are located in Appendix X3.

13.7. *Quality Control for Roadway Operations*:

13.7.1. The contractor should control the HMA placement and compaction process to ensure compliance with the project specifications. Details regarding QC for roadway operations are located in Appendix X3.

13.8. *Documentation*:

13.8.1. The contractor should maintain adequate records of all tests. The records should indicate the test results and the nature of corrective action taken as appropriate. All charts and records documenting the contractor's QC operations and tests should be available to the agency during the performance and upon the completion of the work. The contractor should keep the test results on file for a minimum period of three years following completion of the work.

13.8.2. Test properties for the various materials and mixtures should be charted on forms or other appropriate means in accordance with the applicable requirements of the agency.

13.8.3. If production is terminated in accordance with Appendix X3.4.4 or X3.5.5, the cause and resolution should be documented.

14. HMA ACCEPTANCE PROCEDURES

14.1. *General Requirements*:

14.1.1. Acceptance sampling and testing of HMA involves stratified random sampling that is applied to a series of sublots of HMA. The objective of acceptance testing is to verify that the product meets contract specifications.

14.1.2. The agency will obtain, using the methods required by Section 10, a sample of HMA from each sublot.

14.1.3. HMA properties for acceptance typically include the asphalt binder content, air voids, VMA, and other requirements of the agency. Target values for these HMA properties should be those from the JMF. Acceptance testing also includes density on the roadway.

14.1.4. Acceptance testing will be based on independent samples from the same sublots that are used for QC and, in fact, may include different properties. Lots and sublots will be based on mixture as delivered to the roadway.

14.1.5. The method of Acceptance should be statistically based to evaluate the acceptability of the HMA. Statistically based methods, such as percent within limits using standard deviation, should be used. See Appendix X4.

14.2. *Acceptance for Mixture Properties (Air Voids, VMA, Asphalt Content)*:

14.2.1. *Point of Sampling*—The agency representative should obtain stratified random acceptance samples in accordance with Section 10.2. The samples should be obtained from the HMA behind the screed prior to initial rolling.

Note 3—If a correlation factor between samples taken from a truck at the plant and samples from the roadway behind the screed has been developed, the sample may be taken from the haul truck at the plant.

14.2.2. *Number of Samples*—One sample per sublot in accordance with Section 10.2.2.

14.2.3. *Lot Size*—Lots will be defined for 19.0 mm nominal maximum aggregate size or larger mixture designs and for 12.5 mm or smaller mixture designs. Lots will be further sub-divided into equal sublots not to exceed 1000 Mg (1000 tons) for 19.0 mm or larger mixture or 600 Mg (600 tons) for 12.5 mm or smaller mixture. Typically, four or more sublots constitute a lot. Partial sublots of 100 Mg (100 tons) or less can be added to the previous sublot. Partial sublots greater than 100 Mg (100 tons) can constitute a full sublot. Lots that contain a single sublot could be combined with the previous lot for acceptance purposes.

14.2.4. If a delay of more than four calendar days occurs in any one sublot, a partial sublot should be declared and a new sublot should start when production resumes.

14.3. *Acceptance for In-place Density, Percent Theoretical Maximum Density, (%G_{mm}):*

14.3.1. *Point of Sampling*—The agency representative should determine stratified random acceptance sample locations in accordance with Section 10.3. The locations should be determined after rolling operations are completed.

14.3.2. *Number of Tests*—Two core samples or two nondestructive in-place tests per sublot are used in accordance with Section 10.3.1.

14.3.3. *Lot Size*—Lot and sublot sizes are to be the same as the HMA lots and sublots in accordance with Section 14.2.3.

14.3.4. *Acceptance Testing*—Obtain cores in accordance with ASTM D 5361 from each location and transport the cores to a laboratory for testing. From the HMA sample in each sublot, determine the maximum specific gravity. For each core, measure the bulk specific gravity in accordance with T 166, and calculate density as a percent of theoretical maximum density. Alternately if the variability of test results is acceptable to the Agency, a calibrated nuclear density gauge can be used to determine the bulk specific gravity at each location, in accordance with ASTM D 2950, and used to calculate density as a percent of theoretical maximum density (%G_{mm}).

14.4. *Acceptance Process*:

14.4.1. The Agency will determine acceptable quality limits for HMA properties and in-place density.

14.4.2. Smoothness is also an important acceptance property. The Agency should select a method of measuring smoothness (e.g. rolling straight edge, light-weight or high-speed profilometers) and will develop specific acceptance criteria.

14.4.3. The Agency may also use subjective measures such as segregation to determine the acceptability of the HMA. The Agency may add specific criteria that may not be statistically based.

14.5. *Contractor Tests Used in the Acceptance Decision*:

14.5.1. The use of Contractor tests for project acceptance is permitted when the Agency has developed an Acceptance Program in accordance with Section 14.1.5 that includes independent verification and statistical evaluation of the Contractor's test results. Contractor and Agency sample locations will be selected independently.

14.5.2. The contractor should maintain an acceptance testing program that includes the use of a qualified laboratory and qualified testing personnel, established material sampling frequencies and testing protocols, and reporting procedures. Contractor acceptance samples should be taken from the same point of sampling as used by the Agency.

14.5.3. The Agency should establish a verification sampling and testing program that includes testing of materials by a qualified laboratory and qualified testing personnel on samples taken independently of the contractor's acceptance tests but within the same production period, quantity, area, etc. as the contractor's tests.

14.5.4. The agency should develop a statistical method of comparing the contractor's acceptance and the agency's verification tests to verify the contractor's acceptance test results, such as a comparison of means and standard deviations.

14.5.5. The agency should develop a dispute resolution system in accordance with Section 15 that addresses the disposition of discrepancies occurring between the contractor acceptance and the agency verification tests.

14.5.6. The agency's independent assurance program should include the evaluation of the contractor's qualified laboratory and qualified testing personnel.

14.6. *Pay Factors:*

14.6.1. The Agency should develop a table of pay factors, pay equations, or pay curves based on the method of acceptance.

14.7. *Documentation*:

14.7.1. The agency should maintain adequate records of all acceptance tests. The records should indicate the test results and the acceptance decisions.

14.7.2. Contractor test results that are used for acceptance should be available to the agency during the performance of the work. Test results should be submitted to the agency on forms or other appropriate means in accordance with agency requirements.

15. DISPUTE RESOLUTION

15.1. The agency should establish procedures for addressing tests that do not meet the required specification limits, for identifying dissimilar test results, for providing backup samples, and for resolving differences.

15.1.1. The definition of dissimilar is typically based on the difference between reported values for split samples as related to the number of standard deviations (d2s) for the test. The agency should use AASHTO or ASTM test procedures to determine the range of allowable results between two laboratories. Other valid procedures include statistical tests that compare means and variability of the Acceptance and verification tests results.

15.1.2. The specification should indicate the process by which a backup sample will be taken. Backup samples should be taken at the same time as the original sample.

15.1.3. The dispute resolution process should address the length of time during which an appeal can be made, who will do testing on backup samples, and how the retest values will be used to resolve the dispute.

16. KEYWORDS

16.1. Acceptance plan; acceptance testing; contractor acceptance; control charts; hot mix asphalt; percent within limits; quality assurance; quality control; stratified random sampling; Superpave.

APPENDIXES

(Nonmandatory Information)

X1. STRATIFIED RANDOM SAMPLING

X1.1. *Scope*:

X1.1.1. This method outlines the procedures for selecting sampling sites in accordance with appropriate random sampling techniques. Random sampling is the selection of a sample in such a manner that every portion to be sampled has an equal chance of being selected as the sample. It is intended that all samples, regardless of size, type, or purpose, should be selected in an unbiased manner, based entirely on chance.

X1.2. *Securing Samples*:

X1.2.1. Samples should be taken as directed by the Contractor's representative for QC purposes and the Agency representative for acceptance purposes.

X1.3. *Random Number Table*:

X1.3.1. For test results or measurements to be meaningful, it is necessary that the material to be sampled or measured be selected at random using a table of random numbers. Table X1.1 has been devised for this purpose. To use the table in selecting sample locations, proceed as follows.

X1.3.1.1. Determine the lot size and stratify the lot into a number of sublots per lot for the material being sampled.

X1.3.1.2. For each lot, use consecutive two-digit random numbers from Table X1.1. For example, if the specification requires five sublots per lot and the number 15 is randomly selected as the starting point from Column X (or Column Y) for the first lot, numbers 15–19 would be the five consecutive two-digit random numbers. For the second lot, another random starting point, number 91 for example, is selected and the numbers 91 through 95 are used for the five consecutive two-digit random numbers. The same procedure is used for additional lots.

X1.3.1.3. For samples taken from the roadway, use the decimal values in Column X and Column Y to determine the coordinates of the sample locations.

X1.3.1.4. In situations where coordinate locations do not apply (i.e., plant samples, stockpile samples, etc.), use those decimal values from Column X or Column Y.

Table X1.1—Random Positions in Decimal Fractions (Two Places)

Sequence No.	X	Y
1.	0.29	R 0.66
2.	0.74	R 0.49
3.	0.89	L 0.79
4.	0.60	R 0.39
5.	0.88	R 0.31
6.	0.72	L 0.54
7.	0.12	R 0.08
8.	0.09	L 0.94
9.	0.62	L 0.11
10.	0.71	R 0.59
11.	0.36	L 0.38
12.	0.57	R 0.49
13.	0.35	R 0.90
14.	0.69	L 0.63
15.	0.59	R 0.68
16.	0.06	L 0.03
17.	0.08	L 0.70
18.	0.67	L 0.68
19.	0.83	R 0.97
20.	0.54	R 0.58
21.	0.82	R 0.50
22.	0.66	R 0.73
23.	0.06	L 0.27
24.	0.03	L 0.13
25.	0.55	L 0.29
26.	0.64	L 0.77
27.	0.30	R 0.57
28.	0.51	R 0.67
29.	0.29	R 0.09
30.	0.63	R 0.82
31.	0.53	L 0.86
32.	0.99	R 0.22
33.	0.02	R 0.89
34.	0.61	L 0.87
35.	0.76	R 0.16
36.	0.87	L 0.77
37.	0.41	L 0.10
38.	0.28	R 0.23
39.	0.22	L 0.18
40.	0.21	L 0.94
41.	0.27	L 0.52
42.	0.39	R 0.91
43.	0.57	L 0.10
44.	0.82	L 0.12
45.	0.14	L 0.94
46.	0.50	R 0.58
47.	0.93	L 0.03
48.	0.43	L 0.29
49.	0.99	L 0.36
50.	0.61	R 0.25
51.	0.87	L 0.36
52.	0.34	L 0.19
53.	0.37	R 0.33
54.	0.97	L 0.79
55.	0.13	R 0.56
56.	0.85	R 0.64
57.	0.14	L 0.04
58.	0.99	R 0.74
59.	0.40	L 0.76
60.	0.37	L 0.09
61.	0.90	R 0.74
62.	0.09	L 0.70
63.	0.66	L 0.97
64.	0.89	L 0.55
65.	0.67	L 0.44
66.	0.02	R 0.65
67.	0.93	R 0.17
68.	0.40	R 0.50
69.	0.44	R 0.15
70.	0.03	L 0.60
71.	0.19	L 0.37
72.	0.92	L 0.45
73.	0.20	L 0.85
74.	0.05	R 0.56
75.	0.46	R 0.58
76.	0.43	R 0.91
77.	0.97	L 0.55
78.	0.06	R 0.51
79.	0.72	L 0.78
80.	0.95	L 0.36
81.	0.16	L 0.61
82.	0.29	R 0.47
83.	0.48	R 0.15
84.	0.73	R 0.64
85.	0.05	L 0.94
86.	0.43	L 0.05
87.	0.87	R 0.98
88.	0.37	L 0.71
89.	0.94	L 0.26
90.	0.57	L 0.63
91.	0.26	R 0.80
92.	0.01	L 0.79
93.	0.83	R 0.59
94.	0.71	L 0.21
95.	0.65	L 0.63
96.	0.65	L 0.87
97.	0.72	R 0.92
98.	0.85	L 0.78
99.	0.04	L 0.46
100.	0.29	L 0.95

Note: X = Decimal fraction of total length measured along the road from the starting point.
Y = Decimal fraction measured across the road from either outside edge towards the centerline of the paved lane.

X1.4. *Random Sample*:

X1.4.1. A random number table is a collection of random digits. The random numbers that are presented in Table X3.1 are shown in a two-place decimal format. Note that there are two columns, labeled X and Y. The numbers in either column can be used to locate a random sample when only a single dimension is required to locate the sample (e.g., time, tonnage, and units). When two dimensions are required to locate the sample, the number in the X column is used to calculate the longitudinal location, and the number in the Y column is used to calculate the transverse location. In the Y column, each number is preceded by an L or R, designating that the sample increment is to be located transversely from the left or right edge of the pavement. Figure X1.1 illustrates the procedure. An example demonstrating the use of the random sampling technique follows:

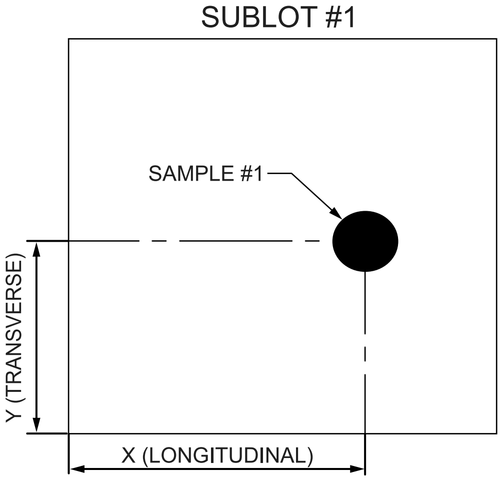

Figure X1.1—Determination of Sample Location Using Random Numbers

X1.5. *Sampling Example by Material Mass*:

X1.5.1. HMA must be sampled to determine the asphalt binder content and other mixture-related criteria. The definitions which define the lot and sublot size are located in Sections 13.3.2 and 14.2.3. The total tonnage for the example project is 21,700 Mg (tons).

X1.5.2. First, identify the lot size and then determine the number of lots, sublot size, and, finally, the point at which samples will be obtained.

X1.5.3. *Lot Size and Number of Lots*—For example, with a 19.0 mm nominal maximum aggregate size mixture, the lot size is 5,000 Mg (tons). Assuming there are 21,700 Mg (tons) of HMA required for the project, the total number of lots is:

$$\text{Number of Lots} = \frac{21{,}700\ \text{Mg (tons)}}{5{,}000\ \text{Mg (tons)/lots}} = 5\ \text{lots}$$

X1.5.4. *Sublot Size*—Based on Section 14.2.3 the sublot size is 1000 Mg (tons). The relationship between lot and sublot size is shown in Figure X1.2. The actual number and size of sublots in a lot could depend on specific conditions if partial sublots are declared during construction.

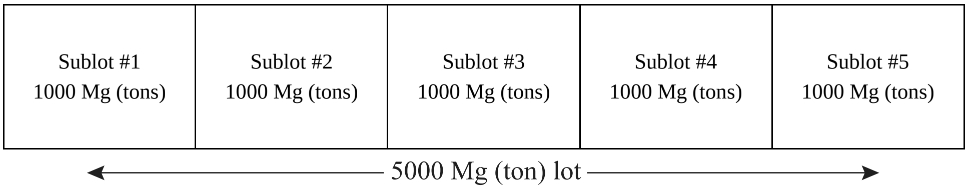

Figure X1.2—Relationship Between Lot and Sublots

X1.5.5. *Sublot Samples*—For example, for HMA property samples, the number of samples per lot is five, one per sublot. Five random numbers are selected from the table of random numbers. A block of numbers from the random number table (Table X1.1) is reproduced below.

Sequence Number	*X*	*Y*
67.	0.93	R 0.17
68.	0.40	R 0.50
69.	0.44	R 0.15
70.	0.03	L 0.60
71.	0.19	L 0.37

X1.5.6. Select random numbers from the Y column only (disregard the L or R). These numbers are 0.17, 0.50, 0.15, 0.60 and 0.37. Multiply the numbers by the size of each sublot as follows to determine the megagram (ton) to be sampled in the sublot.

Sublot	Sublot Random Number	Size Mg (ton)	Sample from Mg (ton)
1	0.17	1000	170
2	0.50	1000	500
3	0.15	1000	150
4	0.60	1000	600
5	0.37	1000	370

X1.5.6.1. The technician must obtain the first sample at approximately the 170th Mg (ton) of the first sublot. The technician must then wait until the first sublot is completed, 1000 Mg (tons), before selecting the second sample at the 500th Mg (ton) of the second sublot. The same sequence is followed for obtaining the remaining three samples.

X1.5.6.2. The sampling sequence for the lot of 5000 Mg (tons) should be:

Sublot 1: 170th Mg (ton)
Sublot 2: 1000 + 500 = 1500th Mg (ton)
Sublot 3: 2000 + 150 = 2150th Mg (ton)
Sublot 4: 3000 + 600 = 3600th Mg (ton)
Sublot 5: 4000 + 370 = 4370th Mg (ton)

Sublot sampling based on mass is illustrated in Figure X1.3.

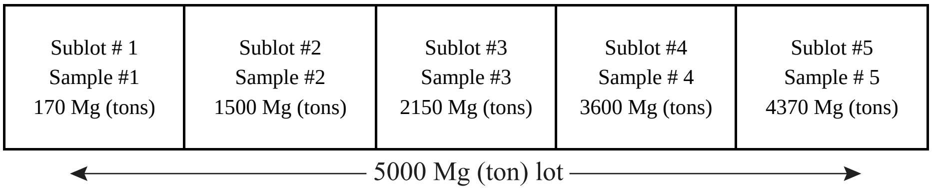

Figure X1.3—Sublot Sample

X2. STATISTICAL CONTROL CHARTS

X2.1. *Process Control*:

X2.1.1. The process control procedure recommended is the use of control charts, particularly statistical control charts. Control charts provide a means of verifying that a process is in control. It is important to understand that statistical control charts do not get or keep a process under control. The plant or construction personnel must still control the process. Control charts simply provide a visual warning mechanism to identify when the Contractor or material supplier should look for possible problems with the process.

X2.1.2. Variation of construction materials is inevitable. The purpose of control charts, then, is not to eliminate variability, but to distinguish between the inherent or chance causes of variability and a system of assignable causes. Chance causes are a part of every process and can be reduced but generally not eliminated. Assignable causes are factors that can be eliminated, thereby reducing variability. Chance causes are something that cannot be eliminated, but it may be possible to reduce their effects. The second cause of variation, assignable causes, can create major problems. However, assignable causes can be eliminated if they can be identified. Examples of assignable causes might be when the gradation for an aggregate blend goes out of specification due to a hole in one of the sieves or because the cold feed conveyor setting is incorrectly adjusted.

X2.1.3. The statistical control chart enables the contractor to distinguish between chance and assignable causes. Based upon statistical theory, construction materials, when under production control, exhibit a “bell-shaped” or normal distribution curve.

X2.1.4. The data, therefore, can be assumed to be within ±3 standard deviations (σ of the mean or target) when the process is in control and only chance causes (variability that the contractor cannot control) are acting on the system. Statistical control charts for average or means rely on the fact that, for a normal distribution, essentially all of the values fall within ±3 standard deviations from the mean. A normal distribution can be used because the distribution of sample means is normally distributed.

X2.1.5. A statistical control chart can be viewed as a normal distribution curve on its side (Figure X2.1). For a normal curve, only about 0.27 percent (1 out of 370) of the measurements should fall outside ±3 standard deviations from the average or mean. Therefore, control limits (indicating that an investigation for an assignable cause should be conducted) are set at $+3\sigma$ and -3σ.

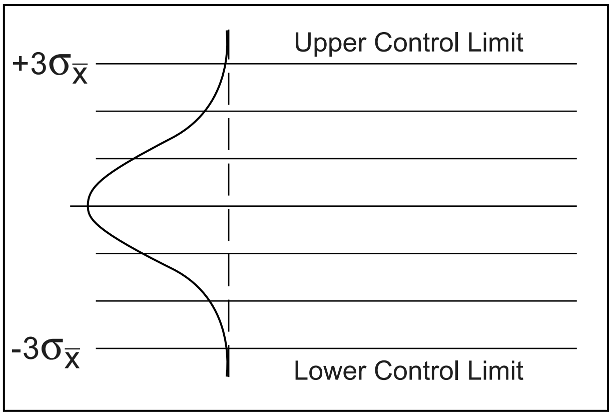

Figure X2.1—Example of a Statistical Control Chart

X2.1.6. A statistical control chart includes a target value, control limits and a series of data points that are plotted. As shown in Figure X2.2, the target value is either the production mean or design value and the control limits are established based on the standard deviation of the properties.

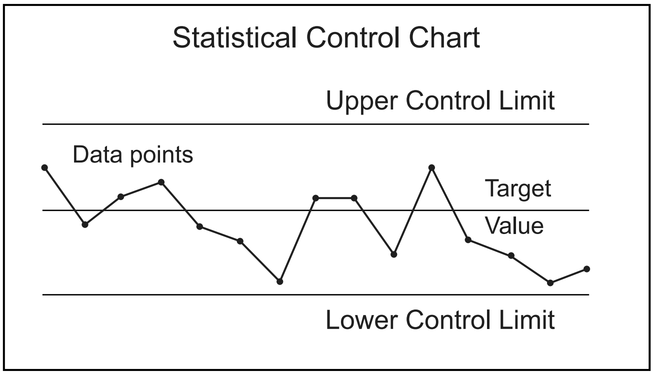

Figure X2.2—Elements of a Statistical Control Chart

X2.2. *Form of Statistical Control Charts to Be Used for HMA*:

X2.2.1. There are many forms of statistical control charts, but the form recommended in this standard practice for construction materials and processes is a control chart which shows individual test data points and a moving average. This process control chart is typically used to control the production process about the target value. Highly variable, individual test data points indicate variability in the process even though the moving average may be acceptable.

X2.2.2. For HMA the process control chart for the moving average has five reference lines that are defined as follows:

- upper action limit is the target value plus three standard deviations (Table X3.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.
- upper warning limit is the target value plus two standard deviations (Table X3.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.
- target value is the value of the property from the declared JMF.

- lower warning limit is the target value minus two standard deviations (Table X3.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.
- lower action limit is the target value minus three standard deviations (Table X3.1) divided by the square root of the number of samples in the moving average. Typically five samples are used.

X2.2.3. Figure X2.3 shows a process control chart for asphalt binder content. The target value for asphalt binder content, 5.7 percent, is obtained from the JMF.

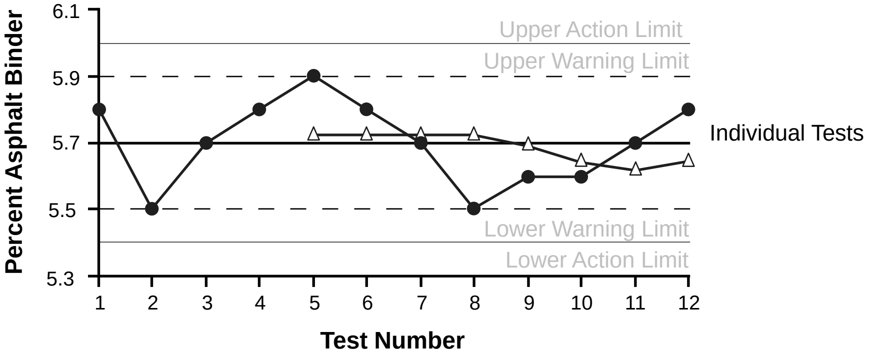

Figure X2.3—Control Chart for Asphalt Binder Content

X2.2.3.1. From Table X1.1 the standard deviation for asphalt binder content determined by extraction is 0.25 percent.

X2.2.3.2. The deviation from the target value for the warning limits for a moving average of five samples is

$$= 2 \times 0.25 / (\sqrt{5})$$

$$= 0.22$$

X2.2.3.3. The upper and lower warning limits are

UWL = 5.7 + 0.22 = 5.9

LWL = 5.7 – 0.22 = 5.5

X2.2.3.4. The deviation from the target value for the action limits for a moving average of five samples is

$$= 3 \times 0.25/(\sqrt{5})$$

$$= 0.33$$

X2.2.3.5. The upper and lower action limits are

UAL = 5.7 + 0.33 = 6.0

LAL = 5.7 – 0.33 = 5.4

X2.2.4. The individual test data points from each sublot are plotted on the chart and connected. This series of data points provides a visual indication of variability. If variability is high, the process can be refined to reduce variability. The moving average of five data points is calculated starting with the fifth data point and plotted on the chart. The moving average data points provide a visual indication of conformance with the target value. It is also possible to detect trends in the production and adjust the operation to bring the moving average closer to the target.

X2.2.5. Figure X2.4 shows a process control chart in which variability is higher than that shown in Figure X2.3. The higher variability is indicated by the individual test results. In addition, the moving average is consistently above the target. Steps should be taken to reduce variability and bring the moving average closer to the target.

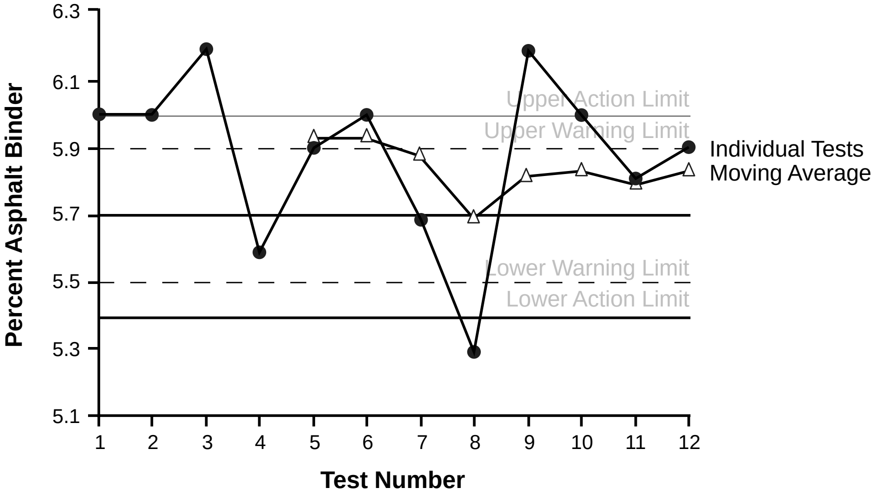

Figure X2.4—Control Chart for Asphalt Binder Content

X3. QUALITY CONTROL REQUIREMENTS FOR HOT MIX ASPHALT

X3.1. *Scope*:

X3.1.1. This appendix provides the details for contractor QC activities for HMA.

X3.2. *Test Equipment Calibration*:

X3.2.1. The equipment calibration or verification documentation should include:

X3.2.1.1. Name of the person performing the calibration or verification;

X3.2.1.2. Identification of the calibration equipment used, e.g., standard weights, proving rings, thermometers, etc;

X3.2.1.3. Last date that the calibration or verification was performed; and

X3.2.1.4. A reference to the calibration procedure used.

X3.2.1.5. Records showing the results of the calibration or verification performed.

X3.3. *Materials Sampling and Testing*:

X3.3.1. Sampling should be performed on each sublot on a random basis. The test methods and minimum frequencies of the QC tests for each HMA design should be designated. Test results should be rounded in accordance with ASTM E 29 using the rounding method.

X3.3.2. *Blended Aggregate*—A minimum of one sample should be obtained and tested for gradation in accordance with T 27 performed on each sublot on a random basis.

X3.3.2.1. *Batch Plants*—The blended aggregate gradation should be determined by calculating the combined gradation of the aggregate from each hot bin.

X3.3.2.2. *Drum Plants*—The blended aggregate gradation should be determined using aggregate samples from the cold feed belt after all materials are placed on the belt. The moisture content of the samples should be determined in accordance with T 255.

X3.3.3. *Recycled Materials*—A minimum of one sample for each 1000 kg (1000 tons) of recycled asphalt materials should be obtained and tested for asphalt binder content in accordance with T 164, gradation in accordance with T 30, and moisture content in accordance with T 255. Asphalt binder content may be determined with T 308 if a calibration factor to T 164 has been determined.

X3.3.4. *Hot Mix Asphalt*—As a minimum, samples should be obtained to determine the asphalt binder content, air voids, and VMA of the HMA. The sample should be obtained in accordance with Section 10.2. The sample should be reduced to testing size in accordance with T 248 or ASTM C 702, Method B. Place the test specimen mass into a heated mold, compact to N_{des} in accordance with T 312, and determine the bulk specific gravity in accordance with T 166. If the HMA requires reheating to achieve the compaction temperature, it should be placed in a loosely sealed, covered container. Oven temperature and time in the oven should be controlled, as defined by the Agency, to prevent a significant change in asphalt absorption and theoretical maximum specific gravity. The maximum specific gravity should be determined in accordance with T 209. One sample should be tested for moisture content in accordance with T 255, asphalt binder content in accordance with T 164 or T 308, and gradation in accordance with T 30. Alternately the asphalt binder content may be determined in accordance with T 287, in which case the gradation should be determined from the combined cold feed aggregates in accordance with T 27. The aggregate consensus properties, coarse aggregate angularity (ASTM D 5821), fine aggregate angularity (T 304), flat and elongated particles (ASTM D 4791), and sand equivalent (T 176) may be required as determined by the agency.

X3.4. *Control Charts*:

X3.4.1. The contractor should use control charts for critical sieves, asphalt binder content, maximum theoretical specific gravity, bulk specific gravity of the compacted HMA, air voids, and VMA to identify variability in the HMA production process. All test results should be recorded on the control chart the same day the tests are conducted. The charts are to be used to determine if the HMA production is in control.

X3.4.2. Target values and warning and action limits for the control charts are determined from the JMF HMA properties and plotted on the control charts. The warning and action limits are determined using typical industry standard deviations for HMA properties as shown in Table X3.1.

X3.4.3. Individual test results and the moving average of the five most current test results should be plotted. Five consecutive individual test results plotted on either side of the target value indicate an HMA composition change. If a HMA compositional change has occurred, modifications should be made to adjust the HMA property back to the target value. If a HMA compositional change has occurred in a non-pay element, the Contractor may elect to change the target value instead of adjusting the HMA property back to the target value.

X3.4.4. For a pay element, if one moving average point falls outside the warning limits, an investigation should be completed and adjustments made to bring the property back within the warning limits. The adjustment should be documented. If two consecutive moving average points fall outside the warning limit or one moving average point falls outside the action limit, production should be terminated, and a new DMF should be established in accordance with Section 9.2.1.

Note X1—In the event that one moving average point falls outside the warning limit, individual data points typically will indicate that the HMA property has been shifting over multiple sublots. If no action is taken to bring the HMA property back to the target value, a second moving average point will fall outside the limits; therefore, a new DMF is needed. In the event one moving average point falls outside the action limit, the individual data point is indicative of a major change in the HMA property. Production should cease, and an investigation should be initiated to determine the cause. If significant changes have occurred in the materials, a new DMF should be developed.

Table X3.1—Typical Industry[a] Standard Deviations for Hot Mix Asphalt Properties (Mixture Composition, Gyratory Properties and In-Place Density)[b]

HMA Composition Property		Extraction	Nuclear Gauge	Ignition Furnace	Cold Feed
Asphalt Binder Content (P_b), %		±0.25	±0.18	±0.13	—
Gradation Passing 4.75-mm and Larger Sieves, %		±3	NA	**	±3
Passing 2.36-mm to 0.150-mm Sieves, %		±2	NA	**	±2
Passing 0.075-mm Sieve, %		±0.7	NA	**	±0.7
Maximum Theoretical Specific Gravity (G_{mm})	±0.015				
Gyratory Compacted HMA Property					
Air Voids (V_a), %	±1.0				
Voids in Mineral Aggregate (VMA), %	±1.0				
Voids Filled with Asphalt (VFA), %	±5				
Bulk Specific Gravity (G_{mb})	±0.022				
In-Place Density					
Roadway Core Density (%G_{mm}), %	±1.4				

[a] Agency-specific standard deviations may be developed in lieu of the industry standard deviation.

[b] NCHRP 9-7 did not develop standard deviations for gradation of aggregate recovered from the ignition furnace; however, the standard deviation is expected to be the same as for cold feed or solvent-extracted aggregates.

X3.4.5. For a non-pay element, if one moving average point falls outside the warning limit, the contractor may elect to change the target value or adjust the property back to the target value. Mixture production should be adjusted within the limits of Table 1, Section 12.1.2. If, after making the adjustment, the mixture property remains outside the warning limit, a new DMF should be developed in accordance with Section 9.2.1.

X3.5. *Roadway Operations*:

X3.5.1. At the beginning of roadway operations the contractor should establish a rolling pattern to meet the minimum specified density. A control strip should be constructed in accordance with Section 12.5. Density will increase up to a certain point, after which a very small increase in density can be obtained with additional roller passes. At this point the density is presumed to have reached its maximum and is then considered to have peaked when additional rolling does not increase the density by more than 20 kg/m^3 (1 lb/ft^3).

X3.5.2. The contractor should use control charts for roadway density to identify variability in the HMA compaction process. All test results should be recorded on the control chart the same day the tests are conducted. The charts are to be used to determine if the HMA compaction process is in control.

X3.5.3. Target values and warning and action limits for the control charts are determined from the control strip described in Section 12.5 and plotted on the control charts. The warning and action limits are determined using typical industry standard deviations for roadway density as shown in Table X3.1.

X3.5.4. Individual test results and the moving average of the five most current test results should be plotted. If an HMA compositional change occurs and a new control strip is established, the target value would be changed.

X3.5.5. If one moving average point falls outside the warning limits, an investigation should be completed and adjustments made to bring the property back within the warning limits. The adjustment should be documented. If two consecutive moving average points fall outside the warning limit or one moving average point falls outside the action limit, the Contractor should terminate production. Prior to resuming production, the Contractor should provide the Agency with the assignable cause for the unsatisfactory density test results and develop a new control strip in accordance with Section 12.5.

X3.5.6. For purposes of QC for in-place density, lots and sublots should be in accordance with Section 13.3.2. Location of in-place sample or test sites should conform to the requirements of Appendix X1 in each sublot. The Contractor should utilize standard nondestructive industry equipment and procedures to provide suitable estimates of the in-place density.

X3.6. *Quality Control Plans*:

X3.6.1. The contractor should develop a QC plan that is expected to be specific to operations in use at any given time. The contractor should be able to make changes as required to respond to changes in the operation. A plan should not be so general as to cover all expected situations. The plan should be contract-specific and should include the following:

X3.6.1.1. Personnel including management personnel and plant and roadway technicians;

X3.6.1.2. Plant operations including stockpile management, material feed systems, HMA storage and truck loading procedures, materials and finished product sampling, and testing procedures;

X3.6.1.3. Transportation of HMA including truck types, release agents, load cover, and truck discharge procedures;

X3.6.1.4. Roadway operations including use of material transfer devices or windrow pickup machines, paver setup such as paver speed, slope and grade control, and screed extensions; and

X3.6.1.5. Compaction operations including roller type and number, roller setup (e.g. amplitude, frequency, or tire pressure), and roller speed.

X4. PERCENT WITHIN LIMITS (PWL) FOR HMA CALCULATED USING STANDARD DEVIATION

X4.1. *Scope*:

X4.1.1. This appendix provides the procedure for determination of the percent of material that is within the specification limits established for the HMA using the mean and standard deviation of the lot.

X4.2. *Significance and Use*:

X4.2.1. The PWL is a calculation used in the agency acceptance plan to determine the acceptability of materials on the project.

X4.3. *Setting of Upper and Lower Specification Limits*:

X4.3.1. Since the PWL procedure is an estimate of the population based on small sample distribution, the agency should set upper and lower specification limits relative to the desired mean and standard deviation. The mean is the target value established by the JMF and the standard deviation is one typically found from test data for the property. Proposed specification limits are evaluated for reasonableness to ensure constructability and performance. Table X4.1 provides typical industry standard deviation values.

Note X2—Agency may use historical standard deviation within the state. At a minimum the standard deviation should be no greater than the typical industry standard deviations in Table X4.1 that were developed during NCHRP 9-7.

X4.3.2. Determine the specification limits and acceptable quality level (AQL). The AQL is usually set to be 90 PWL, which means the specification limits will be ±1.645 standard deviations from the target.

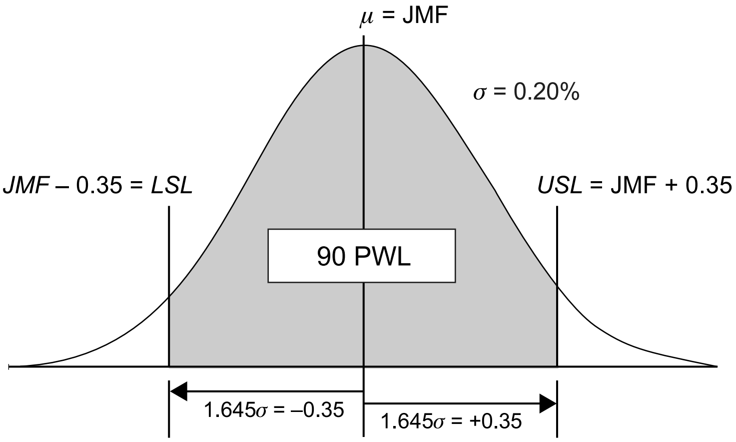

Figure X4.1—AQL Material for the Asphalt Content Example

X4.3.3. The specification limits are determined from the target JMF value and typical standard deviation. For example, if the standard deviation of asphalt binder content is 0.2 percent, HMA within the AQL would be as shown in Figure X4.1. The specification limits are: JMF ± (1.645 × 0.20) = JMF ± 0.33, rounded to ±0.35.

X4.3.4. In another example, if the Agency requires two cores per sublot and sets the specification limits for in-place density with an AQL of 90, the specification limits become 1.645 × 1.4 or ±2.3 percent. For these two examples it would be possible to produce materials within these specification limits, and the performance is expected to be satisfactory.

Table X4.1—Typical Industry Standard Deviations for HMA Properties (HMA Composition, Gyratory Properties and In-Place Density)[a]

HMA Composition Property		Extraction	Nuclear Gage	Ignition Furnace	Cold Feed
Asphalt Binder Content (P_b), %		±0.25	+ 0.18	±0.13	—
Gradation Passing 4.75-mm and Larger Sieves, %		±3	NA	b	±3
Passing 2.36-mm to 0.150-mm Sieve, %		±2	NA	b	±2
Passing 0.075-mm Sieve, %		±0.7	NA	b	±0.7
Maximum Theoretical Specific Gravity (G_{mm})	±0.015				
Gyratory-Compacted HMA Property					
Air Voids (V_a), %	±1.0				
Voids in Mineral Aggregate (VMA), %	±1.0				
Voids Filled with Asphalt (VFA), %	±5				
Bulk Specific Gravity (G_{mb})	±0.022				
In-Place Density					
Roadway Core Density (%G_{mm}), %	±1.4				

a Agency-specific standard deviations may be developed in lieu of the industry standard deviation.

b NCHRP 9-7 did not develop standard deviations for gradation of aggregate recovered from the ignition furnace; however, the standard deviation is expected to be the same as for cold feed or solvent-extracted aggregates.

X4.3.5. For air voids, VMA, and asphalt binder content, the upper and lower specification limits (USL and LSL) are calculated in Section X4.3.2. For in-place density, the LSL may be determined using a target value and offsetting three standard deviations. The target may be obtained from the control strip (Section 12.5) or may be predetermined as a desirable average density. Alternately, the LSL may be set at a predetermined value of desirable minimum density such as 92.0 percent G_{mm}.

Table X4.2—Recommended Specification Limits for HMA Properties

HMA Composition Property		Extraction	Nuclear Gage	Ignition Furnace	Cold Feed
Asphalt Binder Content (P_b), %		±0.41	±0.30	±0.21	—
Gyratory-Compacted HMA Property					
Air Voids (V_a), %	±1.6				
Voids in Mineral Aggregate (VMA), %	±1.6				
Voids Filled with Asphalt (VFA), %	±8				
In-Place Density					
Roadway Core Density (%G_{mm}), %	±2.3				

X4.4. *PWL Calculation*:

X4.4.1. Estimate the PWL in accordance with Sections X4.4.1.1 through X4.4.1.10.

X4.4.1.1. Locate *n* sampling positions in the sublot by use of Appendix X1 or other appropriate random number tables.

X4.4.1.2. Perform tests on each sample taken behind the screed (HMA properties) and each core taken from the roadway (density).

X4.4.1.3. For each test property, determine the average, $\bar{x}$, the lot measurements where n is the number of samples in the lot.

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad (X4.1)$$

X4.4.1.4. For each test property, determine the standard deviation, s, of the lot.

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \qquad (X4.2)$$

X4.4.1.5. For air voids, VMA, and asphalt binder content, calculate both upper and lower quality indices and the associated PWL. For in-place density, calculate the lower quality index and the associated PWL. The method to determine the quality indices follows:

X4.4.1.5.1. Determine the upper quality index, Q_U, by subtracting the average ($\bar{x}$) of the measurements from the USL and dividing the result by s.

$$Q_U = \frac{USL - \bar{x}}{s} \qquad (X4.3)$$

X4.4.1.5.2. Determine the *lower quality index*, Q_L, by subtracting the LSL from the average ($\bar{x}$) and dividing the result by s.

$$Q_L = \frac{\bar{x} - LSL}{s} \qquad (X4.4)$$

X4.4.1.6. For PWL_U, estimate the percentage of material that will fall within the upper tolerance limit by entering Table X4.3 with Q_U using the column appropriate to the total number of measurements, n.

X4.4.1.7. For PWL_L, estimate the percentage of material that will fall within the lower tolerance limit by entering Table X4.3 with Q_L using the column appropriate to the total number of measurements, n.

X4.4.1.8. For air voids, VMA, and asphalt binder content, where both upper and lower limits are used, determine the percent of material that will fall within the limits by adding the percent within the upper specification limit (PWL_U) to the percent within the lower specification limit (PWL_L), and subtracting 100 from the sum.

$$\text{Total PWL} = (PWL_U + PWL_L) - 100 \qquad (X4.5)$$

X4.4.1.9. For in-place density, determine the percent of material that will fall above the lower specification limit (PWL_L).

$$\text{Total PWL} = PWL_L \qquad (X4.6)$$

X4.5. *Example of Percent Within Limits Using Standard Deviation*

X4.5.1. Determine the PWL for air voids, where the average air voids ($\bar{x}$) of the lot is 3.7 percent, the standard deviation is 0.6 percent and the number of samples is five. The range of allowable air voids is 2.4 percent to 5.6 percent.

X4.5.2. Calculate an upper and lower quality index value (Q_U and Q_L) using the following:

$$Q_U = \left(\frac{6.1 - \bar{x}}{s}\right) = \left(\frac{5.6 - \overline{3.7}}{0.6}\right) = 3.16 \qquad (X4.7)$$

$$Q_L = \left(\frac{\bar{x} - \overline{2.4}}{s}\right) = \left(\frac{3.7 - \overline{2.4}}{0.6}\right) = 2.16 \qquad (X4.8)$$

X4.5.3. Determine an upper and lower PWL using Table X4.3 with the number of the samples and the calculated values of Q_U and Q_L.

For $n = 5$ and Q_U =4.00, the $PWL_U = 100$.

Note X3—Since the value of Q_U exceeds the highest value under the column of $n = 5$, the PWL_U equals 100.

Next, for $n = 5$ and $Q_L = 3.00$, the $PWL_L = 100$.

Then, the combined PWL_U and PWL_L is:

$$PWL = (PWL_U + PWL_L) - 100$$
$$PWL = (100 + 100) - 100 = 100$$

where:

s = sample standard deviation;
Q_L = lower quality index value;
Q_U = upper quality index value;
PWL_U = percent within limits on the upper side of the specification;
PWL_L = percent within limits on the lower side of the specification; and
PWL = total percent within limits.

Table X4.3—Quality Index Values for Estimating Percent within Limits

PWL	*n* = 3	*n* = 4	*n* = 5	*n* = 7	*n* = 10	*n* = 15
87	1.06	1.11	1.12	1.12	1.12	1.12
86	1.04	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04
84	1.01	1.02	1.01	1.00	1.00	1.00
83	1.00	0.99	0.98	0.97	0.96	0.96
82	0.97	0.96	0.95	0.93	0.92	0.92
81	0.96	0.93	0.91	0.90	0.89	0.88
80	0.93	0.90	0.88	0.86	0.85	0.85
79	0.91	0.87	0.85	0.83	0.82	0.81
78	0.89	0.84	0.82	0.80	0.79	0.78
77	0.87	0.81	0.78	0.76	0.75	0.75
76	0.84	0.78	0.75	0.73	0.72	0.71
75	0.82	0.75	0.72	0.70	0.69	0.68
74	0.79	0.72	0.69	0.67	0.66	0.65
73	0.76	0.69	0.66	0.64	0.63	0.62
72	0.74	0.66	0.63	0.61	0.60	0.59
71	0.71	0.63	0.60	0.58	0.57	0.56
70	0.68	0.60	0.57	0.55	0.54	0.53
69	0.65	0.57	0.54	0.52	0.51	0.50
68	0.62	0.54	0.51	0.49	0.48	0.48
67	0.59	0.51	0.47	0.46	0.45	0.45
66	0.56	0.48	0.45	0.44	0.43	0.42
65	0.52	0.45	0.43	0.41	0.40	0.39
64	0.49	0.42	0.40	0.38	0.37	0.36
63	0.46	0.39	0.37	0.35	0.34	0.34
62	0.43	0.36	0.34	0.32	0.32	0.31
61	0.39	0.33	0.31	0.30	0.29	0.29
60	0.36	0.30	0.28	0.27	0.26	0.26
59	0.32	0.27	0.25	0.24	0.24	0.23
58	0.29	0.24	0.23	0.21	0.21	0.21
57	0.25	0.21	0.20	0.19	0.18	0.18
56	0.22	0.18	0.17	0.16	0.16	0.15
55	0.18	0.15	0.14	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03
50	0.00	0.00	0.00	0.00	0.00	0.00

Notes: 1. For negative values of Q_U or Q_L, P_U or P_L is equal to 100 minus the tabular P_U or P_L.

2. If the value of Q_U or Q_L does not correspond exactly to a value in the table, use the next higher value.

X5. SAMPLE QA HMA CONSTRUCTION SPECIFICATION

X5.1. This appendix contains an example specification conforming to R 9 to develop a quality assurance plan for HMA. As such the specification contains lists of the test methods to be used, HMA design and submittal requirements, start-up and field adjustment of the mixture, QC requirements, and acceptance procedures. All of these items are included in this standard practice.

X5.2. In addition to those items listed in this standard practice, the Agency needs to add several other items to complete the specification. Among other things, these items should include:

(a) HMA producer requirements. These would be prequalification items established by the Agency for a Contractor to be eligible to supply HMA. Requirements could address plant and equipment as well as personnel and lab facilities.
(b) Specifics of QC plans for aggregate production or handling, asphalt binder control, plant operations, and roadway operations.
(c) Agency specific aggregate requirements.
(d) Special considerations for the use of recycled materials.
(e) Construction requirements such as the preparation of the surface to be overlaid, weather limitations, spreading and finishing, joints, shoulder corrugations, pavement smoothness, coring procedures, and core hole filling procedures.
(f) Pay factors.
(g) Appeal procedures.
(h) Basis of payment including bid item.

EXAMPLE SPECIFICATION

QUALITY ASSURANCE (QA) HOT MIX ASPHALT (HMA) PAVEMENT

HMA.01 DESCRIPTION

This work shall consist of one or more courses of HMA base, intermediate, or surface mixtures constructed on prepared foundations and shall be in reasonably close conformance with the lines, grades, cross-sections, dimensions, and material requirements, including tolerances, shown on the plans or indicated in the specifications.

HMA.02 QUALITY CONTROL

The HMA shall be supplied from a HMA plant in accordance with the HMA producer requirements. The HMA shall be transported and placed according to a roadway quality control plan (QCP) prepared and submitted by the contractor to the engineer at least 15 days prior to commencing HMA paving operations. The aggregate and asphalt binder materials shall be produced and controlled by separate QCPs based on either the agency approved programs or project specific criteria.

HMA Producer Requirements. The Producer takes responsibility for all aspects of the production of quality HMA in accordance with the contract requirements, and the agency monitors the producer’s production, methods of sampling, testing, calibration, verification, inspection procedures, and anticipated frequencies of each. The HMA Producer’s requirements include the following:

1. The producer’s personnel shall include a qualified technician who shall compact and analyze the HMA specimens and perform the maximum specific gravity test. The technician shall supervise all other sampling and testing of materials, the maintenance of control charts, and the maintenance of the project diary.
2. The producer shall provide and maintain a laboratory for process control testing. The laboratory shall have the necessary space, equipment, and supplies for the tests to be performed. The laboratory testing equipment shall meet the requirements of the test methods identified for the required sampling and testing, except that an electronic balance shall be provided. The gyratory compactor shall be on the agency’s list of approved Superpave

gyratory compactors. The test equipment furnished by the Producer shall be properly calibrated or verified and maintained within the limits described in the applicable test method.

3. The producer shall designate the sampling and sample reduction procedures, test methods, sampling locations, and size of samples necessary for the QC. Testing of the samples shall be completed within 48 hours of the time the sample was taken. Test values shall be reported to the nearest 0.1 percent except for the coarse aggregate angularity content and temperature of HMA which shall be reported to the nearest one percent and 1°C (2°F) respectively.
4. The producer shall detail the procedures for the management of the asphalt binder, aggregate, RAP, calibrations, HMA temperature, moisture, storage, and trucking operations to include the cleaning of the truck beds, loading, tarping, and truck unloading at the roadway.
5. The producer shall maintain control charts at the HMA plant laboratory for each DMF and JMF. All control test results shall be recorded on the control charts the same day the tests are conducted. As a minimum the charts shall be maintained until 30 test data points have been plotted. Subsequent to that time, at least 30 test data points shall be continuously displayed.
6. The producer control charts shall include the critical sieve(s) for each aggregate size from stockpile samples, critical sieve(s) for each blended aggregate, and the target mean values for the asphalt binder content, air voids, and VMA as determined from the DMF and the JMF.

QC Plan for Roadway Operations. The contractor shall identify their process to control the HMA placement and compaction processes to ensure compliance with the project specifications. As a minimum:

1. The contractor shall provide a qualified technician who shall conduct QC testing for temperature, density, and smoothness, and monitor paving operations and joint construction.
2. The QCP shall include the contractor’s methodology for balancing the operation including plant production, transportation, placement, and compaction.
3. The QCP shall also include delivery truck management, procedures for unloading the HMA and residue materials from the truck, and material transfer vehicle operations including plans for crossing bridge structures.
4. The paving plan shall include procedures for the material feed system, grade and slope controls, joint construction, HMA sampling and testing plan, temperature, rolling, density, coring, and smoothness testing.
5. The QCP shall also include documentation of all QC testing and equipment used in the HMA operations. The contractor should maintain adequate records of all tests. The records should indicate the test results and the nature of corrective action taken as appropriate. All charts and records documenting the contractor’s QC operations and tests should be available to the agency during the performance and upon the completion of the work. The contractor should keep the test results on file for a minimum period of three years following completion of the work. Test properties for the various materials and HMA should be charted on forms or other appropriate means which are in accordance with the applicable requirements of the agency.

QC Plan for Asphalt Binder Materials. QC of asphalt binder materials from all suppliers shall be in accordance with R 26 and the following:

1. The supplier shall prepare and submit a QCP that covers the manufacture, storage, shipping, and handling of all materials.
2. The supplier shall conduct testing in a laboratory that has been approved by the agency. Participation in the AMRL equipment inspection and proficiency sample programs with satisfactory ratings will be the basis for approval.
3. Specification compliance testing and complete AASHTO testing shall be accomplished at the frequency outlined in the QCP per grade of binder and at least once following feed stock changes. After initial testing, the minimum frequency for specification compliance testing shall be once per month.
4. The supplier shall furnish instructions with each grade of asphalt binder on proper storage and handling of the material.
5. The supplier shall furnish with the shipping report for each load a statement certifying that the asphalt materials have been manufactured according to R 26 and these specifications.
6. The supplier shall maintain detailed records of QC inspections, test results, and shipments for at least three years.

QC Plan for Aggregate Production. The agency should develop a testing program to ensure that aggregates meet specification requirements. The contractor's QCP should include, as a minimum, discussion on the proposed processing, transportation, stockpiling, and plant charging operations and the following:

1. The producer's personnel shall include a qualified technician who shall perform the pertinent duties during critical activities to meet the requirements of the QCP. The technician shall supervise the sampling and testing of materials, the maintenance of control charts, and the maintenance of the project diary.
2. The producer shall provide and maintain a laboratory for process control testing. The laboratory shall have the necessary space, equipment, and supplies for the tests to be performed. The laboratory testing equipment shall meet the requirements of the test methods identified for the required sampling and testing, except that an electronic balance shall be provided. The test equipment furnished by the Producer shall be properly calibrated or verified and maintained within the limits described in the applicable test method.
3. Sampling and testing of all materials that require control for aggregate gradation, decantation, deleterious, and crushed particles shall be in conformance with the AASHTO and agency requirements. Sampling shall be performed on uniform tonnage increments in an unbiased manner, and testing of the samples shall be accomplished in such time as to assure that process control is maintained. Testing shall be performed in accordance with the respective test methods unless otherwise stated by the agency.
4. The producer shall maintain control charts at the aggregate laboratory. All control test results shall be recorded on the control charts the same day the tests are conducted. As a minimum, the charts shall be maintained until 30 test data points have been plotted. Subsequent to that time, at least 30 test data points shall be continuously displayed.
5. The producer's control charts shall include the critical sieve(s) for each aggregate size from stockpile samples and critical sieve(s) for each blended aggregate.
6. The producer shall retain the QC test results for a minimum period of 3 years.

MATERIAL

HMA.03 MATERIALS

Materials shall be in accordance with the following:

Asphalt Binder	
PG Binder	AASHTO M 320
Coarse Aggregates	Agency Requirements
Fine Aggregates	Agency Requirements

HMA.04 DESIGN MIX FORMULA

A design mix formula (DMF) shall be prepared in accordance with HMA.05 and submitted in a format acceptable to the engineer one week prior to use. The DMF shall state the maximum particle size in the mixture. The DMF shall state the calibration factor, test temperature, and absorption factors to be used for the determination of asphalt binder content using the ignition oven in accordance with AASHTO T 308 or by extraction in accordance with AASHTO T 164. The DMF shall state the source, type, and dosage rate of any stabilizing additives. Approval of the DMF will be based on the ESAL and HMA designation. The engineer will assign an HMA identification number. No HMA will be accepted until the DMF has been approved.

The ESAL category identified in the pay item correlates to the following ESAL ranges:

ESAL Category	ESAL
1	< 300 000
2	300 000 to < 3 000 000
3	3 000 000 to < 10 000 000
4	10 000 000 to < 30 000 000
5	≥ 30 000 000

HMA.05 VOLUMETRIC HMA DESIGN

The DMF shall be determined for each mixture from a volumetric design by a design laboratory selected from the Agency's list of approved HMA design laboratories. A volumetric HMA design shall be performed in accordance with the respective AASHTO references as listed below.

Superpave Volumetric Mix Design	AASHTO M 323
Designing Stone Matrix Asphalt (SMA)	AASHTO MP 8
Mixture Conditioning of Hot Mix Asphalt (HMA)	AASHTO R 30
Superpave Volumetric Design for Hot Mix Asphalt (HMA)	AASHTO R 35
Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures	AASHTO T 209
Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage	AASHTO T 283
Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor	AASHTO T 312

The single percentage of aggregate passing each required sieve shall be within the limits of AASHTO M 323.

Dust/calculated effective asphalt binder ratio shall be from 0.6 to 1.2 when the aggregate gradation passes above the primary control sieve control point and 0.8 to 1.6 when the aggregate gradation passes below the control point. The optimum asphalt binder content for dense-graded mixtures shall produce 4.0 percent air voids at N_{des}. The design shall have at least four points, including a minimum of two points above and one point below the optimum. The maximum specific gravity of the uncompacted mixture shall be determined in accordance with AASHTO T 209.

Dense-graded mixtures shall be tested for moisture susceptibility in accordance with AASHTO T 283. The minimum tensile strength ratio (TSR) shall be 80 percent. The 150-mm (6-in.) mixture specimens shall be compacted in accordance with AASHTO T 312. If anti-stripping additives are added to the HMA to meet the minimum TSR requirements, the dosage rate shall be submitted with the DMF.

Changes in the source or types of aggregates shall require a new DMF. A new DMF shall be submitted to the engineer for approval one-week prior to use.

The HMA design compaction temperature for the specimens shall be in accordance with the asphalt binder supplier's recommendations or determined from a temperature–viscosity curve based on AASHTO T 316.

Design criteria for each HMA shall be based on the ESAL value shown in the contract documents. Air void, VMA, and VFA criteria shall be in accordance with AASHTO M 323 and R 35.

HMA.06 RECYCLED MATERIALS

Recycled materials may consist of reclaimed asphalt pavement (RAP). Reclaimed asphalt pavement shall be the product resulting from the cold milling or crushing of an existing HMA pavement. The RAP is processed so that 100 percent will pass the 50-mm (2-in.) sieve when entering the HMA plant. The coarse aggregate in the recycled materials shall pass the maximum sieve size for the HMA being produced.

Recycled materials may be used as a substitute for a portion of the new materials in accordance with AASHTO M 323. The percentages of recycled materials shall be as specified on the DMF.

HMA.07 INITIAL PRODUCTION LOT

At the beginning of production of each HMA design, an initial production lot should be used to evaluate the DMF. The initial production lot should be divided into four sublots as specified in the table below depending on the mixture type.

Initial Production Sublots and Lots

Nom Max Size	Initial Sublot Size	Initial Lot Size
4.75	300	1200
9.5	400	1600
12.5	500	2000
19.0	500	2000
25.0	500	2000
37.5	500	2000

During initial plant start-up, adjustments may be made to assure the plant-produced HMA will meet the design requirements. For the initial production lot, the contractor shall produce HMA within the limits in the table below. The DMF may be adjusted to bring the DMF into compliance with the requirements of AASHTO M 323. The maximum adjustment should be within the following limits:

Allowable DMF Adjustments for Initial Production	
HMA Composition Property	Adjustment Limit, %
Asphalt Binder Content (P_b)	±0.4
Gradation Passing 4.75-mm and Larger Sieves	±4.0
Gradation Passing 2.36-mm to 0.150-mm Sieve	±4.0
Gradation Passing 0.075-mm Sieve	±1.5
Voids in Mineral Aggregate (VMA)	±1.0
Voids Filled with Asphalt (VFA)	±5.0

By the end of the lot, the HMA should be within the limits of the above table. The initial production lot shall be closed out, and the contractor shall declare a JMF.

HMA.08 LOTS AND SUBLOTS

After the initial production lot, lots will be defined for 19.0 mm nominal maximum aggregate size or larger HMA designs and for 12.5-mm or smaller HMA designs. Lots will be further subdivided into equal sublots not to exceed 1000 Mg (1000 tons) for 19.0-mm or larger HMA designs or 600 Mg (600 tons) for 12.5-mm or smaller HMA designs. Typically, four or more sublots constitute a lot. Partial sublots of 100 Mg (100 tons) or less can be added to the previous sublot. Partial sublots greater than 100 Mg (100 tons) can constitute a full sublot. Lots that contain a single sublot could be combined with the previous lot for acceptance purposes.

HMA.09 JOB MIX FORMULA

A job mix formula (JMF) shall be developed by the Contractor. A JMF used for volumetrically accepted contracts in the current or previous calendar year that was developed to N_{des} will be allowed.

HMA.10 ACCEPTANCE OF HMA

For the initial production lots, the properties of each sublot will be measured and compared to the DMF. If the deviation in air voids in any sublot exceeds ±2 percent or in any two sublots exceeds ±1.5 percent, the production should cease, and a new DMF should be developed in accordance with HMA.05. If the deviation for asphalt binder content in any sublot exceeds the limit shown in the table below, the production should cease, and a new DMF should be developed in accordance with HMA.05. If the deviation for any property other than asphalt binder content exceeds two times the limits shown in the table below or any two sublots exceed the limits, the production should cease, and a new DMF should be developed in accordance with HMA.05.

Allowable DMF Adjustments for Initial Production	
HMA Composition Property	Deviation, %
Asphalt Binder Content (P_b)	±0.4
Gradation Passing 0.150-mm and Larger Sieves	±4.0
Gradation Passing 0.075-mm Sieve	±1.5
Voids in Mineral Aggregate (VMA)	±1.0
Voids Filled with Asphalt (VFA)	±5.0

For all lots except the initial production lot, HMA will be accepted for asphalt binder content, VMA at N_{des}, and air voids at N_{des} based on tests performed by the engineer. Acceptance testing for surface mixtures will include tests for moisture content. The engineer will randomly select a location within each sublot for sampling. An acceptance sample will consist of two plate samples with the first being at the random location and the second 0.6 m (2 ft) ahead. A backup sample consisting of two plate samples shall be located 0.6 m (2 ft) towards the center of the mat from the acceptance sample. An additional sample for moisture content shall be located 0.6 m (2 ft) back from the random sample location.

The maximum percent of moisture in the mixture shall not exceed 0.10 from plate samples. Air voids, asphalt binder content, and VMA values will be reported to the nearest 0.1 percent. Moisture and draindown test results will be rounded to the nearest 0.01 percent.

In the event that an acceptance sample is not available to represent a sublot(s), all test results of the previous sublot will be used for acceptance. If the previous sublot is not available, the subsequent sublot will be used for acceptance.

The engineer’s acceptance test results for each sublot will be available when the testing is complete. The contractor may request an appeal of the engineer's test results in accordance with HMA.21.

Determine percent within limits (PWL) and pay factors in accordance with HMA.20.

CONSTRUCTION REQUIREMENTS

HMA.11 GENERAL

Equipment for HMA operations shall be in accordance with Agency requirements.

Fuel oil, kerosene, or solvents shall not be transported in open containers on equipment. Cleaning of equipment and small tools shall not be accomplished on the pavement or shoulder areas.

Segregation, flushing, or bleeding of HMA will not be permitted. Corrective action shall be taken to prevent continuation of these conditions. Segregated, flushed, or bleeding HMA shall be removed if directed. All areas showing an excess or deficiency of asphalt binder shall be removed and replaced.

All HMA that has become loose and broken, mixed with dirt, or is in any way defective shall be removed and replaced.

HMA.12 PREPARATION OF SURFACES TO BE OVERLAID

The subgrade shall be shaped to the required grade and sections, free from all ruts, corrugations, or other irregularities, and uniformly compacted. Surfaces on which HMA is placed shall be free from objectionable or foreign materials at the time of placement.

Compacted aggregate bases and rubblized pavements shall be primed. Milled surfaces and existing surfaces shall be tacked prior to placing HMA. Contact surfaces of curbing, gutters, manholes, and other structures shall also be tacked.

HMA.13 PROCESS CONTROL

The engineer and contractor will jointly review the operations to ensure compliance with the QCP. Continuous violations of compliance with the QCP will result in suspension of paving operations.

HMA.14 WEATHER LIMITATIONS

HMA courses of less than 75 kg/m^2 (138 lb/yd^2) shall be placed only when the ambient temperature, and the temperature of the surface on which it is to be placed, is 7°C (45°F) or above. No HMA shall be placed on a frozen subgrade.

HMA.15 SPREADING AND FINISHING

The HMA shall be placed upon an approved surface by means of approved equipment. Prior to paving, the actual application rate shall be determined.

HMA courses greater than 90 kg/m^2 (165 lb/yd^2) placed under traffic shall be brought up even with each adjacent lane at the end of each workday. HMA courses less than or equal to 90 kg/m^2 (165 lb/yd^2) shall be brought forward concurrently, within practical limits, limiting the work in one lane to not more than one work day of production before moving back to bring forward the adjacent lane.

Hydraulic extensions on the paver will not be permitted for continuous paving operations. Fixed extensions or extendable screeds shall be used on courses greater than the nominal width of the paver except in areas where the paving widths vary. Hydraulic extensions may be used in tapers and added lanes less than 75 m (250 ft) in length.

Automatic slope and grade controls shall be used as outlined in the QCP.

When placing HMA with density not controlled by cores, the speed of the paver shall not exceed 15 m (50 ft) per min. Rollers shall be operated to avoid shoving of the HMA and at speeds not to exceed 4.5 km/h (3 mph). However, vibratory rollers will be limited to 4 km/h (2.5 mph).

The finished thickness of any course shall be at least two times, but not more than four times, the nominal-maximum aggregate particle size as shown on the DMF.

HMA.16 JOINTS

Longitudinal joints in the surface shall be at the lane lines of the pavement. Longitudinal joints below the surface shall be offset from previously constructed joints by approximately 150 mm (6 in.) and be located within 300 mm (12 in.) of the lane line.

Transverse joints shall be constructed by exposing a nearly vertical, full-depth face of the previous course. For areas inaccessible to rollers, other mechanical devices shall be used to achieve the required density.

If constructed under traffic, temporary transverse joints shall be feathered to provide a smooth transition to the driving surface.

HMA.17 DENSITY

Acceptance will be based on lots and sublots in accordance with HMA.08.

Density of the compacted dense-graded HMA will be determined from cores based on samples obtained from two random locations selected by the engineer within each sublot. One core shall be cut at each random location. The transverse core location will be located so that the edge of the core will be no closer than 75 mm (3 in.) from a confined edge or 150 mm (6 in.) from a non-confined edge of the course being placed. The maximum specific gravity will be determined from the sample obtained in HMA.10.

The contractor shall obtain cores in the presence of the engineer with a device that shall produce a uniform 150-mm (6-in.) diameter pavement sample. Coring shall be completed prior to the random location being covered by the next course. Surface courses shall be cored within two workdays of placement. Damaged core(s) shall be discarded and replaced with a core from a location selected by adding 0.3 m (1.0 ft) to the longitudinal location of the damaged core using the same transverse offset.

The contractor and the engineer shall mark the core to define the course to be tested. If the core indicates a course thickness of less than 2.0 times the nominal-maximum aggregate size, the core will be discarded, and a core from a new random location will be selected for testing.

The engineer will take immediate possession of the cores. If the engineer's cores are subsequently damaged, additional coring will be the responsibility of the agency. Subsequent core locations will be determined by subtracting 0.3 m (1.0 ft) from the random location using the same transverse offset.

The density for the HMA will be expressed as the percentage of maximum specific gravity (%G_{mm}) obtained by dividing the average bulk specific gravity by the maximum specific gravity for the sublot times 100. Density values (%G_{mm}) will be reported to the nearest 0.1 percent. Rounding will be in accordance with ASTM E 29 using the rounding method. The engineer will determine the bulk specific gravity of the cores (G_{mb}) in accordance with AASHTO T 166. The maximum specific gravity will be determined in accordance with AASHTO T 209. The target value for density of dense-graded mixtures of each sublot shall be 93.0 percent.

Within one workday of coring operations, the contractor shall clean, dry, and refill the core holes with HMA of similar or smaller-size particles or other approved materials.

Pay factors will be determined in accordance with HMA.20. The engineer's acceptance test results for each sublot will be available when the testing is complete.

HMA.18 SHOULDER CORRUGATIONS

Shoulder corrugations shall be in accordance with the plans.

HMA.19 PAVEMENT SMOOTHNESS

The pavement smoothness will be accepted by means of a profilograph, a 4.9 m (16 ft) long straightedge, or a 3 m (10 ft) long straightedge.

The profilograph shall be used where the following conditions are met:

1. the design speed is greater than 70 km/h (45 mph),
2. the pavement lanes are full width, 0.16 km (0.1 mi.) and or longer, and
3. the HMA is placed on a milled surface or the total application rate is 180 kg/m2 (330 lb/yd2) or greater.

The contractor shall furnish, calibrate, and operate an approved profilograph in accordance with agency requirements. The profilogram produced shall become the property of the agency. The profilograph shall remain the property of the contractor.

The 4.9 m (16 ft) long straightedge shall be used on overlays where the profilograph is not specified. The 4.9 m (16 ft) long straightedge shall be used on all full-width pavement lanes shorter than 75 m (250 ft), on tapers, within 15 m (50 ft) of bridge approaches, and within 15 m (50 ft) of an existing pavement, which is being joined.

The 3 m (10 ft) long straightedge shall be used for transverse slopes, approaches, and crossovers.

All wavelike irregularities and abrupt changes in profile caused by paving operations shall be corrected.

Each finished course of base and intermediate HMA shall be subject to approval. The pavement smoothness shall be checked on any new intermediate course located immediately below a surface course and the surface course at the locations as designated in accordance with agency requirements.

If grinding of the intermediate course is used for pavement smoothness corrections, the grinding shall not precede the surface placement by more than 30 calendar days if open to traffic.

When the 4.9-m (16-ft) straightedge is used on a surface course, the pavement variations shall be corrected to 6 mm ($^1/_4$ in.) or less. When the 3-m (10-ft) straightedge is used, the pavement variations shall be corrected to 3 mm ($^1/_8$ in.) or less.

When the profilograph is being used on a surface course, in addition to the requirements for the profile index, all areas having a high or low point deviation in excess of 8 mm (0.3 in.) shall be corrected. Courses underlying the surface courses that are exposed by corrective actions shall be milled to 25 mm (1 in.) and replaced with surface materials. The initial profile index shall be determined prior to any corrective action. The final profile index will be determined after all corrective action has been completed.

When the profilograph is being used on an intermediate course, all areas having a high or low point deviation in excess of 8 mm (0.3 in.) shall be corrected. When the 4.9-m (16-ft) or 3.0-m (10-ft) straightedge is being used on an intermediate course, all areas having a high or low point deviation in excess of 6 mm ($^1/_4$ in.) shall be corrected.

HMA.20 PAY FACTORS

For all lots except the initial production lot, the percent within limits (*PWL*) shall be estimated for each property (air voids, asphalt binder content, VMA, and in-place density) as follows:

Determine the average, $\overline{x}$, of the lot measurements, where n is the number of samples in the lot.

$$\overline{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

Determine the standard deviation, s, of the lot.

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}}$$

For air voids, asphalt binder content, and VMA, calculate the upper quality index, Q_U, by subtracting the average ($\overline{x}$) of the measurements from the upper specification limit (*USL*) and dividing the results by s. Limits are listed in the table of specification limits (see Table X1).

$$Q_U = \frac{USL - \overline{x}}{s}$$

Estimate the percentage of material that will fall within the upper tolerance limit by entering the table of quality index values with Q_U using the column appropriate to the total number of measurements, n.

For air voids, asphalt binder content, VMA, and in-place density, calculate the lower quality index, Q_L, by subtracting the lower specification limit (*LSL*) from the average ($\overline{x}$) and dividing the result by s.

$$Q_L = \frac{\overline{x} - LSL}{s}$$

Estimate the percentage of material that will fall within the lower tolerance limit by entering the table of quality index values with Q_L using the column appropriate to the total number of measurements, n.

For air voids, asphalt binder content, and VMA, where both upper and lower limits are used, determine the percent of material that will fall within the limits by adding the percent within the upper specification limit (PWL_U) to the percent within the lower specification limit (PWL_L), and subtracting 100 from the sum.

Total PWL = (PWL_U + PWL_L) – 100

For in-place density, determine the percent of material that will fall above the lower specification limit (PWL_L).

Total PWL = PWL_L

Calculate the pay factor (*PF*) for each property with the table of pay factors for different *PWL* values.

For the initial production lot, HMA accepted according to HMA.10 shall be accepted with a pay factor of 1.00. For material produced outside the tolerances of HMA.10, the agency will determine if the material should be left in place.

Table X1—Specification Limits

HMA Composition Property	Specification Limits
Mixture	
Air Voids (V_a) at N_{des}, %	2.7 to 5.3
Asphalt Binder Content by Ignition Furnace, %	±0.2 from JMF
Voids in Mineral Aggregate (VMA) at N_{des}, %	±1.3 from JMF
In-Place Density	
Roadway Core Density (%G_{mm}), %	91.7

Table X2—Quality Index Values for Estimating Percent within Limits

PWL	*n* = 3	*n* = 4	*n* = 5	*n* = 7	*n* = 10	*n* = 15
100	1.16	1.50	1.79	2.23	2.65	3.03
99	1.16	1.47	1.67	1.89	2.04	2.14
98	1.15	1.44	1.60	1.76	1.86	1.93
97	1.15	1.41	1.54	1.67	1.74	1.79
96	1.14	1.38	1.49	1.59	1.65	1.68
95	1.14	1.35	1.44	1.52	1.56	1.59
94	1.13	1.32	1.39	1.46	1.49	1.51
93	1.13	1.29	1.35	1.40	1.43	1.44
92	1.12	1.26	1.31	1.35	1.37	1.38
91	1.11	1.23	1.27	1.30	1.31	1.32
90	1.10	1.20	1.23	1.25	1.26	1.27
89	1.09	1.17	1.19	1.20	1.21	1.22
88	1.07	1.14	1.15	1.16	1.17	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12
86	1.04	1.08	1.08	1.08	1.08	1.08

(Table continued on next page)

Table X2—Quality Index Values for Estimating Percent within Limits (*continued*)

PWL	$n = 3$	$n = 4$	$n = 5$	$n = 7$	$n = 10$	$n = 15$
85	1.03	1.05	1.05	1.04	1.04	1.04
84	1.01	1.02	1.01	1.00	1.00	1.00
83	1.00	0.99	0.98	0.97	0.96	0.96
82	0.97	0.96	0.95	0.93	0.92	0.92
81	0.96	0.93	0.91	0.90	0.89	0.88
80	0.93	0.90	0.88	0.86	0.85	0.85
79	0.91	0.87	0.85	0.83	0.82	0.81
78	0.89	0.84	0.82	0.80	0.79	0.78
77	0.87	0.81	0.78	0.76	0.75	0.75
76	0.84	0.78	0.75	0.73	0.72	0.71
75	0.82	0.75	0.72	0.70	0.69	0.68
74	0.79	0.72	0.69	0.67	0.66	0.65
73	0.76	0.69	0.66	0.64	0.63	0.62
72	0.74	0.66	0.63	0.61	0.60	0.59
71	0.71	0.63	0.60	0.58	0.57	0.56
70	0.68	0.60	0.57	0.55	0.54	0.53
69	0.65	0.57	0.54	0.52	0.51	0.50
68	0.62	0.54	0.51	0.49	0.48	0.48
67	0.59	0.51	0.47	0.46	0.45	0.45
66	0.56	0.48	0.45	0.44	0.43	0.42
65	0.52	0.45	0.43	0.41	0.40	0.39
64	0.49	0.42	0.40	0.38	0.37	0.36
63	0.46	0.39	0.37	0.35	0.34	0.34
62	0.43	0.36	0.34	0.32	0.32	0.31
61	0.39	0.33	0.31	0.30	0.29	0.29
60	0.36	0.30	0.28	0.27	0.26	0.26
59	0.32	0.27	0.25	0.24	0.24	0.23
58	0.29	0.24	0.23	0.21	0.21	0.21
57	0.25	0.21	0.20	0.19	0.18	0.18
56	0.22	0.18	0.17	0.16	0.16	0.15
55	0.18	0.15	0.14	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03
50	0.00	0.00	0.00	0.00	0.00	0.00

Notes: 1. For negative values of Q_U or Q_L, P_U or P_L is equal to 100 minus the tabular P_U or P_L.

2. If the value of Q_U or Q_L does not correspond exactly to a value in the table, use the next higher value.

Pay factors are calculated for each property, air voids at N_{des}, asphalt binder content, VMA at $N_{des,}$ and in-place density (%G_{mm}). The appropriate pay factor for each property is calculated as follows:

Estimated PWL greater than 78:

$$PF = 0.045(PWL) + 96.5$$

Estimated PWL greater than or equal to 42 and less than or equal to 78:

$$PF = -0.006(PWL)2 + 1.4(PWL) + 27.3$$

If the pay factor for any one of the properties is less than 75, the engineer will determine if the material will be required to be removed, other corrective action is to be taken, or left in place at a further reduced pay factor.

For all lots other than the initial production, lot a composite pay factor is determined for each lot based on test results for HMA properties and density in a weighted formula as follows:

$$CPF = 0.20(PF_{\mathrm{BINDER}}) + 0.35(PF_{\mathrm{VOIDS}}) + 0.10(PF_{\mathrm{VMA}}) + 0.35(PF_{\mathrm{DENSITY}})$$

where:

CPF = lot combined pay factor for mixture and density;
PF_{BINDER} = lot pay factor for asphalt binder content;
PF_{VOIDS} = lot pay factor for air voids at N_{des};
PF_{VMA} = lot pay factor for VMA at N_{des}; and
PF_{DENSITY} = lot pay factor for density.

The lot pay adjustment for mixture properties and density is calculated as follows.

$$q_m = L \times U \times (CPF - 100)/100$$

where:

q_m = quality assurance adjustment for mixture and density;
L = lot quantity;
U = unit price for the material, \$/Mg (\$/ton); and
CPF = combined pay factor.

The quality assurance adjustment points for smoothness will be calculated in accordance with the following:

When the pavement smoothness is tested with a profilograph, payment will be based on the final profile index ($PI_{0.0}$) in accordance with the following table:

Table X3—Adjustment for Smoothness

Design Speed Greater than 70 km/h (45 mph)	
Profile Index (*PI*0.0), mm per 0.16 km (in./0.1 mi)	Pay Factor
0 to 20 mm (0.00 to 0.80 in.)	1.06
21 to 25 mm (0.81 to 1.00 in.)	1.05
26 to 30 mm (1.01 to 1.20 in.)	1.04
31 to 35 mm (1.21 to 1.40 in.)	1.03
36 to 40 mm (1.41 to 1.60 in.)	1.02
41 to 50 mm (1.61 to 2.00 in.)	1.01
51 to 60 mm (2.01 to 2.40 in.)	1.00
61 to 65 mm (2.41 to 2.60 in.)	0.96
61 to 70 mm (2.61 to 2.80 in.)	0.92

Note: All pavements with a Profile Index ($PI_{0.0}$) greater than 70 mm (2.80 in.) shall be corrected.

A quality assurance pay factor for smoothness (PF_s) will apply to the typical section including the aggregate base, and the HMA base, intermediate, and surface courses. The quality assurance adjustment for each section will include the total area of each pavement lane excluding shoulders for a 0.16 km (0.1 mi) long section represented by the profile index calculated by the following formula:

$$q_s = (PF_s - 1.00)\sum_{i=1}^{n}\left(A \times \frac{S}{T} \times U\right)$$

where:

q_s = quality assurance adjustment for smoothness for one section;
PFs = pay factor for smoothness;
n = number of layers;
A = area of the section, m^2 (yd^2);
S = spread rate for the material, kg/m^2 (lb/yd^2);
T = conversion factor: 1000 kg/Mg (2000 lb/ton); and
U = unit price for the material, \$/Mg (\$/ton).

For the entire contract, the quality assurance adjustment for smoothness, Q_S, will be the total of the quality assurance adjustments for smoothness, q_s, on each section by the following formula:

$Q_s = \Sigma\, q_s$

Quality assurance pay factors greater than 1.00 will be applicable only to the initial measured profile index, prior to any corrective work. Quality assurance pay factors of 1.00 or less will be applied to pavement sections where corrective work has been completed.

The total quality assurance adjustments for mixture properties, density and smoothness are calculated as follows:

$q = q_m + q_S$

where:

q = total quality assurance adjustment;
q_m = quality assurance adjustment for mixture and density; and
q_S = quality assurance adjustment for smoothness.

HMA.21 APPEALS

If the QC test results do not agree with the acceptance test results, a request, along with the QC test results, may be made in writing for additional testing. Additional testing may be requested for one or more of the following tests: G_{mm}, G_{mb} of the gyratory specimens, asphalt binder content, or bulk specific gravity of the density cores. The request for the appeal for G_{mm}, G_{mb} of gyratory specimens, asphalt binder content, or bulk specific gravity of the density cores shall be submitted within seven calendar days of receipt of the Agency’s written results for that lot. The lot, sublot and specific test(s) shall be specified at the time of the appeal. Upon approval of the appeal, the engineer will perform additional testing as follows:

The backup sample(s) or new cores will be tested in accordance with the applicable test method for the test requested.

G_{mm}. The backup G_{mm} sample will be tested in accordance with AASHTO T 209, Section 9.5.1.

G_{mb} of the Gyratory Specimen. New gyratory specimens will be prepared and tested in accordance with AASHTO T 312 from the backup sample.

Asphalt Binder Content. The backup asphalt binder content sample will be prepared and tested in accordance with the test method that was used for acceptance.

Bulk Specific Gravity of the Density Core. Additional cores shall be taken within seven calendar days unless otherwise directed. Additional core locations will be determined by adding 0.3 m

(1.0 ft) longitudinally to the site of the cores tested using the same transverse offset. The appeal density cores will be tested in accordance with AASHTO T 166.

The appeal results will replace all previous test result(s) for acceptance of HMA in accordance with HMA.10 and density in accordance with HMA.17. The results will be furnished to the contractor.

HMA.22 METHOD OF MEASUREMENT

HMA will be measured by the megagram (ton) of the type specified.

HMA.23 BASIS OF PAYMENT

The accepted quantities for this work will be paid for at the contract unit price per megagram (ton) for QC/QA-HMA, of the type specified, complete in place.

Payment for furnishing, calibrating, and operating the profilograph and furnishing profile information will be made at the contract lump sum price for profilograph, HMA.

Adjustments to the contract payment with respect to mixture, density, and smoothness for mixture produced will be included in a quality assurance adjustment pay item. The unit price for this pay item will be one dollar ($1.00), and the quantity will be in units of dollars. The quantity is the total calculated in accordance with HMA.20.

Payment will be made under the following pay items:

Pay Item	Metric Pay Unit Symbol (English Pay Unit Symbol)
Profilograph, HMA	Lump Sum
QC/QA HMA. _______*	Mg (ton)
Quality Assurance Adjustment	Dollars

* Surface, Intermediate, or Base

Preparation of surfaces to be overlaid shall be included in the cost of other pay items.

Coring and refilling of the core holes shall be included in the cost of other pay items within this section.

No payment will be made for additional anti-stripping additives, appeal coring, or traffic control expenditures related to coring operations.

Corrections for pavement smoothness shall be included in the cost of other pay items within this section.

The price for profilograph, HMA, will be full compensation regardless of how often the profilograph is used or how many profilograms are produced.

Standard Specification for

Zinc-Coated Steel Wire Rope and Fittings for Highway Guardrail

AASHTO Designation: M 30-02 (2006)[1]
ASTM Designation: A 741-98

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Zinc-Coated Steel Wire Rope and Fittings for Highway Guardrail

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ASTM Designation: A 741-98

1. SCOPE

1.1 This specification covers 19- and 25-mm ($^{3}/_{4}$- and 1-in.) zinc-coated steel wire rope and fittings for use in the construction of highway guardrail.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 111M/M 111, Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
- M 120, Zinc
- M 232M/M 232, Zinc Coating (Hot-Dip) on Iron and Steel Hardware
- T 65M/T 65, Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
- T 244, Mechanical Testing of Steel Products

2.2 *ASTM Standard*:

- A 902, Standard Terminology Relating to Metallic Coated Steel Products

3. TERMINOLOGY

3.1 *Definitions*—For definitions of terms used in this specification, refer to ASTM A 902.

4. ORDERING INFORMATION

4.1 Orders for wire rope guardrail material purchased to this specification shall include the following:

4.1.1 Diameter of wire rope,

4.1.2 Type of wire rope construction,

4.1.3 Class of zinc coating required (Table 2), 4.1.4 Quantity of wire rope and length per reel, and

4.1.5 AASHTO designation and year of issue.

Note 1—A typical ordering description is as follows: 19-mm ($^3/_4$-in.) diameter, Zinc-Coated Wire Rope for Guardrail, Type 1 Construction, Class A Coating, 24.4 km (80000 lineal ft) on forty 610 m (2000 ft) reels, M 30-____.

5. MATERIAL

5.1 *Base Metal*—The base metal shall be steel made by any process and shall be of such quality that the finished wire rope and the individual zinc-coated wires shall have the properties as prescribed in this specification.

5.2 *Zinc*—The slab zinc when used for the coating shall be any grade of zinc conforming to M 120.

6. MECHANICAL REQUIREMENTS

6.1 *Breaking Strength*—The zinc-coated steel wire rope shall conform to the mechanical properties in Table 1 when tested in accordance with T 244 and employing a suitable gripping device as covered in Annex A7.3 of T 244.

6.2 *Construction*—The zinc-coated wire rope and individual wires shall conform to the dimension and construction requirements of Table 1.

Table 1—Guard Cable Requirements

Type	Diameter, min, mm (in.)	Construction (No. of Strands × No. of Wires per Strand)	Breaking Strength, min, kN (lbf)	Length of Lay of Strand, max, mm (in.)	Length of Lay of Wires in Strand, max, mm (in.)	Diameter of Coated wires in Strand, mm (in.)
I	19 ($^3/_4$)	3 by 7	110 (25000)	190 (7.5)	114 (4.5)	2.97 to 3.15 (0.117 to 0.124)
II	19 ($^3/_4$)	6 by 19[a] IWRC[b]	190 (42800)	[c]	[c]	Variable
II(a)	19 ($^3/_4$)	6 by 19[a] wire stem + core	190 (42800)	[c]	[c]	Variable
III	25 (1)	7 by 7	200 (45000)	254 (10)	114 (4.5)	2.67 to 2.95 (0.105 to 0.116)

[a] 6 by 19 classification may have from 15 to 26 wires per strand.

[b] IWRC = independent wire rope core.

[c] Length of lay as specified by manufacturer.

6.3 *Ductility of Steel*—The individual zinc-coated wires shall be capable of being wrapped two turns in a close helix at a rate not exceeding 15 turns per minute around a cylindrical steel mandrel equal to three times the nominal diameter of the wire under test without cracking or breaking of the wire.

6.4 *Mass of Zinc Coating*—The class of zinc coating shall be specified by the purchaser. The mass of the zinc coating on the individual wires for the specified class and appropriate wire size shall not be less than that specified in Table 2 when tested in accordance with the stripping test of T 65M/T 65.

Table 2—Minimum Mass of Coating

Nominal Diameter of Coated Wire		Mass of Zinc Coating, min					
		g/m^2 of Uncoated Wire Surface			oz/ft^2 of Uncoated Wire Surface		
mm	in.	Class A Coating	Class B Coating	Class C Coating	Class A Coating	Class B Coating	Class C Coating
1.02 to 1.55, incl	0.040 to 0.061, incl	122	244	366	0.40	0.80	1.20
1.58 to 2.01, incl	0.062 to 0.079, incl	152	305	458	0.50	1.00	1.50
2.03 to 2.34, incl	0.080 to 0.092, incl	183	366	549	0.60	1.20	1.80
2.36 to 2.62, incl	0.093 to 0.103, incl	214	427	641	0.70	1.40	2.10
2.64 to 3.02, incl	0.104 to 0.119, incl	244	488	732	0.80	1.60	2.40
3.05 to 3.61, incl	0.120 to 0.142, incl	259	519	778	0.85	1.70	2.55

6.5 *Adherence of Coating*—The individual zinc-coated wires shall be capable of being wrapped two turns in a close helix at a rate not exceeding 15 turns per minute around a cylindrical steel mandrel equal to three times the nominal diameter of the wire under test without the coating cracking or flaking to such an extent that any zinc can be removed by rubbing with bare fingers. Loosening or detachment during the adherence test of superficial small particles of zinc formed by mechanical polishing of the surface of zinc-coated wire shall not be considered cause for rejection.

6.6 *Appearance*—The individual wires shall be cylindrical in form, of uniform quality, and free of imperfections not consistent with good commercial practice. Each wire shall have a continuous coating of zinc of reasonably uniform thickness.

7. WIRE ROPE

7.1 The wire rope shall be right regular lay, preformed, and of the type of construction shown in Table 1. A right lay is defined as a clockwise twist away from the observer. The type of construction shall be specified by the purchaser.

8. JOINTS AND SPLICES

8.1 *Individual Wires*—The distance between joints in any two individual wires in a strand shall be not less than 457 mm (18 in.). Joints in individual wires shall be either butt-welded or brazed-lap type. Joints made by butt welding shall have all flash removed. When the brazed-lap type of joint is used, the length of the lap shall be not less than three times the diameter of the wire and the overlapping faces shall be smooth, clean, properly fluxed, and completely covered by the brazing metal. All joints shall be recoated after welding so that the joints shall have protection from corrosion equivalent to the zinc-coated wire itself.

8.2 *Strand or Rope*—Strand or rope splices may only be made when authorized in writing by the purchaser.

9. SAMPLING AND TESTING

9.1 One wire rope test specimen shall be taken from each lot. A lot shall consist of not more than 18 Mg (20 tons) of wire rope of one size and type delivered at one time.

9.2 The test specimen shall be of a length to perform conveniently all tests prescribed in this specification.

9.3 A minimum of four wire test specimens shall be cut from each size of main wires in the rope, selected at random for testing for compliance with Sections 6.2, 6.3, 6.4, and 6.5.

9.4 If an individual wire or the rope fails to meet any requirements of this specification, that reel shall be rejected and two additional tests shall be made on samples of wire rope from two different reels in the lot. If failure occurs in either of these tests, the lot of wire rope shall be rejected. The lot may be resubmitted for inspection after testing every reel for the characteristics in which the specimen failed and sorting out the defective reels.

10. INSPECTION

10.1 All tests and inspection shall be made at the place of manufacture unless otherwise specified and shall be so conducted as not to interfere unnecessarily with the operation of the works. The manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy him that the material being furnished is in accordance with this specification. When specified, inspection may be waived and certified copies of test reports furnished. The purchaser reserves the right to test individual wires for compliance to Sections 6.2, 6.3, 6.4, and 6.5 and the zinc-coated wire rope after fabrication.

11. PACKAGING

11.1 Current standard practice is to ship the wire rope on wooden reels. Each reel shall have the length, nominal diameter, type of strand construction, mass of rope, and name or trademark of the manufacturer plainly and indelibly marked on a strong tag, firmly attached, or this information shall be painted on the reel. The wooden reel shall be mountable so that it will revolve and the rope will run off by pulling straight ahead.

12. FITTINGS

12.1 The fittings shall be of the design called for in the plans and shall have the properties necessary to develop the strength of the wire rope.

12.2 Fittings as shown in the plans shall have a uniform coating of zinc conforming to M 111M/M 111 or M 232M/M 232, whichever applies.

13. KEYWORDS

13.1 Galvanized wire; steel wire; wire; zinc-coated carbon steel wire.

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[1] In essential equivalence with ASTM A 741-98 except for the order of the tables.

Standard Specification for

Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

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AASHTO Designation: M 31M/M 31-10[1]
ASTM Designation: A 615/A 615M-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

AASHTO Designation: M 31M/M 31-10[1]

ASTM Designation: A 615/A 615M-09

1. SCOPE

1.1. This specification covers deformed and plain carbon steel concrete reinforcement bars in cut lengths or coils. Steel bars containing alloy additions, such as with the AISI and SAE series of alloy steels, are permitted if the resulting product meets all the other requirements of this specification. The standard sizes and dimensions of deformed bars and their number designations shall be those listed in Table 1 [Table 2]. The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this specification.

1.2. Bars are of three minimum yield strength levels: namely, 280 MPa [40000 psi], 420 MPa [60000 psi], and 520 MPa [75000 psi], designated as Grade 280 [40], Grade 420 [60], and Grade 520 [75], respectively.

1.3. Hot-rolled plain rounds, in sizes up to and including 63.5-mm [2 ½-in.] diameter in coils or cut lengths, when specified for dowels, spirals, and structural ties or supports, shall be furnished under this specification in Grade 280 [40], Grade 420 [60], and Grade 520 [75] (Note 2).

For ductility properties (elongation and bending), test provisions of the nearest smaller nominal diameter deformed bar size shall apply. Requirements providing for deformations and marking shall not be applicable.

1.4. Welding of the material in this specification should be approached with caution since no specific provisions have been included to enhance its weldability. When the steel is to be welded, a welding procedure suitable for the chemical composition and intended use or service should be used (Note 1).

Note 1—The use of the latest edition of ANSI/AWS D1.4 is recommended for welding reinforcing bars. This document describes the proper selection of the filler metals and preheat/interpass temperatures, as well as performance and procedure qualification requirements.

1.5. This specification is applicable for orders in either SI units (M 31M) or in inch-pound units (M 31). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 31.

Table 1—Deformed Bar Designation Numbers, Nominal Masses, Nominal Dimensions, and Deformation Requirements, SI Units

		Nominal Dimensions[a]			Deformation Requirements, mm		
Bar Designation No.[b]	Nominal Mass, kg/m	Diameter, mm	Cross-Sectional Area, mm^2	Perimeter, mm	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
10	0.560	9.5	71	29.9	6.7	0.38	3.6
13	0.994	12.7	129	39.9	8.9	0.51	4.9
16	1.552	15.9	199	49.9	11.1	0.71	6.1
19	2.235	19.1	284	59.8	13.3	0.97	7.3
22	3.042	22.2	387	69.8	15.5	1.12	8.5
25	3.973	25.4	510	79.8	17.8	1.27	9.7
29	5.060	28.7	645	90.0	20.1	1.42	10.9
32	6.404	32.3	819	101.3	22.6	1.63	12.4
36	7.907	35.8	1006	112.5	25.1	1.80	13.7
43	11.38	43.0	1452	135.1	30.1	2.16	16.5
57	20.24	57.3	2581	180.1	40.1	2.59	21.9

[a] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same mass per meter as the deformed bar.

[b] Bar designation numbers approximate the number of millimeters of the nominal diameter of the bar.

Table 2—Deformed Bar Designation Numbers, Nominal Weights, Nominal Dimensions, and Deformation Requirements

		Nominal Dimensions[a]			Deformation Requirements, in.		
Bar Designation No.[b]	Nominal Weight, lb/ft	Diameter, in.	Cross-Sectional Area, in.^{2}	Perimeter, in.	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
3	0.376	0.375	0.11	1.178	0.262	0.015	0.143
4	0.668	0.500	0.20	1.571	0.350	0.020	0.191
5	1.043	0.625	0.31	1.963	0.437	0.028	0.239
6	1.502	0.750	0.44	2.356	0.525	0.038	0.286
7	2.044	0.875	0.60	2.749	0.612	0.044	0.334
8	2.670	1.000	0.79	3.142	0.700	0.050	0.383
9	3.400	1.128	1.00	3.544	0.790	0.056	0.431
10	4.303	1.270	1.27	3.990	0.889	0.064	0.487
11	5.313	1.410	1.56	4.430	0.987	0.071	0.540
14	7.65	1.693	2.25	5.32	1.185	0.085	0.648
18	13.60	2.257	4.00	7.09	1.58	0.102	0.864

[a] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.

[b] Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 160, General Requirements for Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use (Discontinued)
- T 244, Mechanical Testing of Steel Products
- T 285, Bend Test for Bars for Concrete Reinforcement

2.2. *ASTM Standards*:

- A 510/A 510M, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- A 706/A 706M, Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
- A 751, Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3. *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products Preparation for Shipment and Storage

2.4. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)

2.5. *AWS Standard*:

- ANSI/AWS D1.4, Structural Welding Code—Reinforcing Steel

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *deformations*—transverse protrusions on a deformed bar.

3.1.2. *deformed bar*—steel bar with protrusions; a bar that is intended for use as reinforcement in reinforced concrete construction.

3.1.2.1. *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protrusions conform to the provisions of this specification.

3.1.3. *plain bar*—steel bar without protrusions.

3.1.4. *rib*—longitudinal protrusion on a deformed bar.

4. ORDERING INFORMATION

4.1. It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered to this specification. Orders for material under this specification should include the following information:

4.1.1. Quantity (mass) [weight],

4.1.2. Name of the material (deformed and plain carbon steel bars for concrete reinforcement), 4.1.3. Size,

4.1.4. Cut length or coils,

4.1.5. Deformed or plain,

4.1.6. Grade,

4.1.7. Packaging (see Section 21),

4.1.8. AASHTO designation and year of issue, and

4.1.9. Certified mill test reports (if desired). (See Section 19.)

5. MATERIAL AND MANUFACTURE

5.1. The bars shall be rolled from properly identified heats of mold cast or strand cast steel using the electric furnace, basic-oxygen, or open-hearth process.

6. CHEMICAL REQUIREMENTS

6.1. The chemical analysis of each heat of steel shall be determined in accordance with ASTM A 751. The manufacturer shall perform the analysis on test samples taken preferably during the pouring of the heat. The percentages of carbon, manganese, phosphorus, and sulfur shall be determined. The phosphorus content thus determined shall not exceed 0.06 percent.

6.2. An analysis may be made by the purchaser from finished bars. The phosphorus content thus determined shall not exceed that specified in Section 6.1 by more than 25 percent.

7. REQUIREMENTS FOR DEFORMATIONS

7.1. Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

7.2. The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45º. Where the line of deformations forms an included angle with the axis of the bar from 45º to 70º inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformation is over 70º, a reversal in direction is not required.

7.3. The average spacing or distance between deformations on each side of the bar shall not exceed seven-tenths of the nominal diameter of the bar.

7.4. The overall length of deformations shall be such that the gap (measured as a cord) between the ends of the deformations shall not exceed 12.5 percent of the nominal perimeter of the bar. Where the ends terminate in a rib, the width of the rib shall be considered as the gap between these ends. The summation of the gaps shall not exceed 25 percent of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.1416 times the nominal diameter.

7.5. The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1 [Table 2].

8. MEASUREMENTS OF DEFORMATIONS

8.1. The average spacing of deformations shall be determined by measuring the length of a minimum of ten spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space. Spacing measurements shall not be made over a bar area containing bar marking symbols involving letters or numbers.

8.2. The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

8.3. Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot (Note 2) tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 7. No rejection may be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

Note 2—A lot is defined as all the bars of one bar number and pattern of deformation contained in an individual shipping release or shipping order.

9. TENSILE REQUIREMENTS

9.1. The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 3 [Table 4].

Table 3—Tensile Requirements, SI Units

	Grade 280[a]	Grade 420	Grade 520[b]
Tensile strength, min MPa	420	620	690
Yield strength, min Mpa	280	420	520
Elongation in 200 mm, min %			
Bar Designation No.			
10	11	9	—
13, 16	12	9	—
19	12	9	7
22, 25	—	8	7
29, 32, 36	—	7	6
43, 57	—	7	6

[a] Grade 280 bars are furnished only in sizes 10 through 19.

[b] Grade 520 bars are furnished only in sizes 19 through 57.

Table 4—Tensile Requirements

	Grade 40[a]	Grade 60	Grade 75[b]
Tensile strength, min psi	60000	90000	100000
Yield strength, min psi	40000	60000	75000
Elongation in 8 in., min %			
Bar Designation No.			
3	11	9	—
4, 5	12	9	—
6	12	9	7
7, 8	—	8	7
9, 10, 11	—	7	6
14, 18	—	7	6

[a] Grade 40 bars are furnished only in sizes 3 through 6.

[b] Grade 75 bars are furnished only in sizes 11, 14, and 18.

9.2. The yield point or yield strength shall be determined by one of the following methods:

9.2.1. The yield point shall be determined by drop of the beam or halt of the point method as described in Section 13.1.1 of T 244.

9.2.2. Where the steel tested does not exhibit a well-defined yield point, the yield point shall be determined at extension under load using an autographic diagram method or an extensometer as described in Sections 13.1.2 and 13.1.3 of T 244.

The extension under load shall be 0.005 mm/mm [0.005 in./in.] of gauge length (0.5 percent) for Grade 280 [40] and Grade 420 [60] and shall be 0.0035 mm/mm [0.0035 in./in.] of gauge length (0.35 percent) for Grade 520 [75]. When material is furnished in coils, the test sample must be straightened prior to placing it in the jaws of the tensile machine. Straightening shall be done carefully to avoid the formation of local sharp bends and to minimize cold work. Insufficient straightening before attaching the extensometer can result in lower-than-actual yield strength readings.

9.3. The percentage of elongation shall be as prescribed in Table 3 [Table 4] when tested in accordance with Section 13.4 of T 244.

10. BENDING REQUIREMENTS

10.1. The bend-test specimen shall withstand being bent around a pin without cracking on the outside radius of the bent portion when tested in accordance with T 285. The requirements for angle of bending and sizes of pins are prescribed in Table 5 [Table 6]. When material is furnished in coils, the test sample must be straightened prior to placing it in the bend tester.

10.2. The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus which provides:

10.2.1. Continuous and uniform application of force throughout the duration of the bending operation.

10.2.2. Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate.

10.2.3. Close wrapping of the specimen around the pin during the bending operation.

10.3. It is permissible to use more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin. When failures occur under more severe methods, retests shall be permitted under the bend test method prescribed in Section 10.2.

Table 5—Bend Test Requirements, SI Units

Bar Designation No.	Pin Diameter for Bend Test[a]		
	Grade 280	Grade 420	Grade 520
10, 13, 16	$3^1/_2$ *d* [b]	$3^1/_2$ *d*	—
19	5 *d*	5 *d*	5 *d*
22, 25	—	5 *d*	5 *d*
29, 32, 36	—	7 *d*	7 *d*
43, 57, (90°)	—	9 *d*	9 *d*

[a] Test bends 180 degrees unless noted otherwise.

[b] *d* = nominal diameter of specimen.

Table 6—Bend Test Requirements

Bar Designation No.	Pin Diameter for Bend Test[a]		
	Grade 40	Grade 60	Grade 75
3, 4, 5	$3^1/_2$ *d* [b]	$3^1/_2$ *d*	—
6	5 *d* [b]	5 *d*	—
7, 8	—	5 *d*	—
9, 10	—	7 *d*	—
11	—	7 *d*	7 *d*
14, 18, (90°)	—	9 *d*	9 *d*

[a] Test bends 180 degrees unless noted otherwise.

[b] *d* = nominal diameter of specimen.

11. PERMISSIBLE VARIATION IN MASS [WEIGHT]

11.1. The permissible variation shall not exceed 6 percent under nominal mass [weight], except for bars smaller than 9.5 mm [$^3/_8$ in.] plain round, the permissible variation in mass [weight] shall be computed upon the basis of the permissible variation in diameter in ASTM A 510M [ASTM A 510]. For larger bars up to and including 63.5 mm [2 ½ in.], use AASHTO M 160. Reinforcing bars are evaluated on the basis of nominal mass [weights]. In no case shall the overmass [overweight] of any bar be the cause for rejection.

11.2. The specified limit of variation shall be evaluated in accordance with ASTM E 29 (rounding method).

12. FINISH

12.1. The bar shall be free of detrimental surface imperfections.

12.2. Rust, seams, surface irregularities, or mill scale shall not be cause for rejection, provided the weight, dimensions, cross-sectional area, and tensile properties of a hand wire-brushed test specimen are not less than the requirements of this specification.

12.3. Surface imperfections other than those specified in Section 12.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements. Examples include, but are not limited to, laps, seams, scabs, slivers, cooling or casting cracks, and mill or guide marks (Notes 3 and 4).

Note 3—Reinforcing bar intended for epoxy coating application should have surfaces with a minimum of sharp edges to achieve proper cover. Particular attention should be given to bar marks and deformations, where coating difficulties are prone to occur.

Note 4—Deformed bars destined to be mechanically spliced or butt-welded may require a certain degree of roundness in order for the splices to adequately achieve strength requirements.

13. TEST SPECIMENS

13.1. All mechanical tests shall be conducted in accordance with Test Methods and Definitions T 244 including Annex A9.

13.2. Tension test specimens shall be the full section of the bar as rolled. The unit stress determinations on full-sized specimens shall be based on the nominal bar area.

13.3. The bend-test specimens shall be the full section of the bar as rolled.

14. NUMBER OF TESTS

14.1. For bar sizes No. 10 to 36 [3 to 11], inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If, however, material from one heat differs by three or more designation numbers, one tension and one bend test shall be made from both the highest and lowest designation numbers of the deformed bars rolled.

14.2. For bar sizes No. 43 and 57 [14 and 18] bars, one tension test and one bend test shall be made of each size from each heat.

14.3. For all bar sizes, one set of dimensional property tests, including bar mass [weight] and spacing, height, and gap of deformations, shall be made of each bar size rolled from each heat.

15. RETESTS

15.1. If results of an original tension specimen fail to meet the specified minimum requirements and are within 14 MPa [2000 psi] of the required tensile strength, within 7 MPa [1000 psi] of the required yield strength, or within two percentage units of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the lot. Both retest specimens shall meet the requirements of this specification.

15.2. If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in Sections 15.4.2 and 15.4.3, a retest shall be permitted on two random specimens from the same lot. If the results of both test specimens meet the specified requirements, the lot shall be accepted. The retest shall be performed on test specimens that are at air temperature, but not less than 16ºC [60ºF].

15.3. If a mass [weight] test fails for reasons other than flaws in the specimen as described in Section 15.4.3, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

15.4. If the original test or any of the random retests fails because of reasons listed in Sections 15.4.1, 15.4.2, or 15.4.3, the test shall be considered an invalid test:

15.4.1. The elongation property of any tension test specimen is less than that specified and any part of the fracture is outside the middle half of the gauge length, indicated by scribe marks on the specimen before testing,

Note 5—Marking specimens with multiple scribes or punch marks can reduce the occurrence of fracture outside or near these marks and the need for declaring the test invalid.

15.4.2. Mechanical reasons such as failure of testing equipment or improper specimen preparation,

15.4.3. Flaws are detected in a test specimen, either before or during the performance of the test.

15.5. The original results from Sections 15.4.1, 15.4.2, or 15.4.3 shall be discarded and the test shall be repeated on a new specimen from the same lot.

16. INSPECTION

16.1. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

16.2. *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein and may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification, where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

17. REJECTION

17.1. Unless otherwise specified, any rejection based on tests made in accordance with Section 6.2 shall be reported to the manufacturer within five working days from the receipt of samples by the purchaser.

17.2. Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

18. REHEARING

18.1. Samples tested in accordance with Section 6.2 that represent rejected material shall be preserved for 2 weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

19. TEST REPORTS

19.1. When specified in the purchase order, report the following information, on a per-heat basis. Additional items may be reported as requested or desired.

19.1.1. Chemical analysis, including carbon, manganese, phosphorus, and sulfur.

19.1.2. Tensile properties.

19.1.3. Bend test.

19.2. Material Test Report, Certificate of Inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

20. MARKING

20.1. When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

20.2. Each producer shall identify the symbols of his marking system.

20.3. All bars produced to this specification, except plain round bars which shall be tagged for grade, shall be identified by a distinguishing set of marks legibly rolled into the surface of one side of the bar to denote, in the following order:

20.3.1. *Point of Origin*—Letter or symbol established as the producer's mill designation.

20.3.2. *Size Designation*—Arabic number corresponding to bar designation number of Table 1 [Table 2].

20.3.3. *Type of Steel*—Letter *S* indicates that the bar was produced to this specification or for Grade 420 [60] bars only; letters *S* and *W* indicate that the bar was produced to meet both Specifications M 31M/M 31 and ASTM A 706/A 706M.

20.3.4. *Minimum Yield Designation*—For Grade 420 [60] bars, either the number 4 [60] or a single continuous longitudinal line through at least five spaces offset from the center of the bar side. For Grade 520 [75] bars, either the number 5 [75] or two continuous longitudinal lines through at least five spaces offset each direction from the center of the bar. (No marking designation for Grade 280 [40] bars.)

20.3.5. It shall be permissible to substitute: a metric size bar of Grade 280 for the corresponding inch-pound size bar of Grade 40, a metric size bar of Grade 420 for the corresponding inch-pound size bar of Grade 60, and a metric size bar of Grade 520 for the corresponding inch-pound size bar of Grade 75.

21. PACKAGING

21.1. When specified in the purchase order, packaging shall be in accordance with the procedures in ASTM A 700.

21.2. *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

22. KEYWORDS

22.1. Concrete reinforcement; deformations (protrusions); steel bars.

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[1] Agrees with ASTM A 615/A 615M-09 except for the bend testing procedure, which is referenced to T 285 and Section 9.2.2.

Standard Specification for

Steel Wire, Plain, for Concrete Reinforcement

AASHTO Designation: M 32M/M 32-09
ASTM Designation: A 82/A 82M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Wire, Plain, for Concrete Reinforcement

AASHTO Designation: M 32M/M 32-09
ASTM Designation: A 82/A 82M-07

1. SCOPE

1.1. This specification covers cold-drawn, steel wire, as drawn or galvanized, to be used as such or in fabricated form, for the reinforcement of concrete, in sizes not less than 2.03 mm [0.080 in.] nominal diameter.

1.2. Supplement S1 describes high-strength wire, which shall be furnished when specifically ordered. It shall be permissible to furnish high-strength wire in place of regular wire if mutually agreed to by the purchaser and the manufacturer.

1.3. The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. (The inch-pound units are shown in brackets except in Table 6.)

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 55M/M 55, Steel Welded Wire Reinforcement, Plain, for Concrete
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 641/A 641M, Standard Specification for Zinc-Coated (Galvanized) Carbon Steel Wire
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- E 83, Standard Practice for Verification and Classification of Extensometer Systems

2.3. *Military Standard*:

- MIL-STD-129, Marking for Shipment and Storage

2.4. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipments (Civil Agencies)

2.5. *Other Standard*:

- ACI 318, Building Code Requirements for Structural Concrete

3. ORDERING INFORMATION

3.1. It shall be the responsibility of the purchaser to specify all requirements that are necessary for the manufacture and delivery of the wire under this specification. Such requirements to be considered include, but are not limited to, the following:

3.1.1. Quantity (mass) [weight],

3.1.2. Name of material (cold-drawn steel wire for concrete reinforcement),

3.1.3. Wire size number (see Section 8),

3.1.4. Yield strength measurement (see Sections 5.1 and 11.3),

3.1.5. Packaging (see Section 15),

3.1.6. AASHTO designation and year of issue, and

3.1.7. Special requirements, if any (see Supplement S1).

Note 1—A typical ordering description is as follows: 50000 kg [100000 lb] cold-drawn steel wire for concrete reinforcement, size No. W5 in 800 kg [2000 lb] secured coils, to M 32M/M 32-___.

4. MATERIALS AND MANUFACTURE

4.1. The steel shall be made by one or more of the following processes: open-hearth, electric-furnace, or basic-oxygen.

4.2. The wire shall be cold drawn from rods that have been hot rolled from billets.

4.3. Unless otherwise specified, the wire shall be supplied uncoated. When specified as galvanized, it shall be galvanized at finish size.

5. MECHANICAL PROPERTY REQUIREMENTS

5.1. *Tension Tests*:

5.1.1. When tested as described in Methods and Definitions T 244, the material, except as specified in Section 5.1.2, shall conform to the tensile property requirements in Table 1, based on nominal area of wire.

Table 1—Tension Test Requirements

Tensile strength, min MPa [ksi]	550 [80]
Yield strength, min MPa [ksi]	485 [70]
Reduction of area, min percent	30[a]

[a] For material testing over 690 MPa [100 ksi] tensile strength, the reduction of area shall be not less than 25 percent.

5.1.2. When required by the purchaser, yield strength shall be determined as described using a Class B-1 extensometer described in ASTM E 83. The yield strength shall be determined as described in Test Methods and Definitions T 244 at an extension under load of 0.5 percent of gauge length. It shall be permissible to remove the extensometer after the yield strength has been determined. The wire shall meet the requirements of Table 1 or Table 2, whichever is applicable.

5.1.3. For material to be used in the fabrication of welded wire reinforcement, the tensile and yield strength properties shall conform to the requirements given in Table 2, based on nominal area of the wire.

Table 2—Tension Test Requirements [Material for Welded Wire Reinforcement]

	Size MW7.7 [W1.2] and Larger	Smaller Than Size MW7.7 [W1.2]
Tensile strength, min MPa [ksi]	515 [75]	485 [70]
Yield strength, min MPa [ksi]	450 [65]	385 [56]
Reduction of area, min percent	30[a]	30[a]

[a] For material testing over 690 MPa [100 ksi] tensile strength, the reduction of area shall be not less than 25 percent.

5.1.4. The material shall not exhibit a definite yield point as evidenced by a distinct drop of the beam or halt in the gauge of the testing prior to reaching ultimate tensile load.

5.2. *Bend Tests*—The bend-test specimen shall stand being bent at room temperature through 180 degrees without cracking on the outside of the bent portion, as prescribed in Table 3.

Table 3—Bend-Test Requirements

Size Number of Wire	Bend Test
MW45 [W7] and smaller	Bend around a pin the diameter of which is equal to the diameter of the specimen.
Larger than MW45 [W7]	Bend around a pin the diameter of which is equal to twice the diameter of the specimen.

5.3. *Reduction of Area Test*—The reduction of area shall be determined as described in Test Methods and Definitions T 244, and the wire shall conform to the reduction of area requirements in Table 1 and Table 2.

6. PERMISSIBLE VARIATION IN WIRE DIAMETER

6.1. The permissible variation in the diameter of the wire shall conform to the requirements in Table 4.

6.2. The difference between the maximum and minimum diameters, as measured on any given cross section of the wire, shall not exceed the tolerances listed in Table 4 for the given wire size.

Table 4—Permissible Variation in Wire Diameter

Size Number	Nominal Diameter, mm [in.]	Permissible Variation Plus and Minus, mm [in.]
Smaller than MW32 [W5]	under 6.40 [0.252]	0.08 [0.003]
MW32 [W5] to MW77 [W12], incl	6.40 [0.252] to 9.93 [0.391], incl	0.10 [0.004]
Over MW77 [W12] to MW129 [W20], incl	over 9.93 [0.391] to 12.83 [0.505], incl	0.15 [0.006]
Over MW129 [W20]	over 12.83 [0.505]	0.20 [0.008]

7. WORKMANSHIP, FINISH, AND APPEARANCE

7.1. The wire shall be free of detrimental imperfections and shall have a workmanlike finish.

7.2. Galvanized wire shall be produced as described in ASTM A 641/A 641M, regular coating.

7.3. Rust, surface seams, or surface irregularities shall not be a cause for rejection provided the requirements of Section 7.4 are met; and the minimum dimensions and mechanical properties of a hand wire-brushed test specimen are not less than the requirements of this specification.

7.4. Wire intended for welded wire reinforcement shall be sufficiently free of rust and drawing lubricant so as not to interfere with electric resistance welding.

8. GENERAL REQUIREMENTS

8.1. When wire for concrete reinforcement is ordered by size number, the relation between size number, diameter, and area shown in Table 5 and Table 6 shall apply.

Table 5—Dimensional Requirements for Plain Wire—SI Units Wire Sizes

Size Number[a]	Nominal Diameter mm [in.]	Nominal Area mm^2 [$in.^2$]
MW 5	2.52 [0.099]	5 [0.008]
MW 10	3.57 [0.140]	10 [0.016]
MW 15	4.37 [0.172]	15 [0.023]
MW 20	5.05 [0.199]	20 [0.031]
MW 25	5.64 [0.222]	25 [0.039]
MW 30	6.18 [0.243]	30 [0.047]
MW 35	6.68 [0.263]	35 [0.054]
MW 40	7.14 [0.281]	40 [0.062]
MW 45	7.57 [0.298]	45 [0.070]
MW 50	7.98 [0.314]	50 [0.078]
MW 55	8.37 [0.329]	55 [0.085]
MW 60	8.74 [0.344]	60 [0.093]
MW 65	9.10 [0.358]	65 [0.101]
MW 70	9.44 [0.372]	70 [0.109]
MW 80	10.10 [0.397]	80 [0.124]
MW 90	10.70 [0.421]	90 [0.140]
MW 100	11.30 [0.444]	100 [0.155]
MW 120	12.40 [0.487]	120 [0.186]
MW 130	12.90 [0.507]	130 [0.202]
MW 200	16.00 [0.628]	200 [0.310]
MW 290	19.20 [0.757]	290 [0.450]

[a] Table 1 represents a hard metrication of the most readily available size in the welded wire reinforcement industry. Table 5 should be used in projects that are designed using SI units. Table 6 should be used on projects designed using inch-pound units. Areas of wire should be checked with the most efficient and readily available material from producers. Other wire sizes are available, and many manufacturers can produce them in 1-mm^2 [0.0015-$in.^2$] increments.

Table 6—Dimensional Requirements for Plain Wire—Inch-Pound Units

Wire Sizes					
Size Number[a]	Nominal Diameter, in [mm.]	Nominal Area, in.^{2} [mm^2]	Size Number	Nominal Diameter, mm [in.]	Nominal Area mm^2 [in.^{2}]
W0.5	0.080 [2.03]	0.005 [3.23]	W11	0.374 [9.50]	0.110 [71.00]
W1.2	0.124 [3.14]	0.012 [7.74]	W12	0.391 [9.93]	0.120 [77.40]
W1.4	0.134 [3.39]	0.014 [9.03]	W14	0.422 [10.70]	0.140 [90.30]
W2	0.160 [4.05]	0.020 [12.90]	W16	0.451 [11.50]	0.160 [103.00]
W2.5	0.178 [4.53]	0.025 [16.10]	W18	0.479 [12.20]	0.180 [116.00]
W2.9	0.192 [4.88]	0.029 [18.70]	W20	0.505 [12.80]	0.200 [129.00]
W3.5	0.211 [5.36]	0.035 [22.60]	W22	0.529 [13.40]	0.220 [142.00]
W4	0.226 [5.73]	0.040 [25.80]	W24	0.553 [14.00]	0.240 [155.00]
W4.5	0.239 [6.08]	0.045 [29.00]	W26	0.575 [14.60]	0.260 [168.00]
W5	0.252 [6.41]	0.050 [32.30]	W28	0.597 [15.20]	0.280 [181.00]
W5.5	0.265 [6.72]	0.055 [35.50]	W30	0.618 [15.70]	0.300 [194.00]
W6	0.276 [7.02]	0.060 [38.70]	W31	0.628 [16.00]	0.310 [200.00]
W8	0.319 [8.11]	0.080 [51.60]	W45	0.757 [19.20]	0.450 [290.00]
W10	0.357 [9.06]	0.100 [64.50]			

[a] This table represents the most recently available sizes in the welded wire enforcement industry in sizes using inch-pound units. Areas of wire should be checked with the most efficient and readily available material from producers. Other wire sizes are available, and many manufacturers can produce them in 0.0015-in.^{2} increments.

9. SAMPLING

9.1. Test specimens for testing mechanical properties shall be full wire sections and shall be obtained from ends of wire coils as drawn or as galvanized. The specimens shall be of sufficient length to perform testing described in Sections 5.1 and 5.2.

9.2. If any test specimen exhibits obvious isolated imperfections that are not representative of the product, it may be discarded and another specimen substituted.

10. NUMBER OF TESTS

10.1. One tension and one bend test shall be made from each 9000 kg [10 tons] or less of each size of wire or fraction thereof in a lot, or a total of seven samples, whichever is fewer. A lot shall consist of all the coils of a single size offered for delivery at the same time.

11. INSPECTION

11.1. The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to assure him that the material is being furnished in accordance with this specification.

11.2. Except for yield strength, all tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified. Such tests shall be so conducted as not to interfere unnecessarily with the operation of the works.

11.3. The purchaser shall have the option to require a yield strength measurement to determine compliance with yield strength requirements in Section 5.1, and shall specify that the measurement be performed by the manufacturer at the manufacturer's facilities, a recognized laboratory, or the purchaser's representative at the manufacturer's facilities. Such measurements shall be conducted without unnecessarily interfering with the manufacturing operations.

11.4. *For U.S. Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

12. REJECTION

12.1. Material that shows detrimental imperfections subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

12.2. Failure of any of the test specimens to comply with the requirements of this specification shall constitute grounds for rejection of the lot represented by the specimen.

12.3. Any rejection based on tests made in accordance with the specification shall be reported to the manufacturer within 2 weeks of the date of inspection or test. The material must be adequately protected and correctly identified in order that the producer may make a proper investigation.

13. REHEARING

13.1. Rejected materials shall be preserved for a period of at least 2 weeks from the date of inspection, during which time the manufacturer shall have the option to make claim for a rehearing and retesting.

13.2. The manufacturer shall have the option to resubmit the rejected lot for reinspection or retesting by inspecting or testing every coil for the property in which the test specimen failed and sorting out nonconforming coils.

14. CERTIFICATION

14.1. When specified in the purchase order or contract, the purchaser shall be furnished with the manufacturer's written certification that the material was manufactured, sampled, tested, and inspected in accordance with, and meets the requirements of, this specification. When specified in the purchase order or contract, a report of the test results shall be furnished. The certification shall include the specification number, year-date of issue, and revision letter, if any.

14.2. A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document shall meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the manufacturer.

Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

15. PACKAGING AND MARKING

15.1. The size of the wire, AASHTO specification, and name or mark of the manufacturer shall be marked on a tag securely attached to each coil of wire.

15.2. Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

15.3. When specified in the contract or order, and for the direct procurement by or direct shipment to the U.S. government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for military agencies and in accordance with Fed. Std. No. 123 for civil agencies.

16. KEYWORDS

16.1. Concrete reinforcement; reinforced concrete; reinforcing steels; steel wire.

SUPPLEMENTARY REQUIREMENTS

S1. HIGH-STRENGTH WIRE

S1.1. *Scope*:

S1.1.1 This supplement delineates only those details that relate to high-strength wire and to the mechanical requirements for wire having properties generally as described in this specification.

Note S1—Building codes, for example, ACI 318, permit the use of reinforcement with a yield strength up to 550 MPa [80000 psi]. For compatibility with the codes' design provisions for high-strength reinforcement, this supplement prescribes requirements for the mechanical properties of wire that exceed the minimum values for yield strength and tensile strength in Table 1 and Table 2 of this specification.

S1.2. *Mechanical Property Requirements*:

S1.2.1 Minimum yield strength shall be specified in the purchase order in increments of 17.5 MPa [2500 psi]. When tested, the yield strength shall be determined at an extension under load of 0.0035 mm/mm [0.0035 in./in.].

Note S2—To conform to the limit on yield strength in building codes, the minimum yield strength specified in the purchase order should not be greater than 550 MPa [80000 psi].

S1.2.2 Minimum tensile strength shall be 70 MPa [10000 psi] greater than the specified minimum yield strength.

Note S3—A typical order entry line for minimum yield strength is "72500 psi minimum yield strength" or "500 MPa minimum yield strength."

S1.2.3 The minimum reduction of area shall be 30 percent. For material testing over 690 MPa [100000 psi] tensile strength, the reduction of area shall not be less than 25 percent.

S1.3. *Certification*:

S1.3.1 Certification for material produced to this supplement shall include a report of the test results for yield strength, tensile strength reduction of area, and bend tests. Frequency of testing shall conform to Section 10 of this specification or Section 12 of M 55M/M 55, as applicable.

Standard Specification for

Welded Deformed Steel Bar Mats for Concrete Reinforcement

AASHTO Designation: M 54M/M 54-07
ASTM Designation: A 184/A 184M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Welded Deformed Steel Bar Mats for Concrete Reinforcement

AASHTO Designation: M 54M/M 54-07
ASTM Designation: A 184/A 184M-06

1. SCOPE

1.1 This specification covers material in mat (or sheet) form fabricated from deformed steel bars to be used for the reinforcement of concrete. Mats consist of two layers of bars that are assembled at right angles to each other. Mats shall be assembled by welding at the intersections.

1.2 This specification is applicable to orders in either SI units (M 54M) or inch-pound units (M 54).

1.3 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

2.2 *ASTM Standard*:

- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- A 706/A 706M, Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

2.3 *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage

2.4 *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipments (Civil Agencies)

3. ORDERING INFORMATION

3.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered. Such requirements shall include, but are not limited to, the following:

3.1.1 Quantity,

3.1.2 Size and spacing of members in each direction,

3.1.3 Grade required 280, 420 [40, 60],

3.1.4 Type of steel as appropriate (Section 4), and

3.1.5 AASHTO M 54M/M 54 and year of issue.

Note 1—A typical ordering description is as follows: 1000 bar mats to M 54M-_____; fabricated from Grade 280 bars to M 31M-_____; 150 by 150 mm; No. 10 by 3000 mm longitudinal tip to tip, outer bars spaced 1350 mm; No. 10 by 1500 mm transverse, outer bars spaced 2850 mm. [1000 bar mats to M 54-_____; Grade 40; 6 by 6 in.; No. 4 by 120 in. longitudinal tip to tip, outer bars spaced 54 in.; No. 3 by 60 in.; transverse, outer bars spaced 114 in.].

4. MATERIAL AND MANUFACTURE

4.1 Deformed steel bars of Grades 280 [40] used in the manufacture of welded mats shall conform to M 31M [M 31]. Deformed steel bars of Grade 420 [60] used in the manufacture of welded mats shall conform to M 31M [M 31] or ASTM A 706M [A 706].

5. FABRICATION

5.1 Fabricated mats shall be composed of two layers of bars substantially parallel and perpendicular to each other.

5.1.1 Mats shall be assembled by means of welding to provide attachment at intersections.

5.1.1.1 Welds shall provide attachment at all exterior intersections and at not less than alternate interior intersections.

5.1.1.2 The separation of 5 percent or less of all welded intersections of any mat shall not be cause for rejection provided that no more than half of the welds on any one bar are separated.

5.1.1.3 Welding shall be performed in such a manner that the strength and ductility requirements of the material specification in Section 4 are met when a specimen is tested across a point of weld.

Note 2—Welding of the mat intersections has generally been performed without problems, but care should be taken when welding reinforcing bars with carbon equivalent levels above 0.55 percent, in order to prevent cracking in the weld area.

6. MECHANICAL PROPERTIES

6.1 Mats shall be capable of withstanding a static load of 670 N [150 lbf] exerted perpendicular to the plane of the mat tending to separate the bars, with no apparent loosening when applied to one intersection of connected bars.

6.2 *Number of Tests*:

6.2.1 One sample consisting of not fewer than two connections on the same transverse member shall be tested for conformance with the provisions of Sections 5.1.1.3 and 6.1 from each 7000 m^2 [75000 ft^2] of mats or fraction thereof.

6.3 *Test Methods*:

6.3.1 Tension test specimens for determining conformance with Section 5.1.1.3 shall have a welded joint located approximately at the center of the bar being tested, and the cross bar shall extend approximately 25 mm [1 in.] beyond each side. All unit stress determinations shall be based on the nominal area calculated using the nominal diameter specified.

6.3.2 Tests of connections against separation may be performed on an assembled mat by placing blocks under a deformed bar in the upper layer and applying the prescribed load upon the bar in the lower layer.

7. SIZE, DIMENSIONS, AND TOLERANCES

7.1 *Size and Spacing Dimensions*—The sizes, spacings, dimensions, and arrangement of the bar mats shall conform to the design specified by the purchaser. Bars shall extend beyond exterior intersections a distance of not less than 25 mm [1 in.]. The spacing of bars shall average that specified in the design, and the space between individual bars shall not vary more than 6 mm [$^1/_4$ in.] from that specified.

7.2 *Width and Length Tolerances*—The overall length or width of the mats shall not be more than 25 mm [1 in.] greater or less than the specified dimension.

8. FINISH AND SURFACE CONDITION

8.1 The finished mats shall be free of injurious defects in material or workmanship.

8.2 Rust, surface seams, surface irregularities, or mill scale shall not be cause for rejection provided the mass; dimensions, including height of deformation; cross-sectional area; and tensile properties of a hand wire-brushed test specimen are not less than the requirements of this specification.

9. REJECTION AND RETESTS

9.1 Fabricated mats that do not meet the requirements of this specification shall be rejected and reported to the supplier within 5 working days from the receipt of samples by the purchaser.

9.2 In case a test specimen fails to meet the provisions of Section 6.1, two additional samples shall be selected and tested. All retest specimens shall meet the requirements of this specification.

9.3 In case a test specimen fails to meet the provisions of Section 5.1.1.3, all of the remaining bars on the transverse member shall be tested and the average of all tests (including the original test) shall meet the requirements specified in Section 5.1.1.3.

10. INSPECTION AND TEST REPORTS

10.1 *Inspection*—The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's plant that concern the fabrication of the mats ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy that the mats are being furnished in accordance with this specification. All tests and inspection shall be made at the place of fabrication prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with fabricating operations. Inspection as to general workmanship shall be visual.

10.2 *Test Reports on Bar Material*—The manufacturer shall supply test reports showing that the material used in the fabrication of the mats as delivered has fulfilled the tension and bend test requirements of the specified type and grade described in Section 4. The reports shall show the manufacturer's test identification numbers, including the identity of the material.

10.3 A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 3—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI SAC X12.

10.4 *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor shall be responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

11. REHEARING

11.1 Samples tested in accordance with this specification that represent rejected material shall be preserved for 2 weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer shall have the right to make claim for a hearing within that time.

12. PACKAGING AND PACKAGE MARKING

12.1 Packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

12.2 When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for military agencies and with Fed. Std. No. 123 for civil agencies.

12.3 Each bundle of mats shall be marked with a suitable tag showing the name of the manufacturer and other markings to identify it with the order.

Standard Method of Test for

Steel Welded Wire Reinforcement, Plain, for Concrete

AASHTO Designation: M 55M/M 55-09
ASTM Designation: A 185/A 185M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Steel Welded Wire Reinforcement, Plain, for Concrete

AASHTO Designation: M 55M/M 55-09
ASTM Designation: A 185/A 185M-07

1. SCOPE

1.1. This specification covers welded wire reinforcement to be used for the reinforcement of concrete.

Note 1—Welded wire for concrete reinforcement has been described by various terms: welded wire fabric (WWF), fabric, and mesh. The wire reinforcement industry prefers the term "welded wire reinforcement" or WWR as being more representative of the range of products being manufactured. Therefore, the term "welded wire fabric" has been replaced with the term "welded wire reinforcement" in this specification and in related specifications.

1.2. This specification is applicable for orders in either SI units (M 55M) or in inch-pound units (M 55). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity but they are the applicable values when the material is ordered to M 55. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values may result in nonconformance with the specification.

2. REFERENCED DOCUMENTS

AASHTO Standard:

- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement

2.1. *ASTM Standards*:

- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- ASTM Adjuncts: Testing Jig Drawing

2.2. *Military Standard*:

- MIL-STD-129, Marking for Shipment and Storage

2.3. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *convoluted wire*—when wire for welded reinforcement is formed into a sinusoidal wave shape, it is commonly referred to as convoluted wire. The wire is used in the manufacture of cages for certain applications of concrete pipe reinforcing.

3.1.2. *welded wire reinforcement*—as used within the scope and intent of this specification, designates a material composed of cold-drawn steel wire, as drawn or galvanized, fabricated into sheets or rolls by the process of electric-resistance welding. The finished material shall consist essentially of a series of longitudinal and transverse wires arranged substantially at right angles to each other and welded together at points of intersection.

4. ORDERING INFORMATION

4.1. It shall be the responsibility of the purchaser to specify all requirements that are necessary for the manufacture and delivery of the welded wire reinforcement under this specification. Such requirements to be considered include, but are not limited to, the following:

4.1.1. Quantity (mass or square area),

4.1.2. Name of material (welded wire reinforcement for concrete reinforcement),

4.1.3. Wire spacings and sizes,

4.1.4. Minimum yield strength if Supplement S1 of M 32M/M 32 applies.

4.1.5. Yield strength measurement. The purchaser shall have the options described in M 32M/M 32 under the Inspection section (11.3).

4.1.6. Exclusion of oversteeling, if required (Section 9.4.2),

4.1.7. Length and width of sheets or rolls,

4.1.8. Packaging (Section 16),

4.1.9. Request for outside inspection (if not requested, Section 15.1 applies), and

4.1.10. AASHTO Designation and year of issue.

Note 2—A typical ordering description is as follows: 930 m^2 welded wire reinforcement for concrete reinforcement, 100 × 300-W15 × W6 in flat sheets, 2.4 m wide × 6.1 m long, in secured lifts, to M 55M. [10000 ft^2 welded wire reinforcement for concrete reinforcement, 4 × 12 W15 × W6 in flat sheets, 96 in. wide × 240 in. long, in secured lifts, to M 55.]

5. MATERIALS

5.1. The wire used in the manufacture of welded wire reinforcement shall conform to M 32M/M 32 and its Supplement S1 if so ordered.

5.2. Welded wire reinforcement shall be furnished either in flat sheets or in rolls, as specified by the purchaser.

6. MANUFACTURE

6.1. The wires shall be assembled by automatic machines or by other suitable mechanical means that will assure accurate spacing and alignment of all members of the finished welded wire reinforcement.

6.2. Longitudinal and transverse members shall be securely connected at every intersection by a process of electrical-resistance welding, which employs the principle of fusion combined with pressure.

6.3. Wire of proper yield strength and quality when fabricated in the manner herein required shall result in a strong, serviceable, mat-type product having substantially square or rectangular openings. It shall be fabricated and finished in a workmanlike manner and shall conform to this specification.

Note 3—A variation of manufacturing includes the application of one or more longitudinal convoluted wires at one edge of reinforcement for concrete pipe reinforcing cages. This shape allows the cage ends to be expanded to a larger diameter to accommodate the bell-shaped ends of concrete pipe.

7. MECHANICAL PROPERTY REQUIREMENTS

7.1. *Tensile*—Wire for the production of welded wire reinforcement is described in M 32M/M 32. Tensile tests may be made on wire cut from the welded wire reinforcement and tested either across or between the welds; no fewer than 50 percent shall be across the welds. Tensile tests across the weld shall have the welded intersection located approximately at the center of the wire being tested and the cross wire forming the welded intersection shall extend approximately 25 mm [1 in.] beyond each side of the welded intersection.

Note 4—Tensile, reduction of area, and bend testing are normally done at the time the wire is drawn. The manufacturer's finished product shall meet the requirements of this specification and M 32M/M 32.

7.2. *Reduction of Area*—The ruptured section of the tensile specimen shall be measured to determine this property. In the case of a specimen that has been tested across a weld, the measurement shall be made only when rupture has occurred at a sufficient distance from the center of a weld to permit an accurate measurement of the fractured section. The wire shall meet the minimum reduction of area requirements of M 32M/M 32.

7.3. *Bend Test*—The wire shall withstand the bend test as described in M 32M/M 32 and shall be performed on a specimen taken from between the welds.

7.4. *Weld Shear Strength*—The weld shear strength between longitudinal and transverse wires shall be tested as described in Section 8. The minimum average shear value, in Newtons, shall not be less than 241, multiplied by the nominal area of the larger wire in square millimeters [in pounds-force shall not be less than 35000, multiplied by the nominal area of the larger wire in square inches], where the smaller wire is not less than size W1.2 and has an area of 40 percent or more of the area of the larger wire. Typical examples of the 40 percent or more wire size differential area follow:

Larger	Smaller
Size No. W20	Size No. W8
Size No. W15	Size No. W6
Size No. W10	Size No. W4

7.4.1. Reinforcement having a relationship of longitudinal and transverse wires other than those covered in Section 7.4 shall not be subject to the weld shear requirement.

7.4.2. Weld shear tests for determination of conformance to the requirements of Section 7.4 shall be conducted using a fixture as described in Section 8.

7.4.3. Four welds selected at random from the specimen described in Section 11.2 shall be tested for weld shear strength. The transverse wire of each test specimen shall extend approximately 25 mm [1 in.] on each side of the longitudinal wire. The longitudinal wire of each test specimen shall be of such length below the transverse wire so as to be adequately engaged by the grips of the testing machine. It shall be of such length above the transverse wire that its end shall be above the centerline of the upper bearing of the testing device.

7.4.4. The material shall be deemed to conform to the requirements for weld shear strength if the average of the four samples complies with the value stipulated in Section 7.4. If the average fails to meet the prescribed value, all the welds across the specimen shall then be tested. The reinforcement will be acceptable if the average of all weld shear test values across the specimen meets the prescribed minimum value.

8. WELD SHEAR TEST APPARATUS AND METHODS

8.1. As the welds in welded wire reinforcement contribute to the bonding and anchorage value of the wires in concrete, the weld acceptance tests shall be made in a weld tester that stresses the weld in a manner similar to which it is stressed in concrete. In order to accomplish this, the vertical wire in the weld tester shall be stressed in an axis close to its centerline. Also, the horizontal wire shall be held closely to the vertical wire, and in the same relative position, so as to prevent rotation of the horizontal wire. When the welded wire reinforcement is designed with different wire sizes, the larger diameter wire is the “vertical wire” when tested (see Figure 1).[1]

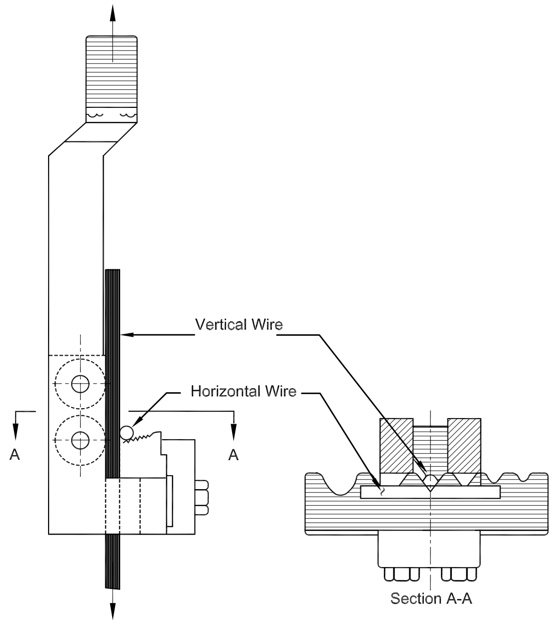

Figure 1—Welded Wire Reinforcement Weld Tester

8.2. Figure 1 shows the details of a typical weld tester together with two anvils that make it possible to test welds for wire up to 16 mm [$^5/_8$ in.] in diameter. This weld tester can be used in most tension testing machines and should be hung in a ball-and-socket arrangement at the center of the machine. This, or a similarly effective fixture designed on the same principle, is acceptable.

8.3. Test specimens should be inserted through the notch in the anvil using the smallest notch available in which the vertical wire will fit loosely. The vertical wire shall be in contact with the surface of the free rotating rollers while the horizontal wire shall be supported by the anvil on each side of the slot. The bottom jaws of the testing machine shall grip the lower end of the vertical wire and the load shall be applied at a rate of stressing not to exceed 690 MPa/min [100000 psi/min].

9. DIMENSIONS, MASS, AND PERMISSIBLE VARIATIONS

9.1. *Width*—The width of welded wire reinforcement shall be considered to be the center-to-center distance between outside longitudinal wires. The permissible variation shall not exceed 13 mm [$^1/_2$ in.] greater or less than the specified width. In case the width of flat sheets or rolls is specified as the overall width (tip-to-tip length of cross wires), the width shall not vary more than ±25 mm [±1 in.] from the specified width.

9.2. *Length*—The overall length of flat sheets, measured on any wire, may vary ±25 mm [±1 in.] or 1 percent, whichever is greater.

9.3. Overhang of the transverse wires shall not project beyond the centerline of each longitudinal edge wire more than a distance of 25 mm [1 in.] unless otherwise specified. When transverse wires are specified to project a specific length beyond the centerline of a longitudinal edge wire, the permissible variation shall not exceed 13 mm [$^1/_2$ in.] greater or less than the specified length.

9.4. The permissible variation in diameter of any wire in the finished welded wire reinforcement shall conform to the tolerances prescribed for the wire before fabrication in M 32M/M 32, with the following exceptions:

9.4.1. Because of the mechanical characteristics of fabricating welded wire reinforcement, the out-of-round requirements shall not apply;

9.4.2. Unless otherwise precluded by the purchaser in 4.1, the manufacturer will be permitted to apply oversized wire (not undersized). The size differential shall not exceed two “W” size increments on sizes W8 and smaller, and four “W” size increments on sizes larger than W8. A “W” size increment is a whole number increment, for example, W5 to W6, or W5.4 to W6.4, etc. In all cases in which such oversteeling is practiced, the producer shall identify the welded wire reinforcement with the style originally ordered.

9.5. The average spacing of wires shall be such that the total number of wires contained in a sheet or roll is equal to or greater than that determined by the specific spacing, but the center-to-center distance between individual members may vary not more than 6.4 mm [$^1/_4$ in.] from the specified spacing. It is understood that sheets of welded wire reinforcement of the specified length may not always contain an identical number of transverse wires and, therefore, may have various lengths of longitudinal overhang.

10. WORKMANSHIP, FINISH, AND APPEARANCE

10.1. Wire of proper grade and quality, when fabricated in the manner herein required, shall result in a strong, serviceable, mesh-type product having substantially square or rectangular openings. It shall be fabricated and finished in a workmanlike manner, as determined by visual inspection, and shall conform to this specification.

11. SAMPLING

11.1. Test specimens for testing mechanical properties shall be obtained by cutting from the finished welded wire reinforcement a full width section, of sufficient length to perform testing described in Sections 7.1 and 7.2.

11.2. Test specimens for determining weld shear properties shall be obtained by cutting from the finished welded wire reinforcement, a full width section of sufficient length to perform testing described in Section 7.4.

11.3. Measurements for conformance to dimensional characteristics shall be made on full sheets or rolls.

11.4. Any test specimen exhibiting obvious imperfections shall be discarded and another specimen substituted.

12. NUMBER OF TESTS

12.1. One test for conformance to tensile strength and bend requirements, and one check for conformance to dimensional characteristics shall be made for each 7000 m^2 [75000 ft^2] of welded wire reinforcement or remaining fraction thereof.

12.2. One test for conformance to weld shear strength requirement shall be made for each 28000 m^2 [300000 ft^2] or remaining fraction thereof.

13. INSPECTION AND TESTS

13.1. The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed to all parts of the manufacturer's facilities that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to assure that the material is being furnished in accordance with this specification.

13.2. Except for yield strength, all tests and inspections shall be made at the manufacture's facilities prior to shipment, unless otherwise specified. Such tests shall be so conducted as not to interfere unnecessarily with the operation of the manufacturer's facilities.

13.3. If the purchaser considers it desirable to determine compliance with the yield strength requirements of M 32M/M 32, yield strength tests may be made in a recognized laboratory, or their representatives may make the test at the mill, if such tests do not interfere unnecessarily with the mill operations.

13.4. *For U.S. Government Procurement Only*—The purchaser shall be furnished a manufacturer's certification of conformance to M 32M/M 32 for each production date or production lot shipped. A production lot shall not exceed 28000 m^2 [300 000 ft^2], and certifications shall be traceable to specified date(s) of production marked on the product bundle prior to shipment. Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspections and test requirements specified herein. Except as otherwise specified in the contract, the contractor shall have the option to use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

14. REJECTION AND REHEARING

14.1. Unless otherwise specified, any rejection shall be reported to the manufacturer within 5 days from the time of selection of test specimens.

14.2. In case a specimen fails to meet the tension or bend test, the material shall not be rejected until two additional specimens taken from other wires in the same sheet or roll have been tested. The material shall be considered as meeting the specification in respect to any prescribed tensile property, provided the tested average for the three specimens, including the specimen originally tested, is equal to or exceeds the required minimum for the particular property in question, and provided further that none of the three specimens develops less than 80 percent of the required minimum for the tensile property in question. The material shall be considered as meeting this specification with respect to bend test requirements, provided both additional specimens satisfactorily pass the prescribed bend test.

14.3. Any material that is found not to meet the requirements of this specification subsequent to its acceptance at the manufacturer's facilities shall be subject to rejection and the manufacturer shall be promptly notified.

14.4. Welded intersections shall withstand normal shipping and handling without becoming broken, but the presence of broken welds, regardless of cause, shall not constitute cause for rejection unless the number of broken welds per sheet exceeds 1 percent of the total number of intersections in a sheet. For material furnished in rolls, not more than 1 percent of the total number of intersections in 14 m^2 [150 ft^2] of welded wire reinforcement shall be broken. Not more than one-half the permissible maximum number of broken welds shall be located on any one wire.

14.5. In the event of rejection because of failure to meet the weld shear requirements, four additional specimens shall be taken from four different sheets or rolls and tested in accordance with Section 8. If the average of all the weld shear tests performed does not meet the requirement, the material shall be rejected.

14.6. In the event of rejection because of failure to meet the requirements for dimensions, the amount of material rejected shall be limited to those individual sheets or rolls that fail to meet this specification.

14.7. Rust, surface seams, or surface irregularities will not be cause for rejection provided the minimum dimensions, cross-sectional area, and tensile properties of a hand wire-brushed test specimen are not less than the requirements of this specification.

14.8. *Rehearing*—Rejected materials shall be preserved for a period of at least 2 weeks from the date of inspection, during which time the manufacturer shall be permitted to make claim for a rehearing and retesting.

15. CERTIFICATION

15.1. If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material. The certification shall include the specification number, year-date of issue and revision letter, if any.

15.2. This conformance is predicated upon testing and acceptance of wire prior to fabrication, coupled with random shear testing during production. The purchaser shall be furnished a manufacturer's certification of conformance to M 32M/M 32 for each production date or production lot shipped. A production lot shall not exceed 28000 m^2 [300 000 ft^2]. Any purchaser shall have the right to invoke any of the provisions of Section 13.4.

15.3. When Supplemental S1 of M 32M/M 32 is specified for the material, test results for yield strength, tensile strength, reduction of area, and bend tests shall be reported (S1.2.1 of M 32M/M 32).

15.4. A material test report, certificate of inspection or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the manufacturer. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 5—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

16. PACKAGING AND MARKING

16.1. Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

16.2. When welded wire reinforcement is furnished in flat sheets, it shall be assembled in bundles of convenient size containing not more than 150 sheets and securely fastened together.

16.3. When welded wire reinforcement is furnished in rolls, each roll shall be secured so as to prevent unwinding during shipping and handling.

16.4. Each bundle of flat sheets and each roll shall have attached thereto a suitable tag bearing the name of the manufacturer, description of the material, M 55M/M 55, and such other information as may be specified by the purchaser.

16.5. When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U.S. military agencies and in accordance with Fed. Std. No. 123 for U.S. government civil agencies.

17. KEYWORDS

17.1. Concrete reinforcement; reinforced concrete; reinforcing steels; steel wire; welded wire reinforcement.

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[1] A detailed drawing showing complete dimensions of the testing jig may be obtained from ASTM Headquarters. Request Adjunct #12-101850-00.

Standard Specification for

Steel Strand, Uncoated Seven-Wire for Concrete Reinforcement

AASHTO Designation: M 203M/M 203-07
ASTM Designation: A 416/A 416M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Strand, Uncoated Seven-Wire for Concrete Reinforcement

AASHTO Designation: M 203M/M 203-07
ASTM Designation: A 416/A 416M-06

1. SCOPE

1.1. This specification covers two types and two grades of steel strand, uncoated seven-wire for use in pretensioned and posttensioned prestressed concrete construction. The two types of strand are low-relaxation and stress-relieved (normal-relaxation). Low-relaxation strand shall be regarded as the standard type. Stress-relieved (normal-relaxation) strand will not be furnished unless specifically ordered, or by arrangement between purchaser and supplier. Grade 1725 [250] and Grade 1860 [270] have minimum ultimate strengths of 1725 MPa [250 ksi] and 1860 MPa [270 ksi], respectively, based on the nominal area of the strand.

1.2. The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.3. The supplementary requirements in S1 shall be specified for 15.24-mm [0.600-in.] diameter uncoated seven-wire steel strand if needed for applications in prestressed ground anchors.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 981, Standard Test Method for Evaluating Bond Strength for 15.2 mm (0.6 in.) Diameter Prestressing Steel Strand, Grade 270, Uncoated, Used in Prestressed Ground Anchors
- E 328, Standard Test Methods for Stress Relaxation for Materials and Structures

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

2.4. *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products Preparation for Shipment and Storage

2.5. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipments (Civil Agencies)

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *strand*—all strand shall be of the seven-wire type having a center wire enclosed tightly by six helically placed outer wires with a uniform pitch of not less than 12 and not more than 16 times the nominal diameter of the strand.

3.1.1.1. *Discussion*—The direction of lay may be either right or left hand; however, strands of different lays should not be spliced together.

4. ORDERING INFORMATION

4.1. Orders for seven-wire low-relaxation or stress-relieved (normal-relaxation) strand under this specification should include the following information:

4.1.1. Quantity (meters) [feet],

4.1.2. Diameter of strand,

4.1.3. Grade of strand,

4.1.4. Type of strand,

4.1.5. Packaging,

4.1.6. AASHTO designation and year of issue, and

4.1.7. Special requirements, if any.

Note 1—A typical ordering description is as follows: 25600 m [84000 ft], 13 mm [0.5 in.], Grade 1860 [270] low-relaxation strand, in 3600-m [12000-ft] reelless packs to M 203M/M 203-____.

5. MATERIALS AND MANUFACTURE

5.1. *Base Metal*—The base metal shall be carbon steel of such quality that when drawn to wire, fabricated into strand, and then thermally treated, it shall have the properties and characteristics prescribed in this specification.

5.2. *Wire*—The wire from which the strand is to be fabricated shall be round and have a dry-drawn finish.

Note 2—This product is a composite of seven wires and is produced to mechanical properties only; the chemical composition of all wires or any individual wire is not pertinent to this application, and heat identity is not necessarily maintained. It is possible that wire from more than one heat may be used in the manufacture of a reel or pack. Traceability is based on pack identity as maintained and reported by the manufacturer.

5.3. *Treatment*—After stranding, low-relaxation strand shall be subjected to a continuous thermal-mechanical treatment to produce the prescribed mechanical properties. For stress-relieved (normal-relaxation) strand, only thermal treatment is necessary. Temper colors that may result from the thermal operation are considered normal for the finished appearance of this strand.

6. MECHANICAL PROPERTIES

6.1. Methods of testing for mechanical properties are described in Appendix A7 of T 244. Low-relaxation strand shall also be tested as prescribed in ASTM E 328.

6.2. *Breaking Strength*—The breaking strength of the finished strand shall conform to the requirements prescribed in Table 1.

6.3. *Yield Strength*—Yield strength in kN [pounds] shall be measured at 1 percent extension under load. The minimum yield strength shall be 90 percent for low-relaxation strand and 85 percent for stress-relieved [normal-relaxation] strand of the breaking strength listed in Table 1. Initial loads for the test and minimum yield strengths are listed in Table 2.

Table 1—Breaking Strength Requirements

Strand Designation No.	Nominal Diameter of Strand, mm [in.]	Minimum Breaking Strength of Strand, kN [lbf]	Nominal Steel Area of Strand, mm^2 [in.^{2}]	Nominal Mass of Strand, g/m [lb/1000 ft]
		Grade 1725 [250]		
6	6.4 [0.250]	40.0 [9000]	23.2 [0.036]	182 [122]
8	7.9 [0.313]	64.5 [14500]	37.4 [0.058]	294 [197]
9	9.5 [0.375]	89.0 [20000]	51.6 [0.080]	405 [272]
11	11.1 [0.438]	120.1 [27000]	69.7 [0.108]	548 [367]
13	12.7 [0.500]	160.1 [36000]	92.9 [0.144]	730 [490]
15	15.2 [0.600]	240.2 [54000]	139.4 [0.216]	1094 [737]
		Grade 1860 [270]		
9	9.53 [0.375]	102.3 [23000]	54.8 [0.085]	432 [290]
11	11.11 [0.438]	137.9 [31000]	74.2 [0.115]	582 [390]
13	12.70 [0.500]	183.7 [41300]	98.7 [0.153]	775 [520]
13a	13.20 [0.520]	200.2 [45000]	107.7 [0.167]	844 [568]
14	14.29 [0.563]	230.0 [51700]	123.9 [0.192]	970 [651]
15	15.24 [0.600]	260.7 [58600]	140.0 [0.217]	1102 [740]
18	17.78 [0.700]	353.2 [79400]	189.7 [0.294]	1487 [1000]

Table 2—Yield Strength Requirements

Strand Designation No.	Nominal Diameter of Strand mm [in.]	Initial Load, kN [lbf]	Minimum Load at 1% Extension, kN [lbf] Low-Relaxation	Minimum Load at 1% Extension, kN [lbf] Normal-Relaxation
		Grade 1725 [250]		
6	6.4 [0.250]	4.0 [900]	36.0 [8100]	34.0 [7650]
8	7.9 [0.313]	6.5 [1450]	58.1 [13050]	54.7 [12300]
9	9.5 [0.375]	8.9 [2000]	80.1 [18000]	75.6 [17000]
11	11.1 [0.438]	12.0 [2700]	108.1 [24300]	102.3 [23000]
13	12.7 [0.500]	16.0 [3600]	144.1 [32400]	136.2 [30600]
15	15.2 [0.600]	24.0 [5400]	216.2 [48600]	204.2 [45900]
		Grade 1860 [270]		
9	9.53 [0.375]	10.2 [2300]	92.1 [20700]	87.0 [19550]
11	11.11 [0.438]	13.8 [3100]	124.1 [27900]	117.2 [26350]
13	12.70 [0.500]	18.4 [4130]	165.3 [37170]	156.1 [35100]
13a	13.20 [0.520]	20.0 [4500]	180.1 [40500]	170.1 [38250]
14	14.29 [0.563]	23.0 [5170]	207.0 [46530]	195.5 [43950]
15	15.24 [0.600]	26.1 [5860]	234.6 [52740]	221.5 [49800]
18	17.78 [0.700]	35.3 [7940]	318.0 [71500]	300.2 [67500]

6.3.1. The extension under load shall be measured by an extensometer calibrated with the smallest division not larger than 0.0001 mm/mm [0.0001 in./in.] of gauge length.

6.4. *Elongation*—The total elongation under load shall not be less than 3.5 percent using a gauge length of not less than 600 mm [24 in.]. It shall be permissible to determine the total elongation value by adding to the 1.0 percent yield extension the percent extension or movement between the jaws gripping the strand after yield determination. The percent is calculated on the new base length of jaw-to-jaw distance.

6.5. *Relaxation Properties*—Low-relaxation strand shall have relaxation losses of not more than 2.5 percent when initially loaded to 70 percent of specified minimum breaking strength or not more than 3.5 percent when loaded to 80 percent of specified minimum breaking strength of the strand after 1000 hours tested under the conditions listed in Sections 6.5.1 through 6.5.7.

6.5.1. If required, relaxation evidence shall be provided from the manufacturer’s records of tests on similarly dimensioned strand of the same grade.

6.5.2. The temperature of the test specimen shall be maintained at 20 ± 2ºC [68 ± 3.5ºF].

6.5.3. The test specimen shall not be subjected to loading prior to the relaxation test.

6.5.4. The initial load shall be applied uniformly over a period of not less than 3 minutes and not more than 5 minutes, and the gauge length shall be maintained constant; load-relaxation readings shall commence 1 minute after application of the total load.

6.5.5. Overstressing of the test specimen during the loading operation shall not be permitted.

6.5.6. The duration of the test shall be 1000 hours or a shorter period of at least 200 hours, provided it can be shown by records that an extrapolation of the shorter period test results to 1000 hours will provide similar relaxation values as the full 1000-hours test.

6.5.7. The test gauge length should be at least 60 times the nominal diameter. If this gauge length exceeds the capacity of the extensometer or testing machine, then it shall be permitted to substitute a gauge length of 40 times the nominal strand diameter.

7. DIMENSIONS AND PERMISSIBLE VARIATIONS

7.1. The size of the finished strand shall be expressed as the nominal diameter of the strand in millimeters [inches].

7.2. The diameter of the center wire of any strand shall be larger than the diameter of any outer wire in accordance with Table 3.

Table 3—Diameter Relation between Center and Outer Wires

Strand Designation No.	Nominal Diameter of Strand		Minimum Difference between Center Wire Diameter and Diameter of Any Outer Wire	
	mm	in.	mm	in.
Grade 1725 [250]				
6	6.4	0.250	0.025	0.001
8	7.9	0.313	0.038	0.0015
9	9.5	0.375	0.051	0.002
11	11.1	0.438	0.064	0.0025
13	12.7	0.500	0.076	0.003
15	15.2	0.600	0.102	0.004
Grade 1860 [270]				
9	9.53	0.375	0.0508	0.002
11	11.11	0.438	0.0635	0.0025
13	12.70	0.500	0.0762	0.003
13a	13.20	0.520	0.0762	0.003
14	14.29	0.563	0.0889	0.0035
15	15.24	0.600	0.1016	0.004
18	17.78	0.700	0.1143	0.0045

7.3. *Permissible Variations in Diameter*:

7.3.1. All Grade 1725 [250] strand shall conform to a size tolerance of ±0.40 mm [±0.016 in.] from the nominal diameter measured across the crowns of the wires.

7.3.2. All Grade 1860 [270] strand shall conform to a size tolerance of +0.65 mm, –0.15 mm [+0.026 in., –0.006 in.] from the nominal diameter measured across the crowns of the wire.

7.3.3. Variation in cross-sectional area and in unit stress resulting therefrom shall not be cause for rejection provided the diameter differences of the individual wires and the diameters of the strand are within the tolerances specified.

7.4. It shall be permitted to furnish, under this specification, specially dimensioned low-relaxation and stress-relieved [normal-relaxation] strands with nominal diameters up to 19 mm [0.750 in.]. The breaking strength shall be defined, and the yield strength, as defined in Section 6.3, shall not be less than 90 percent and 85 percent of the specified minimum breaking strength for low-relaxation and stress-relieved [normal-relaxation] strands, respectively. All other requirements shall apply.

8. WORKMANSHIP, FINISH, AND APPEARANCE

8.1. *Joints*:

8.1.1. There shall be no strand joints or strand splices in any length of the completed strand unless specifically permitted by the purchaser.

8.1.2. During the process of manufacture of individual wires for stranding, welding shall be permitted only prior to or at the size of the last thermal treatment, for example, patenting or control cooling. There shall be no welds in the wire after it has been drawn through the first die in the wire drawing except as provided in Section 8.1.3.

8.1.3. During fabrication of the strand, butt-welded joints are permitted in the individual wires, provided there shall not be more than one such joint in any 45-m [150-ft] section of the completed strand.

8.1.4. When specifically ordered as “Weldless,” a product free of welds shall be furnished. When “Weldless” is specified, the strand is produced as one continuous length with no welds as allowed by Section 8.1.3.

8.2. The finished strand shall be uniform in diameter and shall be free of imperfections not consistent with good commercial stranding practice.

8.3. When the strand is cut without seizings, the wire shall not fly out of position. If any wire flies out of position and can be replaced by hand, the strand will be considered satisfactory.

8.4. The strand shall not be oiled or greased. Slight rusting, provided it is not sufficient to cause pits visible to the unaided eye, shall not be cause for rejection.

Note 3—Guidance for evaluating the degree of rusting on prestressed concrete strand is presented in Sason.[1]

9. SAMPLING

9.1. Test specimens cut from either end of the strand package are permitted. Any specimen found to contain a wire joint should be discarded and a new specimen obtained.

10. NUMBER OF TESTS

10.1. One specimen for test shall be taken from each 18-Mg [20-ton] production lot of finished strand, and tested for breaking strength, yield strength, and elongation.

11. INSPECTION

11.1. If outside inspection is required, the manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy that the material is being furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise agreed upon at the time of purchase, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Note 4—The purchaser should state, at the time of order, whether outside inspection is required or waived.

12. REJECTION

12.1. Failure of any test specimen to comply with the requirements of the specification shall constitute grounds for rejection of the lot represented by the specimen.

12.2. The lot shall be resubmitted for inspection by testing a specimen from each reel or pack and sorting out nonconforming material.

12.3. In case there is a reasonable doubt in the initial testing as to the ability of the strand to meet any requirement of this specification, two additional tests shall be made on a specimen of strand from the same reel or pack, and if failure occurs in either of these tests, the strand shall be rejected.

13. CERTIFICATION

13.1. If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material. The certification shall include the specification number, year-date of issue, and revision letter, if any.

13.2. The manufacturer shall, when requested in the order, furnish a representative load-elongation curve for each size and grade of strand shipped.

13.3. When the modulus of elasticity of a seven-wire strand is provided, the cross-sectional area used to compute that modulus shall also be provided. The area provided in the certification shall be the area used to calculate the modulus of elasticity.

13.4. A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 5—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

14. PACKAGING AND MARKING

14.1. The strand shall be furnished on reels or in reelless packs having a minimum core diameter of 610 mm [24 in.] unless otherwise specified by the purchaser. Lengths on reels or in reelless packs shall be as agreed upon at the time of purchase. The strand shall be well protected against mechanical injury in shipping as agreed upon at the time of purchase. Each reel or reelless pack shall have two strong tags securely fastened to it showing the length, size, types, grade, M 203M/M 203 or ASTM A 416, and the name or mark of the manufacturer. One tag shall be positioned where it will not be inadvertently lost during transit, such as the core of a reelless pack. The other tag shall be on the outside for easy identification.

14.2. *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

15. KEYWORDS

15.1. Prestressed concrete; seven-wire strand [tendon]; steel wire.

SUPPLEMENTARY REQUIREMENTS

Supplementary requirements shall apply only to 15.2-mm [0.600-in.] diameter strand. Grade 270 used in prestressed ground anchors or similar applications shall be specified at the time of order placement. These requirements are not applicable to strand used in prestressed concrete applications.

S1. BOND CAPACITY

S1.1. The results of bond-capacity tests performed in accordance with ASTM A 981 shall be submitted to the purchaser. The strand specimens on which tests were performed shall be from different lots and shall be representative for the strand ordered.

S1.2. The average pull force from six pull tests, performed in accordance with ASTM A 981, required to reach the 0.25-mm [0.01-in.] displacement described therein shall be at least 35.6 kN [8000 lbf] with the individual minimum test value not less than 30.2 kN [6800 lbf]. For any future retests, without changes in the manufacturing method and materials used, three tests shall be considered adequate.

S1.3. *Retests*—If the test specimens fail to satisfy Section S1.2, six additional tests shall be performed, and the results shall satisfy the acceptance criteria. Strand that failed the retest shall not be considered acceptable for the use in prestressed ground anchors.

S1.4. *Annual Test*—The pull tests shall be performed annually as a minimum or repeated when, in the opinion of the producer, a process change is made which is believed could decrease the bond capacity of the strand.

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[1] Sason, A. S. "Evaluation of Degree of Rusting on Prestressed Concrete Strand," *PCI Journal* 37, No. 3 (May/June 1992): 25–30. Reprints of this paper are available from the Precast/Prestressed Concrete Institute, 175 West Jackson Blvd., Suite 1859, Chicago, Illinois 60604.

Standard Specification for

Uncoated Stress-Relieved Steel Wire for Prestressed Concrete

AASHTO Designation: M 204M/M 204-06[1]
ASTM Designation: A 421/A 421M-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Uncoated Stress-Relieved Steel Wire for Prestressed Concrete

AASHTO Designation: M 204M/M 204-06[1]
ASTM Designation: A 421/A 421M-05

1. SCOPE

1.1. This specification covers two types of uncoated stress-relieved, round, high-carbon steel wire commonly used in prestressed linear concrete construction, as follows:

1.1.1. Type BA wire is used for applications in which cold-end deformation is used for anchoring purposes (Button Anchorage), and

1.1.2. Type WA wire is used for applications in which the ends are anchored by wedges, and no cold-end deformation of the wire is involved (Wedge Anchorage).

1.2. Supplement 1 describes low-relaxation wire and relaxation testing for that product.

1.3. This specification is applicable for orders in either SI units (M 204M) or in inch-pound units (M 204). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 204.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 244, Mechanical Testing of Steel Products (including Annex A4)

2.2. *ASTM Standards*:

- E 30-89, Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron
- E 328, Standard Test Methods for Stress Relaxation Tests for Materials and Structures

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

2.4. *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products, Preparation for Shipment and Storage

2.5. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipments (Civil Agencies)

3. ORDERING INFORMATION

3.1. It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered to this specification. Such requirements shall include, but are not limited to, the following:

3.1.1. Quantity (kg) [lb],

3.1.2. Diameter,

3.1.3. Type of anchorage (BA or WA),

3.1.4. Packaging,

3.1.5. AASHTO designation and date of issue, and

3.1.6. Special requirements, if any.

Note 1—A typical ordering description is as follows: 10,000-kg, 6.35-mm diameter wire, Type BA in approximately 450-kg, 1.5-m diameter coils, to M 204M-____. [22,000-lb, 0.250-in. diameter wire, Type BA in approximately 1000-lb, 60-in. diameter coils, to M 204-____.]

4. MANUFACTURE

4.1. *Process*—The steel shall be made by the basic-oxygen, open-hearth, or electric-furnace process.

4.2. *Internal Soundness*—A sufficient discard shall be made to ensure freedom from injurious piping and undue segregation.

4.3. *Wire*—The wire shall be cold-drawn to size and suitably stress relieved after cold drawing by a continuous heat treatment to produce the prescribed mechanical properties.

5. PHYSICAL REQUIREMENTS

5.1. *Tensile Strength*—The tensile strength of Type BA wire and Type WA wire shall conform to the requirements prescribed in Table 1, and shall be determined as prescribed in T 244, including Appendix X4.

Table 1—Tensile Strength Requirements

Nominal Diameter, mm [in.]	Minimum Tensile Strength, MPa [psi]	
	Type BA	Type WA
4.88 [0.192]	[a]	1725 [250000]
4.98 [0.196]	1655 [240000]	1725 [250000]
6.35 [0.250]	1655 [240000]	1655 [240000]
7.01 [0.276]	1620 [235000]	1620 [235000]

[a] This size is not commonly furnished in Type BA wire.

5.2. *Yield Strength*:

5.2.1. The minimum yield strength for all wire, measured by the 1 percent extension under load method, shall not be less than 85 percent of the specified minimum breaking strength.

5.2.2. The extension under load shall be measured by an extensometer calibrated with the smallest division not larger than 0.0001 mm/mm [0.0001 in./in.] of gauge length.

5.2.3. The initial load corresponding to the initial stress prescribed in Table 2 shall be applied to the specimen, at which time the extensometer is attached and adjusted to a reading of 0.001 mm/mm [0.001 in./in.] of gauge length. The load shall then be increased until the extensometer indicates an extension of 1 percent. The load for this extension shall be recorded. The stress corresponding to this load shall meet the requirements for stress at 1 percent extension prescribed in Table 2.

Table 2—Yield Strength Requirements

Nominal Diameter, mm [in.]	Initial Stress, MPa [psi]	Minimum Stress at 1% Extension, MPa [psi]	
		Type BA	Type WA
4.88 [0.192]	200 [29000]	[a]	1465 [212500]
4.98 [0.196]	200 [29000]	1407 [204000]	1465 [212500]
6.35 [0.250]	200 [29000]	1407 [204000]	1407 [204000]
7.01 [0.276]	200 [29000]	1377 [199750]	1377 [199750]

[a] This size is not commonly furnished in Type BA wire.

5.3. *Elongation*—The total elongation under load of all wire shall not be less than 4 percent when measured in a gauge length of 250 mm [10 in.].

The elongation shall be determined by an extensometer which is placed on the test specimen after a load corresponding to the initial stress prescribed in Table 2 is applied. If the fracture takes place outside of the gauge length and the elongation so measured meets the minimum requirements, no further testing shall be required. If the elongation is less than the minimum requirements, the test shall be considered an invalid test and a retest made.

6. DIAMETER AND PERMISSIBLE VARIATIONS

6.1. Wire meeting the requirements of this specification is normally ordered in the diameters shown in Table 1.

6.2. The diameter of the wire shall not vary from the nominal diameter specified by more than ±0.05 mm [±0.002 in.].

6.3. The wire shall not be out-of-round by more than 0.05 mm [0.002 in.].

7. WORKMANSHIP AND FINISH

7.1. *Cast*—A wire sample having a chord length of 1524 mm [60 in.] shall have an offset at the center of the chord of not more than 76 mm [3 in.]. This is equivalent to a chord of an arc of a circle not less than 7.6 m [25 ft] in diameter.

7.2. *Type BA Wire*—Type BA wire shall be of suitable quality to permit cold forming of buttons for anchorage. Splitting shall not be considered a cause for rejection if the button anchorage is capable of developing the minimum required tensile strength of the wire.

7.3. The wire shall be free of kinks.

7.4. The wire shall be furnished in firmly tied coils having a minimum inside diameter of 1219 mm [48 in.]. Each coil shall be of one continuous length.

7.5. There shall be no welds or joints in the finished wire. Any welds or joints made during manufacture to promote continuity of operations shall be removed.

7.6. The wire shall not be oiled or greased. Slight rusting, provided it is not sufficient to cause pits visible to the naked eye, shall not be cause for rejection.

7.7. Temper colors, which may result from the stress-relieving operations, are considered normal for the finished appearance of this strand.

8. CHEMICAL REQUIREMENTS

8.1. Variations in manufacturing processes and equipment among wire manufacturers necessitate the individual selection of an appropriate chemical composition at the discretion of the manufacturer.

8.2. Phosphorus and sulfur values shall not exceed the following:

Phosphorus	0.040 percent
Sulfur	0.050 percent

8.3. The purchaser shall have the right to make an analysis from finished wire representing each heat of steel. Samples for analysis shall be obtained by milling the wire in such a manner as to obtain a sample representative of the entire cross section. Prior to milling, the surface shall be cleaned to remove all foreign matter. All such individual determinations shall not vary from the limits shown in Section 8.2 by more than 0.008 percent.

8.4. For referee purposes, ASTM E 30-89 shall be applied.

9. SAMPLING

9.1. Unless otherwise agreed upon between the manufacturer and the purchaser, one test specimen shall be taken from each ten or fewer coils in a lot (Note 2) and tested to determine compliance with Sections 5.1, 5.2, 5.3, 6, and 7.1.

Note 2—The term “lot” means all the coils of wire of the same nominal wire size contained in an individual shipping release or shipping order.

10. INSPECTION

10.1. The purchaser shall state at the time of order whether outside inspection is required or waived. If outside inspection is required, the manufacturer shall afford the inspector representing the purchaser all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise agreed upon at the time of purchase, and shall be so conducted as not to interfere unnecessarily with the operation of the work.

11. REJECTION

11.1. Unless otherwise specified, any rejection based on tests made in accordance with this specification shall be reported to the manufacturer within a reasonable length of time.

12. CERTIFICATION

12.1. If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material.

12.2. A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 3—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

13. PACKAGING AND MARKING

13.1. The size of the wire, AASHTO specification number, heat number, type of wire, and name or mark of the manufacturer shall be marked on a tag securely attached to each bundle of wire.

13.2. *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. 123 for civil agencies and MIL-STD-129 for military agencies.

14. KEYWORDS

14.1. Cold-drawn wire; prestressed concrete; steel wire (tendon); stress-relieved wire.

SUPPLEMENTARY REQUIREMENTS—LOW-RELAXATION WIRE

S1. SCOPE

S1.1. This supplement delineates only those details that are peculiar to low-relaxation wire, and to the method of relaxation testing related to single wire tendons having properties generally as described in M 204M/M 204.

S2. REFERENCED DOCUMENTS

S2.1. *ASTM Standard*:

- E 328, Recommended Practice for Stress-Relaxation Tests for Materials and Structures

S3. TEST METHOD

S3.1. Low-relaxation strand shall be tested as prescribed in ASTM E 328.

S4. RELAXATION PROPERTIES

S4.1. Low-relaxation wire shall meet the physical requirements of this specification, with the added requirement that relaxation after 1000 hours under the conditions of Section S6 shall not be more than 2.5 percent when initially loaded to 70 percent of specified minimum tensile strength or not more than 3.5 percent when loaded to 80 percent of specified minimum tensile strength of the wire.

S5. YIELD STRENGTH

S5.1. Yield strength of low-relaxation wire as described in Section 5.2 shall not be less than 90 percent of the specified minimum tensile strength of the wire.

S6. CONDITIONS OF RELAXATION TEST

S6.1. If required, relaxation evidence shall be provided from the manufacturer's records of tests on similarly dimensioned wire of the same grade.

S6.2. The temperature of the test specimen shall be maintained at 20 ± 2°C [68 ± 3.5°F].

S6.3. The test specimen shall not be subjected to any loading prior to relaxation test.

S6.4. The initial load shall be applied uniformly over a period of not less than 180 seconds and not more than 300 seconds, and the gauge length shall be maintained constant; load-relaxation readings shall commence 60 seconds after application of the total load.

S6.5. Overstressing of the test specimen during the loading operation shall not be permitted.

S6.6. The duration of the test shall be 1000 hours or a shorter computed period extrapolated to 1000 hours that can be shown by records to provide similar relaxation values.

S6.7. The test gauge length shall be at least 60 times the nominal diameter.

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[1] Agrees technically with ASTM A 421/A 421M-05 except for minor differences in wording.

Standard Specification for

Steel Welded Wire Reinforcement, Deformed, for Concrete

AASHTO Designation: M 221M/M 221-09
ASTM Designation: A 497/A 497M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Welded Wire Reinforcement, Deformed, for Concrete

AASHTO Designation: M 221M/M 221-09
ASTM Designation: A 497/A 497M-07

1. SCOPE

1.1. This specification covers welded wire reinforcement made from cold-worked drawn or rolled deformed wire, or a combination of deformed and nondeformed wires, to be used for the reinforcement of concrete.

Note 1—Welded wire for concrete reinforcement has been described by various terms: welded wire fabric (WWF), fabric, and mesh. The wire reinforcement industry prefers the term "welded wire reinforcement" (WWR) as being more representative of the range of products being manufactured. Therefore, the term "welded wire fabric" has been replaced with the term "welded wire reinforcement" in this specification and in related specifications.

1.2. This specification is applicable for orders in either SI units (M 221M) or in inch-pound units (M 221). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 221. Combining values from the two systems may result in nonconformance with the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 32M/M 32, Steel Wire, Plain, for Concrete Reinforcement
- M 225M/M 225, Steel Wire, Deformed, for Concrete Reinforcement

2.2. *ASTM Standard*:

- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment

2.3. *Military Standard*:

- MIL-STD-129, Marking for Shipment and Storage

2.4. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipments (Civil Agencies)

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *convoluted wire*—when wire for welded wire reinforcement is shaped into a sinusoidal wave shape, it is commonly referred to as convoluted wire. The wire is used in the manufacture of cages for certain applications of concrete pipe reinforcing. Only nondeformed wire is normally subject to convolution.

3.1.2. *welded wire reinforcement*—as used within the scope and intent of this specification, welded wire reinforcement designates a material composed of cold-worked steel wire, fabricated into sheets or rolls by the process of electric-resistance welding. The finished material shall consist essentially of a series of longitudinal and transverse wires arranged substantially at right angles to each other, and welded together at points of intersection.

4. ORDERING INFORMATION

4.1. Orders for material to this specification should include the following information:

4.1.1. Quantity (mass or square area);

4.1.2. Name of material (deformed welded wire reinforcement for concrete reinforcement);

4.1.3. Wire spacing and sizes;

4.1.4. Minimum yield strength if Supplement S1 of M 225 applies; and minimum yield strength if wire conforming to M 32 is to be used and Supplement S1 of M 32 applies;

4.1.5. Exclusion of oversteeling, if required (Section 9.4.1);

4.1.6. Length and width of sheets or rolls;

4.1.7. Packaging (Section 16); and

4.1.8. AASHTO designation and year of issue.

Note 2—A typical ordering description is as follows: 930 m^2 welded deformed wire reinforcement for concrete reinforcement, 150 × 300-D6 × D2 in flat sheets 2.4 m wide by 6.1 m long, in secured lifts, to M 221M-____. [10000 ft^2 welded deformed wire reinforcement for concrete reinforcement, 6 × 12-D6 × D2 in flat sheets 96 in. wide by 240 in. long, in secured lifts, to M 221-___.]

5. MATERIALS

5.1. The wire used in the manufacture of welded wire reinforcement shall conform to M 225 and its Supplement S1, if so ordered, either solely or in combination with wire conforming to M 32 and its Supplement S1.

5.2. Welded wire reinforcement shall be furnished either in flat sheets, or in rolls, as specified by the purchaser.

6. MANUFACTURE

6.1. The wires shall be assembled by automatic machines or by other suitable mechanical means that will assure accurate spacing and alignment of all wires of the finished welded wire reinforcement.

6.2. Longitudinal and transverse wires shall be securely connected at every intersection by a process of electrical-resistance welding, which employs the principle of fusion combined with pressure.

6.3. Wire of proper grade and quality when fabricated in the manner herein required in this specification shall result in a strong, serviceable, mat-type product having substantially square or rectangular openings. It shall be fabricated and finished in a workmanlike manner, shall be free of injurious defects, and shall conform to this specification.

Note 3—A variation of manufacturing includes the application of one or more longitudinal convoluted wires at one edge of welded wire reinforcement for concrete pipe reinforcing cages. This shape allows the cage ends to be expanded to a larger diameter to accommodate the bell-shaped ends of concrete pipe.

7. MECHANICAL PROPERTY REQUIREMENTS

7.1. *Tensile*—Wire for the production of welded wire reinforcement, deformed, is described in M 225M/M 225. Tensile tests may be made on wire cut from the welded wire reinforcement and tested either across or between the welds; no fewer than 50 percent shall be across welds. Tensile tests across a weld shall have the welded intersection located approximately at the center of the wire being tested and the cross wire forming the welded joint shall extend approximately 25 mm [1 in.] beyond each side of the welded joint.

Note 4—Tensile and bend testing are normally done at the time wire is drawn. The manufacturer's finished product still must satisfy the mechanical properties when tested after fabrication.

7.2. *Bend Test*—The wire shall withstand the bend test as described in M 225M/M 225 and shall be performed on a specimen taken from between the welds.

7.3. *Weld Shear Strength*—The weld shear strength between longitudinal and transverse wires shall be tested as described in Section 8. The minimum average shear value in Newtons shall not be less than 241, multiplied by the nominal area of the large wire in square millimeters [or in pounds-force, shall not be less than 35000, multiplied by the nominal area of the larger wire in square inches], where the smaller wire is not less than MD25 [D4] and has an area of 40 percent or more of the area of the larger wire.

7.3.1. Welded wire reinforcement having a relationship of larger and smaller wires other than that covered in Section 7.3 shall meet an average weld shear strength requirement of not less than 3.6 kN [800 lbf] provided that the smaller wire is not smaller than MD25 [D4].

7.3.2. Weld shear tests for determination of conformance to the requirements of Section 7.3 shall be conducted using a fixture as described in Section 8.

7.3.3. Four welds selected at random from the specimen described in Section 11.2 shall be tested for weld shear strength. The transverse wire of each test specimen shall extend approximately 25 mm [1 in.] on each side of the longitudinal wire. The longitudinal wire of each test specimen shall be of such length below the transverse wire so as to be adequately engaged by the grips of the testing machine. It shall be of such length above the transverse wire that its end shall be above the center line of the upper bearing of the testing device.

7.3.4. The material shall be deemed to conform to the requirements for weld shear strength if the average of the four samples complies with the value stipulated in Section 7.3. If the average fails to meet the prescribed value, all the welds across the specimen shall then be tested. The welded wire reinforcement will be acceptable if the average of all weld shear test values across the specimen meets the prescribed minimum value.

8. WELD SHEAR TEST APPARATUS AND METHODS

8.1. As the welds in welded wire reinforcement contribute to the bonding and anchorage value of the wires in concrete, it is imperative that the weld acceptance tests be made in a jig that will stress the weld in a manner similar to which it is stressed in concrete. In order to accomplish this, the vertical wire in the jig must be stressed in an axis close to its center line. Also, the horizontal wire must be held closely to the vertical wire, and in the same relative position to prevent rotation of the horizontal wire. When the welded wire reinforcement is designed with different wire sizes, the larger diameter wire is the “vertical wire” when tested. (See Figure 1.)

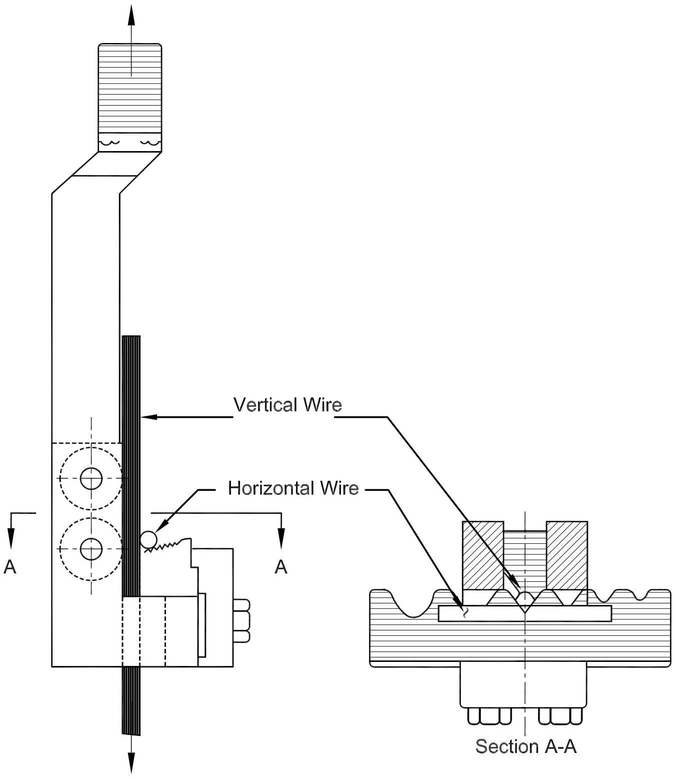

Figure 1—Welded Wire Reinforcement Weld Tester

8.2. Figure 1 shows the details of a typical testing jig together with two anvils, which make it possible to test welds for wire up to 16 mm [0.625 in.] in diameter. This testing jig can be used in most tension testing machines and should be hung in a ball-and-socket arrangement at the center of the machine. This, or a similarly effective fixture designed on the same principle, is acceptable.

8.3. Test specimens should be inserted through the notch in the anvil using the smallest notch available in which the vertical wire will fit loosely. The vertical wire shall be in contact with the surface of the free rotating rollers while the horizontal wire shall be supported by the anvil on each side of the slot. The bottom jaws of the testing machine shall grip the lower end of the vertical wire and the load shall be applied at a rate of stressing not to exceed 690 MPa/min [100 ksi/min].

9. DIMENSIONS

9.1. *Width*—The width of welded wire reinforcement shall be considered to be the center-to-center distance between outside longitudinal wires. The permissible variation shall not exceed ±13 mm [±0.5 in.] than the specified width. In case the width of flat sheets or rolls is specified as the overall width (tip-to-tip length of cross wires), the width shall not vary more than ±25 mm [±1 in.] from the specified width. When measurements involve a convoluted wire, the measurement shall be made to the approximate center of the sinusoidal wave shape.

9.2. *Length*—The overall length of flat sheets, measured on any wire, may vary ±25 mm [±1 in.], or 1 percent, whichever is greater.

9.3. Overhang of the transverse wires shall not project beyond the center line of each longitudinal edge wire more than a distance of 25 mm [1 in.], unless otherwise specified. When transverse wires are specified to project a specific length beyond the center line of a longitudinal edge wire, the permissible variation shall not exceed 13 mm [0.5 in.] greater or less than the specified length.

9.4. The permissible variation in weight of any wire in the finished welded wire reinforcement shall conform to the tolerances prescribed for the wire before fabrication, in M 225M/M 225, with the following exceptions:

9.4.1. Unless otherwise precluded by the purchaser, the manufacturer will be permitted to apply oversized wire (not undersized). The size differential shall not exceed one "D" size increment on sizes D8 and smaller, and two "D" size increments on sizes larger than D8. In all cases in which such oversteeling is practiced, the producer shall identify the welded wire reinforcement with the style originally ordered.

9.5. The average spacing of wires shall be such that the total number of wires contained in a sheet or roll is equal to or greater than that determined by the specific spacing, but the center-to-center distance between individual members may vary not more than 6.4 mm [0.25 in.] from the specified spacing. It is understood that sheets of welded wire reinforcement of the specified length may not always contain an identical number of transverse wires and, therefore, may have various lengths of longitudinal overhang.

10. WORKMANSHIP

10.1. Wire of proper grade and quality, when fabricated in the manner herein required, shall result in a strong, serviceable, mat-type product having substantially square or rectangular openings. It shall be fabricated and finished in a workmanlike manner, as determined by visual inspection, and shall conform to this specification.

11. SAMPLING

11.1. Test specimens for testing mechanical properties shall be obtained by cutting from the finished welded wire reinforcement a full-width section, of sufficient length to perform testing as described in Sections 7.1 and 7.2.

11.2. Test specimens for determining weld shear properties shall be obtained by cutting from the finished welded wire reinforcement, a full-width section of sufficient length to perform testing as described in Section 7.3.3.

11.3. Measurements for conformance to dimensional characteristics shall be made on full sheets or rolls.

11.4. If any test specimen exhibits obvious imperfections, it may be discarded and another specimen substituted.

12. NUMBER OF TESTS

12.1. One test for conformance to tensile strength and bend requirements shall be made for each 7000 m^2 [75000 ft^2] of welded wire reinforcement or remaining fraction thereof. For testing prior to fabrication, one test for each 18 Mg [20 tons] of wire shall be made.

12.2. One test for conformance to weld shear strength requirement shall be made for each 28000 m^2 [300000 ft^2] or remaining fraction thereof.

13. INSPECTION

13.1. The inspector representing the purchaser shall have free entry at all times, while work on the contract of the purchaser is being performed, to all parts of the manufacturer’s works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to assure that the material is being furnished in accordance with this specification.

13.2. Except for yield strength, all tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise specified. Such tests shall be so conducted as not to interfere unnecessarily with the operation of the works.

13.3. If the purchaser considers it desirable to determine compliance with the yield strength requirements of M 225M/M 225, yield strength tests may be made in a recognized laboratory, or their representative may make the test at the mill, if such tests do not interfere unnecessarily with the mill operations.

13.4. *For Government Procurement Only*—The purchaser shall be furnished a manufacturer’s certification of conformance to A 497/A 497M for each production date or production lot shipped. A production lot shall not exceed 28 000 m^2 [300000 ft^2], and certifications shall be traceable to specific date(s) of production marked on the product bundle prior to shipment. Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the contractor shall have the option to use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

14. REJECTION AND RETESTS

14.1. Material that does not meet the requirements of this specification may be rejected. Unless otherwise specified, any rejection shall be reported to the manufacturer within 5 days from the time of selection of test specimens.

14.2. In case a specimen fails to meet the tension or bend test, the material shall not be rejected until two additional specimens taken from other wires in the same sheet or roll have been tested. The material shall be considered as meeting the specification in respect to any prescribed tensile property, provided the tested average for the three specimens, including the specimen originally tested, is equal to or exceeds the required minimum for the particular property in question and provided further that none of the three specimens develops less than 80 percent of the required minimum for the tensile property in question. The material shall be considered as meeting this specification in respect to bend test requirements, provided both additional specimens satisfactorily pass the prescribed bend test.

14.3. Any material that is found not to meet the requirements of this specification subsequent to its acceptance at the manufacturer's facilities shall be subject to rejection and the manufacturer shall be promptly notified.

14.4. Welded joints shall withstand normal shipping and handling without becoming broken, but the presence of broken welds, regardless of cause, shall not constitute cause for rejection unless the number of broken welds per sheet exceeds 1 percent of the total number of joints in a sheet, or if the material is furnished in rolls, 1 percent of the total number of joints in 14 m^2 [150 ft^2] of welded wire reinforcement and, furthermore, provided not more than one-half the permissible maximum number of broken welds are located on any one wire.

14.5. In the event of rejection because of failure to meet the weld shear requirements, four additional specimens shall be taken from four different sheets or rolls and tested in accordance with Section 8. If the average of all the weld shear tests performed does not meet the requirement, the material shall be rejected.

14.6. In the event of rejection because of failure to meet the requirements for dimensions, the amount of material rejected shall be limited to those individual sheets or rolls that fail to meet this specification.

14.7. Rust, surface seams, or surface irregularities shall not be cause for rejection provided the minimum welded wire reinforcement dimensions, cross-sectional area, tensile properties, and weld shear strength of a hand wire-brushed test specimen are not less than the requirements for this specification. The height of deformations above the minimum height requirements (see M 225M/M 225, Table 1 and Table 2) shall not be cause for rejection.

14.8. *Rehearing*—Rejected materials shall be preserved for a period of at least 2 weeks from the date of inspection, during which time the manufacturer may make claim for a rehearing and retesting.

15. CERTIFICATION

15.1. If outside inspection is waived, a manufacturer's certification that the material has been manufactured in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material. The certification shall include the specification number, year-date of issue, and revision letter, if any.

15.2. This conformance is predicated upon testing and acceptance of wire prior to fabrication, coupled with random shear testing during production. The purchaser shall be furnished a manufacturer's certification of conformance to M 221M/M 221 for each production date or production lot shipped. A production lot shall not exceed 28 000 m^2 [300 000 ft^2]. Any purchaser shall have the right to invoke any of the provisions of Section 13.4.

15.3. When Supplement S1 of M 32M/M 32 or M 225M/M 225 is specified for the material, test results for yield strength, tensile strength, and bend tests shall be reported (S1.3.1 of M 32M/M 32, S1.3.1 of M 225M/M 225).

15.4. A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 5—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

16. PACKAGING AND MARKING

16.1. Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

16.2. When welded wire reinforcement is furnished in flat sheets, it shall be assembled in bundles of convenient size containing not more than 150 sheets and securely fastened together.

16.3. When welded wire reinforcement is furnished in rolls, each roll shall be secured so as to prevent unwinding during shipping and handling.

16.4. Each bundle of flat sheets and each roll shall have attached thereto a suitable tag bearing the name of the manufacturer, description of the material, M 225M/M 225, and such other information as may be specified by the purchaser.

16.5. When specified in the contract or order, and for the direct procurement by or direct shipment to the U.S. government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U. S. military agencies and in accordance with Fed. Std. No. 123 for U. S. government civil agencies.

17. KEYWORDS

17.1. Concrete reinforcement; deformed steel wire; reinforcing steels; reinforced concrete; welded wire reinforcement.

Standard Specification for

Steel Wire, Deformed, for Concrete Reinforcement

AASHTO Designation: M 225M/M 225-09
ASTM Designation: A 496/A 496M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel Wire, Deformed, for Concrete Reinforcement

AASHTO Designation: M 225M/M 225-09
ASTM Designation: A 496/A 496M-07

1. SCOPE

1.1. This specification covers deformed steel wire that has been cold worked by drawing, rolling, or both drawing and rolling to be used as produced, or in fabricated form, for the reinforcement of concrete in sizes having nominal cross-sectional areas not less than 6.45 mm^2 [0.01 $in.^2$].

1.2. Supplement S1 describes high-strength wire, which shall be furnished when specifically ordered. It shall be permissible to furnish high-strength wire in place of regular wire if mutually agreed to by the purchaser and manufacturer.

1.3. The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. The inch-pound units are shown in brackets except in Table 1.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 221M/M 221, Steel Welded Wire Reinforcement, Deformed, for Concrete
- T 244, Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- E 83, Standard Practice for Verification and Classification of Extensometer Systems

2.3. *Military Standard*:

- MIL-STD-129, Marking for Shipment and Storage

2.4. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipments (Civil Agencies)

2.5. *ACI Standard*:

- ACI 318, Building Code Requirements for Structural Concrete

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *Deformed steel wire for reinforcement*—as used within the scope and intent of this specification, shall mean any cold-worked, deformed steel wire intended for use as reinforcement in concrete construction, the wire surface having deformations that (1) inhibit longitudinal movement of the wire in such construction, and (2) conform to the provisions of Section 5. It shall be permissible for the deformations to be raised or indented.

3.1.2. *Size number*—as used in this specification, refers to the numerical designation of the wire as tabulated in Table 1 and Table 2 under the column headed “Deformed Wire Size Number,” or a number indicating the nominal cross-sectional area of the deformed wire in square millimeters [hundredths of a square inch].

4. ORDERING INFORMATION

4.1. When deformed wire is ordered by size number, the dimensional requirements shall be as given in Table 1. When deformed wire is ordered to dimensions other than the sizes shown, the nominal dimensions shall be developed from the applicable unit mass per meter of the section.

4.2. It shall be the responsibility of the purchaser to specify all requirements that are necessary for the manufacture and delivery of the wire under this specification. Such requirements to be considered include, but are not limited to, the following:

4.2.1. Quantity (mass) [weight],

4.2.2. Name of material (deformed steel wire for concrete reinforcement),

4.2.3. Wire diameter (see Table 1 and Table 2),

4.2.4. Yield strength measurement (see Sections 8 and 13.3),

4.2.5. Packaging (see Section 17), and

4.2.6. AASHTO designation and year of issue.

4.2.7. Special requirements if any (see Supplement S1).

Note 1—A typical ordering description is as follows: 25,000 kg deformed steel wire for concrete reinforcement, size No. D-12, on pipe carriers, polyethylene shrouded, to M 225M-____. [50,000 lb deformed steel wire for concrete reinforcement, size No. D-12 [MD80], in 800 kg [2,000 lb] secured coils to M 225-____.

Table 1—Dimensional Requirements for Deformed Steel Wire for Concrete Reinforcement—SI Units (U.S. Customary Units)

Nominal Dimensions															
Deformed Wire Size[a, b, c]	(D in.^{2}) (× 100)	Unit Weight		Diameter[d]		Cross-Sectional Area[e]		Perimeter		Spacing, Max		Spacing, Min		Min Avg Height of Deformations	
		kg/m	(lb/ft)	mm	(in.)	mm^2	(in.^{2})	mm	(in.)	mm	(in.)	mm	(in.)	mm[f]	(in.)
MD 25	[D 3.9]	0.196	[0.132]	5.64	[0.222]	25	[0.039]	17.7	[0.698]	7.24	[0.285]	4.62	[0.182]	0.252	[0.010]
MD 30	[D 4.6]	0.235	[0.158]	6.18	[0.243]	30	[0.047]	19.4	[0.764]	7.24	[0.285]	4.62	[0.182]	0.279	[0.011]
MD 35	[D 5.4]	0.275	[0.185]	6.68	[0.263]	35	[0.054]	21.0	[0.826]	7.24	[0.285]	4.62	[0.182]	0.302	[0.012]
MD 40	[D 6.2]	0.314	[0.211]	7.14	[0.281]	40	[0.062]	22.4	[0.883]	7.24	[0.285]	4.62	[0.182]	0.320	[0.013]
MD 45	[D 7.0]	0.353	[0.237]	7.57	[0.298]	45	[0.070]	23.8	[0.936]	7.24	[0.285]	4.62	[0.182]	0.342	[0.014]
MD 50	[D 7.7]	0.392	[0.264]	7.98	[0.314]	50	[0.078]	25.1	[0.987]	7.24	[0.285]	4.62	[0.182]	0.360	[0.014]
MD 55	[D 8.5]	0.432	[0.290]	8.37	[0.329]	55	[0.085]	26.3	[1.04]	7.24	[0.285]	4.62	[0.182]	0.378	[0.015]
MD 60	[D 9.3]	0.471	[0.316]	8.74	[0.344]	60	[0.093]	27.5	[1.08]	7.24	[0.285]	4.62	[0.182]	0.392	[0.015]
MD 65	[D 10.1]	0.510	[0.343]	9.10	[0.358]	65	[0.101]	28.6	[1.13]	7.24	[0.285]	4.62	[0.182]	0.455	[0.018]
MD 70	[D 10.8]	0.549	[0.369]	9.44	[0.372]	70	[0.109]	29.7	[1.17]	7.24	[0.285]	4.62	[0.182]	0.470	[0.018]
MD 80	[D 12.4]	0.628	[0.422]	10.1	[0.397]	80	[0.124]	31.7	[1.25]	7.24	[0.285]	4.62	[0.182]	0.505	[0.020]
MD 90	[D 13.9]	0.706	[0.475]	10.7	[0.421]	90	[0.140]	33.6	[1.32]	7.24	[0.285]	4.62	[0.182]	0.535	[0.021]
MD 100	[D 15.5]	0.785	[0.527]	11.3	[0.444]	100	[0.155]	35.4	[1.40]	7.24	[0.285]	4.62	[0.182]	0.565	[0.022]
MD 120	[D 18.6]	0.942	[0.633]	12.4	[0.487]	120	[0.186]	38.8	[1.53]	7.24	[0.285]	4.62	[0.182]	0.620	[0.024]
MD 130	[D 20.1]	1.02	[0.686]	12.9	[0.507]	130	[0.202]	40.4	[1.59]	7.24	[0.285]	4.62	[0.182]	0.645	[0.025]
MD 200	[D 31.0]	1.57	[1.05]	16.0	[0.628]	200	[0.310]	50.1	[1.97]	7.24	[0.285]	4.62	[0.182]	0.800	[0.031]
MD 290	[D 45.0]	2.28	[1.53]	19.2	[0.757]	290	[0.450]	60.4	[2.38]	7.24	[0.285]	4.62	[0.182]	0.961	[0.0379]

[a] The number following the prefix indicates the nominal cross-sectional area of the deformed wire in square millimeters.

[b] For sizes other than those shown above, the Size Number shall be the number of one hundredths of a square inch in the nominal area of the deformed wire cross section, prefixed by the letters MD.

[c] These sizes represent the most readily available sizes in the welded wire reinforcement industry. Other wire sizes are available and many manufacturers can produce them in 1 mm^2 [0.0015 in.^{2}] increments.

[d] The nominal diameter of a deformed wire is equivalent to the diameter of a plain wire having the same mass per meter as the deformed wire.

[e] The cross-sectional area is based on the nominal diameter. The area in square millimeters [inches] is calculated by dividing the unit mass [weight] in kg/m [lb/in.] by 7×10^{-6} (mass of 1 mm^3 of steel [0.2833 weight of 1 in.^{3} of steel]) or by dividing the unit mass [weight] in kg/m [lb/ft] by 0.007849 (mass of steel 1 mm^2 and 1 m long) [3.4 (weight of steel 1 in.^{2} and 1 ft long)].

[f] The minimum average height of the deformations shall be determined from measurements made on not fewer than two typical deformations from each line of deformations on the wire. Measurements shall be made at the center of indentation as described in Section 7.7.

Table 2—Dimensional Requirements for Deformed Steel Wire for Concrete Reinforcement—U.S. Customary Units Wire Sizes[a]

	Nominal Dimensions			Deformation Requirements			
Deformed Wire Size Number[b, c, d]	Unit Weight, lb/ft (kg/m)	Diameter, in. (mm)[c]	Cross-sectional Area, in.^{2} (mm^2)[e]	Perimeter, in. (mm)	Max, in. (mm)	Min, in. (mm)	Min Avg Height of Deformations, in. (mm)[f, g]
D-1	0.034 [0.051]	0.113 [2.87]	0.010 [6.45]	0.354 [9.00]	0.285 [7.24]	0.182 [4.62]	0.0045 [0.114]
D-2	0.068 [0.101]	0.159 [4.05]	0.020 [12.9]	0.501 [12.7]	0.285 [7.24]	0.182 [4.62]	0.0063 [0.160]
D-3	0.102 [0.152]	0.195 [4.96]	0.030 [19.4]	0.614 [15.6]	0.285 [7.24]	0.182 [4.62]	0.0078 [0.198]
D-4	0.136 [0.202]	0.226 [5.73]	0.040 [25.8]	0.709 [18.0]	0.285 [7.24]	0.182 [4.62]	0.0101 [0.257]
D-5	0.170 [0.253]	0.252 [6.41]	0.050 [32.3]	0.793 [20.1]	0.285 [7.24]	0.182 [4.62]	0.0113 [0.287]
D-6	0.204 [0.304]	0.276 [7.02]	0.060 [38.7]	0.868 [22.1]	0.285 [7.24]	0.182 [4.62]	0.0124 [0.315]
D-7	0.238 [0.354]	0.299 [7.58]	0.070 [45.2]	0.938 [23.8]	0.285 [7.24]	0.182 [4.62]	0.0134 [0.340]
D-8	0.272 [0.405]	0.319 [8.11]	0.080 [51.6]	1.00 [25.5]	0.285 [7.24]	0.182 [4.62]	0.0143 [0.363]
D-9	0.306 [0.455]	0.339 [8.60]	0.090 [58.1]	1.06 [27.0]	0.285 [7.24]	0.182 [4.62]	0.0152 [0.386]
D-10	0.340 [0.506]	0.357 [9.06]	0.100 [64.5]	1.12 [28.5]	0.285 [7.24]	0.182 [4.62]	0.0160 [0.406]
D-11	0.374 [0.557]	0.374 [9.51]	0.110 [71.0]	1.18 [29.9]	0.285 [7.24]	0.182 [4.62]	0.0187 [0.475]
D-12	0.408 [0.607]	0.391 [9.93]	0.120 [77.4]	1.23 [31.2]	0.285 [7.24]	0.182 [4.62]	0.0195 [0.495]
D-13	0.442 [0.658]	0.407 [10.3]	0.130 [83.9]	1.28 [32.5]	0.285 [7.24]	0.182 [4.62]	0.0203 [0.516]
D-14	0.476 [0.708]	0.422 [10.7]	0.140 [90.3]	1.33 [33.7]	0.285 [7.24]	0.182 [4.62]	0.0211 [0.536]
D-15	0.510 [0.759]	0.437 [11.1]	0.150 [96.8]	1.37 [34.9]	0.285 [7.24]	0.182 [4.62]	0.0218 [0.554]
D-16	0.544 [0.810]	0.451 [11.5]	0.160 [103]	1.42 [36.0]	0.285 [7.24]	0.182 [4.62]	0.0225 [0.572]
D-17	0.578 [0.860]	0.465 [11.8]	0.170 [110]	1.46 [37.1]	0.285 [7.24]	0.182 [4.62]	0.0232 [0.589]
D-18	0.612 [0.911]	0.479 [12.2]	0.180 [116]	1.50 [38.2]	0.285 [7.24]	0.182 [4.62]	0.0239 [0.607]
D-19	0.646 [0.961]	0.492 [12.5]	0.190 [122]	1.55 [39.2]	0.285 [7.24]	0.182 [4.62]	0.0245 [0.622]
D-20	0.680 [1.01]	0.505 [12.8]	0.200 [129]	1.59 [40.3]	0.285 [7.24]	0.182 [4.62]	0.0252 [0.640]
D-21	0.714 [1.06]	0.517 [13.1]	0.210 [135]	1.62 [41.3]	0.285 [7.24]	0.182 [4.62]	0.0259 [0.658]
D-22	0.748 [1.11]	0.529 [13.4]	0.220 [141]	1.66 [42.2]	0.285 [7.24]	0.182 [4.62]	0.0265 [0.673]
D-23	0.782 [1.16]	0.541 [13.7]	0.230 [148]	1.70 [43.2]	0.285 [7.24]	0.182 [4.62]	0.0271 [0.688]
D-24	0.816 [1.21]	0.553 [14.0]	0.240 [154]	1.74 [44.1]	0.285 [7.24]	0.182 [4.62]	0.0277 [0.704]
D-25	0.850 [1.26]	0.564 [14.3]	0.250 [161]	1.77 [45.0]	0.285 [7.24]	0.182 [4.62]	0.0282 [0.716]
D-26	0.884 [1.32]	0.575 [14.6]	0.260 [167]	1.81 [45.9]	0.285 [7.24]	0.182 [4.62]	0.0288 [0.732]
D-27	0.918 [1.37]	0.586 [14.9]	0.270 [174]	1.84 [46.8]	0.285 [7.24]	0.182 [4.62]	0.0293 [0.744]
D-28	0.952 [1.42]	0.597 [15.2]	0.280 [180]	1.88 [47.6]	0.285 [7.24]	0.182 [4.62]	0.0299 [0.759]
D-29	0.986 [1.47]	0.608 [15.4]	0.290 [187]	1.91 [48.5]	0.285 [7.24]	0.182 [4.62]	0.0304 [0.772]
D-30	1.02 [1.52]	0.618 [15.7]	0.300 [193]	1.94 [49.3]	0.285 [7.24]	0.182 [4.62]	0.0309 [0.785]
D-31	1.05 [1.57]	0.628 [16.0]	0.310 [200]	1.97 [50.1]	0.285 [7.24]	0.182 [4.62]	0.0314 [0.798]
D-45	1.53 [2.28]	0.757 [19.2]	0.450 [290]	2.38 [60.4]	0.285 [7.24]	0.182 [4.62]	0.0379 [0.961]

[a] In this table only, inch-pound units are regarded as standard and SI units are shown in brackets.

[b] The number following the prefix indicates the nominal cross-sectional area of the deformed wire in square inches [square millimeters].

[c] For sizes other than those shown above, the Size Number shall be the number of one-hundredths of a square inch in the nominal area of the deformed wire cross section prefixed by the letter D.

[d] These sizes represent the most readily available sizes in the welded wire reinforcement industry. Other wire sizes are available and many manufacturers can produce them in 0.0015 in.^{2} [1 mm^2] increments.

[e] The nominal diameter of a deformed wire is equivalent to the diameter of a plain wire having the same weight per foot as the deformed wire.

[f] The cross-sectional area is based on the nominal diameter. The area in square inches [millimeters] is calculated by dividing the unit weight [mass] in lb/in. [kg/mm] by 0.2833 (weight of 1 in.^{3} of steel) [7×10^{-6} (mass of 1 mm^3 of steel)], or by dividing the unit weight [mass] in lb/ft [kg/m] by 3.4 (weight of steel 1 in.^{2} and 1 ft long) [0.007849 (mass of 1 mm^2 and 1 m long)].

[g] The minimum average height of the deformations shall be determined from measurements made on not fewer than two typical deformations from each line of deformations on the wire. Measurements shall be made at the center of indentation as described in Section 6.2.

5. MATERIALS AND MANUFACTURE

5.1. The steel shall be made by one of the following processes: open hearth, electric furnace, or basic oxygen.

5.2. The deformed steel wire shall be produced from rods or bars that have been hot rolled from billets.

6. REQUIREMENTS

6.1. Deformations shall be spaced along the wire at a substantially uniform distance and shall be symmetrically dispersed around the perimeter of the section. The deformations on all longitudinal lines of the wire shall be similar in size and shape. A minimum of 25 percent of the total surface area shall be deformed by measurable deformations.

6.2. Deformed wire shall have two or more lines of deformations.

6.3. The average longitudinal spacing of deformations shall be not less than 3.5 nor more than 5.5 deformations per 25.4 mm [1 in.] in each line of deformations on the wire.

6.4. The minimum average height at the center of typical deformations based on the nominal wire diameters shown in Table 1 and Table 2 shall be as follows:

Wire Sizes	Min Avg Height of Deformations, Percent of Nominal Wire Diameter
D-3 and finer	4
Coarser than D-3 through D-10	$4^1/_2$
Coarser than D-10	5

6.5. The deformation shall be placed with respect to the axis of the wire so that the included angle is not less than 45 degrees or, if deformations are curvilinear, the angle formed by the transverse axis of the deformation and the wire axis shall be not less than 45 degrees. Where the line of deformations forms an included angle with the axis of the wire from 45 degrees to 70 degrees inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the included angle is greater than 70 degrees, a reversal in direction is not required.

7. DIMENSIONS

7.1. The average spacing of deformation shall be determined by dividing a measured length of the wire specimen by the number of individual deformations in any one row of deformations on any side of the wire specimens. A measured length of the wire specimen shall be considered the distance from a point on a deformation to a corresponding point on any other deformation in the same line of deformations on the wire.

7.2. The minimum average height of deformations shall be determined from measurements made on not fewer than two typical deformations from each line of deformations on the wire. Measurements shall be made at the center of indentations.

8. MECHANICAL PROPERTY REQUIREMENTS

8.1. *Tension Tests*:

8.1.1. When tested as described in T 244, the material, except as specified in Section 8.1.2, shall conform to the tensile property requirements in Table 3 based on the nominal area of wire.

Table 3—Tension Test Requirements

	MPa [psi], Min
Tensile strength	585 [85,000]
Yield strength	515 [75,000]

8.1.2. When required by the purchaser, yield strength shall be determined using a Class B-1 extensometer as described in ASTM E 83. The yield strength shall be determined as described in T 244 and an extension of 0.5 percent of gauge length. It shall be permissible to remove the extensometer after the yield strength has been determined. The wire shall meet requirements of Table 3 or 4, whichever is applicable.

8.1.3. For material to be used in the fabrication of welded wire reinforcement, the tensile and yield strength properties shall conform to the requirements given in Table 4, based on the nominal area of the wire.

Table 4—Tension Test Requirements (Material for Welded Wire Reinforcement)

	MPa [psi], Min
Tensile strength	550 [80,000]
Yield strength	485 [70,000]

8.1.4. The material shall not exhibit a definite yield point as evidenced by a distinct drop of the beam or halt in the gauge of the testing machine prior to reaching ultimate tensile load.

8.2. *Bend Test*—The bend-test specimen shall withstand being bent at room temperature through 90 degrees without cracking on the outside of the bent portion, as prescribed in Table 5.

Table 5—Bend Test Requirements

Size Number of Wire	Bend Test
D-6 and smaller	Bend around a pin the diameter that is equal to twice the diameter of the specimen
Coarser than D-6	Bend around a pin the diameter that is equal to four times the diameter of the specimen

9. PERMISSIBLE VARIATION IN MASS [WEIGHT]

9.1. The permissible variation in mass [weight] of any deformed wire is ±6 percent of its nominal weight. The theoretical masses [weights] shown in Table 1, or similar calculations on unlisted sizes, shall be used to establish the variation.

10. WORKMANSHIP, FINISH, AND APPEARANCE

10.1. The wire shall be free of detrimental imperfections and shall have a workmanlike finish.

10.2. Rust, surface seams, or surface irregularities shall not be a cause for rejection provided the requirements of Section 10.3 are met, and the minimum dimensions and mechanical properties of a hand wire-brushed test specimen meet the requirements of this specification.

10.3. Wire intended for welded wire reinforcement shall be sufficiently free of rust and drawing lubricant, so as not to interfere with electric-resistance welding.

11. SAMPLING

11.1. Test specimens for testing mechanical properties shall be full wire sections and shall be obtained from the ends of the wire product as drawn or rolled, or both drawn and rolled. The specimens shall be of sufficient length to perform testing as described in Sections 8.1 and 8.2.

11.2. Any test specimen exhibiting obvious isolated imperfections that are not representative of the product shall be discarded and another specimen substituted.

12. NUMBER OF TESTS

12.1. One tension and one bend test shall be made from each 9,000 kg [10 tons] or less of each size of wire or fraction thereof in a lot, or a total of seven samples, whichever is fewer. A lot shall consist of all the coils of a single size offered for delivery at the same time.

13. INSPECTION

13.1. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer’s facilities that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification.

13.2. Except for yield strength, all tests and inspection shall be made at the manufacture’s facilities prior to shipment, unless otherwise specified. Such tests shall be so conducted as not to interfere unnecessarily with the operation of the manufacturer’s facilities.

13.3. The purchaser shall have the option to require a yield strength measurement to determine compliance with yield strength requirements in Section 8.1, and shall specify that the measurements be performed by the manufacturer at the manufacturer’s facilities, a recognized laboratory, or the purchaser’s representative at the manufacturer’s facilities. Such measurements shall be conducted without unnecessarily interfering with the manufacturing operations.

13.4. *For U.S. Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract, the contractor shall have the option to use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to ensure that material conforms to prescribed requirements.

14. REJECTION

14.1. Material that shows detrimental imperfections subsequent to its acceptance at the manufacturer's facilities shall be rejected, and the manufacturer shall be notified.

14.2. Failure of any of the test specimens to comply with the requirements of this specification shall constitute ground for rejection of the lot represented by the specimen.

14.3. Any rejection based on tests made in accordance with this specification shall be reported to the manufacturer within 2 weeks of the date of inspection or tests. The material shall be adequately protected and correctly identified such that the manufacturer is able to make a proper investigation.

15. REHEARING

15.1. Rejected materials shall be preserved for a period of at least 2 weeks from the date of inspection, during which time the manufacturer may make claim for a rehearing and retesting.

15.2. The manufacturer shall have the option to resubmit the rejected lot for reinspection or retesting by inspecting or testing every coil for the property in which the specimen failed and sorting out nonconforming coils.

16. CERTIFICATION

16.1. When specified in the purchase order or contract, the purchaser shall be furnished with the manufacturer's written certification that the material was manufactured, sampled, tested, and inspected in accordance with, and meets the requirements of, this specification. When specified in the purchase order or contract, a report of the test results shall be furnished. The certification shall include the specification number, year-date of issue, and the revision letter, if any.

16.2. A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the manufacturer. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 2—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI ASC X12.

17. PACKAGING AND MARKING

17.1. The size of the wire, AASHTO designation, and name or mark of the manufacturer shall be marked on a tag securely attached to each coil of wire.

17.2. Unless otherwise specified, packaging, marking, and loading for shipment shall be in accordance with ASTM A 700.

17.3. When specified in the contract or order, and for the direct procurement by or direct shipment to the U.S. Government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for U.S. military agencies and in accordance with Fed. Std. No. 123 for U.S. Government civil agencies.

18. KEYWORDS

18.1. Concrete reinforcement; deformations (indentations); steel wire.

SUPPLEMENTARY REQUIREMENTS

S1. HIGH-STRENGTH WIRE

S1.1. *Scope*:

S1.1.1 This supplement delineates only those details that are relative to high-strength wire and to the mechanical requirements for wire having properties generally as described in this specification.

Note S1.1—Building codes, for example, ACI 318, permit the use of reinforcement with a yield strength up to 550 MPa [80,000 psi]. For compatibility with the codes' design provisions for high-strength reinforcement, this supplement prescribes requirements for the mechanical properties of wire that exceed the minimum values for yield strength and tensile strength in Table 3 and Table 4 of this specification.

S1.2. *Mechanical Property Requirements*:

S1.2.1 Minimum yield strength shall be specified in the purchase order in increments of 17.5 MPa [2500 psi]. When tested, the yield strength shall be determined at an extension under load of 0.35 percent.

Note S1.2—To conform to the limit on yield strength in building codes, the minimum yield strength specified in the purchase order should not be greater than 550 MPa [80,000 psi].

S1.2.2 Minimum tensile strength shall be 70 MPa [10,000 psi] greater than the minimum specified yield strength.

Note S1.3—A typical order entry line for minimum yield strength is, "500 MPa minimum yield strength" or "72,500 psi minimum yield strength."

S1.3. *Certification*:

S1.3.1 Certification for material produced to this supplement shall include a report of the test results for yield strength, tensile strength, and bend tests. Frequency of testing shall conform to Section 12 of this specification and Section 12 of M 221M/M 221 as applicable.

Standard Specification for

Corrosion-Resistant Coated Dowel Bars

AASHTO Designation: M 254-06

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Specification for

Corrosion-Resistant Coated Dowel Bars

AASHTO Designation: M 254-06

1. SCOPE

1.1 This specification covers the materials, manufacture, and installation of coated dowel bars to be used where corrosion-resistant performance is essential and may be used in lieu of stainless or other approved noncorrosive metals. The dowel shall consist of a steel core covered by an organic coating.

1.2 The coated dowels shall be one of the two following types:

Type A—The coating material develops sufficiently low-bond strength with concrete that a bond breaker is not required.

Type B—The coating material develops bond strength with concrete such that a bond breaker is required. The type of bond breaker used shall be as recommended by the coating manufacturer.

1.3 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 255M/M 255, Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties
- T 253, Coated Dowel Bars

2.2 *ASTM Standard*:

- G 12, Standard Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel

2.3 *Other References*:

- FHWA-RD-74-18, "Nonmetallic Coating for Concrete Reinforcing Bars," 1974

3. GENERAL REQUIREMENTS

3.1 The coated dowels shall resist corrosion and degradation caused by roadway deicing materials and normal highway debris.

3.2 The coating shall develop low-bond strengths with portland cement concrete without a bond breaker, if Type A, or with the proper bond breaker if Type B.

3.3 The coating shall resist wear due to abrasion resulting from pavement expansion and contraction.

3.4 The coating used over the steel core shall be continuous on the lateral surface of the dowel.

3.5 Test procedures as stated herein and in T 253 shall apply to both Type A and Type B dowels.

3.6 In the event there is any change in material composition or geometrics of the joint support system, any or all parts of the dowels and assembly are subject to retesting. The frequency of qualification testing will be determined by the purchasing agency.

3.7 The processing facilities of the manufacturer and the fabricator shall be open to inspection by the agent of the purchaser at all times during the manufacturing and fabricating of the material.

3.8 A minimum of 24 dowel bars shall be made available for testing. Of these, a maximum of six bars may be in a basket assembly.

4. MATERIALS

4.1 The core material shall be made of steel meeting the requirements of M 255M/M 255. The grade shall be as specified by the purchasing agency.

4.2 The coating material shall be of organic composition with the exception of the pigment which may or may not be present and which may have an inorganic composition.

Note 1—The Type B coating material may be one of the types recommended in Report No. FHWA-RD-74-18 or other types approved by the purchasing agency.

5. DIMENSIONS

5.1 The core metal shall be 31.8-mm ($1^1/_4$-in.) diameter or as specified by the purchasing agency.

5.2 The nonabraded thickness of the Type A coating shall be 0.64 ± 0.13 mm (25 ± 5 mils). The nonabraded thickness of the Type B coating shall be 0.18 ± 0.05 mm (7 ± 2 mils).

5.3 Coating thickness shall be determined according to ASTM G 12 or by stripping the coating from the bar.

5.4 The dowels shall be supplied to lengths and in support assemblies or baskets as specified by the purchasing agency.

6. PHYSICAL REQUIREMENTS

6.1 The free ends of the dowels shall be saw cut and free of burrs and projections.

6.2 Dowel coatings shall be free from contamination, perforations, cracks, and holidays (pinholes not visually discernible). Checking for holidays shall be performed by the electric-resistance process. A 67.5-volt holiday detector shall be used, as recommended by the manufacturer of the test equipment, for the determination of holidays.

6.3 Any damage that results from welding or mechanical fixation to achieve a fixed-end condition shall not extend more than 25.4 mm (1 in.) in from the weld or point of fixation.

6.4 Welding to achieve a fixed-end condition shall be sufficiently strong to maintain dowel alignment under the forces imposed by concrete placement and construction practices.

6.5 When tested in accordance with T 253, the dowel bars shall have the following properties:

6.5.1 *Load Deflection*—The relative deflection shall not exceed 0.25 mm (0.10 in.) at the 1815-kg (4000-lb) load for any of the three specimens tested.

6.5.2 *Pullout*—The maximum pullout load shall not exceed 1360 kg (3000 lb) for any specimens, and no specimen shall show any corrosion, tears, or perforation due to the pullout and subsequent freeze-thaw testing.

6.5.3 *Abrasion*—The coating shall not have been worn away, perforated, or wrinkled, and none of the three specimens shall show depth or wear exceeding 70 percent of the original coating thickness. Thickness shall be determined according to Section 5.3 of this specification.

6.5.4 *Corrosion*—No corrosion shall be apparent on any of the specimens when viewed under five-power magnification.

6.5.5 *Chemical Resistance*—The coating shall not blister, soften, disbond, develop holidays, nor exhibit any undercutting at the drilled holes.

6.5.6 *Cathodic Disbonding*—No film failure shall take place during the first 1 hour of testing. Such film failure would be evidenced by the evolution of hydrogen gas at the cathode or appearance of corrosion products of steel at the anodes except that such hydrogen evolution or corrosion products at the intentionally cut 6.4-mm ($^1/_4$-in.) holes will not be considered as basis for rejection. However, no undercutting shall be permitted during the remainder of the test period at the intentionally cut 6.4-mm ($^1/_4$-in.) holes in either the anode or cathode.

6.5.7 *Coating Hardness*—The hardness of the coating shall exceed the Knoop Hardness Number of 16.

6.5.8 *Coating Impact Resistance*—No shattering or disbonding of the coating shall occur except at the impact area (area permanently deformed by the tup).

7. SAMPLING

7.1 A minimum of 24 dowel bars, of which up to six may be in a basket assembly, shall be furnished by the manufacturer for testing and verification of the materials and process. The specimens shall be made available to the testing laboratory 120 days prior to their first intended use. When fixed mechanical assembly is being used, a complete assembly with dowels shall be made available upon request by the purchasing agency.

8. DOCUMENTATION

8.1 Tests performed according to this specification shall be the responsibility of the manufacturers and/or coating applicator and may be performed at his laboratory or an independent laboratory approved by the purchasing agency. Upon completion of the tests, all tested specimens shall be properly labeled as to test procedure, and be made available upon request to the purchasing agency.

8.2 The laboratory facilities and procedure must be open to observation by the purchaser while tests are underway. The purchasing agency reserves the right to check any or all parts of the required tests in the agency laboratory or a laboratory of his choice.

8.3 The coated dowel manufacturer and/or coating applicator shall provide certified copies of test reports to the purchasing agency showing all test data.

8.4 For the purpose of identification, the manufacturer or applicator shall provide certification showing the generic type of coating material along with the type and percentages of pigments, diluents, fillers, flexibilizers, and other additives used.

8.5 The coated dowel manufacturer is defined as a company that produces a complete product consisting of dowel bar and coating.

8.6 The coating applicator is defined as a company that applies coatings to dowel bars.

8.7 Rechecks of the coated dowels may be made at the discretion of the purchasing agency. The purchasing agency may delete any of the above specified test procedures during rechecks of any previously approved product.

Standard Specification for

Uncoated High-Strength Steel Bars for Prestressing Concrete

AASHTO Designation: M 275M/M 275-08
ASTM Designation: A 722/A 722M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 2000

Standard Specification for

Uncoated High-Strength Steel Bars for Prestressing Concrete

AASHTO Designation: M 275M/M 275-08
ASTM Designation: A 722/A 722M-07

1. SCOPE

1.1. This specification covers uncoated high-strength steel bars intended for use in pretensioned and posttensioned prestressed concrete construction or in prestressed ground anchors. Bars are of a minimum ultimate tensile strength level of 1035 MPa [150000 psi].

1.2. Two types of bars are provided: Type I bar has a plain surface and Type II bar has surface deformations.

1.3. Supplementary requirements of an optional nature are provided. They shall apply only when specified by the purchaser.

1.4. This specification is applicable for orders in either SI units (M 275M) or in inch-pound units (M 275). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to M 275.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 244, Mechanical Testing of Steel Products
- T 285, Bend Test for Bars for Concrete Reinforcement

2.2. *ASTM Standards*:

- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- E 30-89, Test Methods for Chemical Analysis of Steel, Cast Iron, Open-Hearth Iron, and Wrought Iron

2.3. *Government Standard*:

- MIL-STD-129, Marking for Shipment and Storage

2.4. *U.S. Federal Standard*:

- Fed. Std. 123, Marking for Shipment (Civil Agencies)

3. ORDERING INFORMATION

3.1. Orders for material under this specification should include the following information:

3.1.1. Quantity (mass),

3.1.2. Name of material (uncoated high-strength bars for prestressing concrete),

3.1.3. AASHTO designation and year of issue,

3.1.4. Size and length,

3.1.5. Type,

3.1.6. Special inspection requirements, if desired (Section 12),

3.1.7. Special preparation for delivery, if desired (Section 11),

3.1.8. Load-elongation curve, if required (Section 15), and

3.1.9. Supplementary requirements, if desired.

Note 1—A typical ordering description is as follows: 50 uncoated high-strength bars for prestressing concrete to M 275M/M 275-_____; 26-mm diameter, 12.3 m long, Type II; packed in accordance with ASTM A 700; meeting supplementary bending properties. [50 uncoated high-strength bars for prestressing concrete to M 275M/M 275-____; 1-in. diameter, 40 ft, 6 in. long, Type II; packed in accordance with ASTM A 700; meeting supplementary bending properties.]

4. MATERIALS AND MANUFACTURE

4.1. The bars shall be rolled from properly identified heats of ingot cast or strand-cast steel. The standard sizes and dimensions of Type I and Type II bars shall be those listed in Table 1 and Table 2, respectively.

Table 1—Dimensions for Type I (Plain) Bar

Nominal Diameter		Nominal Weight		Nominal Area[a]	
mm	in.	kg/m	lb/ft	mm^2	$in.^2$
19	$^3/_4$	2.23	1.50	284	0.44
22	$^7/_8$	3.04	2.04	387	0.60
25	1	3.97	2.67	503	0.78
29	$1^1/_8$	5.03	3.38	639	0.99
32	$1^1/_4$	6.21	4.17	794	1.23
35	$1^3/_8$	7.52	5.05	955	1.48

[a] The nominal area is determined from the nominal diameter in inches. Values have been converted from inch-pound units to metric units.

Table 2—Dimensions for Type II (Deformed) Bar

Nominal Diameter[a]		Nominal Weight		Nominal Area[b]	
mm	in.	kg/m	lb/ft	mm^2	$in.^2$
15	$^5/_8$	1.46	0.98	181	0.28
20	$^3/_4$	2.22	1.49	271	0.42
26	1	4.48	3.01	548	0.85
32	$1^1/_4$	6.54	4.39	806	1.25
36	$1^3/_8$	8.28	5.56	1019	1.58
46	$1^3/_4$	13.54	9.10	1664	2.58
65	$2^1/_2$	27.10	18.20	3331	5.16

[a] Nominal diameters are for identification only. Values have been converted from metric to inch-pound units.

[b] The nominal area is determined from the bar weight less 3.5 percent for the ineffective weight of the deformation.

4.2. The bars shall be subjected to cold-stressing to not less than 80 percent of the minimum ultimate strength, and then shall be stress-relieved, to produce the prescribed mechanical properties.

5. CHEMICAL COMPOSITION

5.1. An analysis of each heat of steel shall be made by the manufacturer from test samples taken during the pouring of each heat.

5.1.1. Choice and use of chemical composition and alloying elements, to produce the mechanical properties of the finished bar prescribed in Section 6.2, shall be made by the manufacturer, subject to the limitations in Section 5.1.2.

5.1.2. On heat analysis, phosphorus and sulfur shall not exceed the following:

Phosphorus	0.040 percent
Sulfur	0.050 percent

5.2. A product analysis may be made by the purchaser from the finished bar representing each cast or heat of steel. The phosphorus and sulfur contents thus determined shall not exceed the limits specified in Section 5.1.2 by 0.008 percent.

5.3. ASTM E 30-89 shall be used for referee purposes.

6. MECHANICAL PROPERTIES

6.1. All testing for mechanical properties shall be performed in accordance with the requirements of T 244 Methods and Definitions.

6.2. *Tensile Properties*:

6.2.1. Finished bars shall have a minimum ultimate tensile strength of 1035 MPa [150000 psi].

6.2.2. The minimum yield strength of Type I and Type II bars shall be 85 percent and 80 percent, respectively, of the minimum ultimate tensile strength of the bars. The yield strength shall be determined by either of the methods described in T 244; however, in the extension under load method, the total strain shall be 0.7 percent, and in the offset method the offset shall be 0.2 percent.

6.2.3. The minimum elongation after rupture shall be 4.0 percent in a gauge length equal to 20 bar diameters, or 7.0 percent in a gauge length equal to 10 bar diameters.

6.3. *Test Specimens*—Tension tests shall be made using full-size bar test specimens. Machined reduced section test specimens are not permitted. All unit stress determinations shall be based on the nominal area shown in Table 1 or the effective area shown in Table 2.

6.4. *Number of Tests*—The number of tensile specimens tested shall be one from each 36 Mg [39 tons] or fraction thereof, of each size of bar rolled from each heat but not fewer than two from each heat. The specimens shall be randomly selected following the final processing operation.

6.5. *Retests*:

6.5.1. If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gauge length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

6.5.2. If the results of an original tension test fail to meet specified requirements, two additional tests shall be made on samples of bar from the same heat and bar size, and if failure occurs in either of these tests, the bar size from that heat shall be rejected.

6.5.3. If any test specimen fails because of mechanical reasons such as failure of testing equipment, it shall be discarded and another specimen taken.

6.5.4. If any test specimen develops flaws, it shall be discarded and another specimen of the same size bar from the same heat substituted.

7. REQUIREMENTS FOR DEFORMATIONS

7.1. Material furnished as Type II bar shall have deformations spaced uniformly along the length of the bar. The deformations on opposite sides of the bar shall be similar in size and shape. The average spacing or distance between deformations on both sides of the bar shall not exceed seven-tenths of the nominal diameter of the bar.

7.2. The minimum height and minimum projected area of the deformations shall conform to the requirements shown in Table 3.

Table 3—Deformation Dimensions for Type II Bar

Nominal Diameter		Deformation Dimensions					
		Maximum Average Spacing		Minimum Average Height		Minimum Projected Area[a]	
mm	in.	mm	in.	mm	in.	mm^2/mm	$in.^2/in.$
15	$^5/_8$	11.1	0.44	0.7	0.03	2.4	0.09
20	$^3/_4$	13.3	0.52	1.0	0.04	3.4	0.13
26	1	17.8	0.70	1.3	0.05	4.4	0.17
32	$1^1/_4$	22.5	0.89	1.6	0.06	5.4	0.21
36	$1^3/_8$	25.1	0.99	1.8	0.07	6.1	0.24
46	$1^3/_4$	30.1	1.19	2.2	0.09	7.3	0.29
65	$2^1/_2$	44.5	1.75	2.9	0.11	9.7	0.38

[a] Calculated from equation, minimum projected area = $0.75\pi d\ h/s$ where:
d = nominal diameter,
h = minimum average height, and
s = maximum average spacing.

7.3. *Mechanical Coupling*—For those bars having deformations arranged in a manner to permit coupling of the bars with a screw-on type of coupler, it shall be the responsibility of the finished-bar manufacturer to demonstrate that a bar cut at any point along its length may be coupled to any other length of bar and that a coupled joint supports the minimum specified ultimate tensile strength of the coupled bars. The coupler type shall be provided or designed by the finished-bar manufacturer.

8. MEASUREMENTS OF DEFORMATIONS

8.1. The average spacing of deformations shall be determined by dividing a measured length of the bar specimen by the number of individual deformations and fractional parts of deformations on any one side of the bar specimen. A measured length of the bar specimen shall be considered the distance from a point on a deformation to a corresponding point on any other deformation on the same side of the bar.

8.2. The average height of deformations shall be determined from measurements made on not fewer than two typical deformations. Determinations shall be based on three measurements per deformation: one at the center of the overall length, and the other two at the quarter points of the overall length.

8.3. To indicate adequately the conformity to the dimensional requirements, measurements shall be taken at random from one bar from each 30 Mg [33 tons] of each lot or fraction thereof.

8.4. Insufficient height, insufficient projected area, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot that typical deformation height or spacing does not conform to the minimum requirements prescribed in Section 7. No rejection shall be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

Note 2—The term “lot” shall mean all bars of the same nominal mass per linear meter [weight per linear foot] contained in an individual shipping release or shipping order.

9. PERMISSIBLE VARIATION IN SIZE OR MASS

9.1. For Type I bars, the permissible variation from the nominal diameter specified in Table 1 shall not exceed +0.75, –0.25 mm [+0.030, –0.010 in.].

9.2. For Type II bars, the permissible variation from the nominal mass specified in Table 2 shall not exceed +3 percent, –2 percent.

10. FINISH

10.1. The bars shall be free of defects injurious to the mechanical properties and shall have a workmanlike finish.

11. DELIVERY

11.1. Packaging and loading for shipment shall be in accordance with ASTM A 700.

11.2. When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for military agencies and with Fed. Std. No. 123 for civil agencies.

11.3. Unless otherwise specified in the contract or order, bars shall be grouped by size. Each bundle or lift shall be tagged, showing the heat number, bar size, specification number (M 275M/M 275), and the identity of the finished bar manufacturer. The tags shall display the following statement "High Strength Prestressing Bars." Both ends of each bar shall be painted yellow.

12. INSPECTION

12.1. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

12.2. If specified in the purchase order, the purchaser shall reserve the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that the material furnished conforms to prescribed requirements.

12.3. If outside inspection is waived, the finished-bar manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material.

13. REJECTION

13.1. Unless otherwise specified, any rejection based on tests made in accordance with Section 5.2 shall be reported to the manufacturer within five working days from the receipt of samples by the purchaser.

13.2. Material that shows injurious defects subsequent to its acceptance at the manufacturer's works shall be subject to rejection, and the manufacturer shall be notified.

14. REHEARING

14.1. Samples tested in accordance with Section 5.2 that represent rejected material shall be preserved for 2 weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer shall be permitted to make claim for a rehearing within that time.

15. CERTIFICATION

15.1. If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of this specification shall be the basis of acceptance of the material. The certification shall include the specification number, year-date of issue, and revision letter, if any.

15.2. The manufacturer shall, when required in the order, furnish a representative load-elongation curve for each size and type of bar shipped.

15.3. A modulus of elasticity value of 205 GPa (29700000 psi) shall be used for the purpose of elongation calculation for Type II bars.

Note 3—Experience has shown that plotted load-elongation curves from mill tests on Type II bars vary excessively and are not sufficiently reliable for use in calculating modulus of elasticity values.

15.4. A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) shall be regarded as having the same validity as a counter part printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any existing EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 4—The industry definition as invoked here is: EDI is the computer-to-computer exchange of business information in a standard format such as ANSI SAC X12.

16. KEYWORDS

16.1. High-strength steel bars; prestressed concrete; posttensioning; deformed bars; plain bars.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified in the purchase order or contract.

S1. BENDING PROPERTIES

S1.1. The bend-test specimens shall withstand being bent, at ambient temperature, but in no case less than 15°C [59°F], around a pin without cracking on the outside of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table 4.

Table 4—Supplementary Bend Test Requirements

Nominal Bar Diameters		Diameter of Pin for 135° Bend[a]
mm	in.	
15	$^5/_8$	$d = 6t$
20	$^3/_4$	$d = 6t$
26	1	$d = 6t$
32	$1^1/_4$	$d = 8t$
36	$1^3/_8$	$d = 8t$
46	$1^3/_4$	$d = 10t$
65	$2^1/_2$	$d = 10t$

[a] d = diameter of pin around which specimen is bent.
t = nominal diameter of bar.

S1.2. The bend test shall be made on full-sized specimens of sufficient length to ensure free bending and with apparatus that provides the following:

S1.2.1 Continuous and uniform application of force throughout the duration of the bending operation.

S1.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate or bending about a central pin on a simple span with end supports free to rotate.

S1.2.3 Close wrapping of the specimen around the pin during the bending operation.

S1.3. Other methods of bend testing shall be permitted, but failures due to such methods shall not constitute a basis for rejection.

S1.4. The number of bend-test specimens shall be one from each 20 Mg [22 tons], or fraction thereof, of each size of bar rolled from each heat, but not fewer than two from each heat. The specimens shall be randomly selected following the final processing operation.

S1.5. If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in Sections 6.5.3 and 6.5.4, a retest shall be permitted on two random specimens from the quantity of the finished bar product for each bar size in S1.4. If the results of both test specimens meet the specified requirements, the bars shall be accepted. The retest shall be performed on test specimens that are at air temperature, but not less than 15°C [59°F].

S2. REDUCTION OF AREA

S2.1. The minimum reduction of area from the effective area shall be 20 percent for Type I plain bars.

S3. CHEMICAL REQUIREMENTS

S3.1. The chemical composition determined as specified in Section 5.1 shall be reported to the purchaser or his representative.

Standard Specification for

Epoxy-Coated Reinforcing Bars: Materials and Coating Requirements

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AASHTO Designation: M 284M/M 284-09
ASTM Designation: A 775/A 775M-07b

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Epoxy-Coated Reinforcing Bars: Materials and Coating Requirements

AASHTO Designation: M 284M/M 284-09
ASTM Designation: A 775/A 775M-07b

AASHTO M 284M/M 284-09 is identical to ASTM A 775/A 775M-07b except for the following provision:

1. Add the following to the last sentence of ASTM A 775/A 775M-07b Section 11.4:

   The coating thickness after curing on sheared or cut ends shall be 175 to 450 µm (7 to 18 mils). The patching material used to repair the sheared or cut ends shall not extend beyond 75 mm (3 in.) from the sheared or cut end.

Standard Specification for

Epoxy-Coated Reinforcing Bars: Handling Requirements for Fabrication and Job Site

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AASHTO Designation: M 317M/M 317-03 (2007)
ASTM Designation: D 3963/D 3963M-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Epoxy-Coated Reinforcing Bars: Handling Requirements for Fabrication and Job Site

AASHTO Designation: M 317M/M 317-03 (2007)

ASTM Designation: D 3963/D 3963M-01

AASHTO M 317M/M 317-03 (2007) is identical to ASTM D 3963/D 3963M-01.

Standard Specification for

Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

AASHTO Designation: M 322M/M 322-10
ASTM Designation: A 996/A 996M-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

AASHTO Designation: M 322M/M 322-10
ASTM Designation: A 996/A 996M-09

1. SCOPE

1.1 This specification covers rail-steel and axle-steel bars for concrete reinforcement. Three types of product are included, designated with a “rail symbol” and an “R” for bars made of rail-steel and with an “A” for bars made of axle-steel. The standard sizes and dimensions of deformed bars and their number designations are given in Table 1. All sizes and grades of all types may not be readily available; manufacturers should be consulted to verify availability.

1.2 The text of this specification references notes and footnotes that provide explanatory material. These notes and footnotes, excluding those in tables and figures, shall not be considered as requirements of the specification.

1.3 Type “rail symbol” and Type R are of two minimum yield levels, namely 350 MPa [50 000 psi] and 420 MPa [60 000 psi] designated as Grade 350 [50] and Grade 420 [60], respectively. Type A is of two minimum yield levels, namely 300 MPa [40 000 psi] and 420 MPa [60 000 psi] designated Grade 300 [40] and Grade 420 [60].

1.4 The weldability of the steel is not a requirement of this specification.

1.5 This specification is applicable for orders in either SI units (M 322M) or inch-pound units (M 322).

1.6 The values stated in either SI units or inch-pound units are to be regarded as standard. Within the text, the inch-pound units are shown in brackets. The values stated must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Table 1—Deformed Bar Designation Numbers, Nominal Masses [Weights], Nominal Dimensions, and Deformation Requirements

		Nominal Dimensions[a]			Deformation Requirements, mm		
Bar Designation No.	Nominal Mass [Weight], kg/m [lb/ft]	Diameter, mm [in.]	Cross-Sectional Area, mm^2 [$in.^2$]	Perimeter, mm [in.]	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
10 [3]	0.560 [0.376]	9.5 [0.375]	71 [0.11]	29.9 [1.178]	6.7 [0.262]	0.38 [0.015]	3.6 [0.143]
13 [4]	0.994 [0.668]	12.7 [0.500]	129 [0.20]	39.9 [1.571]	8.9 [0.350]	0.51 [0.020]	4.9 [0.191]
16 [5]	1.552 [1.043]	15.9 [0.625]	199 [0.31]	49.9 [1.963]	11.1 [0.437]	0.71 [0.028]	6.1 [0.239]
19 [6]	2.235 [1.502]	19.1 [0.750]	284 [0.44]	59.8 [2.356]	13.3 [0.525]	0.97 [0.038]	7.3 [0.286]
22 [7]	3.042 [2.044]	22.2 [0.875]	387 [0.60]	69.8 [2.749]	15.5 [0.612]	1.12 [0.044]	8.5 [0.334]
25 [8]	3.973 [2.670]	25.4 [1.000]	510 [0.79]	79.8 [3.142]	17.8 [0.700]	1.27 [0.050]	9.7 [0.383]

[a] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same mass [weight] per meter [foot] as the deformed bar.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 244, Mechanical Testing of Steel Products

2.2 *ASTM Standards*:

- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3 *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products Preparation for Shipment and Storage

2.4 *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)

3. TERMINOLOGY

3.1 *Description of Terms Specific to This Standard*:

3.1.1 *deformations*—transverse protrusions on a deformed bar.

3.1.2 *deformed bar*—steel bar with transverse protrusions; a bar that is intended for use as reinforcement in reinforced concrete construction.

3.1.2.1 *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protrusions conform to the provisions of this specification.

3.1.3 *rib*—longitudinal protrusion on a deformed bar.

4. ORDERING INFORMATION

4.1 It shall be the responsibility of the purchaser to specify all requirements that are necessary for material ordered to this specification. Such requirements shall include, but are not limited to, the following:

4.1.1 Quantity (mass) [weight],

4.1.2 Name of material (rail-steel or axle-steel deformed bars for concrete reinforcement),

4.1.3 Type,

4.1.4 Size,

4.1.5 Grade,

4.1.6 Packaging (see Section 20),

4.1.7 AASHTO designation and year of issue, and

4.1.8 Certified mill test reports (if desired). (See Section 18.)

5. MATERIAL AND MANUFACTURE

5.1 The bars shall be rolled from standard section Tee-rails or from carbon-steel axles for railway cars and locomotives. No other materials, such as those known by the terms “rerolled, rail-steel equivalent, and rail-steel quality,” shall be substituted.

6. CARBON DETERMINATION

6.1 For axle-steel product, the manufacturer shall make a determination for the carbon content of each axle received for manufacture into reinforcing bars. Based on these carbon determinations, all steel axles shall be stocked for subsequent rolling in separated lots by carbon range. The ranges of carbon shall be determined by the manufacturer as those best suited to meet the mechanical requirements.

6.2 When requested by the purchaser, the manufacturer shall report the carbon range for each lot of bars furnished.

7. REQUIREMENTS OF DEFORMATIONS

7.1 Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

7.2 The deformations shall be placed with respect to the axis of the bar so that the include angle is not less than 45 degrees. Where the line of deformations forms an include angle with the axis of the bar from 45 degrees to 70 degrees inclusive, the deformations shall alternately reverse in direction from those on the opposite side. Where the line of deformation is greater than 70 degrees, a reversal in direction shall not be required.

7.3 The average spacing or distance between deformations on each side of the bar shall not exceed seven-tenths of the nominal diameter of the bar.

7.4 The overall length of deformations shall be such that the gap between the ends of the deformations shall not exceed 12.5 percent of the nominal perimeter of the bar. Where the ends terminate in a rib, the width of the rib shall be considered as the gap between these ends. The summation of the gaps shall not exceed 25 percent of the nominal perimeter of the bar. Furthermore, the summation of gaps shall not exceed 25 percent of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.1416 times the nominal diameter.

7.5 The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1.

8. MEASUREMENTS OF DEFORMATIONS

8.1 The average spacing of deformations shall be determined by measuring the length of a minimum of ten spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space. Spacing measurements shall not be made over a bar area containing bar marking symbols involving letters or numbers.

8.2 The average height of deformations shall be determined from measurements made on not fewer than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

8.3 Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot (Note 1) tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 7. No rejection may be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

Note 1—As used within the intent of Sections 8.3 and 14.1, the term “lot” shall mean all the bars of one bar number and pattern of deformations contained in an individual shipping release or shipping order.

9. TENSILE REQUIREMENTS

9.1 The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 2.

9.2 The yield point or yield strength shall be determined by one of the following methods:

9.2.1 The yield point shall be determined by the drop of the beam or halt in the gauge of the testing machine.

9.2.2 Where the steel tested does not exhibit a well-defined yield point, the yield strength shall be determined by the offset method (0.2 percent offset), as described in T 244 (Section 13.2.1).

9.3 The percentage of elongation shall be as prescribed in Table 2.

Table 2—Tensile Requirements

	Grade[a] 300 [40]	Grade 350 [50]	Grade 420 [60]	
Tensile strength, min, MPa [psi]	500 [70 000]	550 [80 000]	600 [90 000]	
Yield strength, min, MPa [psi]	300 [40 000]	350 [50 000]	400 [60 000]	
Elongation in 200 mm [8 in.], min, percent Bar Designation No.:			Rail Symbol and Type R	Type A
10 [3]	11	6	6	8
13, 16, 19 [4, 5, 6]	12	7	6	8
22 [7]	11	6	5	8
25 [8]	10	5	4.5	7

[a] Sizes 10 through 19 may not be readily available; manufacturers should be consulted to verify availability.

10. BENDING REQUIREMENTS

10.1 The bend-test specimen shall withstand being bent around a pin without cracking on the outside of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table 3.

Table 3—Bend-Test Requirements

Bar Designation No.	Pin Diameter for Bend Tests[a]		
	Type Rail Symbol	Type R	Type A
10, 13, 16 [3, 4, 5]	6*d*[b]	$3\,{}^{1}/_{2}d$	$3\,{}^{1}/_{2}d$
19, 22, 25 [6, 7, 8]	6*d*	5*d*	5*d*

[a] Test bends 180°.

[b] *d* = nominal diameter of specimen.

10.2 The bend test shall be made on specimens of sufficient length to ensure free bending and with an apparatus that provides the following:

10.2.1 Continuous and uniform application of force throughout the duration of the bending operation;

10.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate;

10.2.3 Close wrapping of the specimen around the pin during the bending operation.

10.3 It shall be permissible to use other acceptable, more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin. When failures occur under more severe methods, retests shall be permitted under the bend-test method prescribed in Section 10.2.

11. PERMISSIBLE VARIATION IN MASS [WEIGHT]

11.1 Deformed reinforcing bars shall be evaluated on the basis of nominal mass [weight]. The mass [weight] determined using the measured mass [weight] of the test specimen and rounding in accordance with ASTM E 29 shall be at least 94 percent of the applicable mass [weight] per unit length prescribed in Table 1. In no case shall excess mass [overweight] of any deformed bar be cause for rejection.

12. FINISH

12.1.1 The bars shall be free of detrimental surface imperfections.

12.1.2 Rust, seams, surface irregularities, or mill scale shall not be cause for rejection, provided the mass [weight], dimensions, cross-sectional area, and tensile properties of a hand wire-brushed test are not less than the requirements of this specification.

12.1.3 Surface imperfections or flaws other than those specified in Section 12.1.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements. Examples include, but are not limited to, laps, seams, slivers, cooling or casting cracks, and mill or guide marks.

13. TEST SPECIMENS

13.1 All mechanical tests shall be conducted in accordance with T 244, including Annex A9.

13.2 Tension test specimens shall be the full section of bar as rolled.

13.3 The unit stress determinations on full-sized specimens shall be based on the nominal bar area.

13.4 The bend-test specimens shall be the full section of the bar as rolled.

14. NUMBER OF TESTS

14.1 For bar sizes No. 10 to No. 25 [No. 3 to No. 8] inclusive, one tension test and one bend test shall be made from each lot (Note 1) of 9 Mg [10 tons] or fraction thereof. Each lot of rails (“rail symbol” or “R”) shall not vary more than 5 kg/m [10 lb/yd] of nominal mass [weight]. Each lot of axles (Type A) shall be assorted in groups as specified in Section 6.

15. RETESTS

15.1 If results of an original tension specimen fail to meet the specified minimum requirements and are within 14 MPa [2000 psi] of the required tensile strength, within 7 MPa [1000 psi] of the required yield point, or within two percentage points of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the lot. Both retest specimens shall meet the requirements of this specification.

15.2 If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in Sections 15.4.2 and 15.4.3, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification. The retest shall be performed on test specimens that are at air temperature, but not less than 16°C [60°F].

15.3 If a weight [mass] test fails for reasons other than flaws in the specimen as described in Section 15.4.3, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

15.4 If the original test or any of the random retests fails because of any reasons listed in Sections 15.4.1, 15.4.2 or 15.4.3, the test shall be considered an invalid test. The results shall be discarded and the test shall be repeated on a specimen from the same lot.

15.4.1 The elongation property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle half of the gauge length, as indicated by scribe marks on the specimen before testing.

15.4.2 Mechanical reasons such as failure of testing equipment or improper specimen preparation.

15.4.3 Flaws are detected in a test specimen, either before or during the performance of the test.

Note 2—Marking specimens with multiple scribe or punch marks can reduce the occurrence of fracture outside or near these marks and the need for declaring the test invalid.

16. INSPECTION

16.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

16.2 *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein and shall be permitted to use one's own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

17. REJECTION

17.1 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

18. TEST REPORTS

18.1 When specified in the purchase order, report the following information on a per-lot basis. Additional items may be reported as requested or desired.

18.1.1 Carbon level—Type A only,

18.1.2 Tensile properties,

18.1.3 Bend test.

18.2 A material test report, certificate of inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document must meet the requirements of the invoked AASHTO standard(s) and conform to any EDI agreement between the purchaser and the supplier. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

Note 3—The industry definition invoked here is: EDI is the computer to computer exchange of business information in a standard format such as ANSI ASC X12.

19. MARKING

19.1 When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's test identification number.

19.2 Each manufacturer shall identify the symbols of his marking system.

19.3 All bars produced to this specification shall be identified by a distinguishing set of marks legibly rolled into the surface of one side of the bar to denote in the following order:

19.3.1 *Point of Origin*—letter or symbol established as the manufacturer's mill designation;

19.3.2 *Size Designation*—Arabic number corresponding to bar designation number of Table 1;

19.3.3 *Type of Steel*—rail symbol, letter R or letter A, indicating that the bar was produced from rail or axle steel;

19.3.4 *Minimum Yield Designation*—for Grade 420 [60] bars, either the number 4 [60] or a single continuous longitudinal line through at least five spaces offset from the center of the bar side. (There is no marking designation for Grade 350 [50] or Grade 300 [40] bars.)

19.3.5 It shall be permissible to substitute bars having sizes and grades in SI units for bars ordered to the corresponding sizes and grades in inch-pound units.

20. PACKAGING

20.1 When specified in the purchase order, packaging shall be in accordance with the procedures in ASTM A 700.

20.2 *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

21. KEYWORDS

21.1 Concrete reinforcement; deformations (protrusions); steel bars.

Standard Specification for

Materials for Embankments and Subgrades

AASHTO Designation: M 57-80 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Materials for Embankments and Subgrades

AASHTO Designation: M 57-80 (2008)

1. SCOPE

1.1 This specification covers materials for use in the construction of embankments and subgrades.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 191, Density of Soil In-Place by the Sand-Cone Method
- T 224, Correction for Coarse Particles in the Soil Compaction Test
- T 310, In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

3. DEFINITIONS

3.1 Definitions of these materials are given in M 146.

4. GENERAL REQUIREMENTS

4.1 Materials shall be free from detrimental quantities of organic material, such as leaves, grass, roots, and sewage.

4.2 Materials obtained from cuts or borrow areas shall conform to one of the following requirements:

Note 1—See M 145.

4.2.1 *In Embankments*—Materials classified in the A-1, A-2-4, A-2-5, or A-3 groups as in M 145 shall be used when available and shall be compacted to the depth specified to not less than 95 percent of the maximum density per T 99. If material of this character is not available and materials from the A-2-6, A-2-7, A-4, A-5, A-6, or A-7 groups must be used, special attention should be given to the design and construction of the embankment. Materials from these groups shall be compacted to not less than 95 percent of the maximum density and within two percentage points of the optimum moisture content per T 99.

4.2.2 *In Subgrades*—Materials classified in the A-1, A-2-4, A-2-5, or A-3, groups as shown in M 145 shall be used when available and shall be compacted to the depth specified to not less than 95 percent of the maximum density per T 99. Materials in the A-2-6, A-2-7, A-4, A-5, A-6, or A-7 groups may be used if compacted to the depth specified to not less than 95 percent of the maximum density and within two percentage points of the optimum moisture content per T 99.

4.3 Local shale may be used in embankment or subgrade construction if the condition of existing pavements and embankments indicate satisfactory results. Appropriate special specifications shall be prepared for such material.

5. DENSITY REQUIREMENTS

5.1 Density percentage requirements may be specified in terms of T 180, if the resultant density and optimum moisture content are comparable with T 99 under the above conditions.

6. METHODS OF TESTING

6.1 Methods of testing materials for embankments and subgrades shall be in accordance with the standard methods of the American Association of State Highway and Transportation Officials. (See Table 1.)

Table 1—AASHTO Standard Methods

Soil preparation (dry method)	T 87
Soil preparation (wet method)	T 146
Material passing 75-µm (No. 200) sieve	T 11
Sieve analysis	T 27
Mechanical analysis of soils	T 88
Liquid limit	T 89
Plastic limit	T 90
Moisture-density relationship [2.5-kg (5.5-lb) rammer]	T 99
Moisture-density relationship [4.54-kg (10-lb) rammer]	T 180
Density of soil in place	T 191, T 233
Moisture in place by nuclear methods	T 310
Coarse particle correction	T 224

Note 2—Use either T 88 or T 11 and T 27 to determine the particle size distribution as a basis for classification.

Standard Specification for

Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

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Standard Specification for

Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

AASHTO Designation: M 145-91 (2008)

1. SCOPE

1.1 This recommended practice describes a procedure for classifying soils into seven groups based on laboratory determination of particle size distribution, liquid limit, and plasticity index. Evaluation of soils within each group is made by means of a "group index," which is a value calculated from an empirical formula. The group classification, including group index, should be useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases, and bases. However, for the detailed design of important structures, additional data concerning strength or performance characteristics of the soil under field conditions will usually be required.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 146, Wet Preparation of Disturbed Soil Samples for Test

2.2 *ASTM Standard*:

- D 1140, Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 (75-µm) Sieve

Note 1—Either T 88, or T 11 and T 27, or ASTM D 1140 will be used to determine the particle size distribution of soils or soil-aggregate mixtures as a basis for classification.

3. CLASSIFICATION

3.1 The classification is made by using the test limits and group index values shown in Table 1. If a more detailed classification is desired, a further subdivision of the groups shown in Table 1 may be made. An example of the classification with subgroups such as those shown in Table 1 may be made. An example of the classification with such subgroups is shown in Table 2. The liquid limit and plasticity index ranges for the A-4, A-5, A-6, and A-7 soil groups are shown graphically in Figure 2.

Table 1—Classification of Soils and Soil-Aggregate Mixtures

General Classification	Granular Materials (35 Percent or Less Passing 75 µm)			Silt-Clay Materials (More Than 35 Percent Passing 75 µm)			
Group Classification	A-1	A-3[a]	A-2	A-4	A-5	A-6	A-7
Sieve analysis, percent passing:							
2.00 mm (No. 10)	—	—	—	—	—	—	—
0.425 mm (No. 40)	50 max	51 min	—	—	—	—	—
75 µm (No. 200)	25 max	10 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)							
Liquid limit	—			40 max	41 min	40 max	41 min
Plasticity index	6 max	NP	[b]	10 max	10 max	11 min	11 min
General rating as subgrade	Excellent to Good			Fair to Poor			

[a] The placing of A-3 before A-2 is necessary in the "left to right elimination process" and does not indicate superiority of A-3 over A-2.

[b] See Table 2 for values.

Table 2—Classification of Soils and Soil-Aggregate Mixtures

General Classification	Granular Materials (35 Percent or Less Passing 75 µm)							Silt-Clay Materials (More Than 35 Percent Passing 75 µm)			
	A-1			A-2							A-7
Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5, A-7-6
Sieve analysis, percent passing:											
2.00 mm (No. 10)	50 max	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max	50 max	51 min	—	—	—	—	—	—	—	—
75 µm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid limit	—		—	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to Good							Fair to Poor			

[a] Plasticity index of A-7-5 subgroup is equal to or less than *LL* − 30. Plasticity index of A-7-6 subgroup is greater than *LL* − 30. (See Figure 2.)

3.2 *Classification Procedure*—With required test data available, proceed from left to right in Table 1 or Table 2 and the correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification. All limiting test values are shown as whole numbers. If fractional numbers appear on test reports, convert to nearest whole number for purposes of classification. Group index values should always be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc.

4. DEFINITIONS OF GRAVEL, SAND, AND SILT-CLAY

4.1 The terms “gravel,” “coarse sand,” and “silt-clay,” as determinable from the minimum test data required in this classification arrangement and as used in subsequent word descriptions, are defined as follows:

4.1.1 *gravel*—material passing sieve with 75-mm (3-in.) square openings and retained on the 2.00-mm (No. 10) sieve.

4.1.2 *coarse sand*—material passing the 2.00-mm (No. 10) sieve and retained on the 0.425-mm (No. 40) sieve.

4.1.3 *fine sand*—material passing the 0.425-mm (No. 40) sieve and retained on the 75-µm (No. 200) sieve.

4.1.4 *silt clay (combined silt and clay)*—material passing the 75-µm (No. 200) sieve.

4.1.5 Boulders and cobbles (retained on 75-mm (3-in.) sieve) should be excluded from the portion of the sample to which the classification is applied, but the percentage of such material, if any, in the sample should be recorded.

4.1.6 The term “silty” is applied to fine material having plasticity index of 10 or less and the term “clayey” is applied to fine material having plasticity index of 11 or greater.

5. DESCRIPTION OF CLASSIFICATION GROUPS

5.1 *Granular Materials*—Containing 35 percent or less passing 75-µm (No. 200) sieve, Note 2.

5.1.1 *Group A-1*—The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand, and a nonplastic or feebly plastic soil binder. However, this group also includes stone fragments, gravel, coarse sand, volcanic cinders, etc. without soil binder.

5.1.1.1 *Subgroup A-1-a* includes those materials consisting predominantly of stone fragments or gravel, either with or without a well-graded binder of fine material.

5.1.1.2 *Subgroup A-1-b* includes those materials consisting predominantly of coarse sand, either with or without a well-graded soil binder.

5.1.2 *Group A-3*—The typical material of this group is fine beach sand or fine desert blow sand without silty or clay fines or with a very small amount of nonplastic silt. The group includes also stream-deposited mixtures of poorly graded fine sand and limited amounts of coarse sand and gravel.

5.1.3 *Group A-2*—This group includes a wide variety of "granular" materials that are borderline between the materials falling in Groups A-1 and A-3 and silt-clay materials of Groups A-4, A-5, A-6, and A-7. It includes all materials containing 35 percent or less passing the 75-µm (No. 200) sieve that cannot be classified as A-1 or A-3 due to fines content or plasticity or both, in excess of the limitations for those groups.

5.1.3.1 Subgroups A-2-4 and A-2-5 include various granular materials containing 35 percent or less passing the 75-µm (No. 200) sieve and with a minus 0.425-mm (No. 40) portion having the characteristics of the A-4 and A-5 groups. These groups include such materials as gravel and coarse sand with silt contents or plasticity indexes in excess of the limitations of Group A-1, and fine sand with nonplastic silt content in excess of the limitations of Group A-3.

5.1.3.2 Subgroups A-2-6 and A-2-7 include materials similar to those described under Subgroups A-2-4 and A-2-5 except that the fine portion contains plastic clay having the characteristics of the A-6 or A-7 group.

Note 2—Classification of materials in the various groups applies only to the fraction passing the 75-mm (3-in.) sieve. Therefore, any specifications regarding the use of A-1, A-2, or A-3 materials in construction should state whether boulders retained on the 75-mm (3-in.) sieve are permitted.

5.2 *Silt-Clay Materials*—Containing more than 35 percent passing the 75-µm (No. 200) sieve.

5.2.1 *Group A-4*—The typical material of this group is a nonplastic or moderately plastic silty soil usually having the 75 percent or more passing the 75-µm (No. 200) sieve. The group includes also mixtures of fine silty soil and up to 64 percent of sand and gravel retained on 75-µm (No. 200) sieve.

5.2.2 *Group A-5*—The typical material of this group is similar to that described under Group A-4, except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit.

5.2.3 *Group A-6*—The typical material of this group is a plastic clay soil usually having 75 percent or more passing the 75-µm (No. 200) sieve. The group includes also mixtures of fine clayey soil and up to 64 percent of sand and gravel retained on the 75-µm (No. 200) sieve. Materials of this group usually have high-volume change between wet and dry states.

5.2.4 *Group A-7*—The typical material of this group is similar to that described under Group A-6, except that it has the high liquid limits characteristic of the A-5 group and may be elastic as well as subject to high-volume change.

5.2.4.1 Subgroup A-7-5 includes those materials with moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change.

5.2.4.2 Subgroup A-7-6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high-volume change.

Note 3—Highly organic soils (peat or muck) may be classified in an A-8 group. Classification of these materials is based on visual inspection, and is not dependent on percentage passing the 75-µm (No. 200) sieve, liquid limit, or plasticity index. The material is composed primarily of partially decayed organic matter, generally has a fibrous texture, dark brown or black color, and an odor of decay.

These organic materials are unsuitable for use in embankments and subgrades. They are highly compressible and have low strength.

6. GROUP INDEX

6.1 The group index is calculated from the following formula:

Group index = $(F - 35)\,[0.2 + 0.005\,(LL - 40)] + 0.01\,(F - 15)\,(PI - 10)$

where:

F = percentage passing 75-µm (No. 200) sieve, expressed as a whole number. This percentage is based only on the material passing the 75-mm (3-in.) sieve.

LL = liquid limit, and

PI = plasticity index.

6.1.1 When the calculated group index is negative, the group index shall be reported as zero.

6.1.2 The group index should be reported to the nearest whole number.

6.2 Figure 1 may be used in estimating the group index, by determining the partial group index due to liquid limit and that due to plasticity index, then obtaining the total of the two partial group indexes.

6.3 When calculating the group index of A-2-6 and A-2-7 subgroups, only the PI portion of the formula (or of Figure 1) shall be used.

6.4 The following are examples of calculations of the group index:

6.4.1 Assume that an A-6 material has 55 percent passing the 75-µm (No. 200) sieve, liquid limit of 40, and plasticity index of 25. Then,

Group index = $(55 - 35)\,[0.2 + 0.005\,(40 - 40)] + 0.01\,(55 - 15)\,(25 - 10) = 4.0 + 6.0 = 10$

6.4.2 Assume that an A-7 material has 80 percent passing the 75-µm (No. 200) sieve, liquid limit of 90, and plasticity index of 50. Then,

Group index = $(80 - 35)\,[0.2 + 0.005\,(90 - 40)] + 0.01\,(80 - 15)\,(50 - 10) = 20.3 + 26.0$, or 46.3

6.4.3 Assume that an A-4 material has 60 percent passing the 75-µm (No. 200) sieve, liquid limit of 25, and plasticity index of 1. Then,

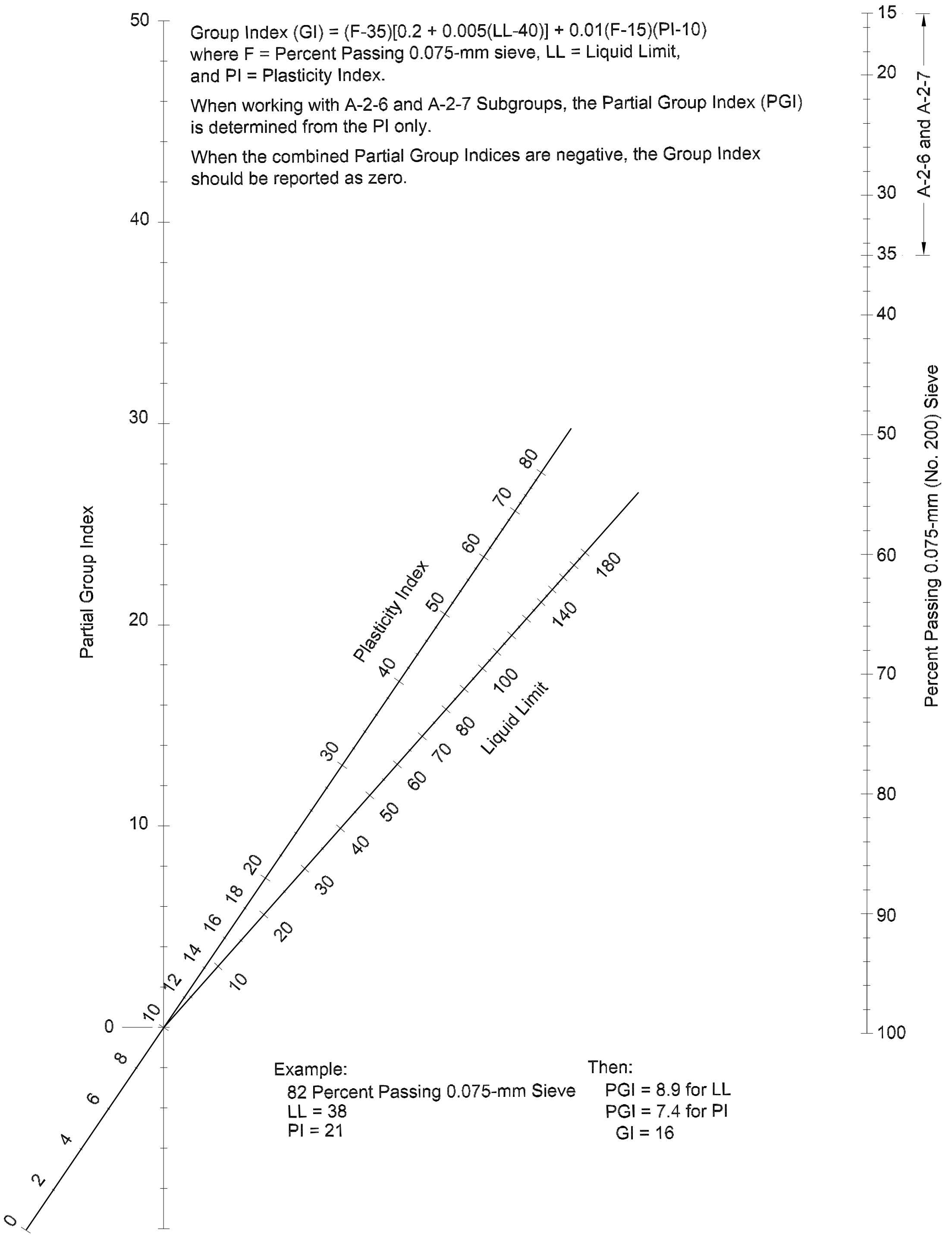
Group index = $(60 - 35)\,[0.2 + 0.005\,(25 - 40)] + 0.01\,(60 - 15)\,(1 - 10) = 25 \times (0.2 - 0.075) + 0.01\,(45)\,(-9) = 3.1 - 4.1 = -1.0$

Report as zero.

6.4.4 Assume that an A-2-7 material has 30 percent passing the 75-µm (No. 200) sieve, liquid limit of 50, and plasticity index of 30. Then,

Group index = $0.01\,(30 - 15)\,(30 - 10) = 3.0$ or 3

(Note that only the PI portion of formula was used.)



Group Index (GI) = (F-35)[0.2 + 0.005(LL-40)] + 0.01(F-15)(PI-10)
where F = Percent Passing 0.075-mm sieve, LL = Liquid Limit,
and PI = Plasticity Index.

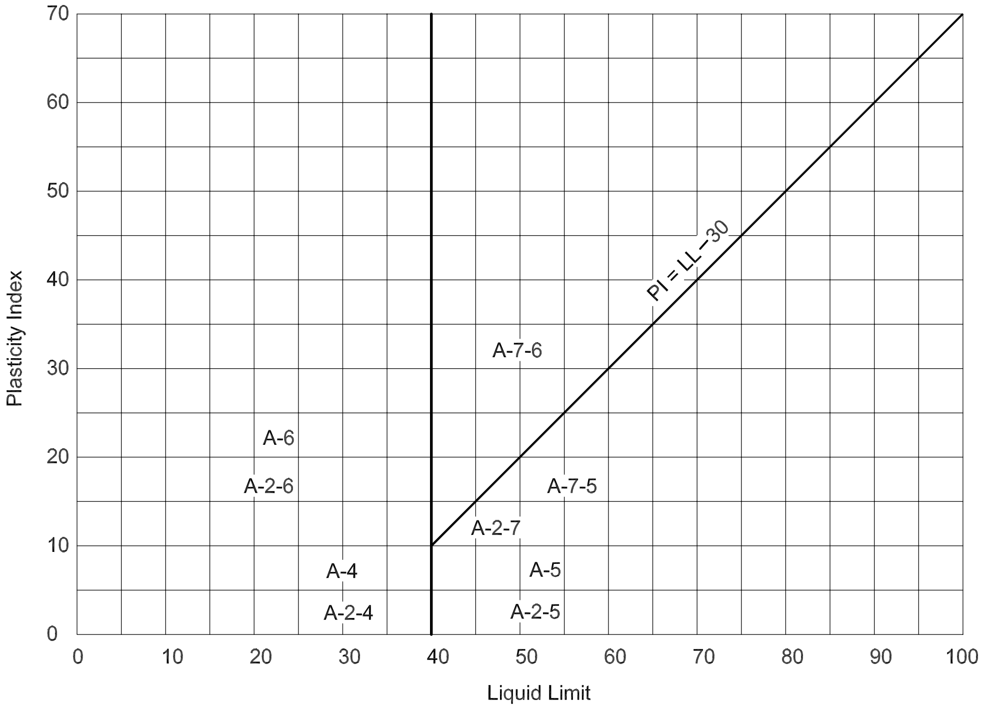
When working with A-2-6 and A-2-7 Subgroups, the Partial Group Index (PGI) is determined from the PI only.

When the combined Partial Group Indices are negative, the Group Index should be reported as zero.

Example:
82 Percent Passing 0.075-mm Sieve
LL = 38
PI = 21

Then:
PGI = 8.9 for LL
PGI = 7.4 for PI
GI = 16

Figure 1—Group Index Chart



Note: A-2 Soils contain less than 35 percent finer than the 75-µm (No. 200) sieve.

Figure 2—Liquid Limit and Plasticity Index Ranges for Silt-Clay Materials

7. BASIS FOR GROUP INDEX FORMULA

7.1 The empirical group index formula devised for approximately within-group evaluation of the "clayey granular materials" and the "silt-clay materials" is based on the following assumptions:

7.1.1 Materials falling within Groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 are satisfactory as subgrade when properly drained and compacted under moderate thickness pavement (base and/or surface course) of a type suitable for the traffic to be carried, or can be made satisfactory by additions of small amounts of natural or artificial binders.

7.1.2 Materials falling within the "clayey granular" Groups A-2-6 and A-2-7 and the "silt-clay" Groups A-4, A-5, A-6, and A-7 will range in quality as subgrade from the approximate equivalent of the good A-2-4 and A-2-5 subgrades to fair and poor subgrades requiring a layer of subbase material or an increased thickness of base course over that required under Section 7.1.1 in order to furnish adequate support for traffic loads.

7.1.3 The assumed critical minimum percentage passing the 75-µm (No. 200) sieve is 35 neglecting plasticity, and 15 as affected by plasticity indexes greater than 10.

7.1.4 Liquid limits of 40 and above are assumed to be critical.

7.1.5 Plasticity indexes of 10 and above are assumed to be critical.

7.1.6 For soils that are nonplastic and when the liquid limit cannot be determined, the group index shall be considered zero.

7.2 There is no upper limit of group index value obtained by use of the formula. The adopted critical values of percentage passing the 75-µm (No. 200) sieve, liquid limit and plasticity index, are based on an evaluation of subgrade, subbase, and base course materials by several highway organizations that use the tests involved in this classification system.

7.3 Under average conditions of good drainage and thorough compaction, the supporting value of a material as subgrade may be assumed as an inverse ratio to its group index; that is, a group index of zero indicates a "good" subgrade material and a group index of 20 or greater indicates a "very poor" subgrade material.

Standard Specification for

Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials

AASHTO Designation: M 146-91 (2008)

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Standard Specification for

Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials

AASHTO Designation: M 146-91 (2008)

1. SCOPE

1.1 These definitions cover terms used in descriptions and specifications of materials occurring as or employed in the construction of subgrades, soil-aggregate base and surface courses, and fills.

1.2 The values stated in SI units are to be regarded as the standard.

2. DEFINITIONS OF ROCK AND SOIL

2.1 *rock*—natural solid mineral matter occurring in large masses or fragments.

2.2 *soil*—sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

2.3 *broken rock*—angular fragments of rock which will be retained on a 75-mm (3-in.) sieve.

2.4 *cobble (cobblestone)*—a rock fragment, usually rounded or semi-rounded, with an average dimension between 75 and 305 mm (3 and 12 in.).

2.5 *boulder*—a rock fragment, usually rounded by weathering or abrasion, with an average dimension of 305 mm (12 in.) or more.

3. DEFINITIONS OF SOIL-AGGREGATE AND ITS COMPONENTS

3.1 *soil-aggregate (dense-graded aggregate)*—natural or prepared mixtures consisting predominately of stone, gravel or sand and containing silt-clay (minus 75-μm (No. 200) material).

3.2 *binder (soil binder)*—portion of soil passing 0.425-mm (No. 40) sieve.

3.3 *stone*—crushed or naturally angular particles of rock that will pass a 75-mm (3-in.) sieve and be retained on a 2.00-mm (No. 10) sieve.

3.3.1 *coarse stone*—stone passing the 75-mm (3-in.) sieve and retained on the 25.0-mm (1-in.) sieve.

3.3.2 *medium stone*—stone passing the 25.0-mm (1-in.) sieve and retained on the 9.5-mm ($^{3}/_{8}$-in.) sieve.

3.3.3 *fine stone*—stone passing the 9.5-mm ($^{3}/_{8}$-in.) sieve and retained on the 2.00-mm (No. 10) sieve.

3.4 *gravel*—rounded particles of rock that will pass a 75-mm (3-in.) sieve and be retained on a 2.00-mm (No. 10) sieve.

3.4.1 *coarse gravel*—gravel passing the 75-mm (3-in.) sieve and retained on the 25.0-mm (1-in.) sieve.

3.4.2 *medium gravel*—gravel passing the 25.0-mm (1-in.) sieve and retained on the 9.5-mm ($^3/_8$-in.) sieve.

3.4.3 *fine gravel*—gravel passing the 9.5-mm ($^3/_8$-in.) sieve and retained on the 2.00-mm (No. 10) sieve.

3.5 *sand*—granular material resulting from the disintegration, grinding, or crushing of rock and which will pass the 2.00-mm (No. 10) sieve and be retained on the 75-µm (No. 200) sieve.

3.5.1 *coarse sand*—sand passing the 2.00-mm (No. 10) sieve and retained on the 0.425-mm (No. 40) sieve.

3.5.2 *fine sand*—sand passing the 0.425-mm (No. 40) sieve and retained on the 75-µm (No. 200) sieve.

3.6 *silt-clay (minus 75-µm (No. 200) material)*—fine soil particles which will pass the 75-µm (No. 200) sieve.

3.6.1 *silt fraction*—material passing the 75-µm (No. 200) sieve and larger than 0.002 mm.

3.6.2 *clay fraction*—material smaller than 0.002 mm.

3.6.3 *colloids*—material smaller than 0.001 mm.

4. DEFINITIONS OF PAVEMENT SUBSTRUCTURE COMPONENTS

4.1 *embankment foundation*—the material on which an embankment is placed.

4.2 *embankment (fill)*—a raised structure of soil, soil-aggregate, or rock.

4.3 *subgrade (basement soil)*—the prepared and compacted soil immediately below the pavement system and extending to such depth as will affect the structural design.

4.4 *subbase*—the layer used in the pavement system between the subgrade and the base course.

4.5 *base*—the layer used in a pavement system to reinforce and protect the subgrade or subbase.

Standard Specification for

Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses

AASHTO Designation: M 147-65 (2008)

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Standard Specification for

Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses

AASHTO Designation: M 147-65 (2008)

1. SCOPE

1.1 This specification covers the quality and grading of sand-clay mixtures; gravel, stone, or slag screenings; or sand, crusher run coarse aggregate consisting of gravel, crushed stone, or slag with or without soil mortar or any combination of these materials for use in the construction of subbase, base and surface courses. The requirements are intended to cover only materials having normal or average specific gravity, absorption, and gradation characteristics. Where other materials are to be used, appropriate limits suitable to their use must be specified.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:
- M 144, Calcium Chloride
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- T 146, Wet Preparation of Disturbed Soil Samples for Test

3. GENERAL REQUIREMENTS

3.1 *Coarse Aggregate*:

3.1.1 Coarse aggregate retained on the 2.00-mm (No. 10) sieve shall consist of hard, durable particles or fragments of stone, gravel, or slag. Materials that break up when alternately frozen and thawed or wetted and dried shall not be used.

3.1.2 Coarse aggregate shall have a percentage of wear, by the Los Angeles test, T 96, of not more than 50.

Note 1—A higher or lower percentage of wear may be specified by the engineer, depending upon the materials available for the work.

3.2 *Fine Aggregate*:

3.2.1 Fine aggregate passing the 2.00-mm (No. 10) sieve shall consist of natural or crushed sand, and fine mineral particles passing the 75-µm (No. 200) sieve.

3.2.2 The fraction passing the 75-µm (No. 200) sieve shall not be greater than two-thirds of the fraction passing the 0.425-mm (No. 40) sieve. The fraction passing the 0.425-mm sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6.

3.3 All material shall be free from vegetable matter and lumps or balls of clay. The soil-aggregate material shall conform to the grading requirements of Table 1. The grading requirements for composite aggregate material will be specified by the engineer.

Table 1—Grading Requirements for Soil-Aggregate Materials

Sieve Designation		Mass Percentage Passing					
Standard, mm	Alternate	Grading A	Grading B	Grading C	Grading D	Grading E	Grading F
50.0	2 in.	100	100	—	—	—	—
25.0	1 in.	—	75–95	100	100	100	100
9.5	$^{3}/_{8}$ in.	30–65	40–75	50–85	60–100	—	—
4.75	No. 4	25–55	30–60	35–65	50–85	55–100	70–100
2.00	No. 10	15–40	20–45	25–50	40–70	40–100	55–100
0.425	No. 40	8–20	15–30	15–30	25–45	20–50	30–70
0.075	No. 200	2–8	5–20	5–15	5–20	6–20	8–25

4. SUBBASE MATERIALS

4.1 Materials for subbase shall conform to the requirements of Sections 3 and 4 for Gradings A, B, C, D, E, or F. The type and grading desired shall be specified.

Note 2—Where local experience has shown that lower percentages passing the 75-µm (No. 200) sieve than are required in Table 1 are necessary for subbase materials in order to prevent damage by frost action, the engineer should specify such lower percentages.

5. BASE COURSE MATERIALS

5.1 Materials for base course shall conform to the requirements of Section 3 for Gradings A, B, C, D, E, or F. The grading desired shall be specified.

Note 3—Where local experience has shown that lower percentages passing the 75-µm (No. 200) sieve than are required in Table 1 are necessary for base course materials in order to prevent damage by frost action, the engineer should specify such lower percentages.

6. SURFACE COURSE MATERIALS

6.1 Materials for surface course shall conform to the requirements of Sections 3 and 4 for Gradings C, D, E, or F. The gradings desired shall be specified.

Note 4—Where it is planned that the soil aggregate surface course is to be maintained for several years without bituminous surface treatment or other superimposed impervious surfacing, the engineer should specify a minimum of eight percent passing 75-µm (No. 200) sieve in lieu of the minimum percentages shown in Table 1 for Grading C, D, or E, and should specify a maximum liquid limit of 35 and plasticity index range of four to nine in lieu of the limits given in Section 3.2.2.

7. MOISTURE CONTENT

7.1 All materials shall contain moisture equal to or slightly below the optimum necessary to insure that the design density requirements are obtained when materials are compacted.

8. ADMIXTURE

8.1 Calcium chloride used for the control of moisture shall meet the requirements of M 144.

9. METHODS OF SAMPLING AND TESTING

9.1 Sampling and testing shall be in accordance with the following standard methods of the American Association of State Highway and Transportation Officials:

- Sampling, T 2
- Sieve analysis, T 27 or T 88
- Preparing samples, T 87
- Liquid limit, T 89
- Plastic limit and plasticity index, T 90
- Percentage of wear, T 96
- Passing 75-µm (No. 200 sieve), T 11

Standard Specification for

Lime for Soil Stabilization

AASHTO Designation: M 216-05 (2009)
ASTM Designation: C 977-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Lime for Soil Stabilization

AASHTO Designation: M 216-05 (2009)

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1. SCOPE

1.1. This specification pertains to quicklime and hydrated lime, either high calcium, dolomitic, or magnesian lime, for use in stabilization of soils. (See Note 2.)

Note 1—Quicklime and hydrated lime act upon clay soils and may render such soils suitable for highway construction and for other load-bearing applications. In most cases, lime causes finely divided clay particles to agglomerate into coarser particles, which improves load-bearing properties and subsequently the lime-treated soil hardens by chemical reaction.

Note 2—No attempt is made to present requirements for by-product lime, commercial lime slurry, etc. Specification requirements for these materials could be better determined on a local basis.

1.2. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- C 25, Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime
- C 50, Standard Practice for Sampling, Sample Preparation, Packaging, and Marking of Lime and Limestone Products
- C 51, Standard Terminology Relating to Lime and Limestone (as used by the Industry)
- C 110, Standard Test Methods for Physical Testing of Quicklime, Hydrated Lime, and Limestone
- D 6276, Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization

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3. CHEMICAL COMPOSITION

3.1. Unless otherwise specified, for definitions of terms used in this specification, refer to Definitions of Terms, ASTM C 51.

3.2. Quicklime and hydrated lime for soil stabilization shall conform to the following chemical composition:

Calcium and magnesium oxides (on a non-volatile basis, minimum percent)	90.0
Carbon dioxide (taken at point of manufacture, maximum percent)	5.0
Free moisture (taken at point of manufacture maximum percent)	2.0

4. PHYSICAL PROPERTIES

4.1. Hydrated lime shall have not more than three percent retained on a No. 30 (0.590-mm) sieve and not more than 25 percent retained on a No. 200 (0.075-mm) sieve.

4.2. *Quicklime*:

4.2.1. *Particle Size of Quicklime*—Quicklime shall all pass a 1.0-in. (25.4-mm) sieve.

4.2.2. Quicklime for soil stabilization shall have a temperature rise of a minimum of 30°C in 20 minutes as measured by ASTM C 110.

4.2.3. *Residue of Quicklime*—Quicklime for soil stabilization shall have not more than 10 percent residue measured by ASTM C 110.

5. FIELD APPLICATIONS

5.1. When quicklimes are used, ensure that thorough mixing of the lime and soil is accomplished and all lime pebbles have been hydrated with additional water and distributed uniformly throughout the soil. There shall be no lime pebbles present before the compaction operation starts. Check by turning soil with a spade at representative intervals and inspect for visible lime pebbles. Care should be exercised on initial dry applications to minimize environmental dusting.

5.2. For hydrated limes, additional water shall be added to the lime-soil mixture to facilitate mixing and uniform distribution of the hydrated lime in the soil layer. There shall be no lime clumps present before the compaction operation starts. Check by turning soil with a spade at representative intervals and inspect for visible lime clumps. Care should be exercised on initial dry applications to minimize environmental dusting.[1]

6. TEST METHOD

6.1. The chemical analysis of quicklime and hydrated lime shall be conducted in accordance with ASTM C 25. (See Appendix X1.)

6.2. The particle size of hydrated lime shall be determined in accordance with the sieve analysis of hydrated lime in accordance with ASTM C 110.

6.3. The appendix to this specification contains a nonmandatory test to approximate the lime-soil proportion for stabilization. A more detailed version of this test appears in ASTM D 6276.

7. SAMPLING, INSPECTION, PACKAGING, AND MARKING

7.1. The sampling, inspection, rejection, retesting, packaging, and marking shall be done in accordance with ASTM C 50.

8. KEYWORDS

8.1. Highway construction; hydrated lime; lime-treated soils; load-bearing; quicklime; soil stabilization.

APPENDIX

(Nonmandatory Information)

X1. METHOD FOR DETERMINING STABILIZATION ABILITY OF LIME

X1.1. This test method usually provides a lime-soil proportion for stabilization. It gives an indication whether the soil in question can be stabilized. For most stabilization work, the results of this test should be verified by performance tests in a soil laboratory.

X1.2. Air dry a sufficient quantity of the soil to be tested and screen through a No. 40 (425-µm) sieve. Store in a closed container to maintain uniform moisture. Determine the mass, to the nearest 0.1 g, a series of 20-g samples of soil and place in separate 150-mL containers with water-tight lids.

X1.3. In the case of quicklime, rapidly crush the lime to pass a No. 6 (3.35-mm) sieve.

X1.4. Determine the mass, to the nearest 0.01 g, a series of quantities of lime equivalent to 2, 3, 4, 5, and 6 percent of the soil sample.

X1.5. Add the lime quantity to the soil sample, mark the container with the appropriate percentage, and mix the dry contents thoroughly.

X1.6. Add the 100 mL of 70ºF carbon dioxide-free distilled water or, if possible, 70ºF actual water to be used on the job to each container of soil and lime. Seal with screw-cap lid and mix the three components by shaking the bottles. Shake each bottle for 30 seconds every 10 minutes for one hour. After one hour, shake vigorously and transfer part of the slurry into a beaker. Measure the pH with a low-sodium error glass electrode (previously standardized to pH 12.45 with an agitated calcium hydroxide slurry). Record the pH reading for each mixture.

X1.7. If the pH readings are 12.40 or higher, the lowest percentage that gives a pH of 12.40 is the percent required to stabilize the soil. If the pH readings do not go beyond pH of 12.30 and two percentages give this reading, the lowest percent to give a pH of 12.30 is the percent required to stabilize the soil. If the highest pH reading is a pH of 12.30 and only the highest percentage lime used gives a pH of 12.30, additional testing is required using higher percentages of lime.

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[1] Further information on soil stabilization construction technique is available from National Lime Association Bulletin No. 326, 200 North Glebe Road, 22203. This information can be accessed online at www.lime.org.

Standard Specification for

Geotextile Specification for Highway Applications

AASHTO Designation: M 288-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Specification for

Geotextile Specification for Highway Applications

AASHTO Designation: M 288-06

1. SCOPE

1.1. This is a materials specification covering geotextile fabrics for use in subsurface drainage, separation, stabilization, erosion control, temporary silt fence, and paving fabrics. This is a material purchasing specification and design review of use is recommended.

1.2. This specification sets forth a set of physical, mechanical, and endurance properties that must be met or exceeded by the geotextile being manufactured.

1.3. In the context of quality systems and management, this specification represents a manufacturing quality control (MQC) document. However, its general use is essentially as a recommended design document.

1.4. This specification is intended to assure both good quality and performance of geotextiles used as listed in Section 1.1, but is possibly not adequate for the complete specification in a specific situation. Additional tests, or more restrictive values for the tests indicated, may be necessary under conditions of a particular application.

1.5. This specification is based on geotextile survivability from installation stresses. Designers should be aware that the classes in this specification reflect this basic premise. Refer to Appendix X1 of this specification for geotextile construction guidelines.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 88, Particle Size Analysis of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

2.2. *ASTM Standards*:[1]

- D 123, Standard Terminology Relating to Textiles
- D 276, Standard Test Methods for Identification of Fibers in Textiles
- D 4354, Standard Practice for Sampling of Geosynthetics for Testing
- D 4355, Standard Test Method for Deterioration of Geotextiles from Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus
- D 4439, Standard Terminology for Geosynthetics
- D 4491, Standard Test Methods for Water Permeability of Geotextiles by Permittivity

- D 4533, Standard Test Method for Trapezoid Tearing Strength of Geotextiles
- D 4632, Standard Test Method for Grab Breaking Load and Elongation of Geotextiles
- D 4751, Standard Test Method for Determining Apparent Opening Size of a Geotextile
- D 4759, Standard Practice for Determining the Specification Conformance of Geosynthetics
- D 4873, Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples
- D 5141, Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device Using Site-Specific Soil
- D 5261, Standard Test Method for Measuring Mass per Unit Area of Geotextiles
- D 6140, Standard Test Method to Determine Asphalt Retention of Paving Fabrics Used in Asphalt Paving for Full-Width Applications
- D 6241, Standard Test Method for Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe

3. DEFINITIONS

3.1. *Formulation*—The mixture of a unique combination of ingredients identified by type, properties, and quantity. For nonwoven geotextiles, a formulation is defined as the exact percentages and types of resin(s), additives, and/or carbon black.

3.2. *Manufacturing Quality Control (MQC)*—A planned system of inspections that is used to directly monitor and control the manufacture of a material that is factory originated. Manufacturing Quality Control is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. Manufacturing Quality Control refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract specifications [ref. EPA/600/R-93/182].

3.3. *Minimum Average Roll Value (MARV)*—For geosynthetics, a MQC tool used to allow manufacturers to establish published values such that the user/purchaser will have a 97.7 percent confidence that the property in question will meet published values. For normally distributed data, MARV is calculated as the typical value minus two standard deviations from documented quality control test results for a defined population from one specific test method associated with one specific property.

3.4. *Minimum Value*—The lowest sample value from documented MQC test results for a defined population from one test method associated with one specific property.

3.5. *Maximum Value*—The highest sample value from documented MQC test results for a defined population from one test method associated with one specific property.

4. PHYSICAL REQUIREMENTS

4.1. Fibers used in the manufacture of geotextiles, and the threads used in joining geotextiles by sewing, shall consist of long-chain synthetic polymers, composed of at least 95 percent by weight of polyolefins or polyesters. They shall be formed into a stable network such that the filaments or yarns retain their dimensional stability relative to each other, including selvages.

4.2. Geotextiles used for subsurface drainage, separation, stabilization, and permanent erosion control applications shall conform to the physical requirements of Section 8. Geotextiles used for temporary silt fence shall conform to the physical requirements of Section 9 and geotextiles used as paving fabrics shall conform to the physical requirements of Section 10.

4.3. All property values, with the exception of apparent opening size (AOS), in these specifications represent MARV in the weakest principal direction (i.e., average test results of any roll in a lot sampled for conformance or quality assurance testing shall meet or exceed the minimum values provided herein). Values for AOS represent MARV.

5. CERTIFICATION

5.1. The contractor shall provide to the engineer a certificate stating the name of the manufacturer, product name, style number, chemical composition of the filaments or yarns, and other pertinent information to fully describe the geotextile.

5.2. The manufacturer is responsible for establishing and maintaining a quality control program to assure compliance with the requirements of the specification. Documentation describing the quality control program shall be made available upon request.

5.3. The manufacturer's certificate shall state that the furnished geotextile meets MARV requirements of the specification as evaluated under the manufacturer's quality control program. A person having legal authority to bind the manufacturer shall attest to the certificate.

5.4. Either mislabeling or misrepresentation of materials shall be reason to reject those geotextile products.

6. SAMPLING, TESTING, AND ACCEPTANCE

6.1. Geotextiles shall be subject to sampling and testing to verify conformance with this specification. Sampling shall be in accordance with the most current ASTM D 4354, using the section titled, "Procedure for Sampling for Purchaser's Specification Conformance Testing." In the absence of purchaser's testing, verification may be based on manufacturer's certifications as a result of testing by the manufacturer of quality assurance samples obtained using the procedure for sampling for manufacturer's quality assurance (MQA) testing. A lot size shall be considered to be the shipment quantity of the given product or a truckload of the given product, whichever is smaller.

6.2. Testing shall be performed in accordance with the methods referenced in this specification for the indicated application. The number of specimens to test per sample is specified by each test method. Geotextile product acceptance shall be based on ASTM D 4759. Product acceptance is determined by comparing the average test results of all specimens within a given sample to the specification MARV. Refer to ASTM D 4759 for more details regarding geotextile acceptance procedures.

7. SHIPMENT AND STORAGE

7.1. The labeling, shipment, and storage of geotextiles shall follow ASTM D 4873. Product labels shall clearly show the manufacturer or supplier name, style name, and roll number. Each shipping document shall include a notation certifying that the material is in accordance with the manufacturer's certificate.

7.2. Each geotextile roll shall be wrapped with a material that will protect the geotextile, including the ends of the roll, from damage due to shipment, water, sunlight, and contaminants. The protective wrapping shall be maintained during periods of shipment and storage.

7.3. During storage, geotextile rolls shall be elevated off the ground and adequately covered to protect them from the following: site construction damage; precipitation; extended ultraviolet radiation, including sunlight; chemicals that are strong acids or strong bases; flames, including welding sparks; temperatures in excess of 71ºC (160ºF); and any other environmental condition that may damage the physical property values of the geotextile.

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8. GEOTEXTILE PROPERTY REQUIREMENTS FOR SUBSURFACE DRAINAGE, SEPARATION, STABILIZATION, AND PERMANENT EROSION CONTROL

8.1. *General Requirements*:

8.1.1. Table 1 provides strength properties for three geotextile classes. The geotextile shall conform to the properties of Table 1 based on the geotextile class required in Table 2, 3, 4, 5, or 6 for the indicated application.

8.1.2. All numeric values in Table 1 represent MARV in the weaker principal direction. The geotextile properties required for each class are dependent upon geotextile elongation. When sewn seams are required, the seam strength, as measured in accordance with ASTM D 4632, shall be equal to or greater than 90 percent of the specified grab strength.

8.2. *Subsurface Drainage Requirements*:

8.2.1. *Description*—This specification is applicable to placing a geotextile against a soil to allow for long-term passage of water into a subsurface drain system retaining the *in situ* soil. The primary function of the geotextile in subsurface drainage applications is filtration. Geotextile filtration properties are a function of the *in situ* soil gradation, plasticity, and hydraulic conditions.

8.2.2. *Geotextile Requirements*—The geotextile shall meet the requirements of Table 2. Woven slit film geotextiles (i.e., geotextiles made from yarns of a flat, tape-like character) will not be allowed. All numeric values in Table 2, except AOS, represent MARV in the weaker principal direction. Values of AOS represent maximum average roll values.

Table 1—Geotextile Strength Property Requirements

			Geotextile Class[a,b]					
			Class 1		Class 2		Class 3	
	Test Methods	Units	Elongation <50%[c]	Elongation ≥50%[c]	Elongation <50%[c]	Elongation ≥50%[c]	Elongation <50%[c]	Elongation ≥50%[c]
Grab strength	ASTM D 4632	*N*	1400	900	1100	700	800	500
Sewn seam strength[d]	ASTM D 4632	*N*	1260	810	990	630	720	450
Tear strength	ASTM D 4533	*N*	500	350	400[e]	250	300	180
Puncture strength	ASTM D 6241	*N*	2750	1925	2200	1375	1650	990
Permittivity	ASTM D 4491	sec^{-1}	Minimum property values for permittivity, AOS, and UV stability are based on geotextile application. Refer to Table 2 for subsurface drainage, Table 3 and Table 4 for separation, Table 5 for stabilization, and Table 6 for permanent erosion control.					
Apparent opening size	ASTM D 4751	mm						
Ultraviolet stability (retained strength)	ASTM D 4355	%						

[a] Required geotextile class is designated in Table 2, 3, 4, 5, or 6 for the indicated application. The severity of installation conditions for the application generally dictates the required geotextile class. Class 1 is specified for more severe or harsh installation conditions where there is a greater potential for geotextile damage, and Classes 2 and 3 are specified for less severe conditions.

[b] All numeric values represent MARV in the weaker principal direction. (See Section 8.1.2.)

[c] As measured in accordance with ASTM D 4632.

[d] When sewn seams are required. Refer to Appendix for overlap seam requirements.

[e] The required MARV tear strength for woven monofilament geotextiles is 250 N.

Table 2—Subsurface Drainage Geotextile Requirements

			Requirements, Percent in Situ Soil Passing 0.075 mm[a]		
	Test Methods	Units	<15	15 to 50	>50
Geotextile class			Class 2 from Table 1[b]		
Permittivity[c,d]	ASTM D 4491	sec–1	0.5	0.2	0.1
Apparent opening size[c,d]	ASTM D 4751	mm	0.43 max avg roll value	0.25 max avg roll value	0.22[e] max avg roll value
Ultraviolet stability (retained strength)	ASTM D 4355	%	50% after 500 h of exposure		

[a] Based on grain size analysis of in situ soil in accordance with T 88.

[b] Default geotextile selection. The engineer may specify a Class 3 geotextile from Table 1 for trench drain applications based on one or more of the following:

1. The engineer has found Class 3 geotextiles to have sufficient survivability based on field experience.
2. The engineer has found Class 3 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
3. Subsurface drain depth is less than 2 m; drain aggregate diameter is less than 30 mm; and compaction requirement is less than 95 percent of T 99.

[c] These default filtration property values are based on the predominant particle sizes of in situ soil. In addition to the default permittivity value, the engineer may require geotextile permeability and/or performance testing based on engineering design for drainage systems in problematic soil environments.

[d] Site specific geotextile design should be performed especially if one or more of the following problematic soil environments are encountered: unstable or highly erodible soils such as non-cohesive silts; gap graded soils; alternating sand/silt laminated soils; dispersive clays; and/or rock flour.

[e] For cohesive soils with a plasticity index greater than seven, geotextile maximum average roll value for apparent opening size is 0.30 mm.

8.2.3. The property values in Table 2 represent default values that provide sufficient geotextile survivability under most construction conditions. Note *b* of Table 2 provides for a reduction in the minimum property requirements when sufficient survivability information is available. The engineer may also specify properties different from those listed in Table 2 based on engineering design experience.

8.3. *Separation Requirements*:

8.3.1. *Description*—This specification is applicable to the use of a geotextile to prevent mixing of a subgrade soil and an aggregate cover material (subbase, base, select embankment, etc.). This specification may also apply to situations other than beneath pavements where separation of two dissimilar materials is required, but where water seepage through the geotextile is not a critical function.

8.3.2. The separation application is appropriate for pavement structures constructed over soils with a California Bearing Ratio equal to or greater than 3 (CBR ≥ 3) (shear strength greater than approximately 90 kPa). It is appropriate for unsaturated subgrade soils. The primary function of a geotextile in this application is separation.

8.3.3. *Geotextile Requirements*—The geotextile shall meet the requirements of Table 3. All numeric values in Table 3 except AOS represent MARV in the weakest principal direction. Values for AOS represent maximum average roll values.

Table 3—Separation Geotextile Property Requirements

	Test Methods	Units	Requirements
Geotextile class			See Table 4
Permittivity	ASTM D 4491	sec–1	0.02[a]
Apparent opening size	ASTM D 4751	mm	0.60 max avg roll value
Ultraviolet stability (retained strength)	ASTM D 4355	%	50% after 500 h of exposure

[a] Default value. Permittivity of the geotextile should be greater than that of the soil ($\Psi_g > \Psi_s$). The engineer may also require the permeability of the geotextile to be greater than that of the soil ($^{kg > ks}$).

Table 4—Required Degree of Survivability as a Function of Subgrade Conditions, Construction Equipment, and Lift Thickness (Class 1, 2, and 3 properties are given in Table 1; Class 1 + properties are higher than Class 1, but not defined at this time and, if used, must be specified by the purchaser)[a]

	Low ground-pressure equipment ≤25 kPa (3.6 psi)	Medium ground-pressure equipment > 25 to ≤50 kPa (>3.6 to ≤ 7.3 psi)	High ground-pressure equipment >50 kPa (>7.3 psi)
Subgrade has been cleared of all obstacles except grass, weeds, leaves, and fine wood debris. Surface is smooth and level so that any shallow depressions and humps do not exceed 450 mm (18 in.) in depth or height. All larger depressions are filled. Alternatively, a smooth working table may be placed.	Low (Class 3)	Moderate (Class 2)	High (Class 1)
Subgrade has been cleared of obstacles larger than small to moderate-sized tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 450 mm (18 in.) in depth or height. Larger depressions should be filled.	Moderate (Class 2)	High (Class 1)	Very High (Class 1+)
Minimal site preparation is required. Trees may be felled, delimbed, and left in place. Stumps should be cut to project not more than ±150 mm (±6 in.) above subgrade. Geotextile may be draped directly over the tree trunks, stumps, large depressions and humps, holes, stream channels, and large boulders. Items should be removed only if placing the geotextile and cover material over them will distort the finished road surface.	High (Class 1)	Very high (Class 1+)	Not recommended

[a] Recommendations are for 150 to 300 mm (6 to 12 in.) initial lift thickness. For other initial lift thicknesses:
300 to 450 mm (12 to 18 in.): reduce survivability requirement one level;
450 to 600 mm (18 to 24 in.): reduce survivability requirement two levels;
>600 mm (24 in.): reduce survivability requirement three levels
For special construction techniques such as prerutting, increase the geotextile survivability requirement one level. Placement of excessive initial cover material thickness may cause bearing failure of the soft subgrade.

8.3.4. The property values in Table 3 represent default values that provide for sufficient geotextile survivability under most construction conditions. The engineer may also specify properties different from those listed in Table 3 based on engineering design and experience.

8.4. *Stabilization Requirements*:

8.4.1. *Description*—This specification is applicable to the use of a geotextile in wet, saturated conditions to provide the coincident functions of separation and filtration. In some installations, the geotextile can also provide the function of reinforcement. Stabilization is applicable to pavement structures constructed over soils with a California Bearing Ratio between one and three ($1 < \text{CBR} > 3$) (shear strength between approximately 30 kPa and 90 kPa).

8.4.2. The stabilization application is appropriate for subgrade soils that are saturated due to a high groundwater table or due to prolonged periods of wet weather. This specification is not appropriate for embankment reinforcement where stress conditions may cause global subgrade foundation or stability failure. Reinforcement of the pavement section is a site specific design issue.

8.4.3. *Geotextile Requirements*—The geotextile shall meet the requirements of Table 5. All numeric values in Table 5 except AOS represent MARV in the weakest principal direction. Values for AOS represent maximum average roll values.

Table 5—Stabilization Geotextile Property Requirements

	Test Methods	Units	Requirements
Geotextile class			Class 1 from Table 1[a]
Permittivity	ASTM D 4491	sec–1	0.05[b]
Apparent opening size	ASTM D 4751	mm	0.43 max avg roll value
Ultraviolet stability (retained strength)	ASTM D 4355	%	50% after 500 h of exposure

[a] Default geotextile selection. The engineer may specify a Class 2 or 3 geotextile from Table 1 based on one or more of the following:

1. The engineer has found the class of geotextile to have sufficient survivability based on field experience.
2. The engineer has found the class of geotextile to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.

[b] Default value. Permittivity of the geotextile should be greater than that of the soil ($\Psi_g > \Psi_s$). The engineer may also require the permeability of the geotextile to be greater than that of the soil ($^{kg > ks}$).

8.4.4. The property values in Table 5 represent default values that provide for sufficient geotextile survivability under most construction conditions. Note 2 of Table 5 provides for a reduction in the minimum property requirements when sufficient survivability information is available. The engineer may also specify properties different from those listed in Table 5 based on engineering design and experience.

8.5. *Permanent Erosion Control*:

8.5.1. *Description*—This specification is applicable to the use of a geotextile between energy absorbing armor systems and the *in situ* soil to prevent soil loss resulting in excessive scour and to prevent hydraulic uplift pressures causing instability of the permanent erosion control system. This specification does not apply to other types of geosynthetic soil erosion control materials such as turf reinforcement mats.

8.5.2. The primary function the geotextile serves in permanent erosion control applications is filtration. Geotextile filtration properties are a function of hydraulic conditions and, *in situ* soil gradation, density, and plasticity.

8.5.3. *Geotextile Requirements*—The geotextile shall meet the requirements of Table 6. Woven slit film geotextiles (i.e., geotextiles made from yarns of a flat, tape-like character) will not be allowed. All numeric values in Table 6 except AOS represent MARV in the weaker principal direction. Values for AOS represent maximum average roll values.

8.5.4. The property values in Table 6 represent default values that provide for sufficient geotextile survivability under conditions similar to or less severe than those described under Note *b* of Table 6. Note *c* of Table 6 provides for a reduction in the minimum property requirements when sufficient survivability information is available or when the potential for construction damage is reduced. The engineer may also specify properties different from those listed in Table 6 based on engineering design and experience.

Table 6—Permanent Erosion Control Geotextile Requirements

			Requirements, Percent in Situ Soil Passing 0.075 mm[a]		
	Test Methods	Units	<15	15 to 50	>50
Geotextile class:					
Woven monofilament geotextiles				Class 2 from Table 1[b]	
All other geotextiles				Class 1 from Table 1[b,c]	
Permittivity[a,d]	ASTM D 4491	sec–1	0.7	0.2	0.1
Apparent opening size [c,d, e]	ASTM D 4751	mm	0.43 max avg roll value	0.25 max avg roll value	0.22[e] max avg roll value
Ultraviolet stability (retained strength)	ASTM D 4355	%		50% after 500 h of exposure	

[a] Based on grain size analysis of *in situ* soil in accordance with T 88.

[b] As a general guideline, the default geotextile selection is appropriate for conditions of equal or less severity than either of the following:

1. Armor layer stone weights do not exceed 100 kg, stone drop height is less than 1 m, and no aggregate bedding layer is required.
2. Armor layer stone weighs more than 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150-mm thick aggregate bedding layer designed to be compatible with the armor layer. More severe applications require an assessment of geotextile survivability based on a field trial section and may require a geotextile with strength properties.

[c] The engineer may specify a Class 2 geotextile from Table 1 based on one or more of the following:

1. The engineer has found Class 2 geotextiles to have sufficient survivability based on field experience.
2. The engineer has found Class 2 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
3. Armor layer stone weighs less than 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150-mm thick aggregate bedding layer designed to be compatible with the armor layer.
4. Armor layer stone weights do not exceed 100 kg, and stone is placed with a zero drop height.

[d] These default filtration property values are based on the predominant particle sizes of *in situ* soil. In addition to the default permittivity value, the engineer may require geotextile permeability and/or performance testing based on engineering design for drainage systems in problematic soil environments.

[e] See the following:

1. Site specific geotextile design should be performed especially if one or more of the following problematic soil environments are encountered: unstable or highly erodible soils such as non-cohesive silts; gap graded soils; alternating sand/silt laminated soils; and /or rock flour.
2. For cohesive soils with a plasticity index greater than seven, geotextile maximum average roll value for apparent opening size is 0.30 mm.

9. TEMPORARY SILT FENCE REQUIREMENTS

9.1. *Description*—This specification is applicable to the use of a geotextile as a vertical, permeable interceptor designed to remove suspended soil from overland water flow. The function of a temporary silt fence is to filter and allow settlement of soil particles from sediment-laden water. The purpose is to prevent the eroded soil from being transported off the construction site by water runoff.

9.2. *Geotextile Requirements*—The geotextile used for temporary silt fence may or may not be supported between posts with wire or polymeric mesh. The temporary silt fence geotextile shall meet the requirements of Table 7. All numeric values in Table 7 except AOS represent MARV. Values for AOS represent maximum average roll values.

9.3. Field monitoring shall be performed to verify that the armor system placement does not damage the geotextile. The minimum height above ground for all silt fences shall be 750 mm. Minimum embedment depth of geotextile shall be 150 mm. Refer to Appendix X1 for more detailed installation requirements.

Table 7—Temporary Silt Fence Property Requirements

				Requirements, Unsupported Silt Fence	
	Test Methods	Units	Supported Silt Fence[a]	Geotextile Elongation ≥50%[b]	Geotextile Elongation <50%[b]
Maximum post spacing			1.2 m	1.2 m	2 m
Grab strength	ASTM D 4632	*N*			
Machine direction			400	550	550
X-Machine direction			400	450	450
Permittivity[c]	ASTM D 4491	sec–1	0.05	0.05	0.05
Apparent opening size	ASTM D 4751	mm	0.60 max avg roll value	0.60 max avg roll value	0.60 max avg roll value
Ultraviolet stability (retained strength)	ASTM D 4355	%	70% after 500 h of exposure	70% after 500 h of exposure	

[a] Silt fence support shall consist of 14-gauge steel wire with a mesh spacing of 150 mm by 150 mm or prefabricated polymeric mesh of equivalent strength.

[b] As measured in accordance with ASTM D 4632.

[c] These default filtration property values are based on empirical evidence with a variety of sediments. For environmentally sensitive areas, a review of previous experience and/or site or regionally specific geotextile tests should be performed by the agency to confirm suitability of these requirements.

10. PAVING FABRIC REQUIREMENTS

10.1. *Description*—This specification is applicable to the use of a paving fabric, saturated with asphalt cement, between pavement layers. The function of the paving fabric is to act as a waterproofing and stress relieving membrane within the pavement structure. This specification is not intended to describe fabric membrane systems specifically designed for pavement joints and localized (spot) repairs.

10.2. *Paving Fabric Requirements*—The paving fabric shall meet the requirements of Table 8. All numeric values in Table 8 represent MARV in the weaker principal direction.

Table 8—Paving Fabric Property Requirements[a]

	Test Methods	Units	Requirements
Grab strength	ASTM D 4632	*N*	450
Ultimate elongation	ASTM D 4632	%	≥50
Mass per unit area	ASTM D 5261	gm/m^2	140
Asphalt retention	ASTM D 6140	1/m^2	[b] [c]
Melting point	ASTM D 276	°C	150

[a] All numeric values represent MARV in the weaker principal direction. (Refer to Section 10.2.)

[b] Asphalt required to saturate paving fabric only. Asphalt retention must be provided in manufacturer certification. (Refer to Section 5.) Value does not indicate the asphalt application rate required for construction. Refer to Appendix for discussion of asphalt application rate.

[c] Product asphalt retention property must meet the MARV value provided by the manufacturer certification. (Refer to Section 5.)

APPENDIX

(Nonmandatory Information)

X1. CONSTRUCTION/INSTALLATION GUIDELINES

X1.1. *General*:

X1.1.1. This Appendix is intended for use in conjunction with M 288 for Geotextiles. The specification details materials properties for geotextiles used in drainage, erosion control, separation/stabilization, silt fences, and pavement overlay application. The material properties are only one factor in a successful installation involving geotextiles. Proper construction and installation techniques are essential in order to ensure that the intended function of the geotextile is fulfilled.

X1.1.2. *Geotextile Identification, Packaging, and Storage*:

X1.1.2.1. Refer to ASTM D 4873.

X1.1.3. *Geotextile Exposure Following Placement*:

X1.1.3.1. Atmospheric exposure of geotextiles to the elements following lay down shall be a maximum of 14 days to minimize damage potential.

X1.1.4. *Seaming*:

X1.1.4.1. If a sewn seam is to be used for the seaming of the geotextile, the thread used shall consist of high strength polypropylene, or polyester. Nylon thread shall not be used. For erosion control applications, the thread shall also be resistant to ultraviolet radiation. The thread shall be of contrasting color to that of the geotextile itself.

X1.1.4.2. For seams that are sewn in the field, the contractor shall provide at least a 2-meter length of sewn seam for sampling by the engineer before the geotextile is installed. For seams that are sewn in the factory, the engineer shall obtain samples of the factory seams at random from any roll of geotextile that is used on the project.

X1.1.4.2.1. For seams that are field sewn, the seams sewn for sampling shall be sewn using the same equipment and procedures as will be used for the production seams. If seams are sewn in both the machine and cross machine direction, samples of seams from both directions shall be provided.

X1.1.4.2.2. The contractor shall submit the seam assembly description along with the sample of the seam. The description shall include the seam type, stitch type, sewing thread, and stitch density.

X1.2. *Drainage Geotextiles*[2] (See Sections 8.1 and 8.2.)

X1.2.1. *Construction*:

X1.2.1.1. Trench excavation shall be done in accordance with details of the project plans. In all instances excavation shall be done in such a way so as to prevent large voids from occurring in the sides and bottom of the trench. The graded surface shall be smooth and free of debris.

X1.2.1.2. In the placement of the geotextile for drainage applications, the geotextile shall be placed loosely with no wrinkles or folds, and with no void spaces between the geotextile and the ground surface. Successive sheets of geotextiles shall be overlapped a minimum of 300 mm, with the upstream sheet overlapping the downstream sheet.

X1.2.1.2.1. In trenches equal to or greater than 300 mm in width, after placing the drainage aggregate, the geotextile shall be folded over the top of the backfill material in a manner to produce a minimum overlap of 300 mm. In trenches less than 300 mm but greater than 100 mm wide, the overlap shall be equal to the width of the trench. Where the trench is less than 100 mm the geotextile overlap shall be sewn or otherwise bonded. All seams shall be subject to the approval of the engineer.

X1.2.1.2.2. Should the geotextile be damaged during installation or drainage aggregate placement, a geotextile patch shall be placed over the damaged area extending beyond the damaged area a distance of 300 mm, or the specified seam overlap, whichever is greater.

X1.2.1.3. Placement of drainage aggregate should proceed immediately following placement of the geotextile. The geotextile should be covered with a minimum of 300 mm of loosely placed aggregate prior to compaction. If a perforated collector pipe is to be installed in the trench, a bedding layer of drainage aggregate should be placed below the pipe, with the remainder of the aggregate placed to the minimum required construction depth.

X1.2.1.3.1. The aggregate should be compacted with vibratory equipment to a minimum of 95 percent Standard AASHTO density unless the trench is required for structural support. If higher compactive effort is required, a Class 1 geotextile as per Table 1 of the M 288 is needed.

X1.2.1.4. Figures X1.1 through X1.3 illustrate various geotextile drainage application details.

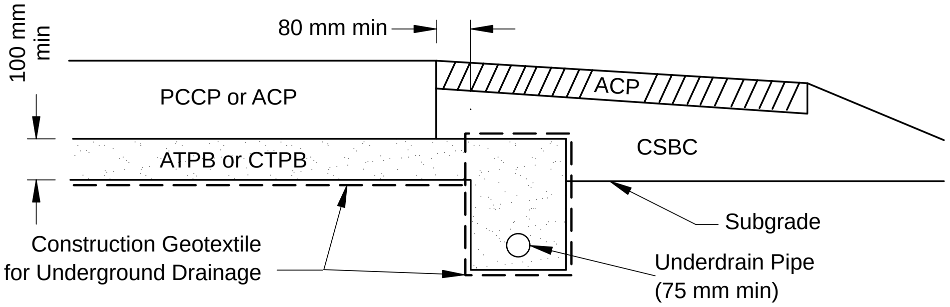

Figure X1.1—Geotextile Drain Requirements for Permeable Bases

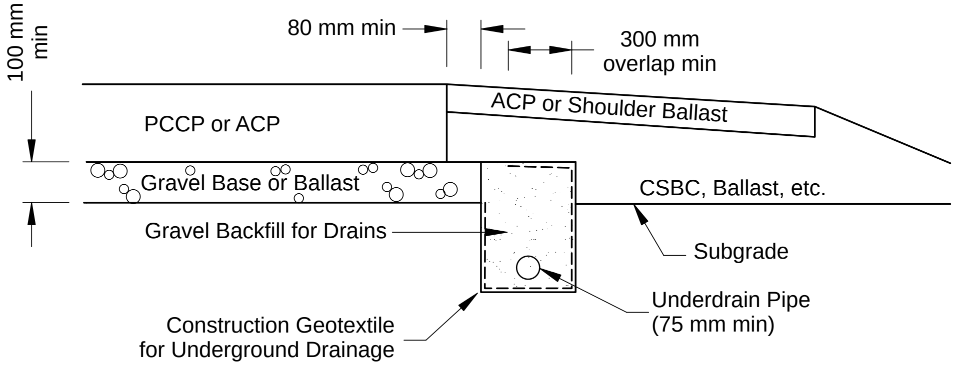

Figure X1.2—Geotextile Wrapped Longitudinal Edge Drain

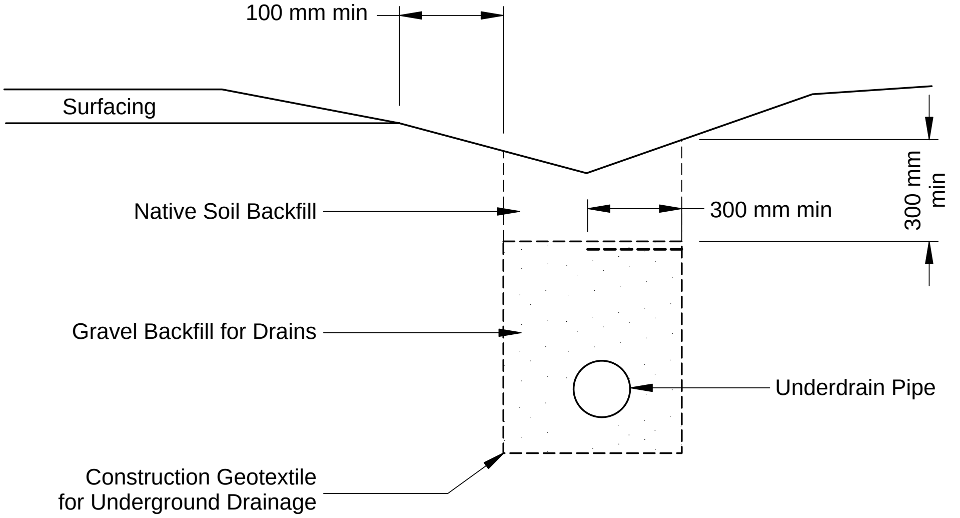

Figure X1.3—Geotextile Wrapped Pavement Under Drain

X1.3. *Separation/Stabilization Geotextiles* (See Sections 8.1, 8.3, and 8.4.):

X1.3.1. *Construction*:

X1.3.1.1. The installation site shall be prepared by clearing, grubbing, and excavation or filling the area to the design grade. This includes removal of topsoil and vegetation.

Note X1—Soft spots and unsuitable areas will be identified during site preparation or subsequent proof rolling. These areas shall be excavated and backfilled with select material and compacted using normal procedures.

X1.3.1.2. The geotextile shall be laid smooth without wrinkles or folds on the prepared subgrade in the direction of construction traffic. Adjacent geotextile rolls shall be overlapped, sewn or joined as required in the plans. Overlaps shall be in the direction as shown on the plans. See Table X1.1 for overlap requirements.

Table X1.1—Overlap Requirements

Soil CBR	Minimum Overlap
Greater than 3	300–450 mm
1–3	0.6–1 m
0.5–1	1 m or sewn
Less than 0.5	Sewn
All roll ends	1 m or sewn

X1.3.1.2.1. On curves, the geotextile may be folded or cut to conform to the curves. The fold or overlap shall be in the direction of construction and held in place by pins, staples, or piles of fill or rock.

X1.3.1.2.2. Prior to covering, the geotextile shall be inspected to ensure that the geotextile has not been damaged (i.e., holes, tears, rips) during installation. The inspection shall be done by the engineer or the engineer's designated representative. It is recommended that the designated representative be a certified inspector.

Damaged geotextiles, as identified by the engineer, shall be repaired immediately. Cover the damaged area with a geotextile patch that extends an amount equal to the required overlap beyond the damaged area.

X1.3.1.3. The subbase shall be placed by end dumping onto the geotextile from the edge of the geotextile, or over previously placed subbase aggregate. Construction vehicles shall not be allowed directly on the geotextile. The subbase shall be placed such that at least the minimum specified lift thickness shall be between the geotextile and equipment tires or tracks at all times. Turning of vehicles shall not be permitted on the first lift above the geotextile.

Note X2—On subgrades having a CBR value of less than one, the subbase aggregate should be spread in its full thickness as soon as possible after dumping to minimize the potential of localized subgrade failure due to overloading of the subgrade.

X1.3.1.3.1. Any ruts occurring during construction shall be filled with additional subbase material, and compacted to the specified density.

X1.3.1.3.2. If placement of the backfill material causes damage to the geotextile, the damaged area shall be repaired as previously described in Section A3.1.2.1. The placement procedures shall then be modified to eliminate further damage from taking place (i.e., increase initial lift thickness, decrease equipment loads, etc.).

Note X3—In stabilization applications, the use of vibratory compaction equipment is not recommended with the initial lift of subbase material, as it may cause damage to the geotextile.

X1.4. *Erosion Control Geotextiles* (See Section 8.5.):

X1.4.1. *Construction*:

X1.4.1.1. The geotextile shall be placed in intimate contact with the soils without wrinkles or folds and anchored on a smooth graded surface approved by the engineer. The geotextile shall be placed in such a manner that placement of the overlying materials will not excessively stretch so as to tear the geotextile. Anchoring of the terminal ends of the geotextile shall be accomplished through the use of key trenches or aprons at the crest and toe of slope. Refer to Figures X1.4 through X1.7 for construction details.

Note X4—In certain applications to expedite construction, 450-mm anchoring pins placed on 600- to 1800-mm centers, depending on the slope of the covered area, have been used successfully.

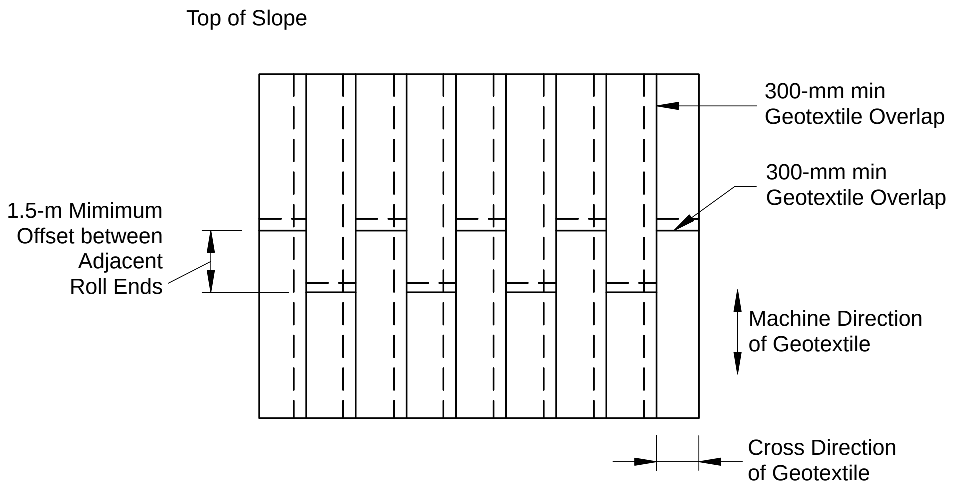

Figure X1.4—Method of Placing Geotextile for Protection of Cut and Fill Slopes

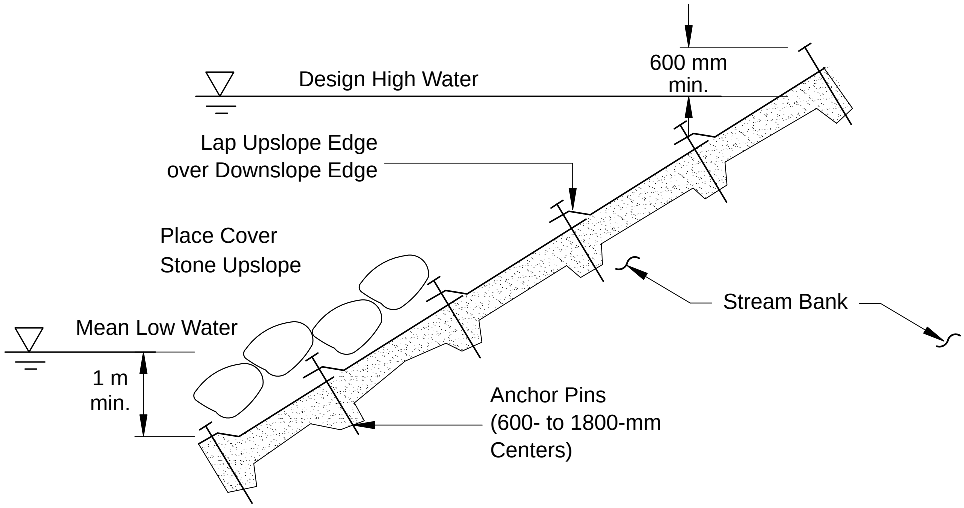

Figure X1.5—Cross Section of Slopes with Riprap

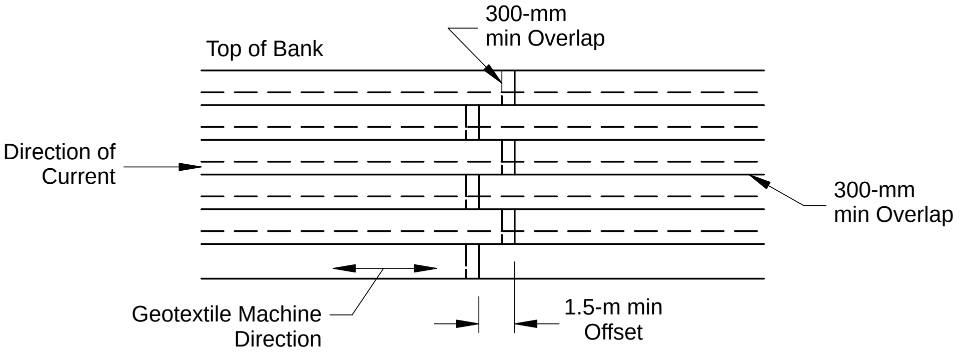

Figure X1.6—Geotextile Placement Scheme for Streambank Protection

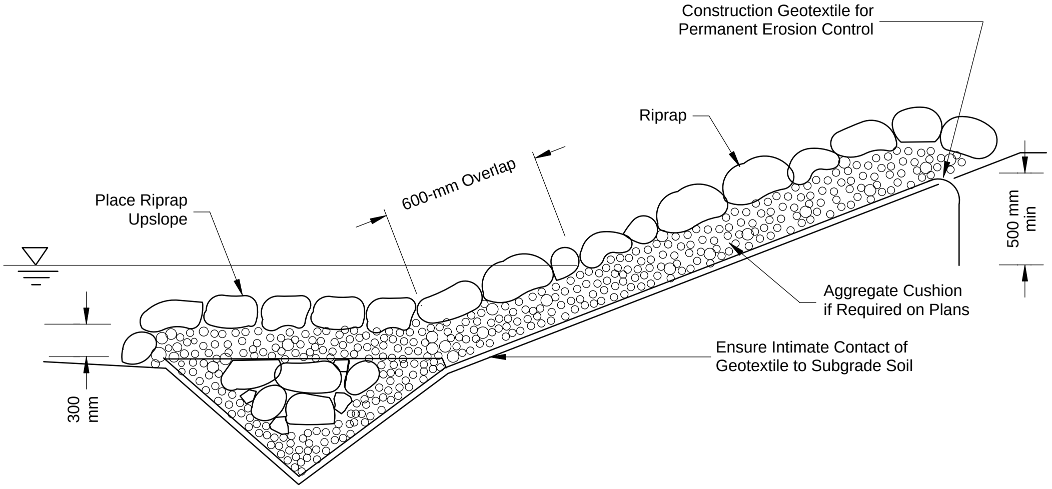

Figure X1.7—Key Detail at Top and Toe of Slope for Geotextiles Used for Permanent Erosion Control

X1.4.1.1.1. The geotextile shall be placed with the machine direction parallel to the direction of water flow, which is normally parallel to the slope for erosion control runoff and wave action (Figure X1.4), and parallel to the stream or channel in the case of streambank and channel protection (Figure X1.6). Adjacent geotextile sheets shall be joined by either sewing or overlapping. Overlapped seams of roll ends shall be a minimum of 300 mm except where placed under water. In such instances the overlap shall be a minimum of 1 m. Overlaps of adjacent rolls shall be a minimum of 300 mm in all instances.

Note X5—When overlapping, successive sheets of the geotextile shall be overlapped upstream over downstream, and/or upslope over downslope. In cases where wave action or multidirectional flow is anticipated, all seams perpendicular to the direction of flow shall be sewn.

X1.4.1.1.2. Care shall be taken during installation so as to avoid damage occurring to the geotextile as a result of the installation process. Should the geotextile be damaged during installation, a geotextile patch shall be placed over the damaged area extending 1 m beyond the perimeter of the damage.

X1.4.1.2. The armor system placement shall begin at the toe and proceed up the slope. Placement shall take place so as to avoid stretching and subsequent tearing of the geotextile. Riprap and heavy stone filling shall not be dropped from a height of more than 300 mm. Stone with a mass of more than 100 kg shall not be allowed to roll down the slope.

X1.4.1.2.1. Slope protection and smaller sizes of stone filling shall not be dropped from a height exceeding 1 m, or a demonstration provided showing that the placement procedures will not damage the geotextile. In underwater applications, the geotextile and backfill material shall be placed the same day. All void spaces in the armor stone shall be backfilled with small stone to ensure full coverage.

X1.4.1.2.2. Following placement of the armor stone, grading of the slope shall not be permitted if the grading results in movement of the stone directly above the geotextile.

X1.4.1.3. Field monitoring shall be performed to verify that the armor system placement does not damage the geotextile.

X1.4.1.3.1. Any geotextile damaged during backfill placement shall be replaced as directed by the engineer at the contractor's expense.

X1.5. *Silt Fence Geotextiles* (See Section 9.):

X1.5.1. *Related Material Requirements*:

X1.5.1.1. Wood, steel, or synthetic support posts having a minimum length of 1 m plus the burial depth may be used. They shall be of sufficient strength to resist damage during installation and to support the applied loads due to material build up behind the silt fence.

Note X6—It has been found that hardwood posts having dimensions of at least 30 mm × 30 mm, No. 2 Southern Pine at least 65 mm × 65 mm, or steel posts of U, T, L, or C shape, weighing 600 g per 300 mm have performed satisfactorily.

X1.5.1.2. Wire or polymer support fence shall be at least 750 mm high and strong enough to support applied loads. Polymer support fences shall meet the same ultraviolet degradation requirements as the geotextile.

Note X7—Wire support fences having at least six horizontal wires and being at least 14-gauge wire have performed satisfactorily. Vertical wires should be a maximum of 150 mm apart.

X1.5.2. *Construction*:

X1.5.2.1. The geotextile at the bottom of the fence shall be buried in a "J" configuration to a minimum depth of 150 mm in a trench so that no flow can pass under the silt fence. The trench shall be backfilled and the soil compacted over the geotextile.

X1.5.2.1.1. The geotextile shall be spliced together with a sewn seam only at a support post, or two sections of fence may be overlapped instead.

X1.5.2.1.2. The contractor must demonstrate to the satisfaction of the engineer that the geotextile can withstand the anticipated sediment loading.

X1.5.2.1.3. See Figure X1.8 for details.

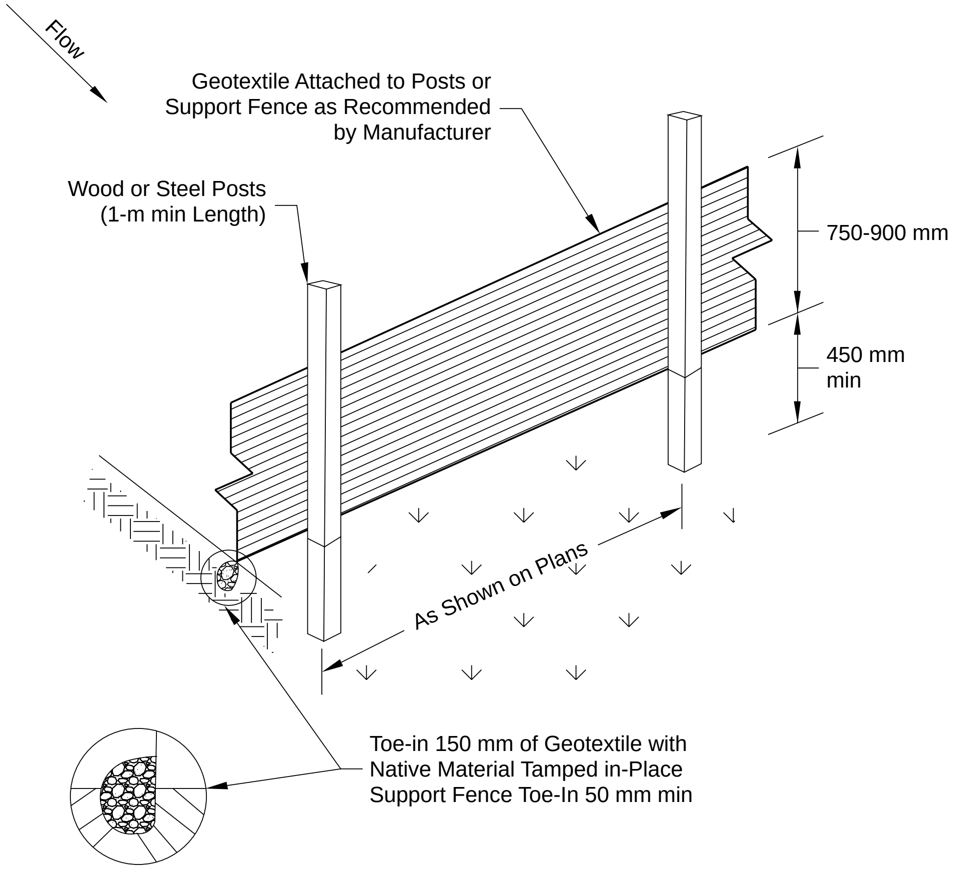

Figure X1.8—Typical Silt Fence Detail

X1.5.2.2. The posts shall be placed at spacing as shown on the project plans. Posts should be driven or placed a minimum of 500 mm into the ground. Depth shall be increased to 600 mm if fence is placed on a slope of 3:1 or greater.

Note X8—Where 500-mm depth is impossible to attain, the posts should be adequately secured to prevent overturning of the fence due to sediment loading.

X1.5.2.3. The support fence shall be fastened securely to the upslope side of the fence post. The support fence shall extend from the ground surface to the top of the geotextile.

X1.5.2.4. When self-supported fence is used, the geotextile shall be securely fastened to fence posts.

X1.5.2.5. Silt fences should be continuous and transverse to the flow. The silt fence should follow the contours of the site as closely as possible. The fence shall also be placed such that the water cannot run off around the end of the fence.

X1.5.2.5.1. The silt fence should be limited to handle an area equivalent to 90 square meters per 3 m of fence. Caution should be used where the site slope is greater than 1:1, and water flow rates exceed 3 L per second per 3 m of fence.

X1.5.3. *Maintenance*:

X1.5.3.1. The contractor shall inspect all temporary silt fences immediately after each rainfall and at least daily during prolonged rainfall. The contractor shall immediately correct any deficiencies.

X1.5.3.1.1. The contractor shall also make a daily review of the location of silt fences in areas where construction activities have altered the natural contour and drainage runoff to ensure that the silt fences are properly located for effectiveness. Where deficiencies exist as determined by the engineer, additional silt fence shall be installed as directed by the engineer.

X1.5.3.1.2. Damaged or otherwise ineffective silt fences shall be repaired or replaced promptly.

X1.5.3.2. Either sediment deposits shall be removed when the deposit reaches half the height of the fence, or a second silt fence shall be installed as directed by the engineer.

X1.5.3.3. The silt fence shall remain in place until the engineer directs it be removed. Upon removal, the contractor shall remove and dispose of any excess sediment accumulations, dress the area to give it a pleasing appearance, and cover with vegetation all bare areas in accordance with contract requirements.

X1.5.3.3.1. Removed silt fence may be used at other locations provided the geotextile and other material requirements continue to be met to the satisfaction of the engineer.

X1.6. *Paving Fabrics* (See Section 10.):

X1.6.1. *Materials*:

X1.6.1.1. The sealant material used to impregnate and seal the paving fabric, as well as bond it to both the base pavement and overlay, shall be a paving grade asphalt recommended by the paving fabric manufacturer, and approved by the engineer.

X1.6.1.1.1. Uncut asphalt cements are the preferred sealant; however, cationic and anionic emulsions may be used provided the precautions outlined in Section A6.3.3 are followed. Cutbacks and emulsions that contain solvents shall not be used.

X1.6.1.1.2. The grade of asphalt cement specified for hot mix design in each geographic location is generally the most acceptable material.

X1.6.1.2. Washed concrete sand may be spread over asphalt saturated paving fabric to facilitate movement of equipment during construction or to prevent tearing or delamination of the paving fabric. Hot mix broadcast in front of construction vehicle tires may also be used to serve this purpose. If sand is applied, excess quantities shall be removed from the paving fabric prior to placing the surface course.

X1.6.1.2.1. Sand is not usually required. However, ambient temperatures are occasionally sufficiently high to cause bleed-through of the asphalt sealant resulting in undesirable paving fabric adhesion to construction vehicle tires.

X1.6.2. *Equipment*:

X1.6.2.1. The asphalt distributor shall be capable of spraying the asphalt sealant at the prescribed uniform application rate. No streaking, skipping, or dripping will be permitted. The distributor shall also be equipped with a hand spray having a single nozzle and positive shut-off valve.

X1.6.2.2. Mechanical or manual lay down equipment shall be capable of laying the paving fabric smoothly.

X1.6.2.3. The following miscellaneous equipment shall be provided: stiff bristle brooms or squeegees to smooth the paving fabric; scissors or blades to cut the paving fabric; brushes for applying asphalt sealant to paving fabric overlaps.

X1.6.2.4. Pneumatic rolling equipment to smooth the paving fabric into the sealant and sanding equipment may be required for certain jobs. Rolling is especially required on jobs where thin lifts or chip seals are being placed. Rolling helps ensure paving fabric bond to the adjoining pavement layers in the absence of heat and weight associated with thicker lifts of asphaltic pavement.

X1.6.3. *Construction*:

X1.6.3.1. Neither the asphalt sealant nor the paving fabric shall be placed when the engineer deems weather conditions unsuitable. Air and pavement temperatures shall be sufficient to allow the asphalt sealant to hold the paving fabric in place. For asphalt cements, air temperature shall be 10ºC and rising. For asphalt emulsions, air temperature shall be 15ºC and rising.

X1.6.3.2. The surface on which the paving fabric is to be placed shall be reasonably free of dirt, water, vegetation, or other debris. Cracks exceeding 3 mm in width shall be filled with suitable crack filler. Potholes shall be properly repaired as directed by the engineer. Fillers shall be allowed to cure prior to paving fabric placement.

X1.6.3.3. The specified rate of asphalt sealant application must be sufficient to satisfy the asphalt retention properties of the paving fabric, and bond the paving fabric and overlay to the old pavement.

Note X9—When emulsions are used, the application rate must be increased to offset water content of the emulsion.

X1.6.3.3.1. Application of the sealant shall be by distributor spray bar, with hand spraying kept to a minimum. Temperature of the asphalt sealant shall be sufficiently high to permit uniform spray pattern. For asphalt cements, the minimum temperature shall be 145ºC. To avoid damage to the paving fabric, however, the distributor tank temperatures shall not exceed 160ºC.

X1.6.3.3.2. Spray patterns for asphalt emulsions are improved by heating. Temperatures in the 55ºC to 70ºC range are desirable. A temperature of 70ºC shall not be exceeded since higher temperatures may break the emulsion.

X1.6.3.3.3. The target width of asphalt sealant application shall be the paving fabric width plus 150 mm. The asphalt sealant shall not be applied any farther in advance of paving fabric placement than the distance the contractor can maintain free of traffic.

X1.6.3.3.4. Asphalt spills shall be cleaned from the road surface to avoid flushing and paving fabric movement.

X1.6.3.3.5. When asphalt emulsions are used, the emulsion shall be cured prior to placing the paving fabric and final wearing surface. This means essentially no moisture remaining.

X1.6.3.4. The paving fabric shall be placed onto the asphalt sealant with minimum wrinkling prior to the time the asphalt has cooled and lost tackiness. As directed by the engineer, wrinkles or folds in excess of 25 mm shall be slit and laid flat.

X1.6.3.4.1. Brooming and/or pneumatic rolling will be required to maximize paving fabric contact with the pavement surface.

X1.6.3.4.2. Overlap of paving fabric joints shall be sufficient to ensure full closure of the joint, but should not exceed 150 mm. Transverse joints shall be lapped in the direction of paving to prevent edge pickup by the paver. A second application of asphalt sealant to the paving fabric overlaps will be required if the engineer judges additional asphalt sealant is needed to ensure proper bonding of the double paving fabric layer.

X1.6.3.4.3. Removal and replacement of paving fabric that is damaged will be the responsibility of the contractor.

Note X10—The problems associated with wrinkles are related to thickness of the asphalt lift being placed over the paving fabric. When wrinkles are large enough to be folded over, there usually is not enough asphalt available from the tack coat to satisfy the requirement of multiple layers of paving fabric. Therefore, wrinkles should be slit and laid flat. Sufficient asphalt sealant should be sprayed on the top of the paving fabric to satisfy the requirement of the lapped paving fabric.

Note X11—In overlapping adjacent rolls of paving fabric, it is desirable to keep the lapped dimension as small as possible and still provide a positive overlap. If the lapped dimension becomes too large, the problem of inadequate tack to satisfy the two lifts of paving fabric and the old pavement may occur. If this problem does occur, then additional asphaltic sealant should be added to the lapped areas. In the application of the additional sealant, care should be taken not to apply too much since excess will cause flushing.

X1.6.3.4.4. Trafficking the paving fabric will be permitted for emergency and construction vehicles only.

X1.6.3.5. Placement of the hot mix overlay should closely follow paving fabric laydown. The temperature of the mix shall not exceed 160ºC. In the event asphalt bleeds through the paving fabric causing construction problems before the overlay is placed, the affected areas shall be blotted by spreading sand. To avoid movement of, or damage to, the seal-coat saturated paving fabric, turning of the paver and other vehicles shall be gradual and kept to a minimum.

X1.6.3.6. Prior to placing a seal coat (or thin overlay such as an open graded friction course), lightly sand the paving fabric at a spread rate of 0.65 to 1 kg/m^2, and pneumatically roll the paving fabric tightly into the sealant.

ADVISORY

It is recommended that, for safety considerations, trafficking of the paving fabric should not be allowed. However, if the contracting agency elects to allow trafficking, the following verbiage is recommended:

"If approved by the engineer, the seal-coat saturated paving fabric may be opened to traffic for 24 to 48 hours prior to installing the surface course. Warning signs shall be placed which advise the motorist that the surface may be slippery when wet. The signs shall also post the appropriate safe speed. Excess sand shall be broomed from the surface prior to placing the overlay. If, in the judgment of the engineer, the fabric surface appears dry and lacks tackiness following exposure to traffic, a light tack coat shall be applied prior to the overlay."

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[1] Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428–2959.

[2] Geotextiles used as sheet drains are not included in the discussions in this section.

Standard Specification for

Glass Cullet Use for Soil-Aggregate Base Course

AASHTO Designation: M 318-02 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Glass Cullet Use for Soil-Aggregate Base Course

AASHTO Designation: M 318-02 (2006)

1. SCOPE

1.1. This specification covers processed glass cullet intended for use as a granular road base material. When properly processed and mixed with natural or crushed aggregate, hauled to and properly spread and compacted on a prepared grade to appropriate density standards, glass cullet can be expected to provide adequate stability and load support for use as road or highway bases. Material described in this specification is not intended to be used in treated or stabilized pavement layers. This specification is intended for use in conjunction with M 147 or with the requirements of the local jurisdiction specifying the properties of natural or crushed aggregate used in the base course. It is not intended for use in base courses in locations where surfacing will not be placed over the base.

Note 1—The engineer is advised to provide appropriate construction specifications to ensure that sufficient compaction is achieved so that further densification of the completed pavement from traffic loadings will be insignificant. The method requires compaction of the material at a suitable moisture content on a firm foundation of a short control strip by means of vibratory or other proven effective rollers or tampers, until no further increase in density results. Compaction requirements should ensure that the average density of the final base course is an appropriate percentage of the maximum density obtained for the control strip; for base courses, achieving on average 98 percent of the maximum control strip density is suggested.

1.2. The values stated in SI units are to be regarded as the standard. The English unit equivalents shown in parentheses may be appropriate, except with regard to sieve sizes and aggregate size as determined by the use of testing sieves, in which case the standard SI designation shown is the standard as required by M 92.

2. DEFINITIONS

2.1. The definitions of base course and other soil-aggregate terms are given in M 146. The term glass cullet as used in this specification refers to a crushed glass container material that is screened and graded for potential use as a substitute material for soil-aggregate base course.

3. REFERENCED DOCUMENTS

3.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- M 147, Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses
- T 2, Sampling of Aggregates
- T 11, Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing

- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 88, Particle Size Analysis of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 193, The California Bearing Ratio
- T 307, Determining the Resilient Modulus of Soils and Aggregate Materials

3.2. *ASTM Standards*:

- D 2940, Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports
- D 4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

4. ORDERING INFORMATION

4.1. The purchaser or specifier shall include the following information in the purchase order or contract documents:

4.1.1. Reference to this specification, including year;

4.1.2. Grading to be furnished for the granular base;

4.1.3. The percentage of glass cullet by mass in the granular base;

4.1.4. The optimum moisture content and maximum density of the granular base; and

4.1.5. Exceptions or additions to this specification.

5. PHYSICAL PROPERTIES AND DELETERIOUS SUBSTANCES IN GLASS CULLET

5.1. Glass cullet shall consist of broken food and beverage containers. China dishes, ceramics, or plate glass shall be limited to a maximum of 5 percent by mass of glass cullet. Refer to Appendix X1 for further discussion of this topic.

5.2. Glass cullet shall be crushed and screened if necessary so that 100 percent of the glass cullet material passes the 9.5-mm ($^3/_8$-in.) sieve.

5.3. Glass cullet shall be free of odor.

5.4. Container tops, paper, labels, food residue, foil, wood, and other deleterious materials shall be limited to a maximum of 1 percent by mass of the glass cullet, of which no more than 0.05 percent by mass of paper shall be permitted. Extraneous soil-like materials shall be limited to a maximum of 2 percent by mass of the glass cullet. Refer to Appendix X3 for a discussion of methods to determine these percentages. Glass cullet shall be free of TV or other cathode ray tubes, fluorescent light bulbs, and any toxic or hazardous materials as defined by the state or local jurisdiction, which the supplier shall certify.

5.5. Glass cullet material shall be processed so as to limit the quantity of shard-like particles to less than 1 percent by mass as measured by ASTM Standard D 4791. Refer to Appendix X4 for further discussion of this topic.

6. SOIL-AGGREGATE MATERIALS AND GLASS CONTENT

6.1. Glass cullet shall be combined with soil-aggregate material to form a blended material conforming to the requirements of M 147, ASTM D 2940, or the requirements of the specifying jurisdiction.

6.2. The supplier shall be permitted to use up to 20 percent by mass of glass cullet in composite glass cullet/soil-aggregate mixtures.

6.3. If the engineer wishes to use a combination of materials that exceeds the glass percentage limit indicated above, then reference should be made to the evaluation methods described in Appendix X2.

6.4. The supplier shall ensure that composite material is uniformly blended.

7. METHODS OF SAMPLING AND TESTING

7.1. Glass cullet soil-aggregate composite shall be sampled and tested in accordance with the following standard methods of the American Association of State Highway and Transportation Officials, except as otherwise provided in this specification:

7.1.1. T 2, Sampling;

7.1.2. T 11, Elutriation;

7.1.3. T 27, Grading;

7.1.4. T 87, Sample Preparation;

7.1.5. T 88, Particle Size Analysis;

7.1.6. T 99, Moisture-Density Relationship;

7.1.7. T 180, Moisture-Density Relationship.

APPENDIXES

(Nonmandatory Information)

X1. CHINA DISHES, CERAMICS, PLATE GLASS, OR GLASS PRODUCTS IN EXCESS OF 5 PERCENT OF THE CONTAINER GLASS CULLET WEIGHT

X1.1. If products such as non-beverage container glass, glass-like products, or ceramics are processed to the specified glass cullet gradations presented above, there is no technical evidence to suggest that their use at levels in excess of 5 percent by mass of the container glass cullet will have an adverse effect on the properties of a granular base. Insofar as these glass products are introduced in percentages less than or equal to 5 percent by mass of the total glass cullet content, little impact is expected. If the engineer wishes to use higher percentages of non-beverage container glass that meets all other requirements of this specification in the base course material, then one of the following laboratory tests or field evaluation tests and acceptance criteria is recommended:

X1.1.1. *Validation by Use of California Bearing Ratio Testing*—The supplier should compare California Bearing Ratio test results (T 193) obtained from a control sample (consisting of natural soil-aggregate material normally used to comply with granular base specifications) and from the composite blend of glass product and natural soil-aggregate proposed for use on the project.

X1.1.2. *Validation by Use of Resilient Modulus Testing*—The supplier should compare Resilient Modulus test results (T 292 and T 307) obtained from a control sample (consisting of natural soil-aggregate material normally used to comply with granular base specifications) and from the composite blend of glass product and natural soil-aggregate proposed for use on the project. Three tests for each condition shall be performed and the values averaged.

X1.1.3. *California Bearing Ratio and Resilient Modulus Criteria*—If the California Bearing Ratio value for the glass product/natural soil-aggregate combination is equal to or greater than that for the control material, and if the average Resilient Modulus value for the glass product/natural soil-aggregate combination is equal to or greater than the average value for the control material alone, then the higher percentage non-container glass product aggregate may be permitted subject to further validation by field validation as defined in Section X1.1.4.

X1.1.4. *Validation by Field Demonstration Application*—The supplier shall show by construction of a test strip or introducing historical data that will demonstrate that higher percentages of non-beverage container glass than those recommended in these specifications do not adversely affect the granular base design and performance by establishing periodic performance reviews (not less than annually) of the field application until such time that the engineer is satisfied with the results.

X2. GLASS CULLET IN EXCESS OF 20 PERCENT BY MASS OF THE COMPOSITE BLEND

X2.1. Experience has shown that the use of less than 20 percent by mass of glass cullet in soil-aggregates produces an efficient combination where the properties of the combination are substantially equivalent to the natural soil-aggregate material alone. Little is known of the performance of combinations of greater than 20 percent by mass of glass cullet aggregate. If the engineer wishes to use higher percentages of glass cullet in the base course material, then the following performance acceptance criteria is recommended:

X2.1.1. *Validation by Use of California Bearing Ratio Testing*—The supplier should compare California Bearing Ratio test results conducted on a control sample consisting of natural soil-aggregate material normally used to comply with granular base specifications to the composite blend of glass cullet and natural soil-aggregate the supplier wishes to use on the project.

X2.1.2. *Validation by Use of Resilient Modulus Testing*—The supplier should compare the results of Resilient Modulus testing on a control sample consisting of natural soil-aggregate material normally used to meet granular base specifications to the natural soil-aggregate material plus the percentage of glass cullet material that the supplier wishes to use on the project. Three tests for each condition shall be performed and the values averaged.

X2.1.3. *California Bearing Ratio and Resilient Modulus Criteria*—If the California Bearing Ratio value for the glass cullet/natural soil-aggregate combination is equal to or greater than that for the control material, and if the average Resilient Modulus value for the glass cullet/natural soil-aggregate combination is equal to or greater than the average value for the control material alone, then the higher percentage glass cullet combination may be permitted subject to further validation by field application as defined in Section X2.1.4.

X2.1.4. *Validation during Field Application*—The supplier shall show by constructing a test strip or introducing historical data that will demonstrate that such higher percentages of glass aggregate than recommended in these specifications does not adversely affect the granular base design and performance by establishing periodic performance reviews of the field application until such time that the engineer is satisfied with the results.

X3. DETERMINATION OF PERCENTAGES OF DELETERIOUS MATERIALS

X3.1. It is recommended that percentages of deleterious materials be determined on a mass basis as described below or some equivalent alternative. In the mass method approach, a representative sample of the glass cullet is taken and dried to constant mass. The sample is then visually segregated into four categories: (1) glass, (2) paper, (3) other deleterious materials, and (4) soils. The percentage of each component may be determined by dividing the mass of the component by the mass of the total sample. Each value would then be multiplied by 100 to yield a percentage. The values so determined can be rounded to the nearest 0.1 percent.

X4. GLASS CULLET PROCESSING AND SAFETY

X4.1. The nature of crushed glass is such that certain crushing processes may generate particles that are elongated or exceptionally sharp, posing a potential safety hazard. Proper processing, which includes glass crushing, can produce a somewhat well-rounded glass particle that can be safely handled. As a result, it is recommended that glass used in granular base applications should be processed so that glass particles retained on a 4.75-mm (No. 4) sieve should not contain more than 1 percent by mass of particles so flat, elongated, or both that the ratio between the maximum and minimum dimensions of a circumscribing rectangular prism exceeds 5:1. Such an evaluation can be performed in accordance with ASTM D 4791. These requirements are intended to ensure that the processed glass cullet will have a minimal amount (less than 1 percent) of long, narrow glass particles that may pose a safety hazard. More stringent requirements may be needed. The ratio is not to be used as a criterion for the evaluation of the engineering properties of glass cullet.

Standard Specification for

Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course

AASHTO Designation: M 319-02 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course

AASHTO Designation: M 319-02 (2006)

1. SCOPE

1.1 This specification covers the use of reclaimed concrete aggregate as an unbound granular base course material. When properly processed, hauled, spread, and compacted on a prepared grade to appropriate density standards, reclaimed concrete aggregate used alone or blended with natural or crushed aggregate can be expected to provide adequate stability and load support for use as road or highway base courses. The approach presented in this specification is suitable for the satisfactory installation of a reclaimed concrete aggregate base course. However, local experience, practices, or materials that have been successfully applied may be used in lieu of this specification. This specification is not intended for use in base courses in locations where surfacing will not be placed over the base course.

1.2 Since reclaimed concrete aggregate is a recycled material, various state and local jurisdiction laws and regulations may be applicable. The user of this specification is cautioned to contact state and local environmental and other local regulators to determine what requirements are appropriate.

1.3 The values stated in SI units are to be regarded as the standard. The English unit equivalents shown in parentheses may be appropriate, except with regard to sieve sizes and aggregate size as determined by the use of testing sieves, in which case the standard SI designation shown is the standard, as required by M 92.

Note 1—The engineer is cautioned to provide appropriate construction specifications to ensure compaction to an extent that further densification of the compacted pavement from traffic loadings will be insignificant. At the time of placement, the reclaimed concrete aggregate material shall contain moisture approximately equal to the optimum moisture content necessary to make certain that the design density requirements are obtained when the material is compacted. Reclaimed concrete aggregate can be expected to exhibit higher absorption than natural aggregate materials. Accordingly, the engineer should expect to experience moderately higher optimum moisture content values than would be expected with natural aggregate materials. The reclaimed concrete aggregate shall be compacted using vibratory or other proven effective rollers or tampers to achieve the required density results. Further discussion of compaction issues is presented in Appendix X1.

Note 2—The engineer should be aware of the highly alkaline nature of reclaimed concrete aggregate, the relatively high degree of solubility of these alkaline materials, and the potential increase in pH that could occur in waters percolating through a reclaimed concrete aggregate base. Depending on the sensitivity of local soils, surface waters, and groundwater to the presence of alkaline material, the engineer should set appropriate limits on the proximity of placement of reclaimed concrete aggregate relative to groundwater and surface waters. Additionally, the presence of water percolating through reclaimed concrete aggregate will induce a corrosive solution with a pH of approximately 11 to 12. Therefore, reclaimed concrete aggregate shall not be used in the vicinity of metal culverts, such as aluminum culverts, that are sensitive to highly alkaline environments.

Note 3—The engineer is cautioned to prevent, or minimize when possible, the use of reclaimed concrete aggregate over a geotextile drainage layer, gravel drain fields, drain field piping, or open soil-lined stormwater retention or detention facilities. Soluble minerals rich in calcium salts and calcium hydroxide can be hydraulically transported from the reclaimed concrete aggregate material. When this occurs and the reclaimed concrete aggregate is located above such porous drainage systems, there is a tendency for the referenced minerals to precipitate out of solution and bind the drainage structure. The mineral deposits formed are sometimes referred to as tufa-like or portlandite deposits. Over time the permeability of the drainage system can be reduced. Further discussion of this topic and recommended drainage evaluation procedures are presented in Appendix X2.

Note 4—The engineer should be aware that reclaimed concrete aggregate used as base course could, with time, gain strength and exhibit a corresponding loss of permeability in the base course layer. This is due to residual cementitious reactions in the concrete material. If the base course is intended for use as a drainage layer, then the fine portion of the reclaimed concrete aggregate should be removed or modified to reduce the potential for this occurrence.

Note 5—The engineer is cautioned that some reclaimed concrete aggregate materials will yield high soundness loss values when subjected to conventional sulfate soundness testing methods, and such testing methods may not be suitable for reclaimed concrete aggregate soundness testing. Further discussion of this topic is presented in Section 6.3 and Appendix X3.

Note 6—The engineer is cautioned to ensure that reclaimed concrete source materials are not contaminated with extraneous solid waste or hazardous materials. Methods and criteria for examining and approving reclaimed concrete materials prior to use should be established by the specifying jurisdiction. This provision is further addressed in Section 7.3.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- M 147, Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 103, Soundness of Aggregates by Freezing and Thawing
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 193, The California Bearing Ratio
- T 307, Determining the Resilient Modulus of Soils and Aggregate Materials

2.2 *ASTM Standards*:

- D 2940, Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports
- D 5101, Standard Test Method for Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio

2.3 *Additional Standards*:

- NY 703-08, Resistance of Coarse Aggregate to Freezing and Thawing (New York State Department of Transportation)
- LS-614, Freezing and Thawing of Coarse Aggregate (Ontario Ministry of Transportation)

3. DEFINITIONS

3.1 The definitions of base course and other soil aggregate terms are given in M 146. For use in this specification, base course shall mean the uppermost unbound granular layer of the pavement structure. The definition for reclaimed concrete aggregate as used in this specification is a manufactured aggregate material that is derived from the crushing, processing, and classification of portland cement concrete construction debris recovered from roadways, sidewalks, buildings, bridges, and other sources.

4. ORDERING INFORMATION

4.1 The purchaser or specifier shall include the following information in the purchase order or contract documents:

4.1.1 Reference to this specification, including year;

4.1.2 Grading to be furnished for the granular base;

4.1.3 Soundness testing requirements; and

4.1.4 Exceptions or additions to this specification.

5. GRADING AND PROPORTIONS

5.1 Reclaimed concrete aggregate or reclaimed concrete aggregate combined with other approved natural or man-made aggregate materials shall comply with the gradation requirements of M 147, ASTM D 2940, or the requirements of the specifying jurisdiction.

5.2 If the contractor/supplier wishes to use combinations of reclaimed concrete aggregate or reclaimed concrete aggregates with other approved aggregate materials, a request shall be made to the engineer for approval. The percentage of materials shall be established as part of a pre-submitted blended aggregate combination. In cases where the contractor/supplier wishes to change the approved combination, a special request for approval shall be made to the engineer. At the engineer’s discretion, revised density acceptance testing shall be required.

5.3 When the engineer permits the contractor/supplier to combine reclaimed concrete aggregate with other approved aggregates, this shall be accomplished by mechanical interlock blending or belt blending to ensure uniform mixing. The contractor/supplier may use other methods of blending if it can be demonstrated to the engineer that the alternate blending method will prevent segregation.

6. PHYSICAL PROPERTIES

6.1 Reclaimed concrete aggregate shall consist of crushed concrete material and natural aggregate particles, derived from the crushing of portland cement concrete, that are hard, durable fragments of stone, gravel, slag, crushed concrete, or sand.

6.2 Reclaimed concrete aggregate shall be limited in plastic soils such that the minus 0.425-mm (No. 40) sieve material when tested for liquid limit (T 89) shall not be greater than 30 and the plasticity index (T 90) shall not be greater than four, and/or, at the discretion of the engineer, the sand equivalent value (T 176) of the minus 0.425-mm (No. 40) sieve material shall be a minimum of 25 percent.

6.3 Reclaimed concrete aggregate shall have a percentage of wear by the Los Angeles abrasion test (T 96) of not more than 50 percent.

6.4 Reclaimed concrete aggregate soundness testing shall be required at the discretion of the engineer. Appendix X3 lists permissible alternative soundness test methods and acceptance criteria. (See Note 5.)

7. DELETERIOUS SUBSTANCES

7.1 Reclaimed concrete aggregate shall contain not more than 5 percent bituminous concrete materials by mass. (See Note 7.)

7.2 Reclaimed concrete aggregate shall contain not more than 5 percent brick by mass. (See Note 7.)

7.3 Reclaimed concrete aggregate material shall be free of all materials that fall under the category of solid waste or hazardous materials as defined by the state or local jurisdiction. (See Note 8.)

7.4 Reclaimed concrete aggregate shall be substantially free of wood, metal, plaster, and gypsum board, when these materials are not classified as solid waste as defined in Section 7.3. (See Notes 8 and 9.)

Note 7—If the engineer wishes to specify reclaimed concrete aggregate material where the percentages of bituminous concrete and/or brick exceed those shown above, an evaluation method for approving higher percentages is presented in Appendix X4.

Note 8—The engineer may select stockpiling as an approach to assist in qualitatively identifying the presence of deleterious materials. Stockpiling can also be used as a means to qualitatively assess the uniformity of the material. When such an approach is used, the stockpile may represent all or part of the material to be used on a project and should be constructed in a manner that will minimize segregation and permit a complete visual examination of the material.

Note 9—Substantially free, in the context of this specification, shall mean percentages of undesirable materials that are less than the following: wood—0.1 percent maximum; metals—0.1 percent maximum; plaster and gypsum board—0.1 percent maximum. At the engineer's discretion these respective quantities may be adjusted if, in the engineer's opinion, such adjustment will not impact the performance of the base course.

8. METHODS OF SAMPLING AND TESTING

8.1 Sample and test the aggregate in accordance with the following standard methods of the American Association of State Highway and Transportation Officials, except as otherwise provided in this specification:

8.1.1 T 2, Sampling;

8.1.2 T 11, Elutriation;

8.1.3 T 27, Grading;

8.1.4 T 87, Sample Preparation;

8.1.5 T 88, Particle Size Analysis;

8.1.6 T 89, Liquid Limit;

8.1.7 T 90, Plastic Limit and Plasticity Index;

8.1.8 T 96, L.A. Abrasion;

8.1.9 T 104, Aggregate; and/or

8.1.10 T 176, Sand Equivalent Test.

APPENDIXES

(Nonmandatory Information)

X1. DENSITY CONTROL METHODS FOR RECLAIMED CONCRETE MATERIALS

X1.1. The traditional method to control density is to perform a proctor test and compare in-place density values with the maximum dry density. Procedural methods have also been used and are based on the performance of standard compaction techniques performed for a designated number of passes, and are usually based on the experience of the specifying agency. In this second approach, once the required numbers of passes are made, the lift is accepted. Both of the previously referenced methods have been successfully applied to reclaimed concrete materials. If reclaimed concrete from different sources is used on a specific job site, however, or if the reclaimed concrete is blended with other natural or manufactured aggregates, density control problems may result. An alternate compaction control method to account for variations in the specific gravity of reclaimed concrete aggregate is presented below.

X1.2. This alternative field control method allows for variations in source materials and automatically adjusts for those changes to ensure maximum compaction of the reclaimed concrete material in the field. In overview, the procedure involves the use of a variable acceptance criteria for compaction based on testing on each designated lot and sublot on a project site. The compaction equipment and compaction practices shall be approved by the engineer. After placing the initial lot at approximately its optimum moisture content as determined in the laboratory, the acceptance degree of compaction is established by measuring the density of the compacted material between each pass of the compaction equipment and continuing such equipment passes until there is no longer an increase in the density. The lift density established in this manner then becomes the acceptance criteria and the lift has met that value and is accepted. All subsequent lots and sublots are placed at or near the moisture content of the first lot and tested in a similar manner. The following is a step-by-step description of this test method.

X1.2.1. *Lot and Sublot Description and Size*—For purposes of control of the compaction of reclaimed concrete aggregate for base course, the base material shall be divided into lots, each of which shall represent approximately 5,000 square meters (5,980 square yards) of base course, or the amount that is placed in one day, whichever is less. When more than one shift is performed on a given day, the engineer may use each shift to define a lot. Each lot will be further subdivided into four sub-lots of approximately 1,250 square meters (1,490 square yards) each or for smaller lots into four sub-lots of approximate equal size.

X1.2.2. After the initial sublot is laid down and moisture is added to achieve a moisture content approximately at the optimum moisture content as determined in the laboratory, a testing plan shall be defined for the measurement of in-place density in at least four different locations in each sublot. The sublot will be compacted and tested for density after each pass. After each of the four locations is tested, the lift shall be compacted with one or more additional passes. After each compaction pass, in-place density testing will again be performed. This sequence shall continue until there is no significant increase or decrease in the density of the lift as the result of an additional pass. In-place density testing shall be performed using an approved testing method. For reasons of this specification, the term “compaction pass” shall mean the passing of the compaction equipment over the entire lot surface one complete time.

X1.2.3. When the compaction described in the Section X1.2 has been achieved, the base course lot shall be considered to be compacted adequately. Such testing shall be ongoing until the project is completed.

X2. TUFA-LIKE DEPOSITS

X2.1. Portland cement concrete contains, among other minerals, a mix of complex calcium salts and calcium hydroxide that can be highly soluble. Once in solution, these minerals will remain so until the conditions of solubility change. This may occur as the result of the evaporation of water, thus resulting in the minerals having a solubility concentration above the solubility constant for that mineral, if temperature conditions change or in the presence of other compounds, such as carbon dioxide, that may react with these minerals to promote precipitation. The resulting mineral deposits are commonly referred to as tufa-like or portlandite deposits. Such deposits may affect the permeability of the geotextiles, gravel drain fields, drain field piping, or open soil-lined stormwater retention or detention facilities placed downgradient of the reclaimed concrete aggregate base. If the supplier wishes to use reclaimed concrete aggregate in the vicinity of geotextiles or fine-grained drainage layers, the following evaluation and acceptance criteria are recommended.

X2.1.1. Validation of geotextile or fine-grained drainage layer permeability by field experience. The supplier may submit evidence to the engineer that the same reclaimed concrete aggregate material has performed satisfactorily with the same geotextile or fine-grained drainage layer to be used on the project for a period of at least 3 years with no perceptible reduction in the permeability of the geotextile.

X2.1.2. Validation of geotextile or fine-grained drainage layer clogging potential by use of comparative permeability testing. The effect of tufa-like deposition on the permeability of geotextiles or fine-grained drainage layers may be determined by use of ASTM D 5101. To determine the potential for geotextile or fine-grained drainage-layer clogging using this method, a control sample (e.g., natural aggregates and geotextile or fine-grained drainage layer) and the reclaimed concrete aggregate and geotextile or fine-grained drainage layer should be tested and compared. During this test the permeability of the natural aggregate-geotextile or fine-grained drainage-layer combination and the reclaimed concrete aggregate-geotextile or fine-grained drainage-layer combination should be recorded after less than 1 week of flow through testing, as described in the ASTM specification, and after 12 weeks of flow through testing. The degree to which reclaimed concrete aggregate might impact a geotextile or fine-grained drainage layer can be assessed by comparing the results of reclaimed concrete aggregate testing and that of a control material to determine the relative impact of using reclaimed concrete aggregate above a geotextile or fine-grained drainage layer. A reduction in permeability by 10 percent or more over the 12-week time period of the reclaimed concrete aggregate sample relative to the control sample would suggest a measurable impact.

X3. SOUNDNESS TESTING OF RECLAIMED CONCRETE AGGREGATE

X3.1. Reclaimed concrete aggregate can be susceptible to sulfate attack when it is tested for soundness using sodium sulfate or magnesium sulfate solution, resulting in high loss values, particularly when sodium sulfate solution is used. Sulfate solution test methods (T 104) may be applied if local experience has found these methods to be satisfactory; however, alternative approaches are available if sulfate solution testing is found to exhibit high-loss values.

X3.2. Alternative test approaches include the following:

X3.2.1. *The No-Test Alternative*—This approach accepts the reclaimed concrete aggregate based on the other quality measures and waives the soundness requirements.

X3.2.2. *AASHTO T 103*—This approach uses a freeze-thaw procedure in water with 25 freeze-thaw cycles and a maximum allowable loss of 20 percent.

X3.2.3. *New York State DOT, Test Method NY 703-08*—This approach uses a test sample saturated in a 3 percent sodium chloride brine solution and a maximum allowable loss of 20 percent.

X3.2.4. *Ontario Ministry of Transportation (MOT), Test Method LS-614*—This approach uses a 3 percent sodium chloride brine solution with five freeze-thaw cycles and a maximum allowable loss of 20 percent.

X4. PROVISIONS FOR USING EXCESS BITUMINOUS CONCRETE OR BRICK

X4.1. If the engineer wishes to use higher percentages of bituminous concrete or brick in the base course material, permitted in Sections 7.2 and 7.3, respectively, of this specification, then one or more of the following performance acceptance criteria is recommended:

X4.1.1. *Validation by Use of California Bearing Ratio (T 193) Testing*—The engineer should compare California Bearing Ratio test results conducted on a control sample, consisting of reclaimed concrete aggregate material that complies with granular base specifications, to the blend of reclaimed concrete aggregate that contains the higher percentage of bituminous concrete and/or brick the supplier wishes to use on the project. If the California Bearing Ratio value for the reclaimed concrete aggregate and bituminous concrete and/or brick combination is equal to or greater than that for the control material, then the higher percentage of bituminous concrete and/or brick combination may be used.

X4.1.2. *Validation by Use of Resilient Modulus (T 307) Testing*—The engineer should compare the results of Resilient Modulus testing on a control sample, consisting of reclaimed concrete aggregate material that complies with the granular base specifications, to the reclaimed concrete aggregate material plus the percentage of bituminous concrete aggregate or brick material that the supplier wishes to use on the project. Three tests for each condition shall be performed and the values averaged. If the average Resilient Modulus value for the reclaimed concrete aggregate and bituminous concrete and/or brick combination is equal to or greater than the average value for the control material alone, then the higher percentage of bituminous concrete and/or brick combination may be used.

X4.1.3. *Validation by Field Application*—The engineer shall show by constructing a test strip or introducing historical data that incorporating percentages of bituminous concrete and/or brick into reclaimed concrete aggregate that are higher than permitted in this specification does not adversely affect the performance of the granular base.

Standard Practice for

Conducting Geotechnical Subsurface Investigations

AASHTO Designation: R 13-03 (2007)[1]
ASTM Designation: D 420-98 (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Conducting Geotechnical Subsurface Investigations

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INTRODUCTION

Investigation and identification of subsurface materials and conducting subsurface investigations involve complex techniques that may be accomplished by many different procedures and may be variously interpreted. These studies are frequently site specific and are influenced by geological and geographical settings; by the purpose of the investigation; by the design requirements for the project proposed; and by the background, training, and experience of the investigator.

This standard practice for soil, rock, and groundwater investigation based on standard procedures will provide a more consistent, uniform, and rational methodology for site evaluations. An acceptable and consistent investigation, sampling, testing, and evaluation program will determine subsurface site conditions and thereby provide the information needed to bring about safer and more cost-effective transportation facilities.

1. SCOPE

1.1. This standard practice identifies recognized methods by which soil, rock, and groundwater conditions may be determined. The objective of the investigation should be to identify and locate, both horizontally and vertically, significant soil and rock types and groundwater conditions present within a given site area and to establish the characteristics of the subsurface materials by sampling and *in situ* testing. Laboratory testing of soil and rock samples is governed by other AASHTO and ASTM standards.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not propose to address all safety concerns associated with its usage. It is the duty and responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 1—The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- M 147, Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses
- T 2, Sampling of Aggregates
- T 194, Determination of Organic Matter in Soils by Wet Combustion

- T 206, Penetration Test and Split-Barrel Sampling of Soils
- T 207, Thin-Walled Tube Sampling of Soils
- T 221, Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements
- T 223, Field Vane Shear Test in Cohesive Soil
- T 225, Diamond Core Drilling for Site Investigation
- T 252, Measurements of Pore Pressures in Soils
- T 267, Determination of Organic Content in Soils by Loss of Ignition
- T 306, Progressing Auger Borings for Geotechnical Explorations

2.2. *ASTM Standards*:

- C 119, Standard Terminology Relating to Dimension Stone
- C 294, Standard Descriptive Nomenclature for Constituents of Concrete Aggregates
- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids
- D 1194, Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings (Withdrawn 2003)
- D 1196, Standard Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
- D 1586, Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 3213, Standard Practices for Handling, Storing, and Preparing Soft Intact Marine Soil
- D 3385, Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer
- D 3404, Standard Guide for Measuring Matric Potential in Vadose Zone Using Tensiometers
- D 3441, Standard Test Method for Mechanical Cone Penetration Tests of Soil
- D 3550, Standard Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils (Discontinued)
- D 3740, Standard Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- D 4083, Standard Practice for Description of Frozen Soils (Visual-Manual Procedure)
- D 4220, Standard Practices for Preserving and Transporting Soil Samples
- D 4394, Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Rigid Plate Loading Method
- D 4395, Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Flexible Plate Loading Method
- D 4403, Standard Practice for Extensometers Used in Rock
- D 4427, Standard Classification of Peat Samples by Laboratory Testing
- D 4428/D 4428M, Standard Test Methods for Crosshole Seismic Testing
- D 4429, Standard Test Method for CBR (California Bearing Ratio) of Soils in Place
- D 4452, Standard Practice for X-Ray Radiography of Soil Samples
- D 4506, Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using a Radial Jacking Test

- D 4544, Standard Practice for Estimating Peat Deposit Thickness
- D 4553, Standard Test Method for Determining In Situ Creep Characteristics of Rock
- D 4554, Standard Test Method for In Situ Determination of Direct Shear Strength of Rock Discontinuities
- D 4555, Standard Test Method for Determining Deformability and Strength of Weak Rock by an In Situ Uniaxial Compressive Test (Discontinued)
- D 4623, Standard Test Method for Determination of In Situ Stress in Rock Mass by Overcoring Method—USBM Borehole Deformation Gauge
- D 4630, Standard Test Method for Determining Transmissivity and Storage Coefficient of Low-Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test
- D 4631, Standard Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using Pressure Pulse Technique (Discontinued)
- D 4645, Standard Test Method for Determination of In Situ Stress in Rock Using Hydraulic Fracturing Method
- D 4700, Standard Guide for Soil Sampling from the Vadose Zone
- D 4719, Standard Test Method for Prebored Pressuremeter Testing in Soils
- D 4729, Standard Test Method for In Situ Stress and Modulus of Deformation Using Flatjack Method
- D 4750, Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well) (Withdrawn 2010)
- D 4879, Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock
- D 4971, Standard Test Method for Determining In Situ Modulus of Deformation of Rock Using Diametrically Loaded 76-mm (3-in.) Borehole Jack
- D 5079, Standard Practices for Preserving and Transporting Rock Core Samples
- D 5088, Standard Practice for Decontamination of Field Equipment Used at Waste Sites
- D 5092, Standard Practice for Design and Installation of Ground Water Monitoring Wells
- D 5093, Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring
- D 5126, Standard Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone
- D 5195, Standard Test Method for Density of Soil and Rock In-Place at Depths Below Surface by Nuclear Methods
- D 6066, Standard Practice for Determining the Normalized Penetration Resistance of Sands for Evaluation of Liquefaction Potential

3. SIGNIFICANCE AND USE

3.1. An adequate soil, rock, and groundwater subsurface investigation provides pertinent information for decision making on one or more of the following subjects:

3.1.1. Location of the proposed construction both vertically and horizontally;

3.1.2. Location and preliminary evaluation of suitable borrow and other local sources of construction material;

3.1.3. Need for special excavating and dewatering techniques;

3.1.4. Investigations of stability in natural slopes and cuts, and embankment foundation stability;

3.1.5. Conceptual selection of embankment types and hydraulic barrier requirements;

3.1.6. Conceptual selection of alternate foundation types and elevations of the corresponding suitable bearing strata;

3.1.7. Development of additional detailed subsurface investigations for specific structures or facilities;

3.1.8. Need for and type of subgrade or embankment foundation treatment or drainage;

3.1.9. Selection of roadway or area pavement type;

3.1.10. Need to identify areas requiring special environmental protection; and/or

3.1.11. Need to identify potential hazardous locations and types of hazardous materials.

3.2. The investigation may require the collection of sufficiently large soil and rock samples of such quality to allow adequate testing to determine the soil or rock classification or mineralogic type, or both, as well as other engineering properties pertinent to the proposed design.

3.3. This standard practice is not meant to be an inflexible description of investigation requirements. Other techniques may be applied as appropriate.

4. RECONNAISSANCE OF PROJECT AREA

4.1. Available technical data from the literature or from personal communication should be reviewed before any field program is started. This includes, but is not limited to, topographic maps, air photos, satellite imagery, geologic maps, statewide or county soil surveys and mineral resource surveys, and engineering soil maps covering the proposed project area. Reports of subsurface investigations of nearby or adjacent projects should be studied.

Note 2—While some older maps and reports may be obsolete and of limited value in light of current knowledge, a comparison of the old with the new will often reveal valuable unexpected information.

4.1.1. The United States Geological Survey and the geological surveys of the various states are the principal sources of geologic maps and reports on mineral resources and groundwater.

4.1.2. United States Department of Agriculture Natural Resources Conservation Service soil survey reports, where available and recent, should enable the engineer to estimate the range in soil profile characteristics to depths of 1.5 or 2.0 m (5 or 6 ft) for each soil mapped.

Note 3—Each soil type has a distinctive soil profile due to age, parent material, relief, climatic condition, and biological activity. Consideration of these factors can assist in identifying the various soil types, each requiring special engineering considerations and treatment. Similar engineering soil properties are often found where similar soil profile characteristics exist. Changes in soil properties in adjacent areas often indicate changes in parent material or relief.

4.2. In areas where descriptive data are limited by inadequate geologic or soils maps, the soil and rock in open cuts in the vicinity of the proposed project should be studied and various soil and rock profiles noted. Field notes of such studies should include data outlined in Section 10.6.

4.3. Where a preliminary map covering the area of the project is desired, it can be prepared on maps compiled from aerial photography that show the ground conditions. The distribution of the predominant soil and rock deposits likely to be encountered during the investigation may be shown using data obtained from geologic maps, landform analysis, and limited ground reconnaissance. Experienced air photo interpreters can deduce much subsurface data from a study of black and white, color, and infrared photographs because similar soil or rock conditions, or both, usually have similar patterns of appearance in regions of similar climate or vegetation.

Note 4—This preliminary map may be expanded into a detailed engineering map by locating all test holes, pits, and sampling stations and by revising boundaries as determined from the detailed subsurface survey.

4.4. In areas where documentary information is insufficient, some knowledge of subsurface conditions can be obtained from land owners, local well drillers, and representatives of the local construction industry.

4.5. Review of past land use (tax maps, fire insurance records, etc.) or changes to local contours, or both, may indicate the possible presence of buried materials that may result in remediative efforts.

5. EXPLORATION PLAN

5.1. Available project design and performance requirements must be reviewed prior to final development of the exploration plan. Preliminary exploration should be planned to indicate the areas of conditions needing further investigation. A complete subsurface soil, rock, and groundwater investigation should encompass the following activities:

5.1.1. Review of available information on the geologic history, rock, soil, and groundwater conditions occurring at the proposed location and in the immediate vicinity of the site;

5.1.2. Interpretation of aerial photography and other remote sensing data;

5.1.3. Field reconnaissance for identification of surficial geologic conditions, mapping of stratigraphic exposures and outcrops, and examination of the performance of existing structures;

5.1.4. On-site investigation of the surface and subsurface materials by geophysical surveys, borings, or test pits;

5.1.5. Recovery of representative disturbed samples for laboratory classification tests of soil, rock, and local construction material. These should be supplemented by undisturbed specimens suitable for the determination of those engineering properties pertinent to the investigation;

5.1.6. Identification of the position of the groundwater table, or water tables, if there is perched groundwater, or of the piezometric surfaces if there is artesian groundwater. The variability of these positions in both short and long time frames should be considered. Color mottling of the soil strata may be indicative of long-term seasonal high groundwater positions;

5.1.7. Identification and assessment of the location of suitable foundation material, either bedrock or satisfactory load-bearing soils;

5.1.8. Field identification of soil sediments and rock, with particular reference to type and degree of decomposition (for example, saprolite, karst, decomposing or slaking shales), the depths of their occurrence, and the types and locations of their structural discontinuities;

5.1.9. Evaluation of the performance of existing installations, relative to their foundation material and environment in the immediate vicinity of the proposed site; and

5.1.10. Determination of the possible presence of buried hazardous material that may result in remediation efforts.

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6. EQUIPMENT AND PROCEDURES FOR USE IN EXPLORATION

6.1. The type of equipment required for a subsurface investigation depends upon various factors including the type of subsurface material, the depth of exploration, the nature of the terrain, and the intended use of the data.

6.2. Hand augers, hole diggers, shovels, and push tube samplers are suitable for exploration of surficial soils to depths of 1 to 5 m (3 to 15 ft). Driven probe rods, without sampling, can indicate obstructions by refusal for similar depth of exploration.

6.3. Earth excavation equipment such as backhoes, draglines, and drilled pier augers (screw or bucket) may be used to allow *in situ* examination of soil deposits and sampling of materials containing very large particles. The engineer should be aware of the possibility of permanent disturbance of potential bearing strata by unbalanced pore pressure in test excavations.

6.4. Power augers and rotary drills with appropriate drill tools suitable for soil investigation and sampling.

6.5. Well drilling equipment may be suitable for deep geologic exploration. Normally samples are in the form of sand-sized cuttings captured from the return flow, but coring devices are available.

6.6. *In situ* instrumentation for settlement and ground movement.

6.7. Small tools or aids such as geology picks, binoculars, magnifying glass, acid, etc.

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7. GEOPHYSICAL EXPLORATION

7.1. Geophysical or remote sensing techniques may assist in mapping the areal extent of geological formations and for evaluating variations in soil and rock properties.

7.1.1. Satellite and aircraft spectral mapping tools such as LANDSAT may be used to find and map the areal extent of subsurface materials and geologic structure. Interpretation of aircraft photographs and satellite imagery may locate and identify significant geologic features that may be indicative of faults and fractures. Some ground control is generally required to verify information derived from remote sensing data.

7.2. Geophysical survey methods can be used to supplement borehole and outcrop data and to interpolate between holes. Seismic, ground penetrating radar, and electrical resistivity methods can be particularly valuable when distinct differences in the properties of contiguous subsurface materials are indicated.

7.3. Shallow seismic refraction/reflection and ground penetrating radar techniques can be used to map soil horizons and depth profiles, water tables, and depth to bedrock in many situations, but depth penetration and resolution vary with local conditions. Electromagnetic induction, electrical resistivity, and induced polarization (or complex resistivity) techniques may be used to map variations in water content, clay horizons, stratification, and depth to aquifer/bedrock. Other geophysical techniques such as gravity, magnetic, and shallow ground temperature methods may be useful under certain specific conditions. Deep seismic and electrical methods are routinely used for mapping stratigraphy and structure of rock in conjunction with logs. Cross-hole shear wave velocity measurements may provide soil and rock parameters for dynamic analyses.

7.3.1. The seismic refraction method may be especially useful in determining depth to, or rippability of, rock in locations where successively denser strata are encountered.

7.3.2. The seismic reflection method may be useful for delineating geological units at depths below 3 m (10 ft). It is not constrained by layers of low seismic velocity and is especially useful in areas of rapid stratigraphic change.

7.3.3. The electrical resistivity method may be similarly useful in determining depth to rock and anomalies in the stratigraphic profile, in evaluating stratified formations where a denser stratum overlies a less dense stratum, and in location of prospective sand-gravel or other sources of borrow material. Resistivity parameters also are required for the design of grounding systems and cathodic protection for buried structures.

7.3.4. The ground penetrating radar method may be useful in defining soil and rock layers and man-made structures in the depth range of 0.3 to 10 m (1 to 30 ft).

7.3.5. Airborne thermal infrared line scanning is useful in locating seepage areas on hills and earthen water impounding structures.

Note 5—Geophysical investigations can be a useful guide in determining boring or test hole locations. If at all possible, the interpretation of geophysical studies should be verified by borings or test excavations.

8. SAMPLING

8.1. Obtain samples that adequately represent each subsurface material that is significant to the project design and construction. The size and type of sample required is dependent upon the tests to be performed, the relative amount of coarse particles present, and the limitations of the test equipment to be used.

Note 6—The size of disturbed or bulk samples for routine tests may vary at the discretion of the geotechnical investigator, but the following quantities are suggested as suitable for most materials:

- *Visual classification*—50 g to 500 g (2 oz to 1 lb)
- *Soil constants and particle size analysis of nongravelly soil*—500 g to 2.5 kg (1 lb to 5 lb)
- *Soil compaction tests and sieve analysis of gravelly soils*—20 kg to 40 kg (40 lb to 80 lb)
- *Aggregate manufacture or aggregate properties tests*—50 kg to 200 kg (100 lb to 400 lb)

8.2. Accurately identify each sample with the boring, test hole, or test pit number and depth below reference ground surface from which it was taken. Place a waterproof identification tag inside the container, securely close the container, protect it to withstand rough handling, and mark it with proper identification on the outside. Keep samples for natural water content determination in sealed containers to prevent moisture loss. When drying of samples may affect classification or engineering properties test results, protect them to minimize moisture loss. ASTM D 4220 and D 5079 address the transportation of samples from field to laboratory.

8.3. Recommended AASHTO and ASTM procedures for sampling are as follows:

8.3.1. AASHTO T 2 describes the sampling of coarse and fine aggregates for the preliminary investigation of a potential source of supply.

8.3.2. AASHTO T 306 describes the use of augers in soil investigations and sampling where disturbed soil samples can be used. Depths of auger investigations are limited by groundwater conditions, soil characteristics, and equipment used.

8.3.3. AASHTO T 206 describes a procedure to obtain representative soil samples for identification and classification laboratory tests and to measure the resistance of the soil to penetration by a standardized sampler. ASTM D 6066 describes a procedure to be used in testing loose sands below the water table for liquefaction studies or when a high level of care is required in drilling these soils.

8.3.4. AASHTO T 207 describes a procedure to recover relatively undisturbed soil samples suitable for laboratory testing.

8.3.5. AASHTO T 225 describes a procedure to recover intact samples of rock and certain soils too hard to sample by T 206 or T 207.

8.3.6. ASTM D 3550 describes a procedure to recover moderately disturbed, representative samples of soil for classification testing and in some cases shear or consolidation testing.

9. CLASSIFICATION OF EARTH MATERIALS

9.1. Identify samples of soil and rock after submission to the laboratory for identification and classification tests in accordance with one or more of the following AASHTO and ASTM standards:

9.1.1. ASTM C 294, Standard Descriptive Nomenclature for Constituents of Concrete Aggregates.

9.1.2. ASTM D 2487, Standard Practice for Classification of Soils for Engineering Purposes.

9.1.3. AASHTO M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes.

9.1.4. ASTM D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).

9.1.5. ASTM D 4083, Standard Practice for Description of Frozen Soils (Visual-Manual Procedure).

10. DETERMINATION OF SUBSURFACE CONDITIONS

10.1. Subsurface conditions are positively defined only at the individual test pit, hole, boring, or open cut examined. Conditions between observation points may be significantly different from those encountered in the exploration. A stratigraphic profile can be developed by detailed investigations only where determinations of a continuous relationship of the depths and locations of various types of soil and rock can be inferred. This phase of the investigation may be implemented by plotting logs of soil and rock exposures in walls of excavations or cut areas and by plotting logs of the test borings. Then one may interpolate between and extrapolate a reasonable distance beyond these logs. The spacing of these investigations should depend on the geologic complexity of the project area and on the importance of soil and rock continuity to the project design. Exploration should be deep enough to identify all strata that might be significantly affected by the proposed use of the site and to develop the engineering data required to allow analysis of the items listed in Section 3 for each project.

Note 7—Plans for a program of intrusive subsurface investigation should consider possible requirements for permits for installation and proper closure of boreholes and wells at the completion of the investigation.

10.2. The depth of exploratory borings or test pits for roadbeds, airport paving, or vehicle parking areas should be to at least 1.5 m (5 ft) below the proposed subgrade elevation. Special circumstances may increase this depth. Borings for structures, excavations, or embankments should extend below the level of significant stress or groundwater influence from the proposed load as determined by a subsurface stress analysis.

10.3. When project construction or performance of the facility may be affected by either pervious water-bearing materials or impervious materials that can block internal drainage, borings should extend sufficiently to determine those engineering and hydrogeologic properties relevant to the project design.

10.4. In all borrow areas, the borings or test pits should be sufficient in number and depth to outline the required quantities of material meeting the specified quality requirements.

10.5. Where frost penetration or seasonal dessication may be significant in the behavior of soil and rock, borings should extend well below the depth from finished grade of the anticipated active zone.

10.6. Exploration records shall be kept in a systematic manner for each project. Such records shall include:

10.6.1. Description of each site or area investigated. Each test hole, boring, test pit, or geophysical test site shall be clearly located (horizontally and vertically) with reference to some established coordinate system, datum, or permanent monument.

10.6.2. Logs of each test hole, boring, test pit, or cut surface exposure shall show clearly the field description and location of each material and any water encountered, either by symbol or word description.

Note 8—Color photographs of rock cores, soil samples, and exposed strata may be of considerable value. Each photograph should include an identifying number or symbol, a date, and reference scale.

10.6.3. Identification of all soils based on AASHTO M 145, ASTM D 2488, D 2607, or D 4083 or such other identification/classification system that meets agency policy and requirements. Identification of rock materials based on ASTM C 119 or C 294. Classification of soil and rock materials is discussed in Section 9.

10.6.4. Record of location and description of seepage and water-bearing zones and piezometric elevations found in each test hole, boring, or test pit.

10.6.5. Record of the precise location of *in situ* test results, such as the penetration resistance or vane shear tests, plate load tests, or other *in situ* tests for engineering properties of soils or rock.

10.6.6. Percentage of core recovery and rock quality designation in core drilling as outlined in Section 8.3.5.

10.6.7. Graphical presentation of field and laboratory data and their interpretation facilitates comprehensive understanding of subsurface conditions.

11. *IN SITU* TESTING

11.1. *In situ* testing is useful for: (a) measurement of soil parameters in their undisturbed condition with all of the restraining or loading effects, or both, of the surrounding soil or rock mass active; and (b) for rapid or closely spaced measurements, or both, of earth properties without the necessity of sampling.

11.2. Recommended AASHTO and ASTM procedures for *in situ* sampling and testing are as follows:

11.2.1. AASHTO T 206 describes a penetration test that has been correlated by many authors with various strength properties of soils.

11.2.2. AASHTO T 235 describes the estimation of the bearing capacity of soil in place by means of field loading tests. The results can be useful for design of spread footings based on static loading conditions. The load test should be performed in conjunction with other field tests, generally in accordance with T 206 or ASTM D 3441 or D 1586 to allow a determination of the applicability of the results.

11.2.3. AASHTO T 223 describes a procedure to measure the *in situ* unit shear resistance of cohesive soils by rotation of a four-bladed vane in a horizontal plane.

11.2.4. ASTM D 3385 describes a procedure for field measurement of the infiltration rate of soils. Water under a constant head is allowed to seep into the top surface of a fixed soil area and the volume rate of inflow into a known volume of soil is measured.

11.2.5. ASTM D 3441 describes the determination of the end bearing and side friction components of the resistance to penetration of a conical penetrometer into a soil mass.

11.2.6. ASTM D 4403 describes the application of various types of extensometers used in the field of rock mechanics.

11.2.7. ASTM D 4429 describes the field determination of the California Bearing Ratio for soil surfaces *in situ* to be used in the design of pavement systems.

11.2.8. ASTM D 4719 describes an *in situ* stress-strain test performed on the walls of a borehole in soil.

11.2.9. *In situ* instrumentation to measure movement such as inclinometers, settlement plates, tiltmeters, etc.

11.3. Corrosion potential should be checked for pH, resistivity, and bacterial potentials where potentially unacceptable changes or damages may occur.

12. INTERPRETATION OF RESULTS

12.1. Interpret the results of an investigation in terms of actual findings and make every effort to collect and include all field and laboratory data from previous investigations in the same area. Extrapolation of data into local areas not surveyed and tested should be made only for conceptual studies. Such extrapolation can be done only where geologically uniform stratigraphic and structural relationships are known to exist on the basis of other data. Cross sections may be developed as part of the site characterization if required to demonstrate the site conditions.

12.1.1. Cross sections included with the presentation of basic data from the investigation should be limited to the ground surface profile and the factual subsurface data obtained at specific exploration locations. Stratigraphic units between the locations of intrusive explorations should only be indicated if supported by continuous geophysical studies.

12.1.2. Cross sections showing interpretations of stratigraphic units and other conditions between intrusive explorations but without support of continuous geophysical profiles should be presented in an interpretive report appendix or in a separate interpretive report. The interpretive cross sections must be accompanied by notes describing anomalies or otherwise significant variations in the site conditions that should be anticipated for the intended design or construction activities.

Note 9—Additional exploration should be considered if there is not sufficient knowledge to develop interpretive cross sections, with realistic descriptions of anticipated variations in subsurface conditions, to meet project requirements.

12.2. Subject to the restrictions imposed by state licensing law, recommendations for design parameters can be made only by professional engineers and geologists specializing in the field of geotechnical engineering and familiar with the purpose, conditions, and requirements of the study. Soil mechanics, rock mechanics, and geomorphological concepts must be combined with a knowledge of geotechnical engineering or hydrogeology to make a complete application of the results of the soil, rock, and groundwater investigation. Complete design recommendations may require a more detailed study than that envisioned by this standard practice.

12.3. Delineate subsurface profiles only from actual geophysical, test hole, test pit, or cut-surface data. Interpolation between locations should be made on the basis of available geologic knowledge of the area and should be clearly identified. The use of geophysical techniques as discussed in Section 7.2 is a valuable aid in such interpolation. Geophysical survey data should be identified separately from sample data or *in situ* test data.

13. REPORT

13.1. The report of a subsurface investigation should include:

13.1.1. The location of the area investigated in terms pertinent to the project. This may include sketch maps or aerial photos on which the test pits, boreholes, and sample areas are located, as well as geomorphological data relevant to the determination of the various soil and rock types. Such data include elevation contours, streambeds, sink holes, cliffs, etc. Where feasible, include in the report a geologic map and/or an agronomic soils map of the area investigated.

13.1.2. A description of the investigation procedures, including all borings and test hole logs, graphic presentation of all compaction, consolidation, or load test data tabulation of all laboratory test results, and graphical interpretations of the geophysical measurements.

13.1.3. Cross sections delineating the extent of the stratigraphic units and note anomalies or otherwise significant conditions.

13.1.4. A summary of the findings obtained under Sections 4, 10, and 12, using subhead titles for the respective sections and appropriate recommendations and disclaimers for the use of the report.

14. PRECISION AND BIAS

14.1. This standard provides qualitative data only; hence, precision and bias are not applicable.

15. KEYWORDS

15.1. Explorations; feasibility studies; field investigations; foundation investigations; geological investigations; geophysical investigation; groundwater; hydrologic investigations; maps; preliminary investigations; reconnaissance surveys; sampling; site investigations; soil surveys; subsurface investigations.

16. REFERENCES

Note 10—There is a vast literature on subsurface investigations ranging from (1) references on the identification, characterization, and measurement of a single site-specific attribute of a soil or rock to (2) references showing how to make broad inferences of surficial and subsurface conditions of very large areas of terrain by interpretation of high altitude photography or satellite imagery. The following listed references are a sample of the technical literature in the subject area of subsurface investigations.

A special note should be made with respect to Reference 16.1. This manual is a comprehensive and exhaustive treatment of the methodology of conducting subsurface investigations for transportation facilities. The manual gives very detailed explanations of the various techniques of subsurface investigations along with hundreds of figures, diagrams, tables, photographs, and references. The manual was authorized by the American Association of State Highway and Transportation Officials in direct response to requests by the Association's Subcommittee on Materials and Subcommittee on Bridges and Structures.

16.1. AASHTO, *Manual on Subsurface Investigations*, American Association of State Highway and Transportation Officials, Washington, DC, 1987.

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[1] This standard practice is similar to and technically equivalent to ASTM D 420-98 (2003).

Standard Practice for

Drilling for Subsurface Investigations Unexpectedly Encountering Suspected Hazardous Material

AASHTO Designation: R 21-96 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Drilling for Subsurface Investigations Unexpectedly Encountering Suspected Hazardous Material

AASHTO Designation: R 21-96 (2009)

1. SCOPE

1.1. This practice is intended to help protect drillers in the event they unexpectedly encounter suspected hazardous materials while performing subsurface investigations. This is accomplished by training the drillers, identifying precautions to minimize risks of contamination, and establishing a procedure to follow if suspected hazardous material is encountered.[1]

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard and Publication*:

- R 13, Conducting Geotechnical Subsurface Investigations
- *Hazardous Waste Guide for Project Development*

2.2. *ASTM Standard*:

- D 420, Standard Guide to Site Characterization for Engineering, Design, and Construction Purposes

3. SIGNIFICANCE AND USE

3.1. There are three basic types of sites. One type is a known hazardous waste site. These sites contain hazardous waste, and have been formally labeled. This includes all Superfund sites and CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. Section 9601–9657) sites. The second type is the nonhazardous site. These sites have no hazardous material at all. The third type, which is the subject of this practice, is one that contains unknown and unanticipated hazardous waste. This practice is intended to help drillers in situations in which they have no advance warning that they will encounter hazardous material.

4. HAZARDOUS MATERIAL IDENTIFICATION

4.1. The first and most important step drillers must take in protecting themselves from contamination is identifying the presence of suspected hazardous material. Proper identification depends on awareness, and knowledge of what to look for. All drillers on staff should be trained how to use their senses and observe their surroundings for clues indicating the presence of hazardous or explosive material.

5. MINIMIZING CONTAMINATION RISK

5.1. Drillers shall take routine precautions to minimize the risk of contamination through proper protective gear, good work habits, and good hygiene. Contaminants enter the body through skin absorption, cuts in the skin, inhalation, ingestion, and skin penetration (radioactivity).

5.1.1. *Proper Protection*—Drillers shall use skin protection (gloves, long-sleeved shirts) and work boots.

5.1.2. *Work Habits*—Drillers shall follow good work habits, including (1) avoiding skin contact with soil and drilling fluid, (2) minimizing the risk of inhaling contaminants by using drilling fluid, and (3) cleaning all equipment and tools before leaving the job site to avoid spreading contamination. (When mud and soil dry out, contaminants can become airborne.)

5.1.3. *Hygiene*—Drillers shall clean off boots, gloves, clothes, etc. before entering a vehicle to avoid spreading contamination beyond the job site and shall wash hands before eating, drinking, smoking, or making skin contact.

6. PROCEDURE

6.1. AASHTO R 13 and ASTM D 420 describe procedures that govern the investigation and site assessment process. Drillers shall take the following precautions in addition to the precautions described in these standards if they encounter hazardous material.

6.1.1. *Assess the Risk*—Determine whether the risk is one of contamination or explosion. Natural gas and some petroleum byproducts are explosive in very high concentrations.

6.1.2. *Contamination*—If the risk is of contamination only, any driller not properly trained should cease drilling and leave the site. Drillers who have successfully completed a 40-hour course in Hazardous Materials Training shall secure the site, while avoiding skin contact, ingestion, and inhalation. After securing the site, the responsible party shall make the necessary notifications. All contaminated material should be handled, contained, and disposed of according to current, established procedures.

6.1.3. *Explosion*—If there is a risk of explosion, the drillers shall leave the site and let the hole vent. If the smell remains or gets stronger, the drillers shall use an explosion risk meter, if they are properly trained and certified (Note 1) to assess the actual risk of explosion. If the risk is significant, the drillers shall properly decommission the hole in accordance with state regulations and proceed to the next location.

Note 1—Drillers must be trained and certified to use the explosion risk meter. The decision to proceed should be made by a responsible, qualified party, with input from the drillers.

7. KEYWORDS

7.1. Driller protection; hazardous material; subsurface exploration.

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[1] AASHTO *Hazardous Waste Guide for Project Development*, February 1990.

Standard Practice for

Decommissioning Geotechnical Exploratory Boreholes

AASHTO Designation: R 22-97 (2005)

American Association of State Highway and Transportation Officials
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Standard Practice for

Decommissioning Geotechnical Exploratory Boreholes

AASHTO Designation: R 22-97 (2005)

INTRODUCTION

The preservation of groundwater resources is a very important issue in the design, construction, and maintenance of the highway infrastructure system. Most projects require some type of on-site subsurface geotechnical investigation to properly design the facilities. These investigations typically involve progressing smaller diameter (<200 mm) exploratory boreholes up to depths of approximately 60 m. In some instances, cone penetrometers or instrumentation devices such as piezometers, monitoring wells, and vane shear tests are used to obtain subsurface information. By progressing exploratory boreholes which may penetrate the water table, a conduit for surface and subsurface aquifer cross contamination may be introduced. In situations in which the investigation may lead to the contamination of groundwater resources, it would be prudent to properly abandon the borehole.

Construction of a borehole seal during decommissioning can add significantly to the time, material, and labor costs of geotechnical exploratory boreholes. Some states have regulations that mandate that all geotechnical exploratory boreholes must be sealed. When that is the case, this standard practice is of limited use, and the reader should consult references pertaining to borehole sealing. If borehole sealing mandates are not in effect, this standard practice may provide some guidelines regarding which boreholes should be sealed, as well as the procedures involved in this determination.

1. SCOPE

1.1 *Types of Boreholes*—This standard practice addresses the permanent decommissioning (closure) of the following types of geotechnical exploratory boreholes. It is specifically intended to address the closure in situations in which hazardous material or solid wastes are determined not to be present.[1] Included in the list of geotechnical exploratory boreholes are:

1.1.1 Boreholes progressed with temporary casing for obtaining soil, rock, and groundwater information;

1.1.2 Uncased boreholes progressed for obtaining soil, rock, and groundwater information using drilling mud or open-hole techniques;

1.1.3 Hollow-stem flight auger boreholes;

1.1.4 Observation wells for monitoring groundwater conditions;

1.1.5 Instrumentation boreholes (i.e., piezometers, Borros points, etc.);

1.1.6 Cone penetrometer boreholes; and

1.1.7 Soil characterization tests (vane shear, dilatometer, etc.).

1.2 *Intent of Practice*—This practice describes the overall process of decommissioning the holes and, as such, includes a systematic approach to completing the process. The typical steps entail an evaluation of the specific site characteristics and potential problems, a review of available decommissioning options including the null option if applicable, selection of an appropriate sealant, and a method of sealing. Specific requirements for the quality control and performance of the sealed borehole are addressed. Record-keeping requirements are noted.

1.3 *Safety—This standard practice does not propose to address all safety concerns associated with its usage. It is the duty and responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of other state regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- R 13, Conducting Geotechnical Subsurface Investigations

2.2 *ASTM Standard*:

- D 5299, Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities

2.3 *National Cooperative Highway Research Program Reports*:

- NCHRP Report 378, *Recommended Guidelines for Sealing Geotechnical Exploratory Holes*
- NCHRP Project 21-4, *Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment*

3. SUMMARY OF GUIDE

3.1 Presently there are numerous state agencies and private contractors who install geotechnical exploratory boreholes for the state transportation programs. Within these agencies, various state regulations and decommissioning procedures are in place. No national or international standards exist for abandoning geotechnical boreholes. This standard practice attempts to provide members of the transportation industry with guidelines and references to follow in evaluating the need for sealing, different sealant materials, methods for sealing, and the associated record keeping for the process.

4. SIGNIFICANCE AND USE

4.1 This standard practice is intended to provide technical information and is not intended to supplant any Federal, state, or municipal regulations which may be in effect in a particular area. For a summary of practices of state transportation departments, see National Cooperative Highway Research Program Report NCHRP Project 21-4, *Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment*, August 1995.

5. MATERIALS

5.1 See NCHRP Report 378, *Recommended Guidelines for Sealing Geotechnical Exploratory Holes*, Chapter Six.

6. PROCEDURE

6.1 Reaching the decision regarding the appropriate type of decommissioning procedure for geotechnical exploratory boreholes is a complex task. Among other factors, the person making the decision must understand the hydrogeology of the area, be aware of any known aquifers in the vicinity, know where various groundwater levels exist, and know the depth and diameter of the borehole. From a practical point of view, the decision regarding the correct type of decommissioning must be studied prior to performing the actual field work.

6.2 The decommissioning process can be broken down into two major processes, backfilling or sealing. These two processes are defined as follows:

6.2.1 *Backfilling*—The practice of placing native soil cuttings or other materials in the hole as a part of the restoration process. This is largely an uncontrolled process and may only inadvertently produce a seal.

6.2.2 *Sealing*—The knowledgeable and conscientious practice of constructing a permanent hydraulic barrier in the hole. This is a carefully controlled practice of hole decommissioning.[2]

6.3 The information for making the decision regarding when a geotechnical exploratory borehole should be sealed must be gathered from a broad spectrum of available resources. The first step to follow in reaching a decision is to perform a review of the existing site data. Data can be collected from a number of sources, including but not limited to:

(a) Geologic reports,
(b) Topographic maps,
(c) Previous borings in the area,
(d) Water well records,
(e) Aquifer maps,
(f) Hazardous site maps,
(g) Survey of industry (pollutant potential),
(h) Survey of existing or proposed landfills, and
(i) State environmental protection agencies.

Making a final decision may require input from various people skilled in different disciplines, such as hydrogeology, geology, drilling, geotechnical engineering, and highway design.

6.4 The goal in decommissioning any hole is to leave, as far as possible, the hydrologic conditions in an unaltered state. This is particularly important where a public water supply is obtained from groundwater in an area. To determine whether this is the case, maps of aquifers used for public water supplies can be obtained from state and local public health agencies and state environmental protection agencies. The need for aquifer protection is as great for private water companies as it is for water supply systems under municipal control.

6.5 A review of geologic reports, water well records, and previous borings can help define where confined aquifers or multiple aquifers are present. Confined aquifers, which are sometimes called artesian aquifers, require special consideration for borehole decommissioning. The confined aquifer is overlain by an impervious layer such as clay or glacial till. When a borehole penetrates the confining layer and enters the underlying aquifer, it is introducing a vertical pathway for aqueous constituents to enter the aquifer. Moreover, the material comprising the confining layer is likely to remain open after the removal of drill rods or casing, so that the avenue for possible contaminants will not be self-sealing. Multiple aquifers are similar to confined aquifers, in that several waterbearing strata of aquifer material are separated by confining impermeable strata. The determination as to whether the medium to be drilled is a confined or multiple aquifer should be made before drilling, or in the field by qualified personnel.

6.6 After information is compiled from the aforementioned sources, it is necessary to make the decision as to whether backfilling or sealing is the most appropriate action. Some boreholes will encounter conditions that mandate sealing in order to safeguard the groundwater resources of the area.

6.6.1 Any boreholes that encounter methane gas should be sealed as quickly as possible. Methane is a naturally occurring explosive gas which may be tapped at relatively shallow depths, and can present a public safety hazard if it is allowed to vent indefinitely from a borehole.

6.6.2 As mentioned earlier, confined aquifers and multiple aquifers are unique geologic conditions, and they require sealing. It is especially important to seal a flowing artesian condition because the groundwater will carry fine material with it as it flows out of the ground, and this may cause future subsidence. Confined aquifers that do not flow to the surface should be sealed as well because of the possibility of cross-contamination of separate and discrete hydrogeologic units.

6.6.3 Boreholes drilled in areas where groundwater is the source of documented large public water supplies should be sealed.

6.6.4 In a heavily populated urban or suburban area, the possibility of future contamination of groundwater is increased because of the density of potential spill sites such as gas stations, landfills, dry cleaning stores, and chemical factories. Boreholes that encounter groundwater in these areas should be sealed.

6.6.5 Boreholes that are drilled in environmentally sensitive areas should be sealed. An example of this would be a piezometer installed in a wetland as part of an environmental impact study.

6.7 Some boreholes do not require sealing, but should be backfilled after use. If backfilling the borehole with native cuttings is justified, care should be taken to compact the upper portion of the native material in the hole to minimize any future subsidence. With any borehole, an open hole should at least be backfilled and not left open, because of the possibility of a hazard to pedestrians and others.

6.7.1 Boreholes that do not encounter groundwater require backfilling, but not sealing, because they do not disturb the hydrologic regime.

6.7.2 If a borehole is located entirely in granular material, it does not require sealing even if groundwater is encountered. After removal of the drilling equipment, granular material will collapse on itself, and the previously existing hydrogeologic conditions will be restored.

6.7.3 If a borehole is located entirely within material of low permeability, backfilling is adequate for decommissioning. An example of this would be a borehole drilled through clay or dense glacial till over shale rock. None of these materials would be considered an aquifer.

6.8 The procedures for properly sealing a borehole are presented in Chapter 7 through Chapter 10 of NCHRP Report 378, *Recommended Guidelines for Sealing Geotechnical Exploratory Holes.*

Note 1—The hole reentry method for sealing penetration holes (Chapter 10) can be used only if the hole remains open on its own after removal of tools.

6.9 It is important that the quality of workmanship and the skills of the drilling personnel who perform the sealing operation are guaranteed. Individual states should determine procedures to qualify personnel for this activity, such as a certification process.

7. RECORD KEEPING

7.1 Proper record-keeping practice is addressed in Chapter 11 of the NCHRP Report 378.

8. INVENTORY OF SEALED BOREHOLES

8.1 In addition to maintaining the sealing records identified in Section 7 of this practice, the borehole should be located using a suitable coordinate system wherever possible. With the advances in Global Positioning technologies and the incorporation of GIS application, complete records and locations of sealed boreholes will provide valuable information to the various state agencies charged with protecting valuable groundwater resources.

9. REFERENCES

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10. ADDITIONAL APPLICATIONS

10.1 The focus of this standard practice is limited to geotechnical exploratory holes. This practice also contains information that may pertain to other activities performed by the transportation industry that result in a vertical conduit being introduced into the ground in an area where protection of groundwater is a consideration.

APPENDIX

(Nonmandatory information)

X1. TERMINOLOGY

X1.1.1. *abandonment*—see *decommissioning*.

X1.1.2. *aquifer*—a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of groundwater to wells or springs.[3]

X1.1.3. *artesian*—groundwater which is under sufficient hydrostatic head to rise above the aquifer containing it. A flowing artesian condition is when water flows up to the surface through a drillhole.

X1.1.4. *artesian well*—a well tapping an aquifer bounded above and below by impermeable beds or beds of distinctly lower permeability than the aquifer itself. The water will rise in the well above the point of initial penetration (above the bottom of the confining or impermeable layer overlying the aquifer). This term includes both flowing and non-flowing wells.[3]

X1.1.5. *backfilling*—the practice of placing native soil cuttings or other materials in the hole as part of the restoration process. This is largely an uncontrolled process and may only inadvertently produce a seal.[4]

X1.1.6. *confined aquifer*—an aquifer that is overlain by a confining bed, which has significantly lower permeability than the aquifer.

X1.1.7. *decommissioning*—the engineered closure of a geotechnical exploratory hole sealed with plugging materials. This term also includes the planning and documenting of all associated activities.

X1.1.8. *geotechnical exploratory borehole*—any temporary cased or uncased borehole completed primarily for the purpose of obtaining geologic or geotechnical data about subsurface soil or rock conditions, and/or for determining groundwater levels. This definition includes all *in situ* testing borings, instrumented boreholes, piezometers, and observation wells.[5]

X1.1.9. *grout*—a fluid mixture of cement, bentonite, and water used to seal the annular space around or between well casings, or to fill and seal abandoned wells or boreholes.[3]

X1.1.10. *monitoring well*—a well designed to obtain a representative groundwater sample and/or to measure the water level elevation over the screened interval.[3]

X1.1.11. *observation well*—a well designed to measure the depth to the water table. An observation well is screened across the water table and usually is installed in unconfined aquifers.[3]

X1.1.12. *permeability*—the ease with which a porous material allows liquid or gaseous fluids to flow through it. For water, this is usually expressed in units of centimeters per second and is termed hydraulic conductivity. Soils and synthetic liners with a permeability for water of 1×10^{-7} cm/sec or less may be considered impermeable.[3]

X1.1.13. *piezometer well*—a well designed to measure the hydraulic potential (water level elevation) at a specific point in the subsurface. A piezometer has a short screen that is positioned entirely beneath the water table.[3]

X1.1.14. *pressure grouting*—a method of forcing grout into specific portions of a well for sealing purposes.[3]

X1.1.15. *public water supply*—any water supply, including source, treatment, storage, transmission, and distribution facilities through which water is furnished for human consumption or other domestic use to any community, collection, or number of individuals, excluding water supplies serving one single family residence.[3]

X1.1.16. *sealing*—the knowledgeable and conscientious practice of constructing a permanent hydraulic barrier in the hole. This is a carefully controlled practice of hole decommissioning.[4]

X1.1.17. *static water level*—the vertical distance from the surface of the ground to the water level in a well when the water level is not affected by pumping or free flow.[3]

X1.1.18. *tremie tube*—a small diameter pipe used to place grout, filter pack material, or other well construction materials in a well.[3]

X1.1.19. *unconfined aquifer*—an aquifer in which there are no confining beds between the zone of saturation and the surface. Also known as a water table aquifer.

X1.1.20. *unconsolidated formation*—any naturally occurring, loosely cemented, or poorly indurated earth material including such materials as uncompacted gravel, sand, silt, and clay. Alluvium, soil, and overburden are terms frequently used to describe such formations.[3]

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[1] For guidance on decommissioning geotechnical exploratory boreholes in hazardous and contaminated sites, refer to ASTM D 5299.

[2] NCHRP Report 378, *Recommended Guidelines for Sealing Geotechnical Exploratory Boreholes*.

[3] Definitions from Chapter 173-160 WAC, "Minimum Standards for Construction and Maintenance of Wells," Washington State Department of Ecology, March 13, 1990.

[4] Definitions from NCHRP 21-4, *Sealing Geotechnical Exploratory Holes to Protect the Subsurface Environment*, August 1995.

[5] Modified from Reference 3.

Standard Practice for

Assessment of Corrosion of Steel Piling for Non-Marine Applications

AASHTO Designation: R 27-01 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Assessment of Corrosion of Steel Piling for Non-Marine Applications

AASHTO Designation: R 27-01 (2006)

1. SCOPE

1.1. This standard practice is focused on corrosion of steel piling for non-marine soil applications.

1.2. This standard practice is divided into two parts: Part I—Environmental Conditions Causing Corrosion of Steel Piling, and Part II—Corrosion Considerations for New and Existing Piling.

1.2.1. Part I of the standard practice describes the current knowledge of the mechanism of underground corrosion to aid the reader in better understanding the controlling factors and identifies the known factors that cause corrosion of piling in non-marine applications.

1.2.2. Part II of the standard practice describes procedures that should be followed to assess the soil corrosivity at a specific site and offers guidance in the selection of corrosion mitigation procedures for new piling installations. Methods are described to evaluate the present condition of existing steel piling. Guidance is provided in the continued use of existing steel piling or reuse of steel piling in new or rehabilitated structures.

1.3. This standard practice does not preclude testing and test methods used to assess design parameters for the placement or continued use of piling.

1.4. Test methods not currently available as AASHTO or ASTM Methods are included in the Appendices of the NCHRP Report 408 (Beavers 1997).

1.5. *This standard practice may involve hazardous materials, operations, and equipment. This standard practice does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 206, Penetration Test and Split-Barrel Sampling of Soils
- T 207, Thin-Walled Tube Sampling of Soils
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 291, Determining Water-Soluble Chloride Ion Content in Soil
- T 306, Progressing Auger Borings for Geotechnical Explorations

2.2. *ASTM Standards*:

- D 512, Standard Test Methods for Chloride Ion In Water

- D 516, Standard Test Method for Sulfate Ion in Water
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 4220, Standard Practices for Preserving and Transporting Soil Samples
- D 4972, Standard Test Method for pH of Soils
- G 51, Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing
- G 57, Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method

3. SIGNIFICANCE AND USE

3.1. This standard practice identifies the factors that cause corrosion of steel piles subjected to subsurface, non-marine environment in underground conditions. It provides procedures to assess the corrosion potential of the piles and offers recommendations on the ways to mitigate the corrosion. By determining the existing condition, the remaining life of the piles can be predicted.

PART I—ENVIRONMENTAL CONDITIONS CAUSING CORROSION OF STEEL PILING

4. MECHANISM OF UNDERGROUND CORROSION

4.1. Corrosion of structural steel in soils is electrochemical in nature. When steel corrodes, the iron atoms in the steel undergo oxidation and lose electrons (Equation 1). Other components in the soil are reduced and gain the lost electrons (some combination of Equations 2, 3, and 4). The electrochemical reaction associated with oxidation is the anodic reaction and the electrochemical reaction associated with reduction is the cathodic reaction. The sites where the anodic and cathodic reactions take place are termed the anode and cathode, respectively. The combination of the anode and the cathode, coupled with current flow between the two, is called a corrosion cell.

4.2. Figure 1 is a schematic of a corrosion cell. As shown in Figure 1, the electrons produced by the oxidation reaction flow from the anode to the cathode in the steel where they are consumed by the reduction reaction. Note that the direction of current flow is opposite to the direction of electron flow since, by definition, current is the flow of positive charge. In the soil, current must flow from the anode to the cathode to maintain charge neutrality. Current flow in the soil is carried by ions, moving through the water in pore spaces between the soil particles.

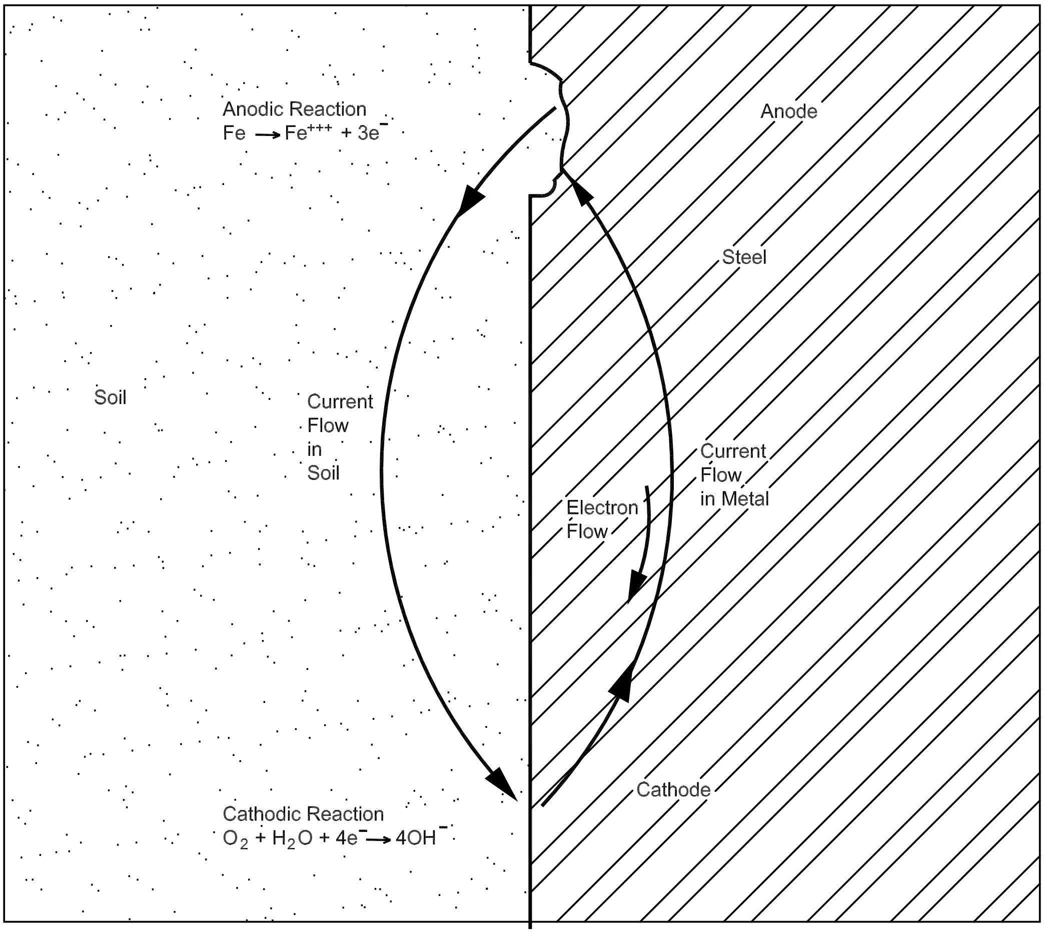

Figure 1—Schematic of a Corrosion Cell

4.3. Oxygen reduction (Equation 2) usually controls the rate of corrosion of steel in soils. This reaction is, in turn, controlled by the rate of movement of oxygen through the soil and water to the steel surface. In the absence of oxygen, reduction of water (Equation 3) can occur. However, this is normally slow enough to cause no significant corrosion damage to steel. Hydrogen ion reduction (Equation 4) occurs when the soil is very acidic and can significantly contribute to the rate of corrosion of steel in such soils. The iron ions produced by oxidation of the steel can eventually react with components in the soil to form corrosion products. For example, Equation 5 shows the iron ions reacting with water to produce rust. Other corrosion-related products are formed on the surface of the metal by the reduction reactions. These products include hydroxide ions (Equations 2 and 3) and hydrogen gas (Equations 3 and 4).

4.3.1. *Oxidation of Iron*:

$$Fe \rightarrow Fe^{+++} + 3e^{-} \qquad (1)$$

4.3.2. *Oxygen Reduction*:

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \qquad (2)$$

4.3.3. *Water Reduction*:

$$2H_2O + 2e^{-} \rightarrow H_2 + 2OH^{-} \qquad (3)$$

4.3.4. *Hydrogen Ion Reduction*:

$$2H^+ + 2e^- \rightarrow H_2 \qquad (4)$$

4.3.5. *Formation of Rust*:

$$2Fe^{+++} + 3H_2O \rightarrow Fe_2O_3 + 6H^+ \qquad (5)$$

4.4. If the anodes and cathodes are very close to each other and evenly distributed on the steel surface, uniform corrosion of the steel occurs. On most underground steel structures, rates of uniform corrosion are low and rarely cause service failures. The most notable exception is where the soil pH is below 4.

4.5. Where the anode and cathode sites are well separated on a steel surface, a "macrocell" is formed. Severe corrosion and resulting service failures can occur when the anode in a macrocell is confined to a relatively small area of the steel. In this instance, the form of corrosion is frequently referred to as pitting. Once macrocells are started on a steel surface, the products of the electrochemical reactions generally cause the macrocell to continue. For example, the reduction reactions cause an increase in the pH at the cathode. Steels form protective films in elevated pH environments, reducing the rate of corrosion. On the other hand, the reactions at the anode reduce the pH. The acidic environment created at the anode causes protective oxide films on the steel to break down, increasing the corrosion rate. As the pH at the anode decreases, the reduction of hydrogen ions may occur locally, further increasing the rate of attack.

4.6. One of the common macrocells on piling in soils is caused by variation in oxygen concentration over the steel surface. Oxygen macrocells frequently develop in stratified soils. Anodes are formed where the oxygen concentration is low, such as in clay soils, and cathodes are formed where the oxygen concentration is high, such as in sandy soils. The water table is another area where oxygen macrocells usually develop. A macrocell also may develop where there is variation in the chloride content of the soil, such as along roads with saltwater run-off. In this macrocell, anodes form in regions of high-chloride concentration.

4.7. Other factors that affect the rate of oxygen macrocell corrosion include the relative surface area of the anode and the cathode, soil resistivity, and microbiological activity. Where the cathode is large and the anode is small, a large current is concentrated at the anode, leading to high rates of corrosion at the anode. Soil corrosivity generally increases with decreasing soil resistivity. Where the soil resistance is high, a high current flow between the anode and cathode cannot occur due to the high voltage (IR) drop in the high resistance soil path. Microbiological activity, or the presence of welds or inclusions in the steel, can also aggravate macrocell corrosion by aiding in the creation of the anodic sites. Further discussion of the effects of resistivity and other parameters on corrosion is given in the NCHRP Report 408.

4.8. Piling and other underground structures also can undergo accelerated corrosion as a result of stray current flow in the soil. Sources of stray current include cathodic protection systems for other structures, direct current (DC) electric transit systems, mining activity, and high voltage DC electric power lines. DC electric current, flowing parallel to a structure, will jump onto that structure if that structure has a lower resistance in the direction of the current flow than the soil. The structure is cathodically protected where the current jumps onto the structure and corrosion is accelerated where the current leaves the structure. Stray current corrosion is most commonly observed on structures that have large dimensions in one horizontal direction, such as pipelines. Sheet piling and other piling that are electrically continuous also can experience stray current corrosion.

4.9. To summarize, corrosion of structural steel in soils is electrochemical in nature and is caused by the presence of oxygen and moisture in the soil. Corrosion is most likely to occur at or above the water table in disturbed stratified soils having low resistivity. For example, fill soils containing man-made materials such as cinders, slag, or ash are known to cause significant corrosion of steel piles. Stray electrical currents flowing in the ground, from sources such as transit systems, also can contribute to corrosion of structural steels in soils.

PART II—CORROSION CONSIDERATIONS FOR NEW AND EXISTING PILING

5. SUMMARY OF APPROACH

5.1. A preliminary investigation (Phase I Site Assessment) is performed to obtain pertinent available information on the surface and subsurface conditions at the site. Information obtained in this investigation may include the position of the piling or pile cap with respect to the groundwater table, the soil characteristics, and the presence of contaminants in the soil. This information is used to determine whether a further (Phase II) assessment is required. In general, a Phase II site investigation is required unless:

5.1.1. The piling or pile cap is or will be below the water table at all times or,

5.1.2. The Phase I site assessment provides the necessary information outlined in the Phase II site investigation to establish the corrosivity of the site.

5.1.3. In cases where there are multiple sites that require investigation, priority should be given to those sites known to contain corrosive materials such as slag, cinders, ash, or other man-made products.

5.2. In the Phase II Site Investigation, continuous soil sampling is performed to a depth of 1 meter below the minimum water table. The testing protocol outlined in Figure 2 is used for analyzing the soil samples. For homogeneous soils, testing is performed every 60 to 90 cm, while testing is performed on each distinct soil layer for inhomogeneous soils. This testing is limited to resistivity, pH, and particle size.

5.3. The flow chart shown in Figure 3 is used, in conjunction with the results of the soil analyses, to determine the likelihood of significant uniform or macrocell corrosion. As shown in the figure, neither form of corrosion is likely to occur at a significant rate if the saturated soil resistivity is greater than approximately 2000 ohm-cm. Depending on the homogeneity, particle size, and pH of the soil, one or both forms of corrosion may occur at a significant rate if the saturated soil resistivity is below 2000 ohm-cm.

5.4. The need for corrosion monitoring, corrosion mitigation, or pile repair or replacement is determined using the flow chart shown in Figure 4. No further testing or analysis is required if the results of the soil analyses indicate there is a low probability of significant uniform or macrocell corrosion. Corrosion monitoring is recommended where one or both forms of corrosion may occur at a significant rate. This corrosion monitoring will establish the rate of corrosion such that a remaining life assessment can be performed. Corrosion mitigation is recommended if the predicted remaining life is less than the design life. Corrosion mitigation is recommended in cases where corrosive soils are present and there is insufficient time for proper corrosion monitoring. Pile repair or replacement is required if there is no predicted remaining life. If the predicted remaining life is much less than the design life, the pile should be excavated and examined to better define the existing condition and the need for repair, replacement, or corrosion mitigation.

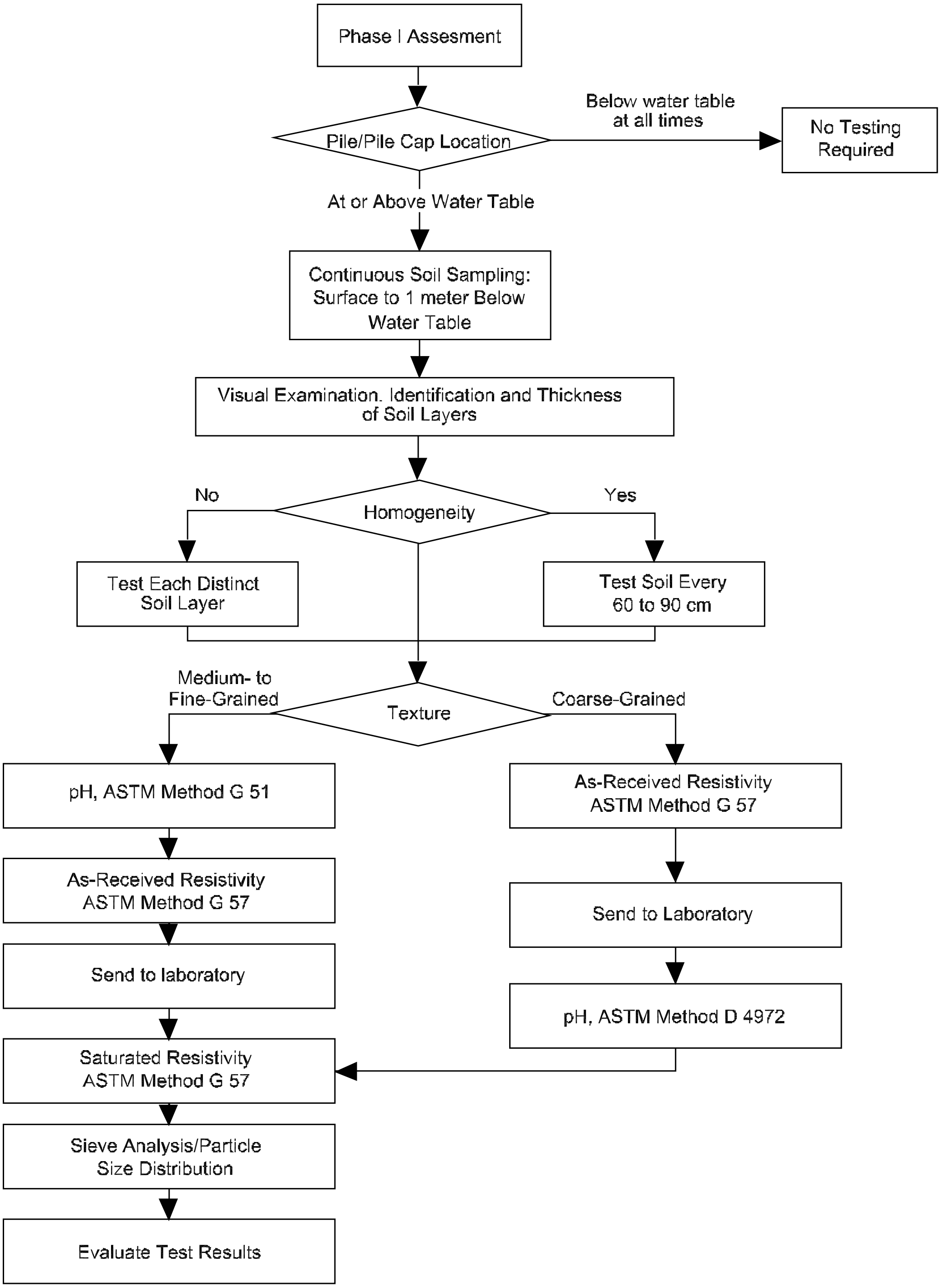

Figure 2—Phase II Site Sampling and Testing Protocol

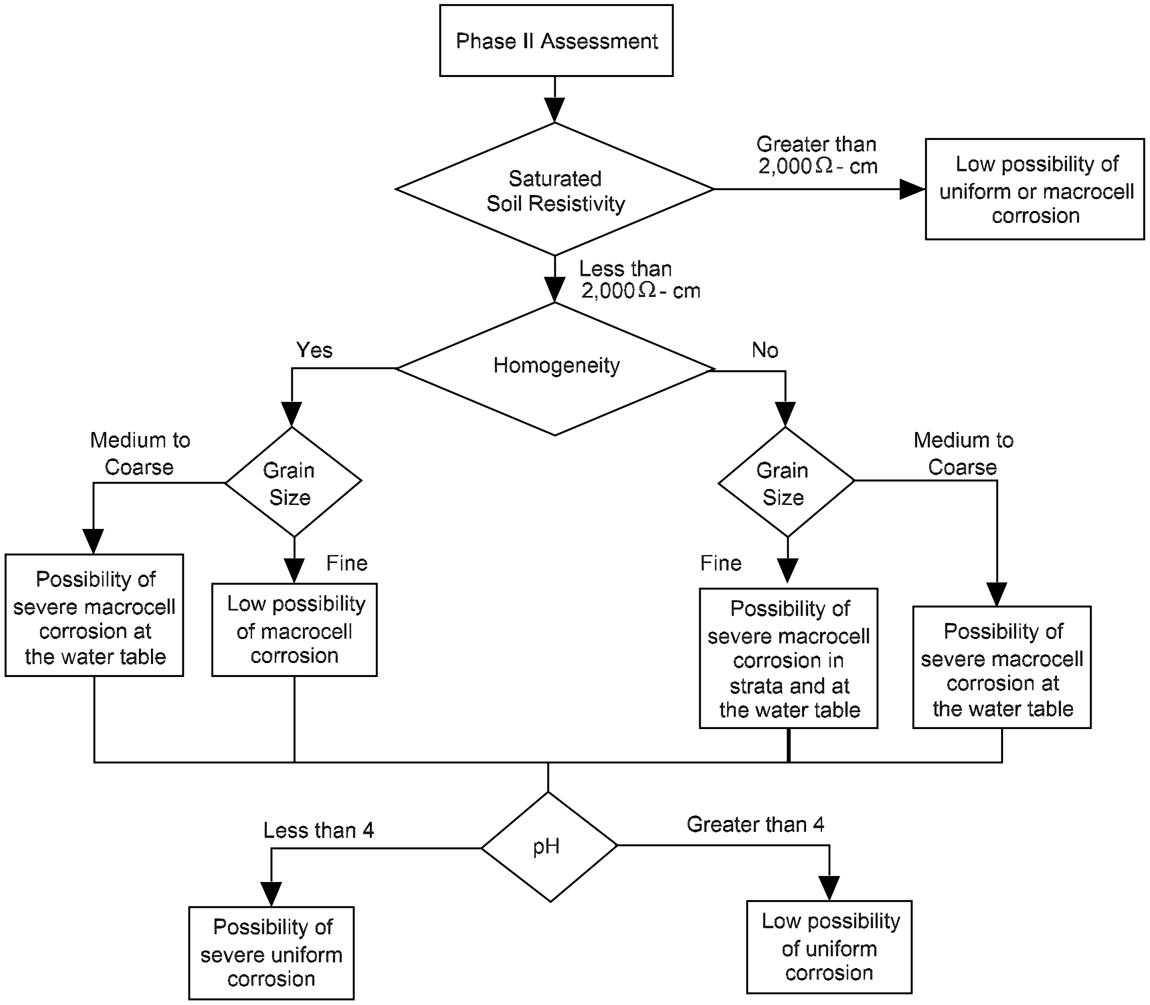

Figure 3—Determination of the Possibility for General and/or Macrocell Corrosion Based on Soil Analysis

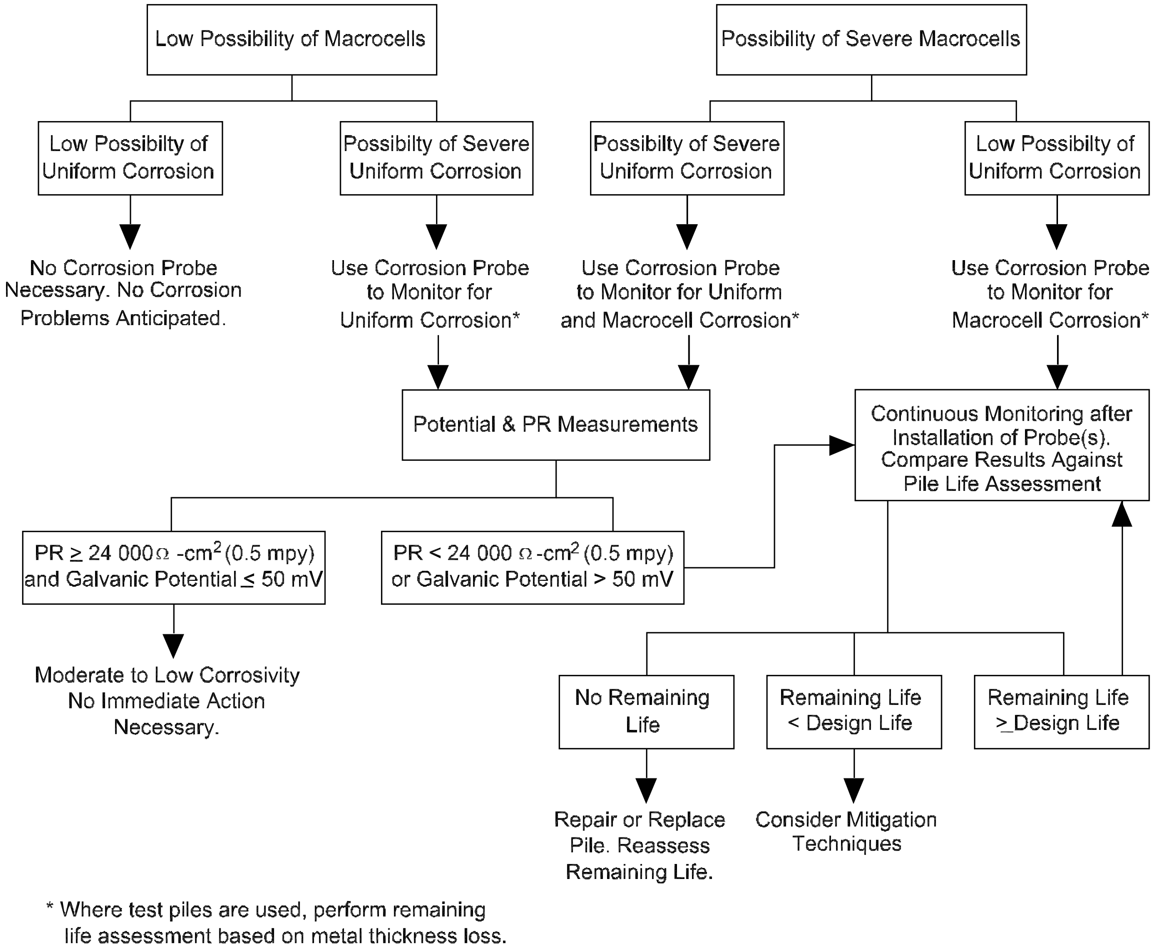

Figure 4—Determination of the Necessity for Electrochemical Testing, Corrosion Monitoring, and Mitigation

6. PHASE I (PRELIMINARY ASSESSMENT)

6.1. The purpose of the Phase I Site Assessment is to obtain pertinent available information on the surface and subsurface conditions to aid in the assessment of soil corrosivity. Information may be available on (1) the position of the pile or pile cap in relation to the groundwater table, (2) the presence of environmental contaminants, (3) characteristics of the soil and rock at the site, and (4) location, fluctuation, and chemistry of the groundwater.

6.2. Possible sources of relevant information for the Phase I Assessment include (1) local and U.S. Geological Survey, (2) USDA Soil Conservation Service, and (3) U.S. and State DOTs.

6.3. All data gathered from the Phase I Assessment should be forwarded to the engineer in charge of the project. These data should be used to determine if a Phase II Site Investigation is required. A Phase II Site Investigation is required unless:

6.3.1. The piling or pile cap is or will be below the water table at all times or,

6.3.2. The Phase I Site Assessment provides the necessary information outlined in the Phase II Site Investigation to establish the corrosivity of the site.

6.3.3. In cases where there are multiple sites that require investigation, priority should be given to those sites known to contain corrosive materials such as slag, cinders, ash, or other man-made products.

7. PHASE II (SITE INVESTIGATION)

7.1. The purpose of the Phase II Site Investigation is to obtain information on soil properties to assess the potential for corrosion of buried steel piles at the site. Figure 2 shows the site sampling and testing protocol.

7.2. *Soil Collection*:

7.2.1. The following quantities of soil are suggested as the minimum sample size suitable for most materials:

Table 1—Minimum Sample Sizes

Test	Total Size	–4.75 mm
Particle Size	50 to 500 g	—
pH	100 g	40 g
Resistivity	2000 g	1800 g

7.2.2. A soil sample with minimal disturbance is preferred for the corrosivity assessment. The following test methods are applicable: T 206, T 207, T 251, and T 255.

7.2.2.1. Continuous samples are preferred, if possible.

7.2.2.2. A 7.6-cm (3-in.) split spoon is an excellent sampling technique in that it provides a non-disturbed, continuous sample of sufficient quantity for the required analyses.

7.2.2.3. Air is the preferred drilling fluid if drilling fluids must be used.

7.2.2.4. If thin-walled tubes are used and the sample is contained for more than 72 hours, the coating in the tube should NOT be oil or any other material that may contaminate the soil sample.

7.2.3. Disturbed samples may be obtained by hand auger or test pit/excavation in the event that a minimally disturbed sample cannot be obtained. Applicable methods include T 203.

7.2.4. Representative samples should be collected, as indicated in Figure 2, to a depth of 1 meter below the water table.

7.2.5. Soil pH and resistivity measurements should be performed in the field (if possible) using ASTM G 51 and G 57, respectively.

7.2.5.1. For determination of pH of coarse-grained soils (gravels), where a stable reading cannot be obtained with ASTM G 51, ASTM D 4972 should be performed in the laboratory. For comparison with ASTM G 51 data, the pH value should be reduced by 0.5 to 1.0 units.

7.3. *Soil Handling*:

7.3.1. *Preserving and Transporting*—The intent, precautions, and procedures of ASTM D 4220 (Group B) are applicable to this practice. Soil samples should be handled in such a way as to preserve moisture and maintain the orientation and integrity of the soil sample. All samples should be placed in sealed glass jars as soon as possible to preserve natural moisture and exclude oxygen. The jars should be clearly labeled as to location, depth, and method of sampling. Ship samples to the laboratory within 1 to 2 days.

7.4. *Laboratory Soil Testing*:

7.4.1. *Sample Reduction*—Sample reduction procedures, if necessary, should not be performed until visual observation is made to describe the soil, thickness, and relationship of the various soil layers. Resistivity and pH should always be determined on the as-received sample prior to sample reduction if not previously determined in the field.

7.4.2. *Description and Identification:*

7.4.2.1. Soil samples should be visually examined in the as-received condition to determine uniformity/homogeneity and particle size.

7.4.2.2. A log of the various soil layers should be recorded and include description, identification, and thickness measurements of the soil layers.

7.4.2.3. Applicable methods include ASTM D 2488 and D 2487. The Unified Soil Classification System (USCS) should be used to classify soil.

7.4.2.4. For non-homogeneous soils, laboratory analyses should be performed on portions of each distinct layer from the surface to a depth of 1 meter below the water table.

7.4.2.5. For homogeneous soils, laboratory analyses should be performed on samples from approximately 60- to 90-cm intervals.

7.4.3. *Resistivity:*

7.4.3.1. The ASTM G 57, Wenner Four-Pin technique, should be used for all soil resistivity measurements.

7.4.3.2. Resistivity measurement should be made using soil finer than 4.75-mm (No. 4) sieve in the as-received condition prior to performing any other soil testing while the natural moisture is still present. Resistivity should also be performed on saturated soil.

7.4.3.3. For saturated measurements, place soil in a glass or plastic jar and saturate with distilled or deionized water. Mix thoroughly, cover, and let sit overnight (at least 14 hours) prior to measurement.

7.4.4. *pH*—Soil pH measurements should be performed in the laboratory using ASTM G 51 if not previously determined in the field. ASTM D 4972 should be used for primarily coarse-grained soils.

7.4.5. *Sulfate:*

7.4.5.1. The ASTM D 516 procedure is applicable.

7.4.5.2. The sulfate calibration curve described in ASTM D 516 may be expanded to accommodate samples whose sulfate concentration is greater than 40 mg/L.

7.4.6. *Chloride*:

7.4.6.1. The chloride concentration shall be determined by either the Mohr method (silver nitrate titration) or by an ion selective electrode. The ASTM D 512 procedure is applicable.

7.4.6.2. If the Mohr Method is used, the pH of the sample (or diluted sample) must be in the range of 6.0 to 8.5. Dilute sulfuric acid or sodium hydroxide may be used to adjust the pH.

7.4.6.3. See T 291 for a list of ions known to interfere with the analysis of chloride.

8. REPORT

8.1. *Report the following information*:

8.1.1. Date, time, depth, and method of sampling;

8.1.2. Sample identification—location and depth;

8.1.3. Position (depth) of the groundwater table;

8.1.4. Test methodology if several methods are applicable; and

8.1.5. All units in metric, followed by English units in parentheses.

9. TEST RESULTS DECISION MATRIX

9.1. All data gathered should be forwarded to the engineer in charge of the project for analysis.

9.2. The flow chart shown in Figure 3 is used to determine the possibility of uniform and or macrocell corrosion based on the soil analysis.

9.3. The flow charts cannot encompass all possibilities for corrosion of steel piling at a given site. Other factors that may contribute to corrosivity at a given site include the presence of chemical contamination, stray DC currents in the soil, and the presence of high concentrations of microbes.

9.3.1. A qualified corrosion specialist should be consulted where it is suspected that these or other unusual conditions that could contribute to corrosion of structural steel piling are present.

9.3.2. Sulfate reducing bacteria are more likely to be present where high-sulfate levels are detected.

9.4. The guidelines provided in the flow charts are not meant to supersede any local, state, or federal requirements.

10. CORROSION PROBES

10.1. The flow chart shown in Figure 4 is used to determine whether corrosion monitoring is required at the site, based on the possibility of uniform and/or macrocell corrosion.

10.1.1. A corrosion probe that is capable of monitoring uniform corrosion (e.g., a polarization resistance (PR) probe or a simple test pile) should be used at sites where soil data indicate a moderate-to-high possibility for uniform corrosion.

Note 1—A test pile is a pile that is removed after a specified exposure period and examined for loss of thickness.

10.1.2. A corrosion probe that is capable of monitoring macrocell corrosion (e.g., a galvanic current probe or test pile) should be used at sites where soil data indicate a moderate-to-high possibility of macrocell corrosion.

10.1.3. A qualified corrosion specialist should be consulted to assist in probe selection and field corrosion rate measurements.

10.2. Corrosion mitigation is recommended in cases where corrosive soils are present and there is insufficient time for proper corrosion monitoring.

10.3. Install probe through the most corrosive soil layers based on the soil analyses. The corrosion probe should be installed in soil as near as possible to the steel pile for long-term corrosion monitoring of new piling, if necessary.

10.3.1. The frequency of measurements and test duration should be established by the person(s) conducting the tests on a site-specific basis.

10.3.2. Procedures for making galvanic current and PR measurements are given in Appendices M and N, respectively, in the NCHRP Report 408.

10.4. Data gathered from the electrochemical measurements should be used to help assess the remaining life of the steel piling, as described below.

11. ESTIMATION OF SERVICE LIFE

11.1. Remaining service life of piles can be estimated if three factors are known. These are: present condition of the piles, rate of degradation of those piles, and the criterion used for the pile failures.

11.2. In establishing the existing condition of piles, two conditions apply:

11.2.1. For new piles, the existing condition is the installed condition.

11.2.2. For existing piles, the condition can be established by excavation and evaluation, or it can be estimated based on the maximum corrosion rate measured electrochemically and the time the pile has been in the ground.

Note 2—The estimated service life, based on the electrochemical measurements, is much less than the design life.

11.3. Estimate rate of piling degradation by (1) direct measurement of dimensional loss of the pile (or test pile) and the time the pile (or test pile) has been in the ground, or (2) the electrochemical corrosion rate measurements.

11.4. Establish remaining service life based on criterion for pile failure.

11.4.1. Failure of steel piling, from a corrosion standpoint, is an average loss equal to 50 percent of the original cross-sectional area.

11.4.2. When using the corrosion rate measurements to calculate sectional loss of an H or sheet pile, be sure to consider metal loss from all sides of the pile.

11.4.3. The section-loss criteria should be used in addition to existing federal, state, and local criterion to determine pile failure.

11.5. The flow chart in Figure 4 shows how the results of the remaining life calculation are used to make decisions with regard to repair, replacement, the application of mitigation techniques, or continued corrosion monitoring of a pile.

11.6. Procedures for excavation and exposure of piling and further details on methods of estimating service life of unprotected bare steel piling are given in Appendix S of the NCHRP Report 408.

12. APPLICATION OF CORROSION MITIGATION

12.1. As shown in Figure 4, corrosion mitigation is recommended where the estimated remaining life is less than the design life.

12.1.1. Possible choices for corrosion mitigation of new piling include the following: cathodic protection, coatings, encasement of pile, remove/replace corrosive fill, alter pile design (for example a thicker cross section), or alternative material of construction for the pile.

12.1.2. Possible choices for corrosion mitigation of existing piling include cathodic protection or remove/replace corrosive fill.

13. KEYWORDS

13.1. Corrosion; corrosion probes; direct current; electrochemical reaction; macrocell; microbiological activity; remaining life; soil resistivity; steel piling.

14. REFERENCES

14.1. Beavers, J. A. and C. L. Durr. *National Cooperative Highway Research Report 408: Corrosion of Steel Piling in Non-Marine Applications.* CC Technologies, Columbus, Ohio for the National Cooperative Highway Research Program Project 10-46, Transportation Research Board, Washington, DC, May 1997.

Standard Practice for

Compost for Erosion/Sediment Control (Filter Berms and Filter Socks)

AASHTO Designation: R 51-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Compost for Erosion/Sediment Control (Filter Berms and Filter Socks)

AASHTO Designation: R 51-10[1]

1. SCOPE

1.1. This specification covers compost produced from various organic by-products for use as a filter berm media for erosion/sediment control. The technique described in this specification is primarily used for temporary erosion/sediment control applications where perimeter controls are required or necessary.

1.2. This technique is appropriate for slopes up to a 2:1 grade (horizontal distance:vertical distance) and on level surfaces and should only be used in areas that have sheet flow drainage patterns (not areas that receive concentrated flows).

1.3. The filter sock technology is appropriate for areas outlined in Section 1.2 as well as areas of high sheet flow erosion, around inlets, and in other disturbed areas of construction sites requiring sediment control. Unlike filter berms, the filter sock technology may be used in areas that have concentrated flow drainage patterns, up to 10 gallons per minute per linear foot of filter sock.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standard*:

- D 2977, Standard Test Method for Particle Size Range of Peat Materials for Horticultural Purposes

2.2. *U.S. EPA Test Method*:

- U.S. EPA Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, 3rd Edition

2.3. *TMECC Sampling and Test Method*:

- *Test Methods for the Examination of Composting and Compost* (TMECC), jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series)

2.4. *Other Standards*:

- U.S. Composting Council Seal of Testing Assurance Program documents
- *Development of Landscape Architecture Specifications for Compost Utilization*, The U.S. Composting Council and the Clean Washington Center, 1997

3. GENERAL DESCRIPTION

3.1. Compost is the product resulting from the controlled biological decomposition of organic material, occurring under aerobic conditions, that has been sanitized through the generation of heat and stabilized to the point that it is appropriate for its particular application. Active composting is typically characterized by a high-temperature phase that sanitizes the product and allows a high rate of decomposition, followed by a lower temperature phase that allows the product to stabilize while still decomposing at a slower rate. Compost should possess no objectionable odors or substances toxic to plants and shall not resemble the raw material from which it was derived. Compost contains plant nutrients but is typically not characterized as a fertilizer.

3.2. Compost may be derived from a variety of feedstocks, including agricultural, forestry, food, or industrial residuals; biosolids (treated sewage sludge); leaf and yard trimmings; manure; tree wood; or source-separated or mixed solid waste.

3.3. Proper thermophilic composting, meeting the U.S. Environmental Protection Agency’s definition for a “process to further reduce pathogens” (PFRP), will effectively reduce populations of human and plant pathogens, as well as destroy noxious weed seeds and propagules.

3.4. Compost is typically characterized as a finely screened and stabilized product that is used as a soil amendment. However, most composts also contain a wood-based fraction (e.g., bark, ground brush and tree wood, wood chips, etc.) that is typically removed before use as a soil amendment. This coarser, woody fraction of compost plays an important role when compost is used in erosion and sediment control. It is even possible to add fresh, ground bark or composted, properly sized wood-based materials to a compost product, as necessary, to improve its efficacy in this application.

3.5. Compost products acceptable for this application must meet the chemical, physical, and biological parameters outlined in Section 4.

4. CHEMICAL, PHYSICAL, AND BIOLOGICAL PARAMETERS

4.1. Compost products specified for use in this application must meet the criteria specified in Table 1. The products’ parameters will vary based on whether vegetation will be established on the filter berm or if it will be self-contained in a filter sock.

4.2. Only compost products that meet all applicable state and federal regulations pertaining to their production and distribution may be used in this application. Approved compost products must meet related state and federal chemical contaminant (e.g., heavy metals, pesticides, etc.) and pathogen limits pertaining to the feedstocks (source materials) in which they were derived.

Table 1—Filter Berm Media Parameters

Parameters[a,b]	Reported as (Units of Measure)	Filter Berm to Be Vegetated	Filter Berm to Be Left Unvegetated	Filter Sock Media
pH[c]	pH units	5.0–8.5	N/A	5.0–8.5
Soluble Salt Concentration[c] (electrical conductivity)	dS/m (mmhos/cm)	Max 5	N/A	N/A
Moisture Content	%, wet weight basis	30–60	30–60	< 60
Organic Matter Content	%, dry weight basis	25–65	25–100	25–100
Particle Size	% passing a selected mesh size, dry weight basis	3 in. (75 mm), 100% passing 1 in. (25 mm), 90% to 100% passing $^{3}/_{4}$ in. (19 mm), 70% to 100% passing $^{1}/_{4}$ in. (6.4 mm), 30% to 75% passing (no more than 60% passing $^{1}/_{4}$ in. (6.4 mm) in high rainfall/flow rate situations) Max particle length of 6 in. (152 mm)	3 in. (75 mm), 100% passing 1 in. (25 mm), 90% to 100% passing $^{3}/_{4}$ in. (19 mm), 70% to 100% passing $^{1}/_{4}$ in. (6.4 mm), 30% to 75% passing (no more than 50% passing $^{1}/_{4}$ in. (6.4 mm) in high rainfall/flow rate situations) Max particle length of 6 in. (152 mm)	2 in. (50 mm), 99% to 100% passing $^{3}/_{8}$ in. (10 mm), 30% to 50% passing (or 50% to 70% retained) Maximum particle length of 2 in. (50 mm)
Stability/Maturity[d]				
Carbon Dioxide Evolution Rate	mg CO_2-C per g OM per day	< 8	N/A	N/A
Physical Contaminants (man-made inerts)	%, dry weight basis	< 1	< 1	< 1

[a] Recommended test methodologies are provided in *Test Methods for the Examination of Composting and Compost* (TMECC, The U.S. Composting Council).

[b] Landscape Architects and Project (Field) Engineers may modify the allowable compost specification ranges based on specific field conditions and plant requirements.

[c] Each specific plant species requires a specific pH range. Each plant also has a salinity tolerance rating, and maximum tolerable quantities are known. When specifying the establishment of any plant or turf species, it is important to understand their pH and soluble salt requirements, and how they relate to the compost in use.

[d] Stability/Maturity rating is an area of compost science that is still evolving, and as such, other various test methods could be considered. Also, never base compost quality conclusions on the result of a single stability/maturity test.

4.3. Very coarse (woody) composts that contain less than 30 percent of fine particles (1 mm in size) should be avoided if optimum reductions in total suspended solids (TSS) is desired or if the berm is to be seeded.

4.4. In regions subject to higher rates of precipitation and/or greater rainfall intensity, larger compost filter berms or filter socks should be used. In these particular regions, coarser compost products are preferred as the filter berm must allow for an improved water percolation rate.

Design Note: Engineers should inquire as to the flow rate per linear foot of filter sock in order to ensure drainage rate of tool being used is in accordance with total watershed management plan. Required flow through rates are outlined in Table 2.

Table 2—Suggested Compost Filter Sock Flow Through Rates

Annual Rainfall/Flow Rate	Flow Rates
Low	4–6 gallons/minute
Average	6–10 gallons/minute
High	>10 gallons/minute

Note 1—Specifying the use of compost products that are certified by the U.S. Composting Council's Seal of Testing Assurance (STA) Program (www.compostingcouncil.org) will allow for the acquisition of products that are analyzed on a routine basis using the specified test methods. STA participants are also required to provide a standard product label to all customers, allowing easy comparison to other products.

5. FIELD APPLICATIONS

5.1. The following steps shall be taken for the proper installation of compost as a filter berm or filter sock media for erosion/sediment control on both level and sloped areas. Either device should be placed as prescribed on the engineering plans.

5.2. *Filter Berms*:

5.2.1. Parallel to the base of the slope, or around the perimeter of affected areas, construct a trapezoidal berm at the dimensions specified in Table 3. In general, when compost filter berms are used to control erosion/sediment near or on a slope, the base of the berm should be twice the height of the berm.

5.2.2. Compost shall be applied to the dimensions specified in Table 3.

Table 3—Compost Filter Berm Dimensions

Annual Rainfall/Flow Rate	Total Precipitation and Rainfall Erosivity Index	Dimensions for the Compost Filter Berm (Height by Width)
Low	1–25 in., 20–90	1 ft by 2 ft–1$^1/_2$ ft by 3 ft (30 cm by 60 cm–45 cm by 90 cm)
Average	26–50 in., 91–200	1 ft by 2 ft–1$^1/_2$ ft by 3 ft (30 cm by 60 cm–45 cm by 90 cm)
High	51 in. and above, 201 and above	1$^1/_2$ ft by 3 ft–2 ft by 4 ft (45 cm by 90 cm–60 cm by 120 cm)

5.2.3. Compost filter berm dimensions should be modified based on specific site (e.g., soil characteristics and existing vegetation) and climatic conditions, as well as particular project-related requirements. The severity of slope grade, as well as slope length, will also influence the size of the berm.

5.2.4. In regions subject to higher rates of precipitation or rainfall intensity, or both, as well as spring snow melt, larger berms should be used. In these regions, and on sites possessing severe grades or long slope lengths, berms possessing a larger dimension may be used. Berms may be placed at the top and the base of the slope, a series of berms may be constructed down the profile of the slope (15–25 ft apart), or berms may be used in conjunction with a compost blanket (surface applied compost). In these particular regions as well as regions subject to wind erosion, coarser compost products are also preferred for use in filter berm construction.

5.2.5. In regions subject to lower rates of precipitation and/or rainfall intensity, smaller berms may be used. However, the minimum filter berm dimensions shall be 1 ft (30 cm) high by 2 ft (60 cm) wide.

Note 2—Specific regions may receive higher rainfall rates, but this rainfall is received through low-intensity rainfall events (e.g., the Northwestern United States). These regions may use smaller berms.

5.2.6. Larger berms should also be used where required to be in place and functioning for more than 1 year.

5.2.7. Compost shall be uniformly applied using an approved spreader unit, such as a pneumatic blower, specialized berm machine, etc. When applied, the compost should be directed at the soil surface, compacting (settling) and shaping the berm to some degree. The filter berm may also be applied by hand when approved by the Project Engineer or Landscape /Designer.

5.2.8. On highly unstable soils, use compost filter berms in conjunction with appropriate structural measures. If used in conjunction with a silt fence, the silt fence fabric shall be laid on the soil surface with the lip facing the slope. The compost filter berm shall be constructed at the uphill base of the silt fence and over the entire fence fabric lip.

5.2.9. Seeding the berm may be done, if desired, in conjunction with pneumatic blowing, or following berm construction with a hydraulic seeding unit, or by hand.

5.3. *Filter Socks*:

5.3.1. Filter socks shall either be made on site or delivered to the jobsite. The filter sock shall be produced from a 5-mil-thick continuous high density polyethylene (HDPE) filament, woven into a tubular mesh netting material with openings in the knitted mesh of $^{3}/_{8}$ in. (10 mm). This shall then be filled with compost meeting the specifications outlined in Table 1 to the diameter of the sock. Filter sock netting materials are also available in biodegradable plastics for areas where removal and disposal are not planned. Filter socks contain the compost, allowing filtration to occur even during peak storm events and concentrated flows.

5.3.2. Filter socks will be placed at locations indicated on plans as directed by the Engineer. Filter socks should be installed parallel to the base of the slope or other affected area, perpendicular to sheet flow. In extreme conditions (i.e., 2:1 slopes), or when sheet flow flows to the area from a parcel above the work zone, a second sock shall be constructed at the top of the slope in order to dissipate flows.

5.3.3. At locations where greater than a 200-ft-long section of ground is to be treated with a filter sock, the sock lengths should be sleeved. After one sock section (200 ft) is filled and tied off (knotted) or zip tied, the second sock section shall be pulled over the first (1–2 ft) and “sleeved” creating an overlap. Once overlapped, the second section is filled with compost starting at the sleeved area to create a seamless appearance. The socks may be staked at the overlapped area (where the sleeve is) to keep the sections together. Sleeving at the joints is necessary because it reduces the opportunity for water to penetrate the joint when installed in the field.

5.3.4. In general, a 12-in. diameter filter sock will replace a normal (24-in.) silt fence, and an 18-in. diameter filter sock will replace a “super silt” (36-in.) silt fence reinforced with steel posts.

5.3.5. If the filter sock is to be left as a permanent filter or part of the natural landscape, it may be seeded at time of installation for establishment of permanent vegetation. The Engineer shall specify seed requirements.

5.3.6. Filter socks may be used in direct flow situations perpendicular to runoff channels not exceeding 3 ft (90 cm) in depth. Normally, 8-in. filter socks should be used. Be sure to stake the filter sock perpendicular to water flow, at a minimum interval of 10 linear feet, using 2-in. (5-cm) wooden stakes. The stakes should be projected through the center of the filter sock and into the soil 1 ft (30 cm) deep and leaving 3–4 in. (7.5–10 cm) protruding above the filter sock.

6. TEST METHODS

6.1. The chemical, physical, and biological analysis of the compost shall be determined in accordance with the *Test Methods for the Examination of Composting and Compost* (TMECC), jointly published by the U.S. Department of Agriculture and the U.S. Composting Council (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). (See Appendix X1.)

6.2. ASTM D 2977 shall be used to determine gradation of the compost.

7. SAMPLING, INSPECTION, PACKING, AND MARKING

7.1. The sampling, testing, packing, and marking of compost samples shall be done in accordance with TMECC 02.01-B (Selection of Sampling Locations for Windrows and Piles).

8. KEYWORDS

8.1. Compost; compost logs; compost socks; compost tubes; compost wattles; erosion control; filter berm; filter logs; filter socks; filter tubes; sediment control; sheet flow.

APPENDIXES

(Nonmandatory Information)

X1. METHODS FOR THE SAMPLING AND CHARACTERIZATION OF COMPOST

X1.1. Sampling procedures to be used for purposes of this specification (and the Seal of Testing Assurance Program) are as provided in 02.01 Field Sampling of Compost Materials, 02.01-B Selection of Sampling Locations for Windrows and Piles of the *Test Methods for the Examination of Composting and Compost* (TMECC), Chapter 2, Section One, Sample Collection and Laboratory Preparation, jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). The sample collection section is available online at http://tmecc.org/tmecc/.

X1.2. Test Methods to be used for purposes of this specification are as provided in the *Test Methods for the Examination of Composting and Compost* (TMECC), jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). A list of such methods is provided in the table below and online at http://tmecc.org/tmecc/.

Table X1.1—Test Methods for Compost Characterization

Compost Parameters	Reported as	Test Method	Test Method Name
pH		TMECC 04.11-A	Electrometric pH Determinations for Compost. 1:5 Slurry Method.
Soluble salts	dS/m (mmhos/cm)	TMECC 04.10-A	Electrical Conductivity for Compost. 1:5 Slurry Method (Mass Basis).
Primary plant nutrients:	%, as-is (wet) and dry weight basis		
Nitrogen	Total N	TMECC 04.02-D	Nitrogen. Total Nitrogen by Combustion.
Phosphorus	P_2O_5	TMECC 04.03-A	Phosphorus. Total Phosphorus.
Potassium	K_2O	TMECC 04.04-A	Potassium. Total Potassium.
Calcium	Ca	TMECC 04.04-Ca	Secondary and Micro-Nutrient Content. Calcium.
Magnesium	Mg	TMECC 04.04-Mg	Secondary and Micro-Nutrient Content. Magnesium.
Moisture content	%, wet weight basis	TMECC 03.09-A	Total Solids and Moisture at 70 ± 5°C.
Organic matter content	%, dry weight basis	TMECC 05.07-A	Matter Method. Loss on Ignition Organic Matter Method.
Particle size	Screen size passing through	TMECC 02.12-B	Laboratory Sample Preparation. Sample Sieving for Aggregate Size Classification.
Stability (respirometry)	mg CO_2-C per g TS per day mg CO_2-C per g OM per day	TMECC 05.08-B	Respirometry. Carbon Dioxide Evolution Rate.
Maturity (Bioassay)		TMECC 05.05-A	Biological Assays. Seedling Emergence and Relative Growth.
Percent Emergence	% (average)		
Relative Seedling Vigor	% (average)		

X2. ADDITIONAL INFORMATION—WEBSITES

X2.1. For additional information on regional precipitation rates or rainfall erosivity indexes go online at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/us_12-month_precip.shtml or http://topsoil.nserl.purdue.edu/nserlweb/weppmain.

X2.2. U.S. Composting Council Seal of Testing Assurance Program documents are available at http://tmecc.org/sta/ or www.compostingcouncil/programs/sta.org.

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[1] This standard was first published as MP 9 in 2003. Revised in 2006. Reconfirmed in 2007. Published as a full standard in 2010.

Standard Practice for

Compost for Erosion/Sediment Control (Compost Blankets)

AASHTO Designation: R 52-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Compost for Erosion/Sediment Control (Compost Blankets)

AASHTO Designation: R 52-10[1]

1. SCOPE

1.1. This specification covers compost produced from various organic by-products for use as a surface mulch for erosion/sediment control on sloped areas. This technique may be used for both temporary and permanent erosion/sediment control applications.

1.2. This technique is appropriate for slopes up to a 2:1 grade (horizontal distance:vertical distance) and should only be used in areas that have sheet flow drainage patterns (not areas that receive concentrated flows). This technique may also be used on up to 1:1 slopes with proper consideration to length of slope and compost application rates (depth).

2. REFERENCED DOCUMENTS

2.1. *ASTM Standard*:

- D 2977, Standard Test Method for Particle Size Range of Peat Materials for Horticultural Purposes

2.2. *U.S. EPA Test Method*:

- U.S. EPA Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, 3rd Edition

2.3. *TMECC Sampling and Test Method*:

- *Test Methods for the Examination of Composting and Compost* (TMECC), jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series)

2.4. *Other Standards*:

- U.S. Composting Council Seal of Testing Assurance Program documents
- *Development of Landscape Architecture Specifications for Compost Utilization*, The U.S. Composting Council and the Clean Washington Center, 1997

3. GENERAL DESCRIPTION

3.1. Compost is the product resulting from the controlled biological decomposition of organic material, occurring under aerobic conditions, which has been sanitized through the generation of heat and stabilized to the point that it is appropriate for its particular application. Active composting is typically characterized by a high-temperature phase that sanitizes the product and allows a high rate of decomposition, followed by a lower temperature phase that allows the product to stabilize while still decomposing at a slower rate. Compost should possess no objectionable odors or substances toxic to plants and shall not resemble the raw material from which it was derived. Compost contains plant nutrients but is typically not characterized as a fertilizer.

3.2. Compost may be derived from a variety of feedstocks, including agricultural, forestry, food, or industrial residuals; biosolids (treated sewage sludge); leaf and yard trimmings; manure; tree wood; or source-separated or mixed solid waste.

3.3. Proper thermophilic composting, meeting the U.S. Environmental Protection Agency's definition for a "process to further reduce pathogens" (PFRP), will effectively reduce populations of human and plant pathogens, as well as destroy noxious weed seeds and propagules.

3.4. Compost is typically characterized as a finely screened and stabilized product that is used as a soil amendment. However, most composts also contain a wood-based fraction (e.g., bark, ground brush and tree wood, wood chips, etc.) that is typically removed before use as a soil amendment. This coarser, woody fraction of compost plays an important role when compost is used in erosion and sediment control. It is even possible to add fresh, ground bark or composted, properly sized wood-based material to a compost product, as necessary, to improve its efficacy in this application.

3.5. Compost products acceptable for this application must meet the chemical, physical, and biological parameters outlined in Section 4.

4. CHEMICAL, PHYSICAL, AND BIOLOGICAL PARAMETERS

4.1. Compost products specified for use in this application are described in Table 1. The products' parameters will vary based on whether vegetation will be established on the treated slope.

4.2. Only compost products that meet all applicable state and federal regulations pertaining to its production and distribution may be used in this application. Approved compost products must meet related state and federal chemical contaminant (e.g., heavy metals, pesticides, etc.) and pathogen limit standards pertaining to the feedstocks (source materials) in which they were derived.

Table 1—Compost Blanket Parameters

Parameters[a,b]	Reported as (Units of Measure)	Surface Mulch to Be Vegetated	Surface Mulch to Be Left Unvegetated
pH[c]	pH units	5.0–8.5	N/A
Soluble Salt Concentration[c] (electrical conductivity)	dS/m (mmhos/cm)	Max 5	Max 5
Moisture Content	%, wet weight basis	30–60	30–60
Organic Matter Content	%, dry weight basis	25–65	25–100
Particle Size	% passing a selected mesh size, dry weight basis	3 in. (75 mm), 100% passing 1 in. (25 mm), 90% to 100% passing $^3/_4$ in. (19 mm), 65% to 100% passing $^1/_4$ in. (6.4 mm), 0% to 75% passing Max particle length of 6 in. (152 mm)	3 in. (75 mm), 100% passing 1 in. (25 mm), 90% to 100% passing $^3/_4$ in. (19 mm), 65% to 100% passing $^1/_4$ in. (6.4 mm), 0% to 75% passing Max particle length of 6 in. (152 mm)
Stability/Maturity[d]			
Carbon Dioxide Evolution Rate	mg CO_2-C per g OM per day	<8	N/A
Physical Contaminants (man-made inerts)	%, dry weight basis	<1	< 1

[a] Recommended test methodologies are provided in *Test Methods for the Examination of Composting and Compost* (TMECC, The U.S. Composting Council).

[b] Landscape Architects and Project (Field) Engineers may modify the allowable compost specification ranges based on specific field conditions and plant requirements.

[c] Each specific plant species requires a specific pH range. Each plant also has a salinity tolerance rating, and maximum tolerable quantities are known. When specifying the establishment of any plant or turf species, it is important to understand their pH and soluble salt requirements, and how they relate to the compost in use.

[d] Stability/Maturity rating is an area of compost science that is still evolving, and as such, other various test methods could be considered. Also, never base compost quality conclusions on the result of a single stability/maturity test.

4.3. Very coarse compost should be avoided if the slope is to be landscaped or seeded as it will make planting and crop establishment more difficult.

4.4. In regions subject to higher rates of precipitation and/or rainfall intensity, higher compost application rates should be used. In these particular regions, as well as regions subject to wind erosion, coarser compost products are preferred.

Note 1—Specifying the use of compost products that are certified by the U.S. Composting Council's Seal of Testing Assurance (STA) Program (www.compostingcouncil.org) will allow for the acquisition of products that are analyzed on a routine basis, using the specified test methods. STA participants are also required to provide a standard product label to all customers, allowing easy comparison to other products.

Where water quality is an issue, or in areas in proximity to sensitive water bodies, the appropriate compost product should be used and vegetating the compost blanket should be considered.

5. FIELD APPLICATIONS

5.1. The following steps shall be taken for the proper installation of compost as a soil blanket for erosion/sediment control on sloped areas.

5.1.1. Slightly roughen (scarify) slopes and remove large clods, rocks, stumps, roots larger than two in. in diameter, and debris on slopes where vegetation is to be established. This soil preparation step may be eliminated where approved by the Project Engineer or Landscape Architect/Designer, or where seeding or planting is not planned. Where practical, track (compact) perpendicular to contours on the slope using a bulldozer before applying compost as a soil blanket.

5.1.2. Apply compost at the rates specified in Table 2.

Table 2—Compost Blanket Application Rates

Annual Rainfall/Flow Rate	Total Precipitation and Rainfall Erosivity Index	Application Rate for Vegetated Compost Surface Mulch[a]	Application Rate for Unvegetated Compost Surface Mulch
Low	1–25 in., 20–90	$\frac{1}{2}$–$\frac{3}{4}$ in. (12.5–19 mm)	1–1$\frac{1}{2}$ in. (25–37.5 mm)
Average	26–50 in., 91–200	$\frac{3}{4}$–1 in. (19–25 mm)	1$\frac{1}{2}$–2 in. (37.5–50 mm)
High	51 in. and above, 201 and above	1–2 in. (25–50 mm)	2–4 in. (50–100 mm)

[a] These lower application rates should only be used in conjunction with seeding and for compost blankets applied during the prescribed planting season for the particular region.

5.1.2.1. Compost blanket application rates should be modified based on specific site (e.g., soil characteristics and existing vegetation) and climatic conditions as well as particular project-related requirements. The severity of slope grade, as well as slope length, will also influence compost application rates.

5.1.2.2. In regions subject to higher rates of precipitation and/or rainfall intensity, higher compost application rates should be used. In these regions, as well as those with spring snow melt and on sites possessing severe grades or long slope lengths, the compost blanket may be used in conjunction with a compost filter berm. The filter berm may be 1–2 ft (30 cm–60 cm) high by 2–4 ft (60 cm–120 cm) wide, and may be placed at the top or base (or both) of the slope. In these particular regions, as well as regions subject to wind erosion, coarser compost products may be preferred.

5.1.2.3. In regions subject to lower rates of precipitation or rainfall intensity, or both, lower compost application rates may be used.

Note 2—Specific regions may receive higher rainfall rates, but this rainfall is received through low-intensity rainfall events (e.g., the Northwestern United States). These regions may use lower compost application rates.

5.1.3. Compost shall be uniformly applied using an approved spreader unit, such as a bulldozer, side discharge manure spreader, etc. Alternatively, apply compost using a pneumatic (blower) unit, or other unit that propels the product directly at the soil surface, thereby preventing water from moving between the soil-compost interface. Thorough watering may be used to improve settling of the compost. Apply compost layer approximately 3 ft (90 cm) over the top of the slope, or overlap it into existing vegetation.

5.1.4. On highly unstable soils, use compost in conjunction with appropriate structural measures.

5.1.5. Dry or hydraulic seeding may be completed following compost application, as required, or during the compost application itself, where a pneumatic unit is used to apply the compost.

6. TEST METHODS

6.1. The chemical, physical, and biological analysis of the compost shall be determined in accordance with the *Test Methods for the Examination of Composting and Compost* (TMECC), jointly published by the U.S. Department of Agriculture and the U.S. Composting Council (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). (See Appendix X1.)

6.2. ASTM D 2977 shall be used to determine compost gradation.

7. SAMPLING, INSPECTION, PACKING, AND MARKING

7.1. The sampling, testing, packing, and marking of compost samples shall be done in accordance with TMECC 02.01-B (Selection of Sampling Locations for Windrows and Piles).

8. KEYWORDS

8.1. Compost; erosion control; sediment control; sheet flow; slope stabilization.

APPENDIXES

(Nonmandatory Information)

X1. METHODS FOR THE SAMPLING AND CHARACTERIZATION OF COMPOST

X1.1. Sampling procedures to be used for purposes of this specification (and the Seal of Testing Assurance program) are as provided in 02.01 Field Sampling of Compost Materials, 02.01-B Selection of Sampling Locations for Windrows and Piles of the *Test Methods for the Examination of Composting and Compost* (TMECC), Chapter 2, Section One, Sample Collection and Laboratory Preparation, jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). The sample collection section is available online at http://tmecc.org/tmecc/.

X1.2. Test Methods to be used for purposes of this specification are as provided in the *Test Methods for the Examination of Composting and Compost* (TMECC), jointly published by the USDA and USCC (2002 publishing as a part of the USDA National Resource Conservation Technical Bulletin Series). A list of such methods is provided in the table below and online at http://tmecc.org/tmecc/.

Table X1.1—Test Methods for Compost Characterization

Compost Parameters	Reported as	Test Method	Test Method Name
pH	pH units	TMECC 04.11-A	Electrometric pH Determinations for Compost. 1:5 Slurry Method.
Soluble salts	dS/m (mmhos/cm)	TMECC 04.10-A	Electrical Conductivity for Compost. 1:5 Slurry Method (Mass Basis).
Primary plant nutrients:	%, as-is (wet) and dry weight basis		
Nitrogen	Total N	TMECC 04.02-D	Nitrogen. Total Nitrogen by Combustion.
Phosphorus	P_2O_5	TMECC 04.03-A	Phosphorus. Total Phosphorus.
Potassium	K_2O	TMECC 04.04-A	Potassium. Total Potassium.
Calcium	Ca	TMECC 04.04-Ca	Secondary and Micro-Nutrient Content. Calcium.
Magnesium	Mg	TMECC 04.04-Mg	Secondary and Micro-Nutrient Content. Magnesium.
Moisture content	%, wet weight basis	TMECC 03.09-A	Total Solids and Moisture at 70 ± 5°C.
Organic matter content	%, dry weight basis	TMECC 05.07-A	Matter Method. Loss on Ignition Organic Matter Method.
Particle size	Screen size passing through	TMECC 02.12-B	Laboratory Sample Preparation. Sample Sieving for Aggregate Size Classification.
Stability (respirometry)	mg CO_2-C per g TS per day mg CO_2-C per g OM per day	TMECC 05.08-B	Respirometry. Carbon Dioxide Evolution Rate.
Maturity (Bioassay)		TMECC 05.05-A	Biological Assays. Seedling Emergence and Relative Growth.
Percent Emergence	% (average)		
Relative Seedling Vigor	% (average)		

X2. ADDITIONAL INFORMATION—WEBSITES

X2.1. For additional information on regional precipitation rates or rainfall erosivity indexes go online at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/us_12-month_precip.shtml or http://topsoil.nserl.purdue.edu/nserlweb/weppmain.

X2.2. Find U.S. Composting Council Seal of Testing Assurance Program documents at http://tmecc.org/sta/ or www.compostingcouncil/programs/sta.org.

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[1] This standard was first published as MP 10 in 2003. Reconfirmed in 2005 and 2007. Published as a full standard in 2010.

Standard Specification for

Wire-Cloth Sieves for Testing Purposes

AASHTO Designation: M 92-10
ASTM Designation: E 11-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Wire-Cloth Sieves for Testing Purposes

AASHTO Designation: M 92-10
ASTM Designation: E 11-09

AASHTO M 92-10 is identical to ASTM E 11-09.

Standard Specification for

Flow Table for Use in Tests of Hydraulic Cement

AASHTO Designation: M 152M/M 152-06[1]
ASTM Designation: C 230/C 230M-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Flow Table for Use in Tests of Hydraulic Cement

AASHTO Designation: M 152M/M 152-06[1]
ASTM Designation: C 230/C 230M-03

1. SCOPE

1.1. This specification covers requirements for the flow table and accessory apparatus (Note 1) used in making flow tests for consistency of mortars in tests of hydraulic cement.

Note 1—To help clarify the design of the flow table and accessory apparatus see the drawing in Figure 1 [Figure 2]. This drawing is for informational purposes only.

1.2. The values stated in either SI units or inch-pound units shall be regarded separately as standard. The values stated are not exact equivalents; therefore, each system must be used independently of the other. It is permissible to use an inch-pound caliper and mold with an SI flow table or an SI caliper and mold with an inch-pound flow table. It is not permissible to mix an SI mold with an inch-pound caliper or an inch-pound mold with an SI caliper.

2. FLOW TABLE AND FRAME

2.1. The flow table apparatus shall consist of an integrally cast rigid iron frame and a circular rigid tabletop 255.0 ± 2.5 mm [10 ± 0.1 in.] in diameter, with a shaft attached perpendicular to the tabletop by means of a screw thread. The tabletop and shaft with contact shoulder shall be mounted on a frame in such a manner that it can be raised and dropped vertically through the specified height of 12.7 ± 0.13 mm [0.500 ± 0.005 in.] for new tables and 12.7 ± 0.38 mm [0.500 ± 0.015 in.] for tables in use, by means of a rotated cam. The tabletop shall have a fine machined plane surface, free of blowholes and surface defects. The top shall be scribed with eight equidistant lines 68 mm [$2^5/_8$ in.] long, extending from the outside circumference toward the center of the table. Each line shall end with a scribed arc, 6 mm [$^1/_4$ in.] long, whose center point is the center of the table top with a radius of 59.5 mm [$2^3/_8$ in.]. The scribe lines shall be made with a 60-degree tool to a depth of 0.25 mm [0.01 in.]. The tabletop shall be of cast brass or bronze having a Rockwell hardness number not less than 25 HRB with an edge thickness of 7.5 mm [0.3 in.], and shall have six integral radial stiffening ribs. The tabletop and attached shaft shall have a mass of 4.08 ± 0.05 kg [9 ± 0.1 lb] and the mass shall be symmetrical around the center of the shaft.

2.2. The cam and vertical shaft shall be of medium carbon machinery steel, hardened where indicated in Figure 1 or Figure 2. The shaft shall be straight and the difference between the diameter of the shaft and the diameter of the bore of the frame shall be not less than 0.05 mm [0.002 in.] and not more than 0.08 mm [0.003 in.] for new tables and shall be maintained at 0.05 to 0.25 mm [0.002 to 0.010 in.] for tables in use. The end of the shaft shall not fall upon the cam at the end of the drop, but shall make contact with the cam not less than 120 degrees from the point of drop. The face of the cam shall be a smooth spiraled curve of uniformly increasing radius from 13 to 32 mm [$^1/_2$ to $1^1/_4$ in.] in 360 degrees and there shall be no appreciable jar as the shaft comes into contact with the cam. The cam shall be so located and the contact faces of the cam and shaft shall be such that the table does not rotate more than one revolution in 25 drops. The surfaces of the frame and of the table which come into contact at the end of the drop shall be maintained smooth, plane, and horizontal and parallel with the upper surface of the table and shall make continuous contact over a full 360 degrees.

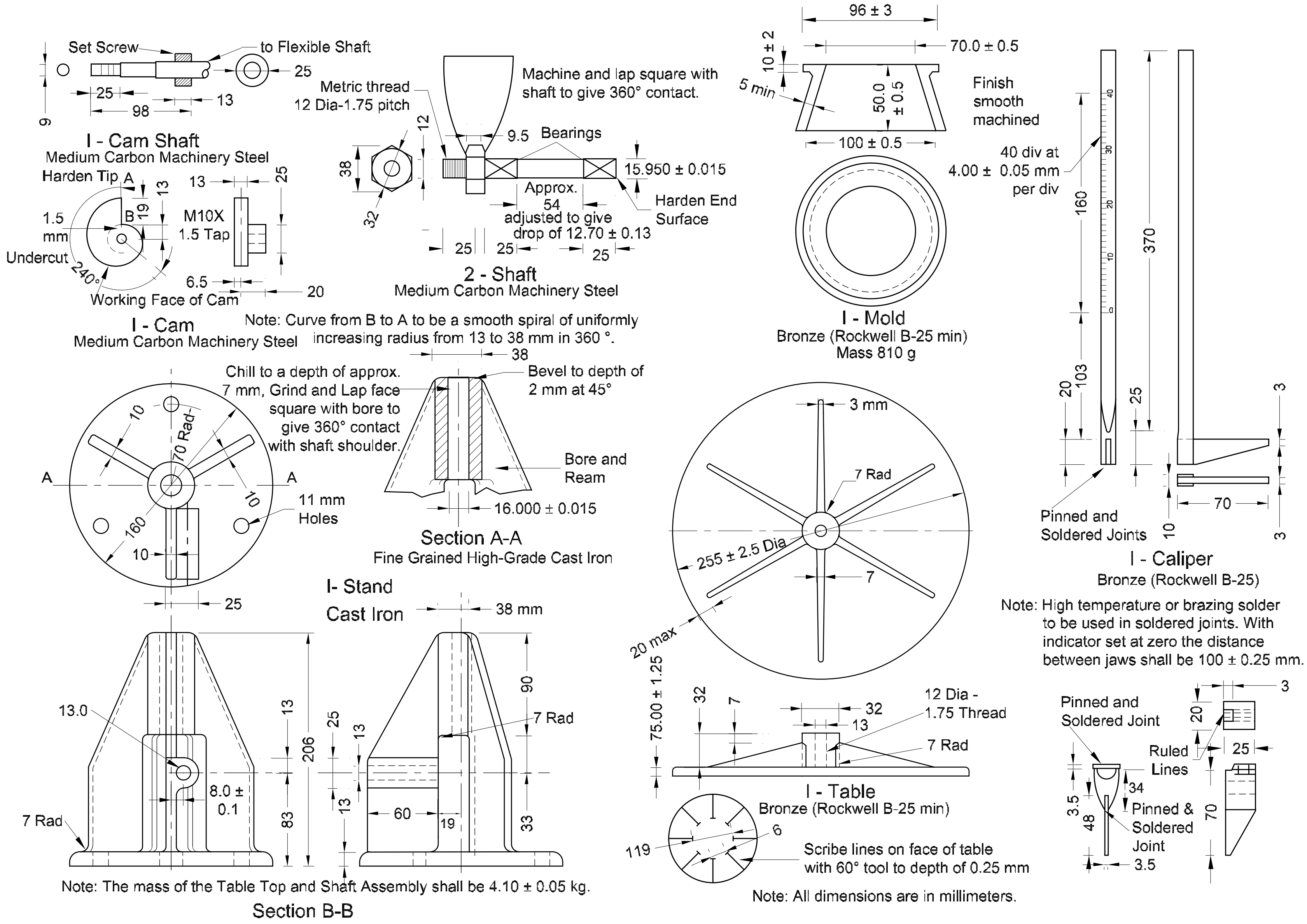
2.3. The supporting frame of the flow table shall be integrally cast of fine-grained, high-grade cast iron. The frame casting shall have three integral stiffening ribs extending the full height of the frame and located 120 degrees apart. The top of the frame shall be chilled to a depth of approximately 6.0 mm [$^1/_4$ in.] and the face shall be ground and lapped square with the bore to give 360 degrees contact with the shaft shoulder. The underside of the base of the frame shall be ground to secure complete contact with the steel plate beneath.

2.4. The flow table shall be driven by a motor (Note 2), connected to the cam shaft through an enclosed worm gear speed reducer and flexible coupling. The speed of the camshaft shall be approximately 100 rpm. The motor drive mechanism shall not be fastened or mounted on the table base plate or frame.

Note 2—A 40 W ($^1/_{20}$ hp) motor has been found adequate.

2.5. The performance of a flow table shall be considered satisfactory if in calibration tests, the table gives a flow value that does not differ by more than five percentage points from flow values obtained with suitable calibration materials.[2] (See Note 3.)

Note 3—Some causes of and solutions to unsatisfactory performance of the flow table may be found in the section on flow tables in the ASTM *Manual of Cement Testing*.



Note: Curve from B to A to be a smooth spiral of uniformly increasing radius from 13 to 38 mm in 360 °.

Note: High temperature or brazing solder to be used in soldered joints. With indicator set at zero the distance between jaws shall be 100 ± 0.25 mm.

Scribe lines on face of table with 60° tool to depth of 0.25 mm

Note: The mass of the Table Top and Shaft Assembly shall be 4.10 ± 0.05 kg.

Note: All dimensions are in millimeters.

Figure 1—Flow Table and Accessory Apparatus (SI Units)

3. FLOW TABLE MOUNTING

3.1. The flow table frame shall be tightly bolted to a cast iron or steel plate at least 25 mm [1 in.] thick and 250 mm [10 in.] square. The top surface of this plate shall be machined to a smooth plane surface. The plate shall be anchored to the top of a concrete pedestal by four 13-mm [$^1/_2$-in.] bolts that pass through the plate and are imbedded at least 150 mm [6 in.] in the pedestal. The pedestal shall be cast inverted on the base plate. A positive contact between the base plate and the pedestal shall be obtained at all points. No nuts or other such leveling devices shall be used between the plate and the pedestal. Leveling shall be effected by suitable means under the base of the pedestal.

3.2. The pedestal shall be 250 to 275 mm [10 to 11 in.] square at the top, and 375 to 400 mm [15 to 16 in.] square at the bottom, 625 to 750 mm [25 to 30 in.] in height, and shall be of monolithic construction cast from concrete having a density of at least 2240 kg/m^3 [140 lb/ft^3]. A stable gasket cork padding, 13 mm [$^1/_2$ in.] thick and the same size as the pedestal bottom or four pieces of padding 13 mm [$^1/_2$ in.] thick and approximately 100 mm [4 in.] square, shall be inserted under the pedestal of the four corners, respectively. The flow table shall be checked frequently for levelness of the tabletop, stability of the pedestal and tightness of bolts and nuts in the table base and the pedestal table. (A torque of 27 N·m [20 lb·ft] is recommended when tightening those fastenings.)

3.3. The tabletop, after the frame has been mounted on the pedestal, shall be level along two diameters at right angles to each other, in both the raised and lowered positions.

4. FLOW TABLE LUBRICATION

4.1. The vertical shaft of the table shall be kept clean and shall be lightly lubricated (See Note 4) with a light oil (SAE-10). Oil shall not be present between the contact faces of the tabletop and the supporting frame. Oil on the cam face will lessen wear and promote smoothness of operation. The table should be raised and permitted to drop a dozen or more times just prior to use if it has not been operated for some time.

Note 4—It has been demonstrated that an absence of lubrication on the table shaft will significantly reduce the flow reading.

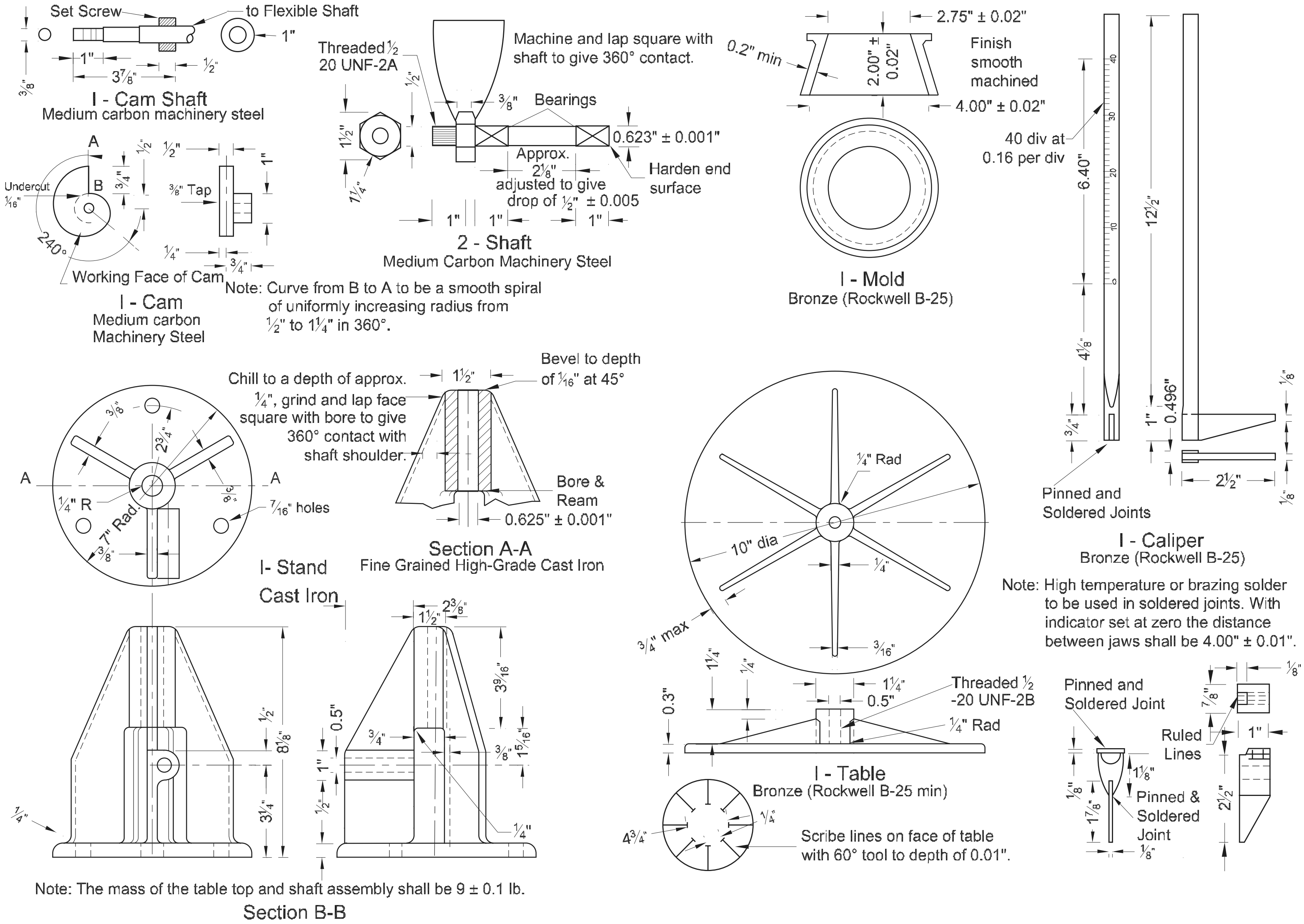


Figure 2—Flow Table and Accessory Apparatus (U.S. Customary Units)

5. MOLD AND CALIPER

5.1. The conical mold for casting the flow specimen shall be of cast bronze or brass, constructed as shown in Figure 1 or Figure 2. The Rockwell hardness number of the metal shall be not less than 25 HRB. The height of the mold shall be 50.0 ± 0.5 mm [2.00 ± 0.02 in.]. The diameter of the top opening shall be 70.0 ± 0.5 mm [2.75 ± 0.02 in.] for new molds and 70.0 + 1.3 and –0.5 mm [2.75 + 0.05 and –0.02 in.] for molds in use. The diameter of the bottom opening shall be 100.0 ± 0.5 mm [4.00 ± 0.02 in.] for new molds and 100.0 + 1.3 and –0.5 mm [4.00 + 0.05 and –0.02 in.] for molds in use.

The surfaces of the base and top shall be parallel and at right angles to the vertical axis of the cone. The mold shall have a minimum wall thickness of 5 mm [0.2 in.]. The outside of the top edge of the mold shall be shaped so as to provide an integral collar for convenient lifting of the mold. All surfaces shall be machined to a smooth finish. A circular shield approximately 255 mm [10 in.] in diameter, with a center opening approximately 100 mm [4 in.] in diameter, made of nonabsorbing material not attacked by the cement, shall be used with the flow mold to prevent mortar from spilling on the tabletop.

5.2. A caliper consisting of one fixed jaw and one jaw movable along a permanent scale, conforming to the design and dimensions shown in Figure 1 or Figure 2 (Note 5), shall be provided for measuring the diameter of the mortar after it has been spread by the operation of the table. The scale shall be machine divided into 40 increments with 4.0 mm [0.16 in.] between divisions with major division lines every five divisions and the increment number every 10 divisions (Note 5). The construction and accuracy of the instrument shall be such that the distance between the jaws shall be 100 ± 0.25 mm [4 ± 0.01 in.] when the indicator is set at zero.

Note 5—The caliper shown in Figure 1 or Figure 2 is graduated to indicate one-fourth of the actual flow percentage, so that the readings of four measurements on the caliper may be added to give the flow value without the necessity of calculating the average of four individual measurements of the total flow.

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[1] Except for the use of SI units this method agrees with ASTM C 230-03.

[2] Such a material may be obtained from the Cement and Concrete Reference Laboratory at the National Institute of Standards and Technology, Washington, DC 20234.

Standard Specification for

Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

AASHTO Designation: M 201-08
ASTM Designation: C 511-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

AASHTO Designation: M 201-08
ASTM Designation: C 511-06

1. SCOPE

1.1. This specification includes requirements for mixing rooms where paste and mortar specimens are prepared; and for moist cabinets, moist rooms, and water storage tanks where paste, mortar and concrete test specimens are stored.

1.2. Values in SI units shall be obtained by measurement in SI units or by appropriate conversion, using the Rules for Conversion and Rounding given in IEEE/ASTM SI 10, of measurements made in other units.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- C 51, Standard Terminology Relating to Lime and Limestone (as used by the Industry)
- E 77, Standard Test Method for Inspection and Verification of Thermometers

2.2. *IEEE/ASTM Standard*:

- SI 10, American National Standard for use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *mixing room, n*—a room with controlled temperature and relative humidity where cement paste and mortar specimens are prepared.

3.1.2. *moist cabinet, n*—a compartmented storage facility of moderate dimensions with controlled temperature and relative humidity.

3.1.3. *moist room, n*—a “walk-in” storage facility with controlled temperature and relative humidity, commonly called a fog room when the prescribed relative humidity is achieved by the atomization of water.

4. REQUIREMENTS FOR CEMENT MIXING ROOMS

4.1. The temperature of the air in the vicinity of the mixing slab, molds, and base plates shall be maintained at 23.0 ± 4.0ºC and at a relative humidity of not less than 50 percent.

4.2. The temperature of the mixing water used to prepare cement paste and mortar specimens shall be 23.0 ± 2.0ºC.

5. TEMPERATURE MEASURING DEVICES

5.1. *Reference Temperature Measuring Devices*—used to verify the temperature recorder must be accurate and readable to 0.5ºC. A copy of the certificate or report that verifies the accuracy shall be available in the laboratory.

Note 1—The ice-point method described in ASTM E 77 may be used to ensure that no damage to the reference thermometer has occurred during shipping.

5.2. *Temperature Recorder*—shall record temperatures every 15 minutes or less and shall be accurate and readable to 1 ºC. The data from the recorder shall be evaluated at a minimum of once each week. A record of this evaluation documenting the date checked, a confirmation that the data are within the required temperature range, and the name of the individual performing this evaluation shall be maintained in the laboratory. (Note 2)

Note 2—This requirement may be satisfied by an initialed and dated temperature recorder chart. Brief changes in the temperature due to door openings should be ignored.

5.2.1. The temperature recorder shall be verified at least every 6 months or whenever there is a question of accuracy.

5.2.1.1. For moist cabinets and rooms, position the reference temperature measuring device in a readable position in air as near as practical to the temperature recorder probe. Keep the door closed for at least 5 min prior to taking readings. Record the temperature readings of both the temperature recorder and the reference temperature measuring device. When taking these readings, the reference temperature measuring device shall remain in the moist cabinet or room and read immediately upon opening the door.

5.2.1.2. For water storage tanks, position the reference temperature measuring device in a readable position in water as near as practical to the temperature recorder probe. Without removing the reference temperature measuring device from the water, record the temperature readings of both the temperature recorder and the reference temperature measuring device after the temperatures have stabilized.

5.2.1.3. Verify the accuracy of the temperature recorder by comparing the reading of the temperature recorder with that of the reference temperature measuring device during the normal operation of the moist cabinet, moist room, or water storage tanks. If the difference between the temperature readings is greater than 1ºC, the temperature recorder shall be adjusted to within 0.5ºC of the reference temperature-measuring device.

6. REQUIREMENTS FOR MOIST CABINETS AND MOIST ROOMS

6.1. *General*—The atmosphere in a moist cabinet or moist room shall have a temperature of 23.0 ± 2.0°C and a relative humidity of not less than 95 percent. The moisture in the atmosphere shall be saturated to the degree needed to ensure that the exposed surfaces of all specimens in storage will both look moist and feel moist at all times. All moist cabinets and moist rooms shall be equipped with a temperature recorder. The use of humidity recording devices is optional. Shelves on which fresh specimens are placed shall be level.

6.1.1. The air in a moist cabinet or moist room must be nearly saturated with moisture in order to provide specified storage conditions. In many cases, saturation is below optimum during periods when specimens are being placed in or removed from storage. Measurements of relative humidity should not be made at such obviously inopportune times.

6.1.2. The air temperature inside the moist cabinet or moist room shall be controlled with provisions made for heating or cooling, or both, as may be necessary. This shall be accomplished in one of two ways:

6.1.2.1. Thermostatically control the air temperature within the moist cabinet or moist room when surrounding space is not conditioned. In this case the sensing element for the controls shall be located inside the moist cabinet or moist room.

6.1.2.2. Thermostatically control the space surrounding the moist cabinet or moist room and manually control the temperature within the moist cabinet or moist room.

6.1.3. In either of the preceding cases, the laboratory shall demonstrate the ability of the controls to maintain the required temperature in the moist cabinet or moist room over an extended period of time. Data from the temperature recorder that indicate that the temperatures are within the temperature limits specified in 6.1 shall be required as evidence of this ability.

6.2. *Moist Cabinets*—A moist cabinet shall be constructed of durable materials and the doors shall be tightfitting. The specified relative humidity shall be maintained by the use of one or more fog sprays, water sprays, or curtains of water on the inner walls that are so directed that the discharge will collect in a pool at or near the bottom of the moist storage section.

6.3. *Moist Rooms*:

6.3.1. *General*—The walls of a moist room shall be constructed of durable materials, and all openings shall be provided with tight-fitting doors or windows (Note 3). The specified relative humidity may be maintained in any convenient and suitable manner (Note 4).

Note 3—Well-insulated walls will substantially help maintain necessary conditions.

Note 4—A fog spray found suitable for this purpose is shown in Figure 1.

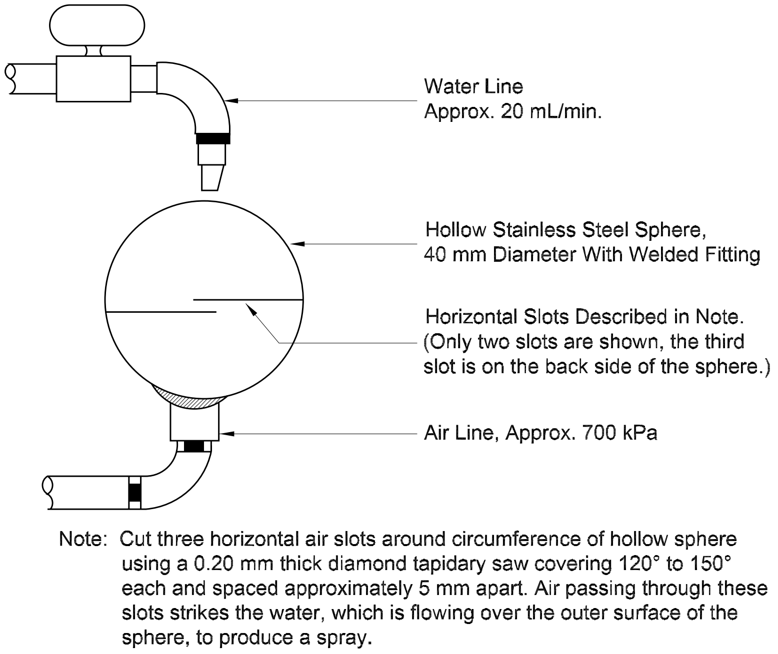

Figure 1—Example of a Fog Spray for Maintaining Relative Humidity in Moist Rooms (Full Scale)[1]

6.3.2. *Moist Rooms Used in Cement Testing*—Durable shelving that is properly shielded to prevent droplets of water from falling on the surfaces of freshly molded specimens shall be available within each moist room.

6.3.3. *Moist Rooms Used in Concrete Testing*—Atmospheric conditions within each moist room shall be such that test specimens in storage shall have free water maintained on their entire surface area at all times. Specimens shall not be exposed to dripping or running water.

7. REQUIREMENT FOR WATER STORAGE TANKS

7.1. *General*—Tanks shall be constructed of non-corroding materials. Provision for automatic control of water temperature at 23.0 ± 2.0ºC shall be made where a tank is located in a room not having temperature controlled within that range and in any other instance where difficulty in maintaining temperatures within the specified range is encountered. With the exception of water storage tanks located in a moist room or moist cabinet, all water storage tanks shall be equipped with a temperature recorder with its sensing element in the storage water. For the purpose of temperature recording, a group of water storage tanks may be considered one tank if the following three conditions are met: (1) all the tanks are interconnected with tubing that allows the water to flow between the tanks, (2) some means of circulation is provided between tanks, and (3) temperature variation between the tanks must not exceed 1.0ºC when checked and recorded weekly. The water in a storage tank shall be saturated with calcium hydroxide to prevent leaching of calcium hydroxide from the specimens (Note 5). Water not saturated with calcium hydroxide (high-calcium hydrated lime) may affect test results due to leaching of lime from the test specimens and shall not be used in storage tanks. To maintain saturation with calcium hydroxide, excess calcium hydroxide shall be present. For the purposes of lime saturation to prevent leaching, lime means high-calcium hydrated lime, not calcium carbonate (limestone) (see ASTM C 51). The water in the storage tank shall be thoroughly stirred at intervals not to exceed one month to help replace calcium ions that have depleted. Tanks shall be cleaned and refilled with water containing 3 g/L of calcium hydroxide at intervals not to exceed 24 months (Note 6).

Note 5—pH is not a reliable indicator of lime saturation in storage tank water since severe reductions in dissolved calcium ions can occur before pH values are significantly reduced.

Note 6—The 3 g/L level is intended to provide a quantity of calcium hydroxide approximately two times that required for initial saturation.

7.2. Do not use continuously running fresh water or demineralized water in storage tanks because it may affect test results due to excessive leaching. A closed system, circulating the saturated limewater between or among storage tanks, may be used.

8. KEYWORDS

8.1. Cement paste; concrete; mixing rooms; moist cabinets; moist rooms; mortar; water storage tanks.

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[1] One spray will supply sufficient water to supply moisture to a space of 25 m^3. Hollow spheres available through McMaster Carr Supply Co., P.O. Box 4355, Chicago, IL 60680-4355.

Standard Specification for

Weighing Devices Used in the Testing of Materials

AASHTO Designation: M 231-95 (2006)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Specification for

Weighing Devices Used in the Testing of Materials

AASHTO Designation: M 231-95 (2006)

1. SCOPE

1.1 This specification covers requirements for scales and balances, and the loose standard masses used with balances, used in the testing of construction materials.

1.2 The requirements included are descriptive of the balances required by a number of AASHTO test methods. The general-purpose balances described herein may not be sufficiently accurate for certain tests, especially where a high degree of accuracy is required at large capacities. In such instances, the requirements for the balance should be included in the test method.

1.3 The requirements included herein are not sufficiently descriptive to be used as purchase specifications without amplification by the potential purchaser.

1.4 The values stated in SI units are to be regarded as the standard.

2. CLASSIFICATION

2.1 Weighing devices are divided into two classes of analytical balances, designated A and B, and five classes of general purpose scales or balances, designated G1, G2, G5, G20, and G100, based on readability.

2.2 Standard masses classified as Class 1, 2, 3, and 4, listed in ASTM E 617, may be used with the analytical balances. Standard masses listed in Table 2, Section 2.23 of *NIST Handbook 44* (1992 Edition) may be used with general-purpose balances.

3. TERMINOLOGY

3.1 *acceptance tolerance*—the maximum permissible deviation from correct indication for new standard masses or balances, and standard masses or balances having received major servicing. Usually equal to one-half of the maintenance tolerance.

3.2 *accuracy*—maximum permissible deviation of indications of a balance or scale from the true value within applicable tolerances.

3.3 *balance*—an instrument for determining mass, in its simplest form having a beam supported exactly in the middle having two pans of equal mass suspended from its extremities. Generally, weighing devices of a relatively high degree of accuracy used for determinations of mass in the laboratory.

3.4 *direct-reading balance*—a balance on which the mass of applied loads of various magnitudes is either automatically indicated, or is indicated by means of a calibrated weighbeam, throughout all or a portion of the range of the balance.

3.5 *equal-arm balance*—a balance having a beam supported exactly in the middle, having two pans suspended from its extremities, in which the mass of unknown quantity on one pan is compared with a set of standards of mass in the other pan. There may or may not be a weighbeam.

3.6 *general-purpose masses*—standard masses used for general mass determination, generally being less accurate than standard analytical masses.

3.7 *maintenance tolerance*—maximum permissible deviation from correct indication for masses or balances in service.

3.8 *off-center loading*—application of a load to the pan of a balance or scale at a point displaced from the center of the support axis of the load-receiving element.

3.9 *readability*—the smallest unit of mass that can be read without estimation over the given range of measurement either directly or by use of a vernier or micrometer.

3.10 *scale*—an instrument or machine used for mass determination, usually embodying a system of multiplying levers. Generally considered to have a lesser degree of accuracy than balances.

3.11 *sensitivity*—mass required to produce a discernible movement in the indicating system of the balance or scale.

3.12 *sensitivity requirement*—the minimum change in the position of rest of the indicating element of a scale or balance in response to a specified change in test load on the load-receiving element of the scale or balance.

3.13 *simple balance*—a balance designed primarily for use in conjunction with a set of standard masses. There may or may not be a weighbeam.

3.14 *standard analytical masses*—working standards of mass used for analytical work, having relatively small tolerances from the stated values.

4. REQUIREMENTS

4.1 *Analytical Balances*—Analytical balances of the class specified shall conform to the requirements of Table 1. These requirements apply both to balances with built-in masses and balances used with separate masses. The class for standard masses is suggested to provide the required accuracy (Note 1).

Table 1—Standard Analytical Balances

Balance Class	Accuracy	Sensitivity	Readability[a]	Class of Standard Masses[b]	Capacity[c]
A	0.0002 g	0.0001 g	0.0001 g	1, 2, or 3	200 g
B	0.002 g	0.001 g	0.001 g	3	200 g

[a] Readability of markings on direct reading balances.

[b] Class suggested for use with simple balances.

[c] Maximum capacity generally available with balances of the accuracy and sensitivity indicated for the class. Varies depending on the manufacturer, and whether direct reading or simple balance.

Note 1—The tolerances for standard masses are such that a single mass deviating by the full tolerance may cause the balance to exceed the accuracy requirement. In general, an individual mass will deviate only slightly from the stated value, and groups of masses will have some with a positive variation and some with a negative variation, which will tend to be compensating.

4.2 *General Purpose Balances and Scales*—General purpose weighing devices shall conform to the accuracy, readability, and sensitivity indicated in Table 2. Within any interval equal to 10 percent of the capacity of the balance, the difference in the load indications shall be accurate to within 0.1 percent of the difference in masses (Note 2). The device shall not be loaded in excess of its nominal or stated capacity.

Table 2—General Purpose Balances and Scales

Class	Readability and Sensitivity	Accuracy[a]
G 1	0.01 g	0.02 g or 0.1 percent
G 2	0.1 g	0.2 g or 0.1 percent
G 5	1 g	2 g or 0.1 percent
G 20	5 g	5 g or 0.1 percent
G 100	20 g	20 g or 0.1 percent

[a] Accuracy equal to the mass stated or 0.1 percent of the test load, whichever is greater, throughout the range of use.

Note 2—This requirement is to ensure linear performance of balance or scale. It is recommended that it be checked at five or more points throughout its range.

4.2.1 The balance selected for use is based on the accuracy, readability, sensitivity, and capacity required for the test being performed. Subportions of the sample are to be weighed to at least the accuracy indicated by the device required for the total sample (Note 3).

Note 3—Balances have considerable variation in quality. Less expensive balances may be unable to provide the required accuracy for the full range of the capacity of the device, especially if subjected to rough field usage.

4.2.2 Balances indicating in the Avoirdupois system (pounds and ounces), or separate masses used with such devices, shall meet levels of accuracy, readability, and sensitivity equivalent to those shown in Table 2 for balances and Table 4 for masses.

4.3 *Balance Condition*—The physical design and condition of a balance shall be such that the balance will meet the requirements of Sections 4.1 and 4.2.

4.3.1 Repeated determinations of the mass of a test load shall yield load indications that agree with each other within the sensitivity specification for the balance.

4.3.2 Mechanisms for adding or subtracting built-in internal masses shall function smoothly.

4.3.3 Dials and mass increment indicators shall display clearly the readings they were designed to show.

4.3.4 The accuracy requirement shall be met for any point of application of a test load on the balance pan or other mass receiving element.

4.4 *Masses*—Masses shall be selected so that the requirements for accuracy, sensitivity, and/or readability specified in Sections 4.1 and 4.2 are met when the masses are used with the appropriate balance.

4.4.1 *Standard Analytical Balances*—Analytical masses for use with equal arm balances should be Class 1, 2, 3, or 4, as appropriate for the accuracy of the balance with which they are to be used. The requirements for these masses are described in ASTM E 617. Applicable tolerances are shown in Table 3. Class 1 and 2 masses are reference masses, generally used for verification of masses of lesser classes, although Class 2 masses are used as working masses for high precision mass determinations. Classes 3 and 4 are considered to be working masses (Note 1).

Table 3—Tolerances for Standard Analytical Masses

	Acceptance Tolerances					
	Class 1[a]		Class 2[b]			
	Tolerance		Tolerance		Class 3[c]	Class 4[c]
Denomination	Individual, mg	Group, mg	Individual, mg	Group, mg	Tolerance, mg	Tolerance, mg
1000 g	2.5		5.0		10.0	20.0
500 g	1.2		2.5		5.0	10.0
300 g	0.75	1.35	1.5	2.7	3.0	6.0
200 g	0.50		1.0		2.0	4.0
100 g	0.25		0.50		1.0	2.0
50 g	0.12		0.25		0.60	1.2
30 g	0.074	0.16	0.15	0.29	0.45	0.90
20 g	0.074		0.10		0.35	0.70
10 g	0.050		0.074		0.25	0.50
5 g	0.034		0.054		0.18	0.36
3 g	0.034		0.054		0.15	0.30
2 g	0.034	0.065	0.054	0.105	0.13	0.26
1 g	0.034		0.054		0.10	0.20
500 mg	0.010		0.025		0.080	0.16
300 mg	0.010		0.025		0.070	0.14
200 mg	0.010	0.020	0.025	0.055	0.060	0.12
100 mg	0.010		0.025		0.050	0.10
50 mg	0.010		0.014		0.042	0.085
30 mg	0.010		0.014		0.038	0.075
20 mg	0.010	0.020	0.014	0.034	0.035	0.070
10 mg	0.010		0.014		0.030	0.060
5 mg	0.010		0.014		0.028	0.055
3 mg	0.010		0.014		0.026	0.052
2 mg	0.010	0.020	0.014	0.034	0.025	0.050
1 mg	0.010		0.014		0.025	0.050

[a] Maintenance tolerances same as acceptance tolerances.

[b] Maintenance tolerances for standard masses below 100 mg are the same as acceptance tolerances. For standard masses 100 mg and above, the maintenance tolerances are twice the acceptance tolerances.

[c] Maintenance tolerances are twice the acceptance tolerances.

4.4.2 *General Purpose Masses*—General purpose masses for use with equal arm balances should conform to the requirements of *NIST Handbook 44* (1992 Edition), Table 2, Section 2.23, Weights. Masses for use with single pan balances shall have sufficient accuracy so that the balances meet the requirements for such devices. Applicable tolerances are shown in Table 4.

Table 4—Tolerances for General Purpose Masses

Denomination	Maintenance Tolerance[a]	Denomination	Maintenance Tolerance[a]
20 kg	1500 mg	30 g	30 mg
10 kg	1000 mg	20 g	20 mg
5 kg	800 mg	10 g	15 mg
3 kg	500 mg	5 g	10 mg
2 kg	400 mg	3 g	8 mg
1 kg	250 mg	2 g	6 mg
500 g	175 mg	1 g	4 mg
300 g	150 mg	500 mg	3.0 mg
200 g	100 mg	300 mg	2.0 mg
100 g	70 mg	200 mg	1.5 mg
50 g	40 mg	100 mg	1.0 mg

[a] Acceptance tolerances on new masses are one-half the maintenance tolerances.

Standard Specification for

Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests

AASHTO Designation: M 261-96 (2009)[1]
ASTM Designation: E 501-08

American Association of State Highway and Transportation Officials
444 North Capitol Street NW, Suite 249
Washington, DC 20001

Standard Specification for

Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests

AASHTO Designation: M 261-96 (2009)[1]
ASTM Designation: E 501-08

1. SCOPE

1.1 This specification covers the general requirements for the standard rib tire for pavement friction testing. The tire covered by this specification is only for use in evaluation of tire-pavement friction.

1.2 Terminology in this specification is consistent with ASTM E 867.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 242, Frictional Properties of Paved Surfaces Using a Full-Scale Tire

2.2 *ASTM Standards*:

- D 297, Standard Test Methods for Rubber Products—Chemical Analysis
- D 412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
- D 1054, Standard Test Method for Rubber Property—Resilience Using a Goodyear-Healey Rebound Pendulum
- D 1765, Standard Classification System for Carbon Blacks Used in Rubber Products
- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- D 3182, Standard Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets
- E 501, Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests
- E 867, Standard Terminology Relating to Vehicle-Pavement Systems

3. MATERIALS AND MANUFACTURE

3.1 The individual standard tires shall conform to the design standards of Section 6. Dimensions, masses, and permissible variations are given in Section 6 and in Figure 1.

3.2 Tread compounding, fabric processing, and all steps in tire manufacturing shall be certified to ensure that the specifications are met.

3.3 A small raised guideline shall be molded on the tire shoulder area to provide a rapid visual check as to whether the maximum wear level for testing has been reached. Tires should be removed from service as recommended in Section 11.5. The marking on the tire should include the following information:

- G78-15,
- Standard Pavement Test Tire—Not for General Highway Use,
- ASTM E 501,
- (Manufacturer’s Name or Trademark),
- Directional arrow on side of tire,
- Rim: 15 × 6JJ.

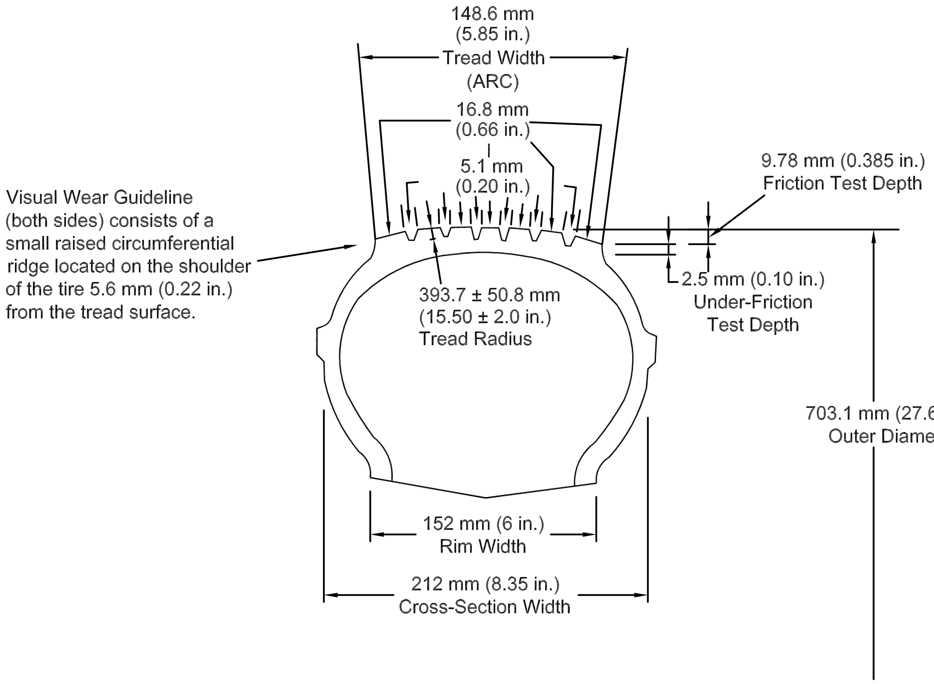

Figure 1—Tire Section, Including Inflated Tire Dimensions

4. MATERIAL REQUIREMENTS

4.1 The compounding requirements for the tread compound are given in Table 1.

Table 1—Compounding of Tread Rubber[a]

Material	Parts per Hundred of Rubber (PPHR)
SBR 1712[b]	89.38
BR-1208[c]	35.00
N339[d]	75.00
High aromatic oil	22.12
Zinc oxide	3.00
Stearic acid	2.00
6PPD[e]	2.00
Paraffin wax	2.00
Sulfur	1.80
TBBS[f]	1.10
DPG[g]	0.10

[a] ASTM D 3182

[b] Styrene-butadiene rubber (23.5 percent styrene) 37.5 parts of high-aromatic oil

[c] High cis-polybutadiene

[d] N339 Carbon Black. See ASTM D 1765.

[e] Dimethyl butylphenyl phenylenediamine

[f] Butyl benzothiazole sulfenamide

[g] Diphenyl guanidine

4.2 *Fabric*—The fabric shall be polyester body or carcass plies and fiberglass belt plies.

Note 1—Certain proprietary products have been specified since exact duplication of properties of the finished tire may not be achieved with other similar products. This inclusion does not in any way comprise a recommendation for these proprietary products, nor against similar products of other manufacturers, nor does it imply any superiority over any such similar products.

5. PHYSICAL REQUIREMENTS

5.1 The physical and mechanical test requirements are given in Table 2.

Table 2—Physical Requirements of Tread Compound

Tensile sheet cure at 150˚C (302˚F), min	30
300 percent modulus, MPa (psi) (ASTM D 412)	6.9 ± 1.4 (1000 ± 200)
Tire tread durometer (ASTM D 2240)	58 ± 2
Specific gravity (ASTM 297)	1.13 ± 0.02
Tensile strength, min, MPa (psi) (ASTM D 412)	13.8 (2000)
Elongation, min, percent (ASTM D 412)	500

6. DIMENSIONS, MASSES, AND PERMISSIBLE VARIATIONS

6.1 *General*—Details of dimensions are listed as follow and are shown in Figure 1. Where tolerances are not specified, tire dimensions are subject to manufacturers' normal tolerances.

6.1.1 *Construction*—The tire shall be a size G78-15 tubeless type, belted bias construction (two body plies plus two belt plies). The tread width shall be 149 mm (5.85 in.) and the cross-sectional tread radius shall be 394 mm ± 51 mm (15.50 in. ± 2.0 in.). The tire shall have a recommended cross-section width of 212 mm (8.35 in.) and a recommended section height of 161 mm (6.34 in.) when mounted on a Tire and Rim Association 15 × 6 (381 × 152 mm) JJ rim. The cured crown angles shall be 33 ± 2 degrees for the body plies, and 27 ± 2 degrees for the belt plies.

6.1.2 *Ribs*—The tire shall have seven plain ribs of 16.8 mm (0.66 in.) width each. Both sides of the shoulder ribs shall be parallel from the tread surface down to a depth equal to the wear guideline.

6.1.3 *Grooves*—The tire shall have six straight grooves of 5.1-mm (0.20-in.) width each. Each groove shall be parallel to the radius of the tread radius arc and shall have a full radius at the bottom of the groove. Each groove shall have a uniform friction test depth of 9.8 mm (0.385 in.) maximum and shall have an under-tread thickness of 2.5 mm (0.10 in.).

6.1.4 *Wear Indicators*—There shall be six rows of tread wear indicators spaced uniformly around the tire circumference and directly across the full tread width in all six grooves. These tread wear indicators shall be 1.6 mm (0.063 in.) deep and approximately 12.7 mm (0.50 in.) long. A visual wear guideline shall be located on the shoulder of the tire 5.6 mm (0.22 in.) from the tread surface as shown in Figure 1.

7. WORKMANSHIP

7.1 Tires shall be free of defects in workmanship and material.

8. TEST METHODS

8.1 *Tensile Sheet Cures*—ASTM D 3182.

8.2 *Modulus (300 percent)*—ASTM D 412.

8.3 *Tensile Sheet Durometer*—ASTM D 2240, using a Type A Shore durometer.

8.4 *Specific Gravity*—ASTM D 297.

8.5 *Tensile Strength*—ASTM D 412.

8.6 *Elongation*—ASTM D 412.

8.7 *Tire Tread Durometer*—ASTM D 2240.

8.7.1 Use a Type A durometer 12.7-mm (0.5-in.) diameter presser foot. Shore, code XAHAF is recommended.

8.7.2 The durometer shall be calibrated at a reading of 60 hardness.

8.7.3 Condition the tire and durometer to equilibrium at 23 ± 2ºC (73.4 ± 3.6ºF) before determining tread hardness.

8.7.4 The tire tread hardness is to be determined by averaging at least one set of six readings. A set is one reading taken in the center of each rib, excluding the center rib. It is recommended that additional sets of readings be taken around the tread circumference.

8.7.5 Apply presser foot to the tire tread as rapidly as possible without shock, keeping the foot parallel to the tread surface. Apply just sufficient pressure to obtain firm contact between presser foot and tire tread surface. Read the durometer scale within 1 second after presser foot is in contact with the tire tread, but after initial maximum transient, which may occur immediately after contact is made.

9. CERTIFICATION

9.1 Tires are to be inflated and measured prior to shipment. Upon request, the manufacturer shall furnish the purchaser certification that the test tire meets this specification.

9.2 All tires under certification shall be subject to the manufacturer's normal variation.

10. PACKAGING AND PRESERVATION

10.1 The tires should be kept dry under ordinary atmospheric conditions in subdued light, 21 ± 14ºC (70 ± 25 F). Tires should not be stored near electric motors, welders, or other ozone-generating equipment.

11. RECOMMENDATIONS FOR TIRE USE AND OPERATIONAL REQUIREMENTS

11.1 The tire is for pavement friction testing only and is not designed for general highway service. Necessary transport of test equipment should be on commercial tires.

11.2 A new tire break-in of 320 km (200 miles) minimum should be made on tires by the purchaser before using the tire for testing.

11.3 The tire shall be operated with not less than 165 kPa (24 psi) inflation.

11.4 The recommended static test load on the tire shall be 4825 N (1085 lbf) with loading to a maximum of 6150 N (1380 lbf) permissible, at 165 kPa (24 psi) inflation.

11.5 Tire should be mounted so that it is rotated in the direction of the arrow on the side of the tire.

11.6 When irregular wear or damage results from tests or when the remaining groove depth in any groove is 4.2 mm (0.165 in.) or less, the use of the tire as a standard test tire shall be discontinued.

11.7 **Caution**—Measured friction force or friction number may be influenced by tire tread depth and/or hardness. The magnitude of this dependence is a function of the water depth, pavement characteristics, test speed, and tire-aging effects.

12. KEYWORDS

12.1 Friction; pavement; rib tire.

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[1] Except for terminology, figures, and the use of SI units, this specification agrees with ASTM E 501-08.

Standard Specification for

Smooth-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests

AASHTO Designation: M 286-96 (2009)[1]
ASTM Designation: E 524-08

American Association of State Highway and Transportation Officials
444 North Capitol Street NW, Suite 249
Washington, DC 20001

Standard Specification for

Smooth-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests

AASHTO Designation: M 286-96 (2009)[1]
ASTM Designation: E 524-08

1. SCOPE

1.1 This specification covers the general requirements for the smooth-tread standard tire for pavement testing. The tire covered by this specification is intended for evaluation of tire-pavement friction.

1.2 The terminology in this specification is consistent with ASTM E 867.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 242, Frictional Properties of Paved Surfaces Using a Full-Scale Tire

2.2 *ASTM Standards*:

- D 297, Standard Test Methods for Rubber Products—Chemical Analysis
- D 412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
- D 1054, Standard Test Method for Rubber Property—Resilience Using a Goodyear-Healey Rebound Pendulum
- D 1765, Standard Classification System for Carbon Blacks Used in Rubber Products
- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- D 3182, Standard Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets
- E 867, Standard Terminology Relating to Vehicle-Pavement Systems

3. MATERIALS AND MANUFACTURE

3.1 The individual standard tires shall conform to the design standards of Section 6. Dimensions, masses, and permissible variations are given in Section 6 and in Figure 1.

3.2 Tread compounding, fabric processing, and all steps in tire manufacturing shall be certified to ensure that the specifications are met.

3.3 A small raised guideline shall be molded on the tire shoulder area to provide a rapid visual check as to whether the maximum wear level for testing has been reached. Tires should be removed from service as recommended in Section 11.5. The marking on the tire should include the following information:

- G78-15
- Special Purpose Pavement Test Tire—Not for General Highway Use
- Directional arrow on side of tire
- ASTM E 524
- (Manufacturer's Name or Trademark)
- Rim: 15 × 6JJ

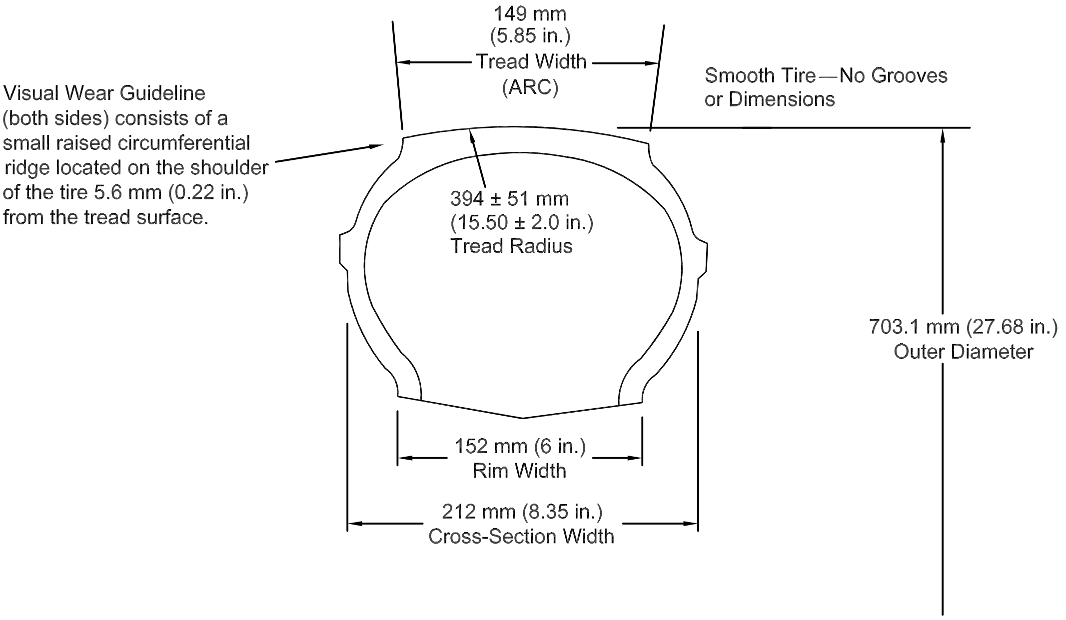

Figure 1—Tire Section Including Inflated Tire Dimensions

4. MATERIAL REQUIREMENTS

4.1 The compounding formulation for the tread portion of the tire is given in Table 1.

Table 1—Compounding of Tread Rubber[a]

Material	Parts per Hundred of Rubber (PPHR)
SBR 1712[b]	89.38
BR-1208[c]	35.00
N339[d]	75.00
High aromatic oil	22.12
Zinc oxide	3.00
Stearic acid	2.00
6PPD[e]	2.00
Paraffin wax	2.00
Sulfur	1.80
TBBS[f]	1.10
DPG[g]	0.10

[a] ASTM D 3182

[b] Styrene-butadiene rubber (23.5 percent styrene) 37.5 parts of high-aromatic oil

[c] High cis-polybutadiene

[d] N339 Carbon Black. See ASTM D 1765.

[e] Dimethyl butylphenyl phenylenediamine

[f] Butyl benzothiazole sulfenamide

[g] Diphenyl guanidine

4.2 *Fabric*—The fabric shall be polyester body or carcass plies and fiberglass belt plies.

Note 1—Certain proprietary products have been specified since exact duplication of properties of the finished tire may not be achieved with other similar products. This inclusion does not in any way comprise a recommendation for these proprietary products, nor against similar products of other manufacturers, nor does it imply any superiority over any such similar products.

5. PHYSICAL REQUIREMENTS

5.1 The physical and mechanical test requirements are given in Table 2.

Table 2—Physical Requirements of Tread Compound

Tensile sheet cure at 150˚C (302˚F), min	30
300 percent modulus, MPa (psi) (ASTM D 412)	6.9 ± 1.4 (1000 ± 200)
Tire tread durometer (ASTM D 2240)	58 ± 2
Specific gravity (ASTM D 297)	1.13 ± 0.02
Tensile strength, min, MPa (psi) (ASTM D 412)	13.8 (2000)
Elongation, min, percent (ASTM D 412)	500

6. DIMENSIONS, MASSES, AND PERMISSIBLE VARIATIONS

6.1 *General*—Details of dimensions are shown in Figure 1. Where tolerances are not specified, tire dimensions are subject to manufacturer's normal tolerances.

6.1.1 *Design and Construction*—The tire shall be a size G78-15 tubeless type, belted bias construction (two-body plies plus two-belt plies). The tread width shall be 149 mm (5.85 in.) and the cross-sectional tread radius shall be 394 ± 51 mm (15.50 ± 2.0 in.). The tread shall have a thickness of 9.8 mm (0.385 in.) and an under-tread thickness of 2.5 mm (0.10 in.). The tire shall have a recommended cross-section width of 212 mm (8.35 in.) and a recommended section height of

161 mm (6.34 in.) when mounted on a Tire and Rim Association 15 by 6 (381 by 152 mm) JJ rim. The cured crown angles shall be 33 ± 2 degrees for the body plies, and 27 ± 2 degrees for the belt plies.

6.1.2 *Wear Indicators*—A visual wear guideline shall be located on the shoulder of the tire 5.6 mm (0.22 in.) from the tread surface as shown in Figure 1.

7. WORKMANSHIP

7.1 Tires shall be free of defects in workmanship and materials.

8. TEST METHODS

8.1 *Tensile Sheet Cures*—ASTM D 3182.

8.2 *Modulus (300 percent)*—ASTM D 412.

8.3 *Tensile Sheet Durometer*—ASTM D 2240, using a Type A Shore durometer.

8.4 *Specific Gravity*—ASTM D 297.

8.5 *Tensile Strength*—ASTM D 412.

8.6 *Elongation*—ASTM D 412.

8.7 *Tire-Tread Durometer*—ASTM D 2240 in addition to the following procedures.

8.7.1 Use a Type A durometer 12.7-mm (0.5-in.) diameter presser foot. (Shore Code XAHAF is recommended.)

8.7.2 The durometer shall be calibrated at a reading of 60 hardness.

8.7.3 Condition the tire and durometer to equilibrium at 23 ± 2ºC (73.4 ± 3.6ºF) before determining tread hardness.

8.7.4 The tire tread hardness is to be determined by averaging at least one set of six readings. A set should consist of readings taken at equally spaced intervals across the tread. It is recommended that additional sets of readings be taken around the tread circumference.

8.7.5 Apply presser foot to the tire tread as rapidly as possible without shock, keeping the foot parallel to the tread surface. Apply just sufficient pressure to obtain firm contact between the presser foot and the tire tread surface. Read the durometer scale within 1 second after the presser foot is in contact with the tire tread, but after initial maximum transient, which may occur immediately after contact is made.

9. CERTIFICATION

9.1 Tires are to be inflated and measured prior to shipment. Upon request, the manufacturer shall furnish the purchaser certification that the test tire meets this specification.

9.2 All tires under certification shall be subject to the manufacturers' normal variation.

10. PRESERVATION

10.1 Tires shall be kept dry under ordinary atmospheric conditions in subdued light, 21 ± 14ºC (70 ± 25ºF). Tires should not be stored near electric motors, welders, or other ozone generating equipment.

11. RECOMMENDATIONS FOR TIRE USE AND OPERATIONAL REQUIREMENTS

11.1 The tire is intended for pavement friction testing only and is not designed for general highway service. Commercial tires should be used for necessary transporting of test equipment.

11.2 A new tire break-in of 320 km (200 miles) minimum should be made on tires by the purchaser before using the tire for testing.

11.3 The tire shall be operated with not less than 165 kPa (24 psi) inflation.

11.4 The recommended static test load on the tire shall be 4825 N (1085 lbf), with loading to a maximum of 6150 N (1380 lbf) permissible, at 165 kPa (24 psi) inflation.

11.5 Tire should be mounted so that it is rotated in the direction of the arrow on the side of the tire.

11.6 When irregular wear or damage results from tests or when the tire is worn to the wear line, the use of the tire as a standard test tire shall be discontinued.

11.7 **Caution**—Measured friction force or friction number may be influenced by tire tread hardness. The magnitude of this dependence is a function of the water depth, pavement characteristics, test speed, and tire-aging effects.

12. KEYWORDS

12.1 Friction; friction force; friction number; pavement; tire-pavement.

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[1] Except for terminology, figures, and the use of SI units, this specification agrees with ASTM E 524-08.

Standard Practice for

Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer

AASHTO Designation: R 32-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer

AASHTO Designation: R 32-09

1. SCOPE

1.1 This standard practice covers the annual calibration of the load cell and the deflection sensors and the monthly relative calibration of the deflection sensors of a falling weight deflectometer (FWD). It is used to establish calibration factors for correcting FWD measurements.

1.2 This procedure is not applicable to the calibration of cyclic loading and other types of pavement deflection testing equipment.

1.3 Annual calibration is performed at least once per year or as soon as possible after a deflection sensor or a load cell has been replaced on the FWD. It shall be performed by a certified technician.

1.4 Monthly relative calibration is performed on the deflection sensors at least once per month and immediately after a deflection sensor is replaced. A certified technician is not required.

1.5 The procedure results in calibration factors that are entered into the FWD software as multipliers. When the FWD measurements are multiplied by the calibration factors, the result is a set of measurements that have been corrected to agree with the calibration instrumentation.

1.6 Calibration procedures may vary slightly among FWD types. This procedure can be used for all types of FWDs with minor modifications within the limits of the reference calibration equipment.

1.7 This procedure has been automated in the software package *WinFWDCal*. It is required that the computer program be used to carry out the procedure.

1.8 To use this procedure, the FWD computer must be capable of electronic data transfer.

1.9 Data files for all types of FWDs can be read by the *WinFWDCal* software. The PDDX file format (see Section 3.1.9) is required for data input. FWD data files that are in native format can be converted to PDDX format using *PDDXconvert*, which is both an integral component in *WinFWDCal* and a stand-alone utility.

1.10 The values stated in SI units are to be regarded as standard. Imperial units given in parentheses are for information purposes only.

1.11 *This standard practice may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns associated with its use. It is the responsibility of the* *user of this standard practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

- R 33, Calibrating the Reference Load Cell Used for Reference Calibrations for Falling Weight Deflectometer
- T 256, Pavement Deflection Measurements

2.2 *Other document:*

- FHWA-HRT-07-040, FWD Calibration Center and Operational Improvements: Redevelopment of the Calibration Protocol and Equipment

3. TERMINOLOGY

3.1 *Definition of Terms Specific to this Standard*:

3.1.1 *certified technician*—an individual who has demonstrated proficiency at performing FWD calibrations during an annual quality assurance review and been issued a certificate of compliance. The certification procedure is described in detail in Report No. FHWA-HRT-07-040.

3.1.2 *data acquisition system*—the signal conditioner, data acquisition board, data acquisition software, computer, and cabling. It is connected to either the reference load cell or the accelerometer.

3.1.3 *FWD deflection sensor*—device used to measure the deflection response for a given load (e.g., geophones, accelerometers, or other devices).

3.1.4 *FWD load cell*—device located under the loading mechanism in an FWD that measures the load response of the FWD system.

3.1.5 *drop sequence*—the sequence of load levels with replicate drops at each load level used during reference calibration.

3.1.6 *final gain factor*—calibration factor for the load or deflection sensor at the end of the calibration procedure. The final calibration is entered into the FWD operating program as the final step in the calibration process.

3.1.7 *initial gain factor*—calibration factor for the load or deflection sensor that was present in the FWD operating program before the start of calibration.

3.1.8 *interim gain factor*—calibration factor for the deflection sensor resulting from averaging all trials of reference calibration.

3.1.9 *Pavement Deflection Data Exchange (PDDX)*—the file format required by *WinFWDCal*. This format is described in Report No. FHWA-HRT-07-040.

3.1.10 *reference calibration*—term used to describe the calibration of either the FWD load cell or deflection sensors against a separate reference measuring system. For load cell calibration, the reference system is a custom-made reference load cell; and for deflection sensors, it is a precision accelerometer.

3.1.11 *reference gain factor*—calibration factor determined by one trial during reference calibration.

3.1.12 *relative calibration*—term used to describe a calibration procedure in which the deflection sensors are calibrated relative to one another. No outside reference system is used.

3.1.13 *relative gain factor*—calibration factor determined by one trial during relative calibration.

3.1.14 *WinFWDCal*—the software required for data acquisition and data analysis for FWD calibration.

4. SUMMARY OF METHOD

4.1 In annual calibration, the deflection sensors and load cell from the FWD are first calibrated against independently calibrated reference devices. This calibration process, which is called “reference calibration,” can be performed at a regional calibration center or any other properly equipped location. Information on the location of these centers is available.[1]

4.1.1 The FWD load cell is calibrated against a custom-made reference load cell, which enables the FWD load cell to be calibrated without being removed from the testing equipment.

4.1.2 The FWD deflection sensors are removed from their holders on the FWD and mounted in a rigid stand where they are calibrated against a precision accelerometer (with the accelerometer signal being double integrated by *WinFWDCal*). The sensors are stacked vertically in the stand, one above another, so that all sensors, including the accelerometer, are subjected to the same pavement deflection.

4.1.3 Next, the calibration of the FWD deflection sensors is further refined by comparing them to each other in a process referred to as “relative calibration.” As such, it serves as the final step in the annual calibration process. In annual calibration, the same sensor stand is used for both reference and relative calibration.

4.2 Monthly relative calibration uses a relative calibration stand supplied by the FWD manufacturer. It is a quick means to periodically verify that the sensors are functioning properly and consistently. Monthly relative calibration assumes that the overall mean deflection, as determined from simultaneous measurements by the full set of deflection sensors, yields an accurate estimate of the true deflection. This assumption requires that the deflection sensors must have first been subjected to the annual calibration procedure.

4.2.1 The relative calibration procedure used for monthly relative calibration is different from that used for annual calibration.

4.3 Acceptance criteria for annual calibration and monthly relative calibration, based upon the repeatability of the calibration factors, are identified in the calibration procedure. If accepted, the new gain factors shall be entered into the FWD operating program.

5. SIGNIFICANCE AND USE

5.1 Calibration of both the load cell and the deflection sensors provides a means of comparison of results from different FWD types and manufacturers.

5.2 Calibration ensures consistency in the data collection among various agency FWDs.

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6. APPARATUS

6.1 *Facilities*—Indoor space with easy access for FWD and towing vehicle, a level floor large enough so that the FWD trailer and the towing vehicle can sit level during the test, a reasonably constant temperature (between 10 and 38°C) and humidity (40 to 90 percent, noncondensing), heated, but not necessarily air-conditioned, and good security for the calibration equipment.

6.1.1 *Test Pad*—4- by 5-m (12- by 15-ft) slab with a 2.5-m (8-ft) wide clear zone around perimeter (for maneuvering FWDs and the reference data acquisition system) having a smooth, crack-free portland cement concrete surface.

Note 1—While an isolated test pad is recommended, it is not required, provided that all other facilities requirements, especially the minimum slab deflection requirement and sufficient slab damping, are achieved. The slab dimensions (4 by 5 m) are suggested, and other dimensions may be satisfactory.

Note 2—A modest amount of hairline cracking is permissible. Should the test pad develop cracks which are visibly open (1.5 mm (0.06 in.) or more), it shall be replaced.

6.1.1.1 The test pad should be isolated (by impregnated felt bond breaker, sawed and caulked joint, or similar means) from the surrounding floor area.

6.1.1.2 The test pad shall have a slab deflection of at least 300 microns (12 mils) due to 70-kN (16,000-lb) load at the position of the deflection sensor calibration stand when the FWD is in the specified position for calibration.

Note 3—Fatigue calculations indicate that acceptable fatigue life can be achieved with a 125-mm (5-in.) thick portland cement concrete slab resting on a 200-mm (8-in.) open-graded crushed stone base. A layer of filter fabric shall be placed below the base to protect it from intrusion of subgrade fines. To achieve adequate deflections, the subgrade modulus shall be less than 80 MPa (12,000 psi) with bedrock deeper than 7 to 9 m (25 to 30 ft). Where bedrock exists at depths of 4 to 8 m (15 to 25 ft), a subgrade modulus of 50 MPa (7500 psi) or less will be needed. Test pads located where bedrock is less than 4 m (15 ft) deep are likely to be very sensitive to minor variations in subgrade moisture, and hence are not advisable.

Note 4—If deflections in this range cannot be achieved, then it may be necessary to relocate the FWD to a different pavement. In general, a concrete pavement on a relatively weak subgrade will yield the required deflection amplitude.

6.1.1.3 The sensor holder shall be located not closer than 150 mm (6 in.) from the edge of the test pad, but it is not required, nor is it possible, that the test pad shall deflect uniformly across the entire area of the pad.

6.2 *Equipment*—The following equipment is needed in the calibration facility:

Note 5—Drawings of each of the special items of equipment, cabling diagrams, and the data acquisition software, *WinFWDCal* and *PDDXconvert*, are available.[1]

6.2.1 *Signal Conditioner*—Measurements Group Inc. Vishay Model 2310 signal conditioner[2] with power cable and stabilizer bar.

6.2.2 *Data Acquisition Board (DAQ)*—Keithley Model KUSB-3108 data acquisition board.[3]

6.2.3 *Connecting Cables*—Vishay to accelerometer, Vishay to load cell, Vishay to DAQ, and DAQ to computer USB port.

6.2.4 *Computer*—A laptop or desktop computer capable of running Windows *XP* or higher software, having at least four USB ports.

6.2.5 *Reference Load Cell*—Custom-built reference load cell (300-mm diameter) calibrated annually to 106 kN (24,000 lb) capacity.

6.2.6 *Reference Accelerometer*—Silicon Designs Model 2220-005 ± 5 g accelerometer mounted in a custom-built aluminum box housing.

6.2.7 *Accelerometer Calibration Platform*—Custom-built aluminum platform capable of being leveled. Used for daily calibration of the accelerometer and for storage of the accelerometer when it is not in use.

6.2.8 *Data Acquisition Software*—*WinFWDCal* and *PDDXconvert*.

6.2.9 *Deflection Sensor Calibration Stands*—Custom-built welded aluminum stands with shelves for ten deflection sensors and one reference accelerometer. One design is used with geophones and another with seismometers. Used for annual calibration.

6.2.10 *Ball-joint Anchor*—Custom-built hardware, bolted to the floor or test pad, for coupling the deflection sensor calibration stand to the pavement.

6.2.11 *Relative Calibration Stand*—Provided by the FWD manufacturer with as many positions as the number of active deflection sensors. Used for monthly relative calibration.

7. FALLING WEIGHT DEFLECTOMETER SET UP

7.1 The FWD shall be in good operating condition prior to performing reference calibration. Particular attention shall be paid to cleaning the deflection sensor bases, where appropriate, to ensure that they seat properly in the sensor stand. Also, verify that the FWD load plate is firmly attached to the load cell and the swivel (if so equipped) is well lubricated. All electrical connectors shall be inspected and, if necessary, cleaned and firmly seated.

7.2 During set up, FWD-specific information will need to be transferred electronically from the FWD computer files to the calibration computer. The *WinFWDCal* software will provide guidance to accomplish this.

7.3 If the FWD is trailer-mounted, the trailer shall remain attached to the towing vehicle throughout the entire calibration period.

7.4 The FWD shall be at room temperature and should be set up as it is used under normal operating procedures.

7.5 Before beginning any calibration work, and throughout the entire calibration period, there shall be no data filters in operation in the FWD operating program. Verify that all smoothing or filtering has been turned off.

7.6 A series of warm-up drops shall be performed immediately prior to beginning calibration.

7.7 The drop sequence used for calibration shall be determined in a two-step process.

7.7.1 The FWD owner shall specify the load levels to be used during calibration. A minimum of three and a maximum of four load levels shall be specified. The highest load level shall not exceed 80 kN (18 000 lb) ± 10 percent.

Note 6—Heavy weight deflectometers (HWD) can achieve the target load levels by taking off all of the removable weights.

7.7.2 With the accelerometer in the sensor stand and the stand mounted in the ball-joint anchor, use the *WinFWDCal* software to determine the minimum number of replicate drops. More than the minimum number of drops may be used, not to exceed ten drops per load level.

7.7.3 Program the drop sequence in the FWD computer, progressing from the lowest to the highest load level. Provide for a pause after each drop or manually control the FWD. The same number of drops shall be used at each load level. The same drop sequence shall be used for both load and deflection sensor calibration.

7.7.4 If three load levels are used, the minimum number of drops in the sequence shall be 18 and the maximum number shall be 30. For four load levels, the minimum number of drops shall be 20 and the maximum shall be 40.

8. LOAD CELL CALIBRATION SET UP

8.1 If the reference load cell has not been calibrated within the past 12 months, then it shall be recalibrated in accordance with R 33.

8.2 Hook up the cables and warm up the electronics for at least 30 minutes before beginning a calibration.

8.3 Zero the signal conditioner with the load plate high, so that there is no external load on the reference load cell. For accurate results, it is critically important that the reference load cell be zeroed with the FWD load plate in the raised position. The signal conditioner excitation and gain must be set exactly to the levels at which the reference load cell was calibrated. The software will provide guidance to accomplish this.

8.4 Position the FWD so that the load plate is near the center of the calibration test pad, or on any other stiff, smooth concrete surface. Sweep the area beneath the load plate to assure there will be no sand or other loose debris under the reference load cell.

8.5 Position the reference load cell beneath the FWD load plate, making sure that the three guides are aligned around the plate. Verify that the load plate sits squarely on the load cell and on the pavement.

Note 7—After applying three seating drops, it should not be possible to slide a piece of paper under the load plate anywhere around the perimeter of the plate or under any of the support feet of the reference load cell.

9. DEFLECTION SENSOR CALIBRATION SET UP

9.1 Hook up the cables and warm up the electronics for at least 30 minutes before beginning a calibration.

9.2 The signal conditioner excitation and gain must be set exactly to the specified levels. The software will provide guidance to accomplish this.

9.3 Calibrate the accelerometer, mounted in an aluminum box, using the calibration platform. The platform shall be carefully adjusted using the bubble level to assure that the accelerometer is aligned with Earth's gravity field. The accelerometer shall be calibrated in both +1 g and –1 g fields by inverting the box briefly. The *WinFWDCal* software will provide on-screen instructions. The calibration shall be repeated after 4 hours.

Note 8—Care must be taken to avoid dropping the accelerometer box during the calibration process because the shock may damage the accelerometer.

9.4 Position the FWD so the load plate is as close as possible to the ball-joint anchor.

9.5 Connect the sensor stand to the ball-joint anchor and tighten all bolts securely. Slippage between the stand and the base, or between the base and the concrete test pad, shall not be allowed. The ball joint shall rotate with slight friction. It is important that the FWD shall not come in contact with the sensor stand during the calibration.

9.6 Attach the accelerometer box in position in the sensor stand.

9.7 Remove the FWD deflection sensors from the FWD and position them in the sensor stand in accordance with the *WinFWDCal* on-screen instructions.

Note 9—For monthly relative calibration, the sensor stand supplied by the FWD manufacturer shall be used; only Section 9.7 is needed; and the procedure in Section 12 shall be used.

10. ANNUAL DEFLECTION SENSOR CALIBRATION PROCEDURE

10.1 *Reference Calibration*—Deflection sensor reference calibration consists of performing two trials, in which all of the sensors are calibrated simultaneously in the sensor stand. The position of the sensors in the stand is inverted between the trials. Spare deflection sensors shall not be calibrated unless they have separate, dedicated signal conditioning channels in the FWD microprocessor.

10.1.1 The reference calibration drop sequence established during set up (Section 7.7) shall be used. The load plate shall not be raised at any time during the sequence.

10.1.2 Perform the drop sequence for the first reference calibration trial. Review and accept or reject the data for each drop. The *WinFWDCal* software will graphically display the deflection-time data after each drop.

10.1.3 At the conclusion of the drop sequence, transfer the FWD data electronically to the calibration computer and review the results. For each sensor, *WinFWDCal* will regress the FWD output (independent variable) versus the reference deflection sensor (dependent variable) forced through zero. The slope of the regression line for each sensor, when multiplied times the initial gain factor, gives the reference gain factor.

10.1.4 The slope for an individual sensor is acceptable if its reported standard error is not more than 0.0020. The trial is acceptable if the standard errors for all sensors are not more than 0.0020.

10.1.5 If the first trial is acceptable, continue with the second trial. Repeat Section 10.1. Invert the sensors in the stand before the second trial according to the diagram displayed by *WinFWDCal*.

10.2 *Interim Gain Factor Acceptance Criteria*—Evaluate the data as follows:

10.2.1 After two trials have been accepted, *WinFWDCal* will calculate the average reference gain factor for each sensor and display the results as the interim gain factors (one gain factor for each sensor).

10.2.2 *WinFWDCal* will calculate the difference in the reference gain factors for each sensor between the two trials and the root-mean-square (RMS) difference for all sensors. If the RMS difference is no more than 0.003, then the reference calibration test is complete.

10.2.3 If the RMS difference is greater than 0.003, this indicates that some sensors may not be sufficiently repeatable. Two more reference calibration trials shall be performed. Repeat Section 10.1. *WinFWDCal* will calculate the standard deviations of the reference gain factors for each sensor for the four trials. If each of the standard deviations is no more than 0.003, then the reference calibration test is complete.

10.2.4 The average of the four reference gain factors for each sensor shall be reported as the interim gain factors.

10.3 *Relative Calibration*—Reference calibration is followed by relative calibration, using the same sensor stand. Two trials are performed. For each trial, 40 drops shall be applied from the highest drop height used in reference calibration. The sensors shall not be repositioned in the sensor stand before the first trial.

Note 10—The *WinFWDCal* software will adjust the FWD data collected in the relative calibration using the interim calibration factors internally. Do *not* enter the interim factors in the FWD operating program before performing relative calibration.

10.3.1 Perform the drop sequence for the first relative calibration trial.

10.3.2 At the conclusion of the drop sequence, transfer the FWD data electronically to the calibration computer and review the results. For each sensor, *WinFWDCal* will calculate the means ratio. The means ratio multiplied times the interim gain factor gives the relative gain factor.

10.3.3 *WinFWDCal* does an analysis of variance (ANOVA) for the data and reports the standard error. The trial is acceptable if the standard error is not more than 3 microns (0.12 mils).

Note 11—The *WinFWDCal* software will display a plot of the data for the 40 drops. The graph should be scanned to detect outliers (for instance, a loose sensor in the stand).

10.3.4 If the standard error is greater than 3 microns (0.12 mils) the trial shall be rejected. Repeat Section 10.3. (Do not reposition the sensors in the sensor stand.) If acceptable results cannot be obtained after four trials, no further effort shall be made to calibrate the deflection sensors.

Note 12—The reason why the standard error exceeds 3 microns should be investigated and corrected, if possible, before repeating the procedure.

10.3.5 If the first trial is acceptable, continue with the second trial. Repeat Section 10.3. Invert the sensors in the stand before the second trial according to the diagram displayed by *WinFWDCal*.

10.4 After two trials have been accepted, *WinFWDCal* will calculate the average relative gain factor for each sensor, and report the results as the final gain factors.

11. ANNUAL LOAD CELL CALIBRATION PROCEDURE

11.1 *Reference Calibration*—Reference load cell calibration consists of at least two trials.

11.1.1 The reference calibration drop sequence established during set up (Section 7.7) shall be used. The load plate shall not be raised at any time during the sequence.

11.1.2 Perform the drop sequence for the first reference calibration trial. Review and accept or reject the data for each drop. The *WinFWDCal* software will graphically display the deflection-time data after each drop.

11.1.3 At the conclusion of the drop sequence, transfer the FWD data electronically to the calibration computer and review the results. For each sensor, *WinFWDCal* will regress the FWD output (independent variable) versus the reference load cell (dependent variable) forced through zero. The slope of the regression line for each sensor, when multiplied times the initial gain factor, gives the reference gain factor.

11.1.4 The slope for the trial is acceptable if its reported standard error is not more than 0.0020.

11.1.5 If the first trial is acceptable, continue with the second trial. Repeat Section 11.1.

11.1.6 After two trials have been accepted, *WinFWDCal* will calculate the average reference gain factor and report the results as the final gain factor. If the range of the two reference gain factors is not more than 0.003, then the final gain factor shall be accepted. The reference calibration test is complete.

11.1.7 If the results are outside the allowable range, a third reference calibration trial shall be performed. Repeat Section 11.1.

11.1.8 If the standard deviation of the gain factors for three acceptable trials is not more than 0.003, then the results of the three trials shall be averaged and reported as the final gain factor for the load cell. The reference calibration test is complete.

11.1.9 If the standard deviation exceeds 0.003, the reference load cell calibration procedure shall be repeated (one more trial), yielding a fourth gain factor.

Note 13—The reason why the standard deviation exceeds 0.003 should be investigated and corrected, if possible, before repeating the procedure.

11.1.10 If the standard deviation of all calibrations (four acceptable trials) is not more than 0.003, the average of all four results shall be reported as the final gain factor for the load cell, and the reference calibration test is complete. If acceptable results cannot be obtained after four trials, no further effort shall be made to calibrate the load cell.

12. ANNUAL CALIBRATION ACCEPTANCE AND CERTIFICATION

12.1 *Evaluation and Acceptance of Final Gain Factors*—The *WinFWDCal* software will perform the needed calculations. Evaluate the data as follows:

12.1.1 The final gain factors from this calibration shall be compared to the corresponding gain factors from the previous calibration (i.e., the initial gain factors). There shall be no more than a 1 percent difference, either higher or lower, for each individual deflection sensor and for the load cell. If this criterion is satisfied, then final gain factor for the sensor shall be accepted. If this criterion is not satisfied for a sensor, then evaluate it according to the next criterion.

12.1.2 The final gain factor for the sensor shall fall within a range of 0.980 to 1.020. If this criterion is satisfied, then the final gain factor for the sensor shall be accepted. If this criterion is not satisfied for the sensor, then evaluate it according to the next criterion.

12.1.3 If a historical record of previous calibrations for the sensor is available for a period of 4 years or more, and there are at least three previous calibration results over this period of time, then the time rate of change of the final gain factor for the sensor shall be no more than 0.1 percent per year. If this criterion is satisfied, then the final gain factor for the sensor shall be accepted.

12.2 *Certificate of Calibration*—If the final calibration results meet the acceptance criteria for all sensors, a certificate of calibration listing the final gain factors for the load cell and each deflection sensor shall be issued by *WinFWDCal*.

12.2.1 The final gain factors shall be entered into the FWD operating program.

13. MONTHLY RELATIVE CALIBRATION PROCEDURE

13.1 Monthly relative calibration can serve one of two purposes. With regular use, it is a means to verify that the deflection sensors are functioning properly and consistently. It can also be used to replace a damaged sensor, providing a gain factor for the replacement sensor for short-term use until an annual calibration can be done.

Note 14—Monthly relative calibration uses a calibration stand provided by the FWD manufacturer. The deflection sensors are stacked vertically in the stand, one above another, so that all sensors are subjected to the same pavement deflection. Position in the stand may have an effect on the deflection readings. To compensate for this, the sensors are rotated through all positions in the stand. *This rotation procedure is different from the relative calibration procedure done for annual calibration.*

Note 15—Monthly relative calibration relies on collecting a large number of data that can be averaged to reduce the significance of random measurement errors. Deflections in excess of 500 microns (20 mils) are needed for the results to be accurate. *WinFWDCal* does the statistical data analysis to compute adjustment ratios and final gain factors from the data. Since a large number of drops are involved, the properties of the pavement materials may change due to compaction or liquefaction during the procedure. However, all of the sensors are equally affected, so as long as the effect is not too extreme, the adjustment ratios are still accurate.

13.1.1 Some FWDs have fewer than or more than seven active deflection sensors. If they do, these procedures shall be modified to calibrate the actual number of active sensors in use on the FWD. Any number of sensors will work as long as the calibration stand will accept them.

13.1.2 Remove all of the deflection sensors from their holders on the FWD. Make sure that the sensors are labeled (e.g., from one to seven) with respect to their normal position on the FWD. The center sensor shall be defined as D1 for this procedure.

13.1.3 Position the deflection sensors in the stand for the first set.

13.1.4 The sensor stand shall be held in a vertical position. Mark the location where it rests so that it can be relocated precisely on the same spot. This should be done by gluing a washer to the pavement or by chipping a small divot in the pavement with a chisel or a screwdriver.

13.1.5 Select the FWD drop height and the distance from the loading plate to the sensor stand to yield deflections near 500 microns ± 100 microns (20 mils ± 4 mils).

Note 16—If deflections in this range cannot be achieved, choose another location. A concrete pavement on a relatively weak subgrade will usually yield the required deflection. This procedure may be carried out at any location that satisfies the deflection requirement.

13.1.6 Warm up the FWD and condition the test point by repeating a sequence of ten drops until the loads and deflections that are registered are nearly uniform. The deflections in a sequence of ten drops should not show a steadily increasing or decreasing trend.

13.1.7 Lower the FWD loading plate. Do *not* raise the loading plate or move the FWD during the relative calibration testing. This will assure a constant distance between the center of the load plate and the base of the sensor stand.

13.1.8 For each set, make two seating drops (no data recorded) followed by five replicate drops (for which data are recorded) while holding the stand in a vertical position.

13.1.9 At the end of each set, rotate the sensors in the stand. The general progression is for the sensors to move from the bottom toward the top of the stand. With a nine-sensor FWD, a total of 45 drops shall be recorded (nine sets of five replicate drops for each set). With a seven-sensor FWD, 35 drops shall be recorded.

13.2 *Relative Calibration Data Analysis*—Follow the *WinFWDCal* on-screen instructions for set up of the procedure. Transfer the FWD data file electronically to the *WinFWDCal* software program for analysis. Options are provided in the software to indicate whether a normal data analysis or a special analysis for sensor replacement is required.

13.3 *Adjustment of Calibration Factors: Normal Analysis*—Normal analysis is used when no sensor is being replaced.

13.3.1 The *WinFWDCal* software will report the adjustment ratios and the gain factors for each deflection sensor. Adjustment of the gain factors in the FWD operating system shall be made only when those changes are both significant and verified to be necessary. The following guidelines shall be used to evaluate the need for adjustment of the gain factors:

13.3.1.1 If all of the adjustment ratios are between 0.997 and 1.003 inclusive, they are not statistically significantly different from a ratio of 1.000. The calculated adjustments are trivial. The calibration test is complete, and no change of the gain factors shall be made.

13.3.1.2 When the adjustment ratios for one or more sensors fall outside of the range 0.997 to 1.003, a second relative calibration trial shall be performed. Repeat Section 13.1. If the gain factors for each sensor in both trials agree within 0.003, the need for the adjustment has been verified. The gains shall be adjusted for *all* sensors. The gain factors for each sensor for the two trials shall be averaged and entered in the FWD operating system. The calibration test is complete.

13.3.1.3 If, for one or more sensors, the difference in the gains for the two trials is greater than 0.003, reject the first two trials and perform two more trials. If the second attempt also exceeds the allowable difference, the annual calibration procedure (Section 10) shall be performed as soon as possible.

13.4 *Adjustment of Calibration Factors: Sensor Replacement*—When replacing a damaged deflection sensor, the monthly calibration procedure should be used to determine a gain factor for the replacement sensor. The calculations are done by the *WinFWDCal* software, and a gain factor is reported only for the replacement sensor.

13.4.1 Two relative calibration trials shall be performed. If the two gain factors for the replacement sensor agree within 0.003, then the gain factors for the two trials shall be averaged and entered in the FWD operating system. The calibration test is complete.

13.4.2 If the difference is greater than 0.003, two more relative calibration trials shall be performed. Repeat Section 13.1. *WinFWDCal* will report the average gain factor from the four trials and the standard deviation. If the standard deviation is not more than 0.003, then the average gain factor shall be entered in the FWD operating system. The calibration test is complete.

13.4.3 If the standard deviation of the four trials is more than 0.003, no further effort shall be made to calibrate the replacement sensor. The annual calibration procedure (Section 10) shall be performed as soon as possible.

14. REPORT

14.1 *The calibration certificate shall report the following information*:

14.1.1 Calibration date;

14.1.2 Listing of the original load cell serial number and gain factor;

14.1.3 Listing of the original deflection sensor positions, serial numbers, and gain factors;

14.1.4 Final load cell gain factor; and

14.1.5 Final deflection sensor gain factors for each sensor.

15. PRECISION AND BIAS

15.1 *Load Cell Calibration*:

15.1.1 Seventeen load cell calibration trials were done in 2006 by three FWD calibration operators using a Dynatest FWD. No difference between operators was found. The overall standard deviation of the final calibration factor was 0.00152. The 95th percentile repeatability using a Student's *t-test* uses a multiplier of 2.11.

For this example, the precision and bias statement would read:

Precision and Bias Statement for Dynatest Load Cell Calibration:

The 95 percent repeatability of the final gain factor: 0.321 percent.
No reproducibility statement is available at this time.
There is no bias expected in the final gain factor.

15.2 *Geophone Calibration*:

15.2.1 Nine geophone calibration trials were done in 2006 by three FWD calibration operators using a Dynatest FWD. No difference between operators was found. The overall pooled standard deviation of the final calibration factors for all nine geophones was 0.00245. By using the pooled standard deviation, the normal distribution multiplier of 1.96 may be used.

For this example, the precision and bias statement would read:

Precision and Bias Statement for Dynatest Geophone Calibration:

The 95 percent repeatability of the final gain factor: 0.480 percent.
No reproducibility statement is available at this time.
There is no bias expected in the final gain factor.

16. KEYWORDS

16.1 Falling weight deflectometer; FWD; calibration; geophones; load cell; pavement deflection; pavement testing; seismometers; sensors.

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[1] Data acquisition software is available from the Customer Support Services of the Long-Term Pavement Performance Program at the Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, Virginia; E-mail: ltppinfo@dot.gov; telephone number: (202) 493-3035.

[2] Suitable signal conditioners are available from Measurements Group Inc.; telephone number: (606) 881-0205.

[3] Suitable data acquisition boards are available from Keithley Instruments, Inc.; telephone number (800) 552-1115.

Standard Practice for

Calibrating the Reference Load Cell Used for Reference Calibrations for Falling Weight Deflectometer

AASHTO Designation: R 33-03 (2008)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Calibrating the Reference Load Cell Used for Reference Calibrations for Falling Weight Deflectometer

AASHTO Designation: R 33-03 (2008)[1]

1. SCOPE

1.1. The reference load cell is a precision instrument that requires regular and thorough calibration.

1.2. It is essential that the reference load cell be calibrated using a testing machine that is properly maintained and accurately calibrated.

1.3. The reference load cell and its cable and the associated signal conditioner are considered a *system* of instruments which are to be calibrated together and used together.

1.4. *This standard practice may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- R 32, Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer

2.2. *ASTM Standard*:

- E 74, Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines

3. SUMMARY OF METHOD

3.1. The reference load cell system is calibrated against a recently calibrated universal testing machine.

3.2. The reference load cell system is conditioned in the testing machine by loading it three times to 1.2 times the highest load to be measured by the falling weight deflectometer (FWD) (for a typical FWD 100 kN (20 000 lb)).

3.3. Loads are applied at a rate of 5 kN (1000 lb) per minute and read from both the load cell system and the testing machine.

3.4. Develop a polynomial regression equation with an estimated standard error of less than 20 N (50 lb) and a coefficient of determination of better than 0.98. A third- to fifth-degree polynomial will provide these limits.

3.5. The regression coefficients are entered into the data acquisition software used for the reference load cell system.

4. SIGNIFICANCE AND USE

4.1. In order to be confident in the calibration factors derived in the FWD load cell calibration, the reference load cell must be calibrated against known loads.

5. TERMINOLOGY

5.1. *Description of Terms Specific to This Standard*:

5.1.1. *reference load cell*—custom-built calibration device used to calibrate the in-place load cell on the FWD.

5.1.2. *reference load cell system*—system composed of the reference load cell, its cables, and the associated signal conditioners. This system must be maintained for use in the FWD load cell calibrations.

6. APPARATUS

6.1. *Testing Machine*—A static testing machine, hydraulic or screw-powered, with a load capacity of at least 200 kN (50 000 lb) or 2.5 times the maximum load to be measured by the FWD should be used for the reference load cell calibration. The high capacity of the testing machine assures that the test frame will be adequately rigid. The testing machine shall have several load ranges, among them a range slightly higher than 1.2 times the maximum load to be measured by the FWD. Care must be taken to avoid overloading the reference load cell during its calibration.

Note 1—Alternatively, a servo-controlled, closed-loop testing system such as an MTS machine with a capacity of 200 kN (50 000 lb) or 2.5 times the maximum load to be measured by the FWD can be used for this purpose. Newer digital systems can provide the accuracy required for this purpose.

6.2. *Signal Conditioner*—The signal conditioner should be sanctioned by the manufacturer of the calibration load cell.

6.3. *Data Acquisition Board*—A data acquisition board with resolution of 16 bit or better should be used for calibration.

6.4. *Triggering System*—An adequate software- or hardware-driven, digital or analog triggering system should be used to synchronize the signals from the data acquisition boards.

7. PREPARATION OF APPARATUS

7.1. The testing machine shall be calibrated according to ASTM E 74 or the manufacturer's recommendation within 12 months prior to conducting this procedure. The device(s) used to calibrate the universal testing machine shall be certified to be traceable to the National Institute of

Standards and Technology (NIST) calibration(s). The certificate of calibration provided for the testing machine shall be used to develop an adjustment algorithm that will correct the indicated load on the testing machine to the NIST load.

7.2. The data acquisition board should be calibrated as per recommendation of the manufacturer.

7.3. The signal conditioner amplifier shall be balanced according to the procedure described in the manufacturer's instruction manual. With the signal input terminals shorted together, at a gain of 100, the AC noise on the ±10-volt output shall be 1 millivolt or less.

7.4. Inspect the reference load cell carefully before calibration. Verify that the cable and the connectors are making proper contact.

7.4.1. Make a continuity check to verify that there are no breaks in the wires. Verify that the Allen screws on the load cell are tight.

Note 2—The load cells are typically torqued to a level suggested by the manufacturer and set with Locktite during assembly. *These screws shall not be loosened unless it is absolutely necessary*. If any of the screws are loosened, they shall be removed one at a time and their threads cleaned. Locktite shall be reapplied to their threads, and they shall be torqued to the specified level.

7.4.2. It is of utmost importance to utilize the software and associated hardware provided by the appropriate agencies in accordance with their instructions. Special attention should be paid to setting up the signal conditioning gains, filters, and input and output voltages precisely as recommended by the responsible agency. The Federal Highway Administration Long-Term Pavement Performance Program has developed several programs that can be used as guidelines.

8. PROCEDURE

8.1. Attach the cable from the signal conditioner to the reference load cell and turn on the signal conditioner.

8.2. Warm up the testing machine for at least 15 minutes.

8.3. Carefully align and center the system under the upper loading block of the testing machine.

8.4. Apply a nominal load of 100 kN (20 000 lb) or 1.2 times the maximum load to be measured by the FWD to the reference load cell three times, unloading after each repetition. Apply the load at a rate in the range of 20 kN to 100 kN (5000 lb to 20 000 lb) per minute. With the servo-valve closed-loop systems, apply three pulses of about 100 kN (20 000 lb) or 1.2 times the maximum load to be measured by the FWD.

8.5. Apply load at a rate no faster than 5 kN (1000 lb) per minute. Either manually or digitally, record the load from the calibration load cell and the voltage output (or number of bits) from the load cell being verified. Take readings at 5-kN (1000-lb) intervals up to a maximum load of 100 kN (20 000 lb) or 1.2 times the maximum load to be measured by the FWD. While releasing the load, record a reading at 50 kN (10 000 lb) and at zero load.

If a servo-valve, closed-loop hydraulic system is used, apply pulses with duration of 100 msec or less at 5-kN (10 000-lb) increments to a maximum load of 100 kN (20 000 lb) or 1.2 times the maximum load to be measured by the FWD. Repeat the process at least three times at each load level.

9. CALCULATIONS

9.1. Using a spreadsheet program, enter the results of the calibrations as follows:

9.1.1. In one column, enter the loads registered by the testing machine (i.e., 0, 5, 10, etc.).

9.1.2. If necessary, correct these loads to the NIST traceable loads, based on the certificate of calibration for the testing machine.

9.1.3. Also subtract the tare weight of the upper bearing block from the loads, if applicable.

9.1.4. In another column, enter the voltage output of the load cell being verified. If the number of bits on the data acquisition board is registered, convert them to voltage.

9.2. Conduct a polynomial-regression analysis between the corrected calibration load cell (as the Y variable) versus voltage output from the load cell being verified (as the X variable).

9.2.1. Evaluate the polynomial solution according to the following criteria:

9.2.1.1. The standard error of the Y estimate should be less than ±20 N (50 lb).

9.2.1.2. The coefficient of determination should be greater than 0.98.

Note 3—To optimize the fitting process, start with a first-degree polynomial (i.e., a line) and increase the number of polynomial terms until the two criteria above are met. If the two criteria cannot be met up to a fifth-degree polynomial, either repeat the calibration process or contact the manufacturer of the reference calibration set up for assistance.

9.3. The regression coefficients shall be recorded and entered in the data acquisition program.

10. REPORT

10.1. *Report the following information*:

10.1.1. Date of the calibration, and

10.1.2. The regression coefficients from Section 9.3.

11. FREQUENCY OF CALIBRATION

11.1. Calibration of the reference load cell shall be performed at least once per year. It shall also be performed immediately after any changes to the set up of the calibration load system.

12. PRECISION AND ACCURACY

12.1. No precision or accuracy statements are available at this time.

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[1] This standard is based on SHRP Product 5004.

Standard Practice for

Installing, Monitoring, and Processing Data of the Traveling Type Slope Inclinometer

AASHTO Designation: R 45-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Installing, Monitoring, and Processing Data of the Traveling Type Slope Inclinometer

AASHTO Designation: R 45-08

1. SCOPE

1.1. This practice provides instructions for installation, monitoring, and data reduction for the *traveling type* slope inclinometer for use with guide casing. A slope inclinometer is a precision instrument that measures lateral displacement of a guide casing resulting from the movement of earth, concrete, or other masses. This type of instrument can be used to detect and monitor movements in earth- and rock-fill dams, highway embankments and foundations, excavation slopes, sheet pile bulkheads, concrete retaining walls, and other structures. Since the instrument is waterproof, it can be used on projects where normal measurements would not be feasible, such as the displacement of the lower portion of a pipe pile. The data, which are well suited for computer reduction, can be used to interpret shear zones in landslide areas and as a basis for predicting impending shear failures or structural failures based on the amount and rate of lateral deformation occurring.

1.2. The practice is divided into the following parts:

1.2.1. Part I, Installing Slope Inclinometer Guide Casing;

1.2.2. Part II, Monitoring Slope Inclinometer Guide Casing; and

1.2.3. Part III, Data Computations and Analysis.

1.3. The values stated in SI units are to be regarded as the standard.

PART I—INSTALLING SLOPE INCLINOMETER GUIDE CASING

2. APPARATUS

2.1. *Drilling Equipment*:

2.1.1. Drill rig capable of drilling a hole with diameter large enough to accommodate the particular size slope inclinometer casing used and allow for adequate backfilling. The depth of the hole needed varies with the particular installation, locale, and/or discretion of the engineer. Normally, a drill rig capable of drilling a 203-mm (8-in.) diameter hole to the desired installation depth may be used. A smaller drill rig may be used for shallow depth installations.

2.2. *Guide Casing*:

2.2.1. Guide casing, usually round extruded plastic, with four equally spaced longitudinal grooves on the inside of the casing compatible with the particular torpedo sensor used. However, some casing may not be grooved because the torpedo sensor maintains proper orientation by use of locking metal orientation rods. Some inclinometers may be used in square steel casing with the torpedo sensor guide wheels tracking in opposite corners of the casing. The casing comes in assorted diameters and may come in any convenient length, such as 1.52- or 3.05-m (5- or 10-ft) sections.

2.3. *Couplings*:

2.3.1. The couplings may be extruded plastic with four equally spaced grooves and usually come in 152-mm (6-in.) lengths. In cases where settlement is expected, longer couplings may be used to join the sections of casing. The resulting gap between casing sections allows the casing to telescope together as compression of the surrounding materials occurs. Alternately, a coupling mechanism may be included as part of the guide casing.

2.4. *Installation Tools*:

2.4.1. Inclinometer guide casing installation tools specified by the manufacturer, normally consisting of hacksaw, casing clamp, casing anchor (recommended), tape measure, and a device for marking casing grooves such as a felt tip marker or file. A special wheel groove alignment tool, duct or masking tape, and solvent cement may be needed for plastic casing. A vibrator and/or grout pump may be used for backfill compaction and placement if necessary.

2.5. *Plugs*:

2.5.1. Plugs compatible with the particular guide casing are used for protecting the top and bottom of the casing from mud and debris. A conical plug may be used to ease insertion of the casing into a rough-sided hole.

2.6. *Protective Device (Optional)*:

2.6.1. Hole cover or other protective device to minimize vandalism and large enough (152 mm (6 in.)) to allow the cable clamp-guide wheel assembly to be installed on top of the casing. A metal pipe with either a threaded cap or hinged lid with hasp and lock may be used. For protection from impacts by construction traffic, bollards or barriers may be installed.

3. DRILLING AND HOLE PREPARATION

3.1. The size of the drill hole should be large enough to accommodate the particular size casing used and depends on the particular installation, locale, materials encountered, depth of the hole, available backfill materials, or the discretion of the engineer. Larger holes facilitate backfilling. Minimum diameter may be only sufficient to accommodate the casing used. This is applicable in cases where the material may close quickly. Normally, the drill hole may be approximately two times the outside diameter of the casing or a minimum of 127 to 152 mm (5 to 6 in.). The hole should be as vertical as possible (vertical inclination should be less than 3 degrees), and drilled several meters (at least 3 m, or as directed by the engineer) into stable material below or beyond the anticipated zone of movement. Usually, the borehole should extend into rock or soil to achieve sufficient rigidity to provide the fixity of the inclinometer. The bottom 3 m (or as directed by the engineer) of the inclinometer casing should be embedded below the lowest possible failure plane and should extend into hard or very dense material to assure that the future readings do not show any movement at the bottom of the inclinometer casing.

3.2. The hole usually should be cleaned by flushing with water or blowing compressed air before attempting to install the inclinometer casing. Depending on the installation, sometimes it is necessary to leave drilling mud (if it is used) in the borehole to control caving, thereby allowing proper backfill.

3.3. Any means of accomplishing a boring is satisfactory as long as it is suitable to the engineer and conditions at the site. If the ground is firm and the hole will remain open without steel casing, then either a dry hole (drilled with a continuous flight auger) or a water-filled hole (drilled with a chopping bit or a rotary bit and using water to flush out the cuttings) is satisfactory.

3.3.1. Hollow stem augers may be used with success because the augers can be pulled after installation of the slope inclinometer casing. If the hole is likely to squeeze in because of soft soils or cave because of sand, drilling mud may be used and left in the hole upon completion of the boring.

3.3.2. If drilling mud is used, some difficulty may be encountered in making the inclinometer casing go down completely in the hole, but this may be remedied by filling the casing with water or other physical means.

3.4. Steel or any other type of casing may be used if justified to prevent the hole from caving. Usually, steel flush joint drill casing may be used. The steel casing should be a diameter large enough to allow backfill material to be placed in the annular space between the steel casing and outside of the slope inclinometer casing. The backfill material then can be shoveled or poured in small amounts while at the same time pulling the steel casing in small increments. Care should be taken so that the backfill material does not lock the steel casing to the slope inclinometer casing. In extremely difficult cases, steel casing may be left in place upon completion of the boring. However, steel casing tends to thicken any zones of movement. Care should be taken to maintain proper orientation of the slope inclinometer casing while backfilling.

3.5. Inclinometers may be installed in structures and retaining walls to monitor performance and stability. Casing may be incorporated into the structure design or installed after construction by drilling or coring. To prevent damage, casing designed for installation during construction may be placed inside a construction casing, which is grouted into place.

4. INCLINOMETER CASING INSTALLATION

4.1. Any type of soil inclinometer casing may be used as long as it meets the slope inclinometer manufacturer’s requirements and is compatible with the particular sensor torpedo used. Usually, plastic casing is used in most installations; however, steel or other types of casing may be used under certain conditions such as embedment in concrete structures.

Orientation of the casing tracking grooves should be properly maintained throughout installation. The grooves should be oriented parallel and perpendicular to the anticipated direction of movement or at the discretion of the engineer. However, groove orientation of the casings in different holes should be consistent to avoid confusion. The installation may be expedited if the casing is preassembled and coupled together in units of 3.05 to 7.62 m (10 to 25 ft) each.

The following is a brief explanation of the installation techniques for typical casing; reference should be made to the manufacturer’s instruction manual for a more detailed explanation. Refer to Figure 1.

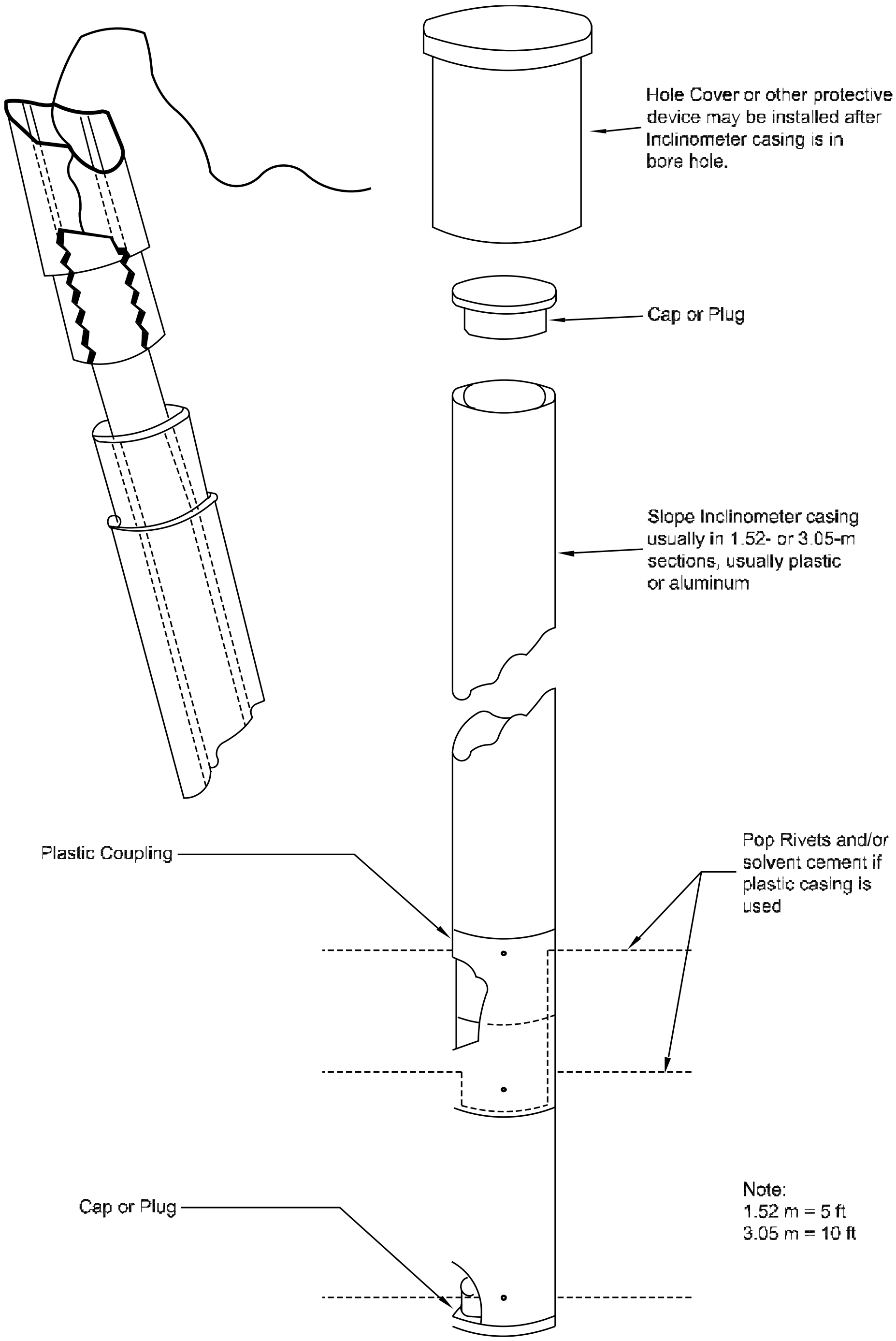

Figure 1—Typical Assembly of Slope Inclinometer Casing

4.2. *Casing*:

4.2.1. Attach a plug to the bottom section of casing by using solvent cement, pop rivets, self-locking devices provided with the casing, or other manufactured supplied coupling. If required, attach a plastic coupling to the top end of casing with solvent cement, pop rivets, self-locking devices provided with the casing, or other supplied coupling.

4.2.2. Lower the first section of casing into the boring with the plug on the lower end and the coupling attached to the top. A casing clamp should be attached approximately 0.3 to 0.6 m (1 to 2 ft) from the top of the casing.

4.2.3. Each end of the casing may be marked with a scribe line or felt tip marker to prevent rivets, if used, from being placed in the instrument tracking grooves. Either solvent cement compatible with the casing, self-locking devices, pop rivets, and/or other manufactured supplied coupling may be used to join the casing and couplings. Any combination of these methods may be used for extremely deep installations.

4.2.4. The two sections are carefully attached together, thus lining up the tracking grooves. The casing ends should be butted together. The two sections may be attached with pop rivets, solvent cement, self-locking device, and/or other manufactured supplied coupling. Casing clamps may be used to prevent the casing from falling into the hole. Lower and attach another section of casing and repeat the previous procedure until the casing rests on the bottom of the hole. Cut off any excess casing to a desirable height with a hacksaw. The predetermined orientation of the instrument tracking grooves should be properly maintained. Installation procedures are the same for telescoping couplings except special fasteners are usually used to automatically align the grooves. If telescoping couplings are used, the casing should not be allowed to rest on the bottom of the borehole, where the weight of the casing would cause the sections to telescope together. Pop rivets or any similar products may be used to prevent the telescoping couplings from collapsing during installation. Pop rivets should not be placed directly in the alignment of the casing's grove. One to two aluminum rivets are recommended (or as directed by the engineer) to prevent the casing from collapsing. The rivets shall be installed about $^1/_2$ in. from the edge of the section body (with telescoping sleeves extended to accommodate settlement). A typical telescoping coupler allows 6 inches of compression or extension.

4.3. The couplings of the casing may or may not be watertight. If the boring is filled with drilling mud, the mud may enter the casing as it is installed. Likewise, the injection of grout to fill the annular space around the casing may result in grout entering the casing.

4.3.1. In such instances, the casing should be flushed with clean water before the grout has hardened. A stiff brush may also be lowered down the casing during washing to ensure that the longitudinal grooves are clean. Inflow of mud or grout may be lessened by waxing, gluing, or taping all joints.

4.4. If sand or gravel is used as the backfill material and groundwater measurements are desired from the installation, small holes or slots may be drilled into the bottom section of inclinometer casing.

5. BACKFILLING THE INCLINOMETER CASING

5.1. The quality and extent of backfilling the slope inclinometer casing depends on the particular installation, groundwater conditions, type of backfill materials, or discretion of the engineer. Best results are obtained if care is taken in backfilling to eliminate any voids, bridging, or settlement in the backfill material. An air impelled or other type vibrator may be used to alleviate bridging. Backfill materials should be of similar shear strength to the *in situ* materials.

5.2. A cap may be placed over the top end of the casing prior to backfilling to prevent any backfill materials falling into the casing.

5.3. *Dry Sand*:

5.3.1. Dry sand may be used when the boring is dry, relatively shallow, and of a fairly small diameter, about 127 to 203 mm (5 to 8 in.). The sand should be clean, dry, and of uniform size, if possible. Standard Ottawa sand is ideal; washed concrete sand is acceptable. The sand may be densified by vibrations, shoveled, or poured slowly through a wire screen to eliminate bridging. Sometimes, sand may settle later and produce both vertical and horizontal deformations of the casing, which are not the result of ground movements. Water may be used to backfill the hole to eliminate any voids or bridging and densify the sand.

5.4. *Pea Gravel*:

5.4.1. Any gravel suitable to the engineer may be used. Pea gravel [9.5 mm (or $^3/_8$ in.)] or No. 9 crushed limestone chips are examples. The gravel may be shoveled slowly in small increments to eliminate any bridging that might occur. Gravel may be used in deeper boreholes where groundwater measurements would be desirable.

5.5. *Cement Grout Backfill*:

5.5.1. A very desirable backfill material is cement grout. This may consist of a lean cement grout, a clay cement grout, or a thixotropic drill mud. A mixture of three bags [22.7 kg/bag (50 lb/bag)], hydrated lime to one bag [42.6 kg/bag (94 lb/bag)] Portland cement, or a mixture of Portland cement with 15 percent Bentonite by volume may be considered good grout mixes. Another simple economical mix is to use ready-mixed “mortar mix” with sufficient water to allow it to be poured into the borehole. The grout mix shall mimic the installation ground conditions. The grout may be poured around the casing from the ground surface (if the borehole stays open and dry) or it may be injected through a small-diameter pipe lowered in the annular space between the casing and the boring. The grout pipe should be 6 to 12 in. from the bottom of the borehole to prevent it from plugging up.

5.5.2. If outer steel casing or hollow stem augers was installed in the hole, it should be pulled before the grout sets. Cement grout backfill is not desirable when groundwater measurements are required. The steel casing or hollow stem auger should be pulled straight up to prevent any spiraling of the inclinometer casing. As each section of the steel casing or hollow stem auger is pulled out of the ground, additional grout should be placed to top off the borehole preventing unwanted cave-ins.

5.6. If needed, install the hole cover or other protective device over the top of the casing prior to completion of backfilling. Then backfill around and inside the hole cover, leaving enough casing exposed to allow room for the clamp-guide wheel assembly.

5.7. If needed, buoyancy of the casing may be overcome by applying weight to the casing by filling the casing with water. If necessary, a down force applied from the bottom such as a steel pipe or drill rod may be used to hold the casing in place.

5.8. Pertinent identification information, including hole location and depth, may be permanently marked on the inside of the hole cover lid. Depending on the situation, the initial readings should be deferred at least 24 hours to allow the backfill to settle and the casing to stabilize. After the casing and hole cover have been installed and backfilled, it may be desirable to reference the casing guide grooves to magnetic north so that subsequent readings are made on the same grooves.

PART II—MONITORING SLOPE INCLINOMETER GUIDE CASING

6. APPARATUS

6.1. *Slope Inclinometer Instrument*:

6.1.1. Readout unit, sensor torpedo, and interconnecting cable.

6.2. Guide wheel clamp assembly.

6.3. Optional casing extension with coupling attached.

6.4. Occasionally, problems are encountered in twisting the casing after installation. This twist is due either to irregularities in the manufacturing processes of the casing or by rotation of the joints during placement. Several types of instruments are commercially available to measure the spiral, which can be compensated for during displacement calculations.

7. INSTRUMENTS

7.1. Various types of instruments are commercially available. The inclinometer torpedo sensor generally has a two-wheel assembly, each of which consists of a rigid wheel for guidance and a spring-loaded wheel for orientation. These wheel assemblies are located near each end of the inclinometer. The configuration produces a voltage output, which is measured at the ground surface with a readout unit. Some units are capable of storing required data, which can be downloaded onto a computer for data reduction and analysis.

Note 1—Because of their reliability and popularity, brief descriptions and explanations will be given for the accelerometer-type torpedo sensor slope inclinometers. Most manufacturers recommend obtaining readings from the bottom progressing to the top for each complete survey. Refer to Figure 2.

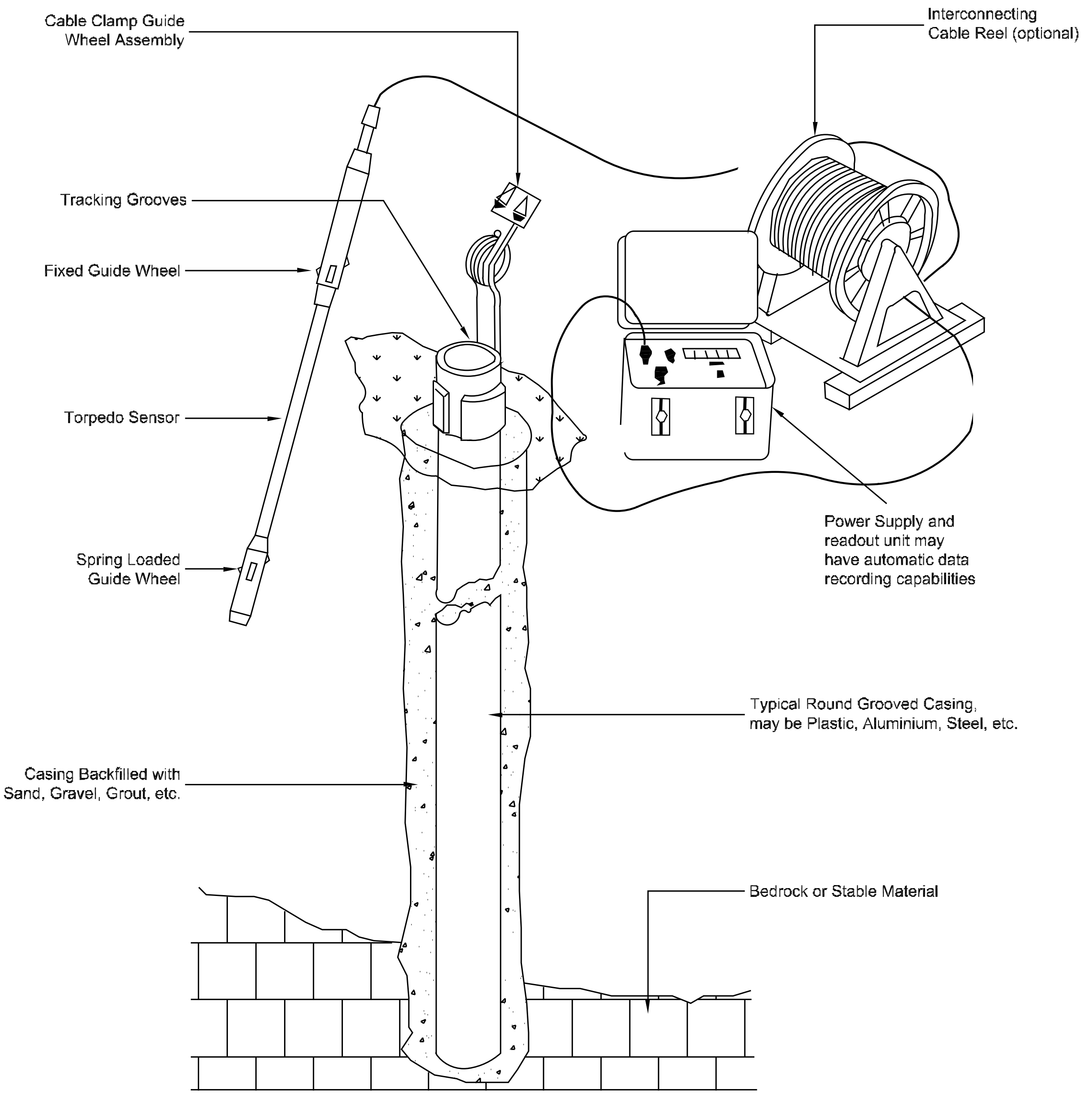

Figure 2—Typical Slope Inclinometer Installation and Monitoring Equipment

8. MONITORING WITH THE ACCELEROMETER-TYPE SENSOR

8.1. *Description*:

8.1.1. The accelerometer-type inclinometer sensor differs somewhat from the typical instrument in that it usually has a smaller outside diameter between the two-wheel assemblies. Separated by a distance of usually 610 mm (24 in.), each assembly may consist of two fixed wheels, 90 degrees apart, and a spring-loaded wheel on the opposite side of the probe (135 degrees from either of the fixed wheels). Sometimes only one fixed wheel and one spring-loaded wheel mounted 180 degrees apart are used in each assembly. The lower wheel assembly is free to rotate approximately 5 degrees to accommodate irregularities in the casing. The angle of inclination is determined from a readout unit that may relate a geometric function of the angle of inclination to a current obtained from one or two servo-accelerometers in the probe. The data is normally stored on a computer chip in the readout device to allow for upload to a computer for data reduction and analysis.

8.2. *Operation*:

8.2.1. The operating technique starts with a visual check of the O-ring seal to ensure water tightness in the cable connector after the components are assembled. A quick calibration to ensure that the unit is functional is completed by placing the probe into the borehole in a specified groove, taking a reading, and then placing the probe in the opposite groove and taking a reading. Disregarding the sign, the two readings should be within 20 dial units of each other. After this check, the probe is lowered to the bottom of the borehole to begin incremental readings. Care should be taken not to bump the inclinometer probe at the bottom of the casing. The probe should be allowed time to equilibrate for about 5 minutes at the bottom of the casing before taking the first set of readings. Through the use of a switch on the readout unit, readings can be taken both in the plane through the spring-loaded wheel and perpendicular to it, thus reducing the number of times the inclinometer must traverse the casing. To reduce irregularities, a second series of readings is taken with the probe rotated 180 degrees from the first position.

8.3. *Maintenance*:

8.3.1. Certain maintenance must be performed to keep the unit operable. The connector between the inclinometer and the electrical cable should be kept free of water and dirt (as for all electrical contacts). The condition of the O-ring in the connector should be checked regularly since water-filled casings create large pressure heads acting against it. Three power sources are usually permitted: (a) internal battery, (b) external battery, and (c) a/c power. The internal batteries are usually a rechargeable type that must be replaced periodically. Any additional recommendations by the equipment manufacturer should also be followed.

PART III—DATA COMPUTATIONS AND ANALYSIS

9. PROCEDURES

9.1. The casing is usually assumed to be vertical for the first set of readings. All subsequent readings are compared to this initial or index set of readings.

9.2. Refer to the individual manufacturer's operating manual for recording data, and data reduction. The procedure of data reduction recommended by most manufacturers involves a summation of readings in opposite direction and then multiplication by a calibration factor to obtain the deflection of the casing from vertical. Subsequent readings are compared to initial readings to obtain change of inclination at any depth.

10. DATA SHEET

10.1. The typical data sheet usually contains columns for the individual readings, the initial difference, the subsequent reading difference, the change, and accumulated change. Refer to the manufacturer's operation manual.

11. PLOTTING DATA

11.1. The slope inclinometer movement is usually plotted as a time plot of the accumulated deflection versus depth. The computer program can be used efficiently to plot rate, magnitude, depth, and direction of movement, although the data is easily plotted by hand. Follow the manufacturer's operating manual for instructions.

Standard Specification for

Preservatives and Pressure Treatment Processes for Timber

AASHTO Designation: M 133-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Preservatives and Pressure Treatment Processes for Timber

AASHTO Designation: M 133-10

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1. SCOPE

1.1. This specification covers the wood preservatives, the preservative treatment processes, the results of treatment, the inspection and testing of preservatives and of treatment, and the identification of properly treated timber.

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2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 168, Wood Products
- T 32, Sampling and Testing Brick
- T 62, Distillation of Creosote and Creosote-Coal Tar Solutions
- T 72, Saybolt Viscosity
- T 73, Flash Point by Pensky-Martens Closed Tester
- T 115, Method of Test for Distillation of Petroleum Products

2.2. *ASTM Standards*:

- D 96-99 (1998), Standard Test Methods for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure) (Withdrawn 2000)
- D 287, Standard Test Method for API Gravity of Crude Petroleum and Petroleum Products (Hydrometer Method)
- D 453-94 (2000)^{e1}, Standard Test Method for Tar Acids in Creosote-Coal Tar Solutions (Withdrawn 2006)

2.3. *American Wood-Preservers' Association Standards*: [1]

- A1, Standard Methods for Analysis of Creosote and Oil-Type Preservatives
- A2, Standard Methods for Analysis of Waterborne Preservatives and Fire-Retardant Formulations
- A3, Standard Methods for Determining Penetration of Preservatives and Fire Retardants
- A4, Standard Methods for Sampling Wood Preservatives
- A5, Standard Methods for Analysis of Oil-Borne Preservatives
- A6, Method for the Determination of Oil-Type Preservatives and Water in Wood
- A7, Standard for Wet Ashing Procedures for Preparing Wood for Chemical Analysis
- A9, Standard Method for Analysis of Treated Wood and Treating Solutions by X-ray Spectroscopy
- A11, Standard Method for Analysis of Treated Wood and Treating Solutions by Atomic Absorption Spectroscopy

- A12, Wood Densities for Preservative Retention Calculations
- A13, Standard Method of Analysis for Acid Number of Naphthenic Acids in Copper Naphthenate
- A14, Standard Method for Determination of Water-Extractable Copper in Copper Naphthenate
- A18, Standard for Determination of Quaternary Ammonium Compounds in Wood by 2-Phase Titration
- A21, Standard Method for Analysis of Wood and Wood Treating Solutions by Inductively Coupled Plasma Emission Spectrometry
- A28, Standard Method for Determination of Propiconazole and Tebuconazole in Wood, in Waterborne Formulations and in Treating Solutions by HPLC
- A31, Standard Methods for the Analysis of Solutions and Wood for Azoles by Gas Chromatography (GC)
- A37, Standard for Determination of Quaternary Ammonium Compounds in Wood and Wood Treating Solutions by Potentiometric Titration Using Sodium Tetraphenylborate
- M2, Standard for Inspection of Treated Products Treated with Preservatives
- M3, Standard Quality Control Procedures for Wood Preserving Plants
- M4, Standard for the Care of Preservative-Treated Wood Products
- M6, Brands Used on Forest Products
- P1/P 13, Standard for Creosote Preservative
- P2, Standard for Creosote Solutions
- P3, Standard for Creosote-Petroleum Solution
- P4, Standard for Petroleum Oil for Blending with Creosote
- P5, Standard for Waterborne Preservatives
- P8, Standard for Oil-Borne Preservatives
- P9, Standards for Solvents and Formulations for Organic Preservative Systems
- U1, Use Category System: User Specification for Treated Wood

2.4. *International Code Council–Evaluation Service, Inc. (ICC–ES)*:

- AC326, Acceptance Criteria for Proprietary Wood Preservative Systems–Common Requirements for Treatment Process, Test Methods and Performance

3. GENERAL REQUIREMENTS

3.1. Standards of the American Wood-Preservers' Association (AWPA) and specified commercial standards are incorporated herein by reference. Attention is called to the fact that all preservatives are not equally effective on all species of wood or under all conditions of exposure. The engineer preparing the plans and specifications should select the type of preservatives, retentions, and species best suited for his purpose and conditions.

3.2. International Code Council Evaluation Service, Inc. (ICC-ES) requirements and specified commercial standards are incorporated herein by reference. Treated wood product reports issued by the ICC-ES as Evaluation Service Reports (ESRs) must be current as posted on the ICC-ES website www.icc-es.org and in compliance with AC326. The treated wood product's report must allow for the end-use that is required by the project specifications.

4. TIMBER QUALITY

4.1. The properties of the timber selected for preservative treatment shall conform to the requirements of M 168.

5. PRESERVATIVE QUALITY

5.1. The following named preservatives are acceptable in this specification. The properties shall be those set forth in the referenced AWPA Standards:

5.1.1. *Creosote*—P 1/P 13.

5.1.2. *Creosote-Coal Tar Solution*—P 2.

5.1.3. *Creosote-Petroleum Solution*—P 3.

5.1.4. *Petroleum for Blending with Creosote*—P 4.

5.1.5. *Pentachlorophenol*—P 8.

5.1.6. *Solvents Used in Pentachlorophenol Solutions*—P 9.

5.1.7. *Acid Copper Chromate*—P 5.

5.1.8. *Ammoniacal Copper Zinc Arsenate*—P 5.

5.1.9. *Chromated Copper Arsenate, Type C*—P 5.

5.1.10. *Ammoniacal Copper Quat, Type B*—P 5.

5.1.11. *Copper Naphthenate*—P 8.

5.1.12. *Alkali Copper Quat, Type C*—P 5.

5.1.13. *Copper Azole, Type A (CBA-A)—P 5.*

5.1.14. *Copper Azole, Type B (CA-B)*—P 5.

5.1.15. *Alkaline Copper Quat, Type D*—P 5.

5.1.16. *Copper Azole, Type C (CA-C)*—P 5.

5.1.17. *Propiconazole Tebuconazole Imidacloprid (PTI)*—P 5.

5.2. The following preservative systems are acceptable by means of a published and current ICC-ES Report (ESR) and are in compliance with AC326.

5.2.1. Micronized Copper Quaternary.

5.2.2. Micronized Copper Azole.

5.2.3. Dispersed Copper Azole Type C (μCA-C).

6. PRESERVATIVE TREATMENT PROCESSES AND RESULTS

6.1. Wood products shall be treated in accordance with the ICC-ES Evaluation Report or AWPA Standard U1–Use Category System: User Specification for Treated Wood. A Use Category appropriate for the application shall be established in accordance with Standard U1 Sections 2 and 3. Specific requirement for various commodities can then be found in Section 6.

6.1.1. *Sawn Products*—U1, Section 6, Commodity Specification A (Includes all sawn posts and lumber).

6.1.2. *Round Timber Piling*—U1, Section 6, Commodity Specification E.

6.1.3. *Round Poles*—U1, Section 6, Commodity Specification D (16 feet or longer).

6.1.4. *Round Posts*—U1, Section 6, Commodity Specification B (Less than 16 feet long).

6.1.5. *Wood Composites*—U1, Section 6, Commodity Specification F (includes plywood).

6.2. Field treatment of cuts, holes and injuries to treated wood products shall be in accordance with AWPA Standard M4.

7. INSPECTION AND MARKING

7.1. Treatment shall conform to the quality requirements described in the ICC-ES Evaluation Report or AWPA M3–Standard Quality Control Procedures for Wood Preserving Plants. The wood treater shall apply to each piece of treated timber a legible brand, mark or tag indicating the name of the treater and the specification symbol or specification requirements to which the treatment conforms. Acceptable symbols of compliance shall be similar to brands listed in AWPA M6, or as provided for in the plans or special provisions.

7.2. The engineer shall be provided adequate facilities and free access to the necessary parts of the treating plant for inspection of material, workmanship, and treating processes, to determine that the contract requirements are met. Inspection of the treatment and products shall conform to the requirements of AWPA M2–*Standard for Inspection of Wood Products Treated with Preservatives*. The engineer reserves the right to retest all materials after delivery to the job site and to reject all materials that do not meet the requirements of the contract. Reinspection at the job site may include assay to determine retention of preservatives and extraction and analysis of preservative to determine its quality.

8. METHODS OF SAMPLING AND TESTING

8.1. The sampling and testing of wood preservatives shall be in accordance with the following standard methods of the American Association of State Highway and Transportation Officials (AASHTO), the American Society for Testing Materials (ASTM), and the American Wood-Preservers' Association (AWPA):

8.1.1. *Sampling Wood Preservatives*—AWPA A4.

8.1.2. *Specific Gravity at 38/15.5°C of Creosote Solution*—AWPA A1.

8.1.3. *Water in Creosote*—AWPA A1.

8.1.4. *Insoluble Matter in Creosote*—AWPA A1.

8.1.5. *Distillation of Creosote*—AASHTO T 62; AWPA A1.

8.1.6. *Tar Acids in Creosote and Creosote-Coal Tar Solutions*—ASTM D 453.

8.1.7. *Specific Gravity of Petroleum*—ASTM D 287.

8.1.8. *Flash Point of Petroleum (Pensky-Martens)*—AASHTO T 73.

8.1.9. *Viscosity, Saybolt*—AASHTO T 72.

8.1.10. *Analysis of Water-Borne Preservatives*—AWPA A2.

8.1.11. *Analysis of Oil-Borne Preservatives*—AWPA A5.

8.1.12. *Chromium, Copper, Arsenic and Zinc in Water-borne Preservatives by X-ray*—AWPA A9, by ICP—AWPA A21, by AA—AWPA A11.

8.1.13. *Naphthenic Acid in Copper Naphthenate*—AWPA A13.

8.1.14. *Water-Extractable Copper in Copper Naphthenate*—AWPA A14

8.1.15. *Quaternary Compounds in ACQ Preservative or Micronized Copper Quaternary*—AWPA A18 or A37.

8.1.16. *Propiconazole and Tebuconazole in Waterborne Preservatives by HPLC*—AWPA A28.

8.1.17. *Azoles in Waterborne Preservatives and Wood by Gas Chromatography (GC)*—AWPA A31.

8.1.18. *Imidacloprid in Waterborne Preservatives and Wood by HPLC*—AWPA A43.
Wood Densities for Preservative Retention Calculations—AWPA A12.

8.1.19. *Standard for Wet Ashing Procedures for Preparing Wood for Chemical Analysis*—AWPA A7.

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[1] Available from American Wood-Preservers' Association, P.O. Box 361784, Birmingham, AL 35236-1784, Tel: (205) 733-4077, www.awpa.com.

Standard Specification for

Wood Products

AASHTO Designation: M 168-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Wood Products

AASHTO Designation: M 168-07

1. SCOPE

1.1. This specification provides a compilation of specifications covering commercial grades and species of lumber and other wood products for highway construction as indicated below. More detailed requirements will be found in the various specifications cited for specific products.

1.1.1. Lumber,

1.1.2. Structural-Glued Laminated Timber,

1.1.3. Piling,

1.1.4. Posts, and

1.1.5. Structural Composite Lumber.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards and Publications:*

- M 133, Preservatives and Pressure Treatment Processes for Timber
- *LRFD Bridge Design Specifications*

2.2. *ASTM Standards*:

- D 9, Standard Terminology Relating to Wood and Wood-Based Products
- D 25, Standard Specification for Round Timber Piles
- D 245, Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber
- D 1165, Standard Nomenclature of Commercial Hardwoods and Softwoods
- D 1990, Standard Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens
- D 2555, Standard Practice for Establishing Clear Wood Strength Values
- D 3737, Standard Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)
- D 5456, Standard Specification for Evaluation of Structural Composite Lumber Products
- D 6570, Standard Practice for Assigning Allowable Properties for Mechanically Graded Lumber

2.3. AASHTO, *American Road and Transportation Builders Association (ARTBA)*, The Associated General Contractors of America (AGC):

- *A Standardized Guide to Highway Barrier Hardware*

2.4. *National Institute of Standards and Technology (NIST)*:

- Voluntary Standard PS 20, American Softwood Lumber Standards

2.5. *U.S. Forest Service*:

- General Technical Report, FPL-GTR-113, Wood Handbook, Wood as an Engineering Material

2.6. *American National Standards Institute (ANSI)*:

- ANSI/AITC A 190.1, Structural-Glued Laminated Timber

3. DEFINITIONS

3.1. *board*—lumber that is less than 38 mm standard (2 in. nominal) thickness and greater than 38 mm standard (2 in. nominal) width. Boards less than 140 mm standard (6 in. nominal) width are sometimes called strips.

3.2. *dimension*—lumber with a thickness from 38 mm standard (2 in. nominal) up to but not including 114 mm standard (5 in. nominal) and a width of greater than 38 mm standard (2 in. nominal).

3.3. *dressed lumber*—lumber that has been planed (surfaced).

3.4. *factory and shop lumber*—lumber intended to be cut up for use in further manufacture. It is graded on the percentage of the area that will produce a limited number of cuttings of a specified minimum size and quality.

3.5. *lumber grade*—quality designation of lumber established in accordance with established grading rules developed and adopted by grading rules-writing agencies, which is certified by either the American Lumber Standards Committee Board of Review or a nationally recognized equivalent system.

3.6. *grading rules-writing agency*—organizations that write and publish grading rules for lumber based upon NIST PS 20 guidelines and that are accredited by the American Lumber Standard Committee Board of Review or nationally recognized equivalent system.

3.7. *hardwood*—generally, one of the commercial species groups or one of the botanical groups of trees that have vessels or pores and broad leaves, in contrast to the conifers or softwoods. The term has no reference to actual hardness of the wood.

3.8. *heartwood*—the wood extending from the pith to the sapwood, the cells of which no longer participate in the life process of the tree. Heartwood may contain phenolic compounds, gums, resins, and other materials that usually make it darker and more decay resistant than sapwood.

3.9. *lumber*—the product of the saw and planing mill for which manufacturing is limited to sawing, resawing, passing lengthwise through a standard planing machine, crosscutting to length, and matching. Lumber may be made from either softwood or hardwood.

3.10. *nominal size*—as applied to timber or lumber, the size by which it is known and sold in the market (often differs from actual size).

3.11. *rough lumber*—lumber that has not been dressed (surfaced) but has been sawed, edged, and trimmed.

3.12. *softwood (conifers)*—generally, one of the botanical groups of trees that have a needlelike or scalelike leaves.

3.13. *structural composite lumber*—lumber that is a reconstituted (manufactured) lumber product for structural applications, which is either laminated veneer lumber or parallel strand lumber bonded with an exterior adhesive.

3.14. *structural-glued laminated timber*—an engineered, stress-rated product of a timber laminating plant, comprising assemblies of specially selected and prepared wood laminations securely bonded together with adhesives. The grain of all laminations is approximately parallel longitudinally. The laminations may be composed of pieces end joined to form any length, of pieces placed or bonded edge to edge to make any width, or of pieces bent to curved form during bonding.

3.15. *stress graded lumber*—lumber that has been graded based upon grading rules developed, adopted, and published by grading rules-writing agencies that have been certified by the American Lumber Standards Committee Board of Review or equivalent system; or lumber having assigned working stresses and modulus of elasticity values in accordance with accepted basic principles of strength grading, and the provisions on NIST Voluntary Product Standard PS 20.

3.16. *structural lumber*—lumber that is intended for use where allowable properties are required. The structural lumber grade is based on the strength or stiffness of the piece as related to anticipated use.

3.17. *timber*—lumber that is standard 114 mm (nominal 5 in.) or more in the least dimension.

3.18. *yard lumber*—a little-used term for lumber of all sizes and patterns that is intended for general building purposes having no design property requirements.

3.19. *worked lumber*—lumber that has been dressed, matched, shiplapped, and/or patterned.

4. CLASSIFICATION

4.1. *Species of Wood*:

4.1.1. The standard commercial and botanical names of the species of wood recognized in the specification are as described in ASTM D 1165.

4.1.1.1. Some species may be covered under more than one set of grading rules. In such cases, the applicable grading rules shall be as specified in the contract.

4.1.1.2. Some grading rules provide for the inclusion of additional species under the established commercial name of the lumber.

4.1.2. *Limitation of Use*:

4.1.2.1. Wood for structural purposes shall not be used in exposed permanent structures without pressure impregnation of a preservative in accordance with M 133.

4.1.2.2. The heartwood of the following species is high in decay resistance and, when specified, may be used without preservative treatment:

Softwoods	Hardwoods
Bold Cypress, old growth	Chestnut
Cedar	Locust, Black
Juniper	Oak, White
Redwood, old growth	Osage, Orange
Yew, Pacific	Walnut, Black

4.2. *Hardwoods*:

4.2.1. *Grading*—Lumber from hardwood species shall be graded in accordance with grading rules that conform to the basic provision of NIST PS 20 and that are developed, adopted, and published by grading rules-writing agencies that are certified by the American Lumber Standards Committee Board of Review or nationally recognized equivalent system.

4.2.1.1. Hardwood lumber, which is intended for structural use with design stress, shall be stress graded lumber that is graded in conformance with nationally accepted standards such that the lumber will meet the required stress values listed in Section 13.2 Division I of the *AASHTO Standard Specification for Highway Bridges* or in Section 8.4 of the *AASHTO LRFD Bridge Design Specifications*.

4.2.2. *Classification*—Hardwood lumber shall be classified and stress graded marked according to the use, manufacturing, and size classification listed in NIST PS 20 as outlined below.

4.2.2.1. Use classification shall be Yard Lumber, Structural Lumber, and Factory and Shop Lumber.

4.2.2.2. Manufacturing classification shall be Rough Lumber, Dressed (Surfaced) Lumber, and Worked Lumber.

4.2.2.3. Size classification shall be Nominal Size Designations of Boards, Dimension, and Timbers; Rough Dry Sizes; and Dressed Sizes.

4.2.3. *Stress Grading*—As appropriate, either ASTM D 245, ASTM D 1990, ASTM D 2555, or ASTM D 6570 and/or other equivalent nationally recognized technical standards shall be used to develop working stress and modulus of elasticity values for Stress Graded Structural Lumber.

4.2.3.1. Design values developed by grading rules agencies may be used provided they were developed in accordance with nationally accepted standards. The purchaser may request a report from the rules writing agency explaining how the design values of working stress and modulus of elasticity were derived.

4.3. *Softwoods*:

4.3.1. *Grading*—Lumber from softwood species shall be graded in accordance with grading rules that conform to the basic provisions of NIST PS 20 and are developed, adopted, and published by grading rules-writing agencies that are certified by the American Lumber Standards Committee Board of Review or a nationally recognized equivalent system.

4.3.1.1. Softwood lumber, which is intended for structural use with design stress, shall be stress graded lumber that is graded in conformance with nationally accepted standards such that the lumber will meet the required stress values listed in Section 13.2 Division I of the *AASHTO Standard Specifications for Highway Bridges* or in Section 8.4 of the *AASHTO LRFD Bridge Design Specifications.*

4.3.2. *Classification*—Softwood lumber shall be classified and stress-grade marked according to the use, manufacturing, and size classifications listed in NIST PS 20 as outlined below.

4.3.2.1. Use classifications shall be Yard Lumber, Structural Lumber, and Factory and Shop Lumber.

4.3.2.2. Manufacturing classifications shall be Rough Lumber, Dressed (Surfaced) Lumber, and Worked Lumber.

4.3.2.3. Size classifications shall be Nominal Size Designations of Boards, Dimension, and Timbers; Rough Dry Sizes; and Dressed Sizes.

4.3.3. *Stress Grading*—As appropriate, either ASTM D 425, ASTM D 1990, ASTM D 2555, or ASTM D 6570 and/or other equivalent nationally recognized technical standards shall be used to develop working stress and modulus of elasticity values for Stress Graded Structural Lumber.

4.3.3.1. Design values developed by grading rules agencies may be used provided they were developed in accordance with nationally accepted standards. The engineer may request a report from the rules-writing agency explaining how the design values of working stress and modulus of elasticity were derived.

4.4. *Structural Composite Lumber*:

4.4.1. The ASTM D 5456 or equivalent nationally recognized standard shall be used to develop working stresses and modulus values for Structural Composite Lumber; however, the values shall not be less than the minimum values as specified by the *AASHTO Standard Specifications for Highway Bridges* or *AASHTO LRFD Bridge Design Specifications.*

4.5. *Structural Glued-Laminated Timber*:

4.5.1. ASTM D 3737 or equivalent nationally recognized standard shall be used to develop working stresses and modulus values for Structural Glued-Laminated Lumber; however, the values shall not be less than the minimum values as specified by the *AASHTO Standard Specification for Highway Bridges* or the *AASHTO LRFD Bridge Design Specifications*.

5. PRODUCTS

5.1. *Lumber*:

5.1.1. All lumber shall conform with the applicable softwood or hardwood lumber grading standards. The following requirements shall be specified in the purchase order:

5.1.1.1. The nominal dimensions: thickness, width, and length of each item required;

5.1.1.2. The grade required or the stress-grade rating of lumber required, including any special requirements, such as provisions for heartwood content, freedom from wane, seasoning condition, etc.;

5.1.1.3. Manufacturing classification such as rough, dressed, or worked lumber;

5.1.1.4. The allowable species according to standard commercial name;

5.1.1.5. The name of the agency that will be responsible for grading, inspecting, and grade marking the lumber;

5.1.1.6. The year of issue of the applicable grading rules; and

5.1.1.7. Preservative treatment required.

5.2. *Structural-Glued Laminated Timber*:

5.2.1. Requirements for the dimensions, grade combinations, lumber for laminating, appearance grades, adhesives, and laminating of structural-glued laminated timber as well as inspection and test procedures, marking, and the certification by a qualified inspection and testing agency shall be in conformance with ANSI/AITC A 190.1. Species, grade, and design values for Structural-Glued Laminated Timber shall conform to the *AASHTO Standard Specifications for Highway Bridges* or *AASHTO LRFD Bridge Design Specifications*.

5.3. *Piling*:

5.3.1. Round timber piles shall conform to ASTM D 25.

5.4. *Posts*:

5.4.1. Posts shall be of sound wood, free of decay, excessive knots, and insect attack and shall otherwise conform to the provisions of this specification.

5.4.1.1. *Fence Posts*—Posts shall be preservative-treated in accordance with Section 4.1.2 except where the contract plans permit use of decay-resistant varieties. Posts to be driven shall be machine-pointed prior to treatment.

5.4.1.2. *Guardrail Posts*—Guardrail posts shall be a stress grade of 8.2 MPa (1200 psi) or more, conforming to the applicable standards contained in AASHTO-ARTBA-AGC, *A Standardized*

Guide to Highway Barrier Hardware. When a preservative is required, framing and boring shall be completed prior to treatment in accordance with M 133.

5.4.1.3. *Sign Posts*—Rectangular posts shall be surfaced four sides (S4S), conforming to the provisions of this specification. When a preservative is required, framing and boring shall be completed prior to the treatment in accordance with M 133.

5.5. *Structural Composite Lumber*:

5.5.1. Requirements for grade, adhesives, and laminating of Structural Composite Lumber as well as inspection and test procedures, marking and the certification by a qualified inspection and testing agency shall be in conformance with ASTM D 5456. Species, grades, and design values for Structural Composite Lumber shall conform to the *AASHTO Standard Specifications for Highway Bridges* or the *AASHTO LRFD Bridge Design Specifications*.

As an aid to the user of this volume, the following tabulation shows equivalencies between AASHTO and ASTM specifications. Where an asterisk (*) follows the ASTM number, there is a difference between the two specifications. These differences are explained in the endnote accompanying each individual specification.

AASHTO ***Specifications***	**ASTM** ***Equivalent***	**AASHTO** ***Specifications***	**ASTM** ***Equivalent***
M 17-07	D 242-04	M 167M/M 167-09	A 761/A 761M-04
M 29-03 (2007)	D 1073-06	M 169-09	A 108-07
M 30-02 (2006)	A 741-98*	M 170-10	C 76-08a
M 31M/M 31-10	A 615/A 615M-09	M 170M-10	C 76M-08a
M 32M/M 32-09	A 82/A 82M-07	M 171-05	C 171-03
M 33-99 (2007)	D 994-98 (2003)	M 175M/M 175-05 (2009)	C 444M-03 and C 444-03
M 36-03 (2007)	A 760/A 760M-01a	M 176M/M 176-07	C 654M-05a and C 654-05a
M 43-05 (2009)	D 448-08	M 178M/M 178-07	C 412M-05a and C 412-05a
M 45-06	C 144-04*	M 194M/M 194-06	C 494/C 494M-05*
M 54M/M 54-07	A 184/A 184M-06	M 195-06	C 330-04
M 55M/M 55-09	A 185/A 185M-07	M 196-92 (2008)	B 745/B 745M-95
M 85-09	C 150-09	M 197-06	B 744/B 744M-05*
M 86M/M 86-09	C 14M-07 and C 14-07	M 198-10	C 990-09*
M 91-10	C 32-09	M 199M/M 199-10	C 478M-09 and C 478-09*
M 92-10	E 11-09	M 201-08	C 511-06
M 102M/M 102-06	A 668/A 668M-04	M 202M/M 202-08	A 328/A 328M-07
M 103M/M 103-06	A 27/A 27M-05	M 203M/M 203-07	A 416/A 416M-06
M 107-09	B 22-08*	M 204M/M 204-06	A 421/A 421M-05*
M 108-09	B 100-08	M 205M/M 205-08	C 470/C 470M-02a*
M 111M/M 111-09	A 123/A 123M-08	M 206M/M 206-10	C 506M-09 and C 506-09*
M 114-10	C 62-08	M 207M/M 207-10	C 507M-09 and C 507-09*
M 120-08	B 6-07	M 208-01 (2009)	D 2397-02
M 138M/M 138-08	B 152/B 152M-06a	M 210-10	C 490-08*
M 140-08	D 977-05	M 213-01 (2010)	D 1751-04 (2008)
M 143-03 (2007)	D 632-01*	M 216-05 (2009)	C 977-03
M 144-07	D 98-05	M 219-92 (2008)	B 746/B 746M-92
M 148-05	C 309-03*	M 220-84 (2007)	D 2628-91 (2005)
M 152M/M 152-06	C 230/C 230M-03*	M 221M/M 221-09	A 497/A 497M-07
M 153-06	D 1752-04a*	M 225M/M 225-09	A 496/A 496M-07
M 154-06	C 260-01*	M 227M/M 227-97 (2005)	A 663/A 663M-89 (2000)
M 156-97 (2009)	D 995-95b (2002)*	M 232M/M 232-10	A 153/A 153M-09*
M 160M/M 160-08	A 6/A 6M-07	M 235M/M 235-03 (2007)	C 881-99*
M 163M/M 163-07	A 743/A 743M-06	M 240-10	C 595-09
M 164-05 (2008)	A 325-04b	M 241M/M 241-09	C 685/C 685M-07*
M 164M-06	A 325M-04b	M 242M/M 242-08	C 655M-07 and C 655-07*

AASHTO ***Specifications***	**ASTM** ***Equivalent***	**AASHTO** ***Specifications***	**ASTM** ***Equivalent***
M 245-00 (2008)	A 762/A 762M-98	M 291-09	A 563-07*
M 246-05	A 742/A 742M-03	M 291M-07	A 563M-06
M 253-05 (2008)	A 490-04a	M 292M/M 292-10	A 194/A 194M-09
M 253M-05	A 490M-04a	M 293-10	F 436-09*
M 255M/M 255-05 (2008)	A 675/A 675M-03$^{\epsilon 1}$	M 293M-06	F 436M-04
M 259-98 (2006)	C 789-95a*	M 295-07	C 618-05
M 259M-00 (2008)	C 789M-98*	M 297-10	D 3542-08
M 261-96 (2009)	E 501-94 (2000)*	M 298-10	B 695-04 (2009)*
M 262-10	C 822-08b*	M 299-10	B 696-00 (2009)
M 264-03 (2007)	D 2680-01*	M 302-06	C 989-05
M 270M/M 270-10	A 709/A 709M-09a*	M 307-07	C 1240-05
M 273-00 (2008)	C 850-95a*	M 315-07	C 443-05a
M 273M-00 (2008)	C 850M-98*	M 315M-09	C 443M-07
M 275M/M 275-08	A 722/A 722M-07	M 317M/M 317-03 (2007)	D 3963/D 3963M-01
M 279-09	A 116-05	M 322M/M 322-10	A 996/A 996M-09
M 280-09	A 121-07	M 324-08	D 6690-06a
M 281-96 (2008)	A 702-89 (1994)$^{\epsilon 1}$	M 327-09	C 465-99 (2005)
M 282-99 (2007)	D 3406-95 (2006)	R 5-08	D 3628-06*
M 284M/M 284-09	A 775/A 775M-07b	R 13-03 (2007)	D 420-98 (2003)*
M 285M/M 285-07	A 744/A 744M-06	R 14-88 (2007)	D 4552-92 (2004)*
M 286-96 (2009)	E 524-08*	R 39-07	C 192/C 192M-06

ASTM *Specifications*	**AASHTO *Equivalent***	**ASTM *Specifications***	**AASHTO *Equivalent***
A 6/A 6M-07	M 160M/M 160-08	A 996/A 996M-09	M 322M/M 322-10
A 27/A 27M-05	M 103M/M 103-06	B 6-07	M 120-08
A 82/A 82M-07	M 32M/M 32-09	B 22-08*	M 107-09
A 108-07	M 169-09	B 100-08	M 108-09
A 116-05	M 279-09	B 152/B 152M-06a	M 138M/M 138-08
A 121-07	M 280-09	B 695-04 (2009)*	M 298-10
A 123/A 123M-08	M 111M/M 111-09	B 696-00 (2009)$^{\epsilon 1}$	M 299-10
A 153/A 153M-09*	M 232M/M 232-10	B 744/B 744M-05*	M 197-06
A 184/A 184M-06	M 54M/M 54-07	B 745/B 745M-95	M 196-92 (2008)
A 185/A 185M-07	M 55M/M 55-09	B 746/B 746M-92	M 219-92 (2008)
A 194/A 194M-09	M 292M/M 292-10	C 14M-07 and C 14-07	M 86M/M 86-09
A 325-04b	M 164-05 (2008)	C 32-09	M 91-10
A 325M-04b	M 164M-06	C 62-08	M 114-10
A 328/A 328M-07	M 202M/M 202-08	C 76-08a	M 170-10
A 416/A 416M-06	M 203M/M 203-07	C 76M-08a	M 170M-10
A 421/A 421M-05*	M 204M/M 204-06	C 144-04*	M 45-06
A 490-04a	M 253-05 (2008)	C 150-09	M 85-09
A 490M-04a	M 253M-05	C 171-03	M 171-05
A 496/A 496M-07	M 225M/M 225-09	C 192/C 192M-06	R 39-07
A 497/A 497M-07	M 221M/M 221-09	C 230/C 230M-03*	M 152M/M 152-06
A 563-07*	M 291-09	C 260-01*	M 154-06
A 563M-06	M 291M-07	C 309-03*	M 148-05
A 615/A 615M-09	M 31M/M 31-10	C 330-04	M 195-06
A 663/A 663M-89 (2000)	M 227M/M 227-97 (2005)	C 412M-05a and C 412-05a	M 178M/M 178-07
A 668/A 668M-04	M 102M/M 102-06	C 443-05a	M 315-07
A 675/A 675M-03$^{\epsilon 1}$	M 255M/M 255-05 (2008)	C 443M-07	M 315M-09
A 702-89 (1994)$^{\epsilon 1}$	M 281-96 (2008)	C 444M-03 and C 444-03	M 175M/M 175-05 (2009)
A 709/A 709M-09a*	M 270M/M 270-10	C 465-99 (2005)	M 327-09
A 722/A 722M-07	M 275M/M 275-08	C 470/C 470M-02a*	M 205M/M 205-08
A 741-98*	M 30-02 (2006)	C 478M-09 and C 478-09*	M 199M/M 199-10
A 742/A 742M-03	M 246-05	C 490-08*	M 210-10
A 743/A 743M-06	M 163M/M 163-07	C 494/C 494M-05*	M 194M/M 194-06
A 744/A 744M-06	M 285M/M 285-07	C 506M-09 and C 506-09*	M 206M/M 206-10
A 760/A 760M-01a	M 36-03 (2007)	C 507M-09 and C 507-09*	M 207M/M 207-10
A 761/A 761M-04	M 167M/M 167-09	C 511-06	M 201-08
A 762/A 762M-98	M 245-00 (2008)	C 595-09	M 240-10
A 775/A 775M-07b	M 284M/M 284-09	C 618-05	M 295-07

ASTM ***Specifications***	**AASHTO** ***Equivalent***	**ASTM** ***Specifications***	**AASHTO** ***Equivalent***
C 654M-05a and C 654-05a	M 176M/M 176-07	D 994-98 (2003)	M 33-99 (2007)
C 655M-07 and C 655-07*	M 242M/M 242-08	D 995-95b (2002)*	M 156-97 (2009)
C 685/C 685M-07*	M 241M/M 241-09	D 1073-06	M 29-03 (2007)
C 789-95a*	M 259-98 (2006)	D 1751-04 (2008)	M 213-01 (2010)
C 789M-98*	M 259M-00 (2008)	D 1752-04a*	M 153-06
C 822-08b*	M 262-10	D 2397-02	M 208-01 (2009)
C 850-95a*	M 273-00 (2008)	D 2628-91 (2005)	M 220-84 (2007)
C 850M-98*	M 273M-00 (2008)	D 2680-01*	M 264-03 (2007)
C 881-99*	M 235M/M 235-03 (2007)	D 3406-95 (2006)	M 282-99 (2007)
C 977-03	M 216-05 (2009)	D 3542-08	M 297-10
C 989-05	M 302-06	D 3628-06*	R 5-08
C 990-09*	M 198-10	D 3963/D 3963M-01	M 317M/M 317-03 (2007)
C 1240-05	M 307-07	D 4552-92 (2004)*	R 14-88 (2007)
D 98-05	M 144-07	D 6690-06a	M 324-08
D 242-04	M 17-07	E 11-09	M 92-10
D 420-98 (2003)*	R 13-03 (2007)	E 501-94 (2000)*	M 261-96 (2009)
D 448-08	M 43-05 (2009)	E 524-08*	M 286-96 (2009)
D 632-01*	M 143-03 (2007)	F 436-09*	M 293-10
D 977-05	M 140-08	F 436M-04	M 293M-06

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Revisions for 30th Edition of Standard Specifications for Transportation Materials and Methods of Sampling and Testing—Part 1

The balloted technical changes listed below are also indicated in the specifications by a change bar in the left margin. Non-balloted editorial changes do not receive the change bar.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
M 20-70 (2004)	Penetration-Graded Asphalt Cement	2b	Deleted in 2009.
M 31M/M 31-10	Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement	4g	Revised to maintain equivalency with ASTM A 615/A 615M-09.
M 43-05 (2009)	Sizes of Aggregate for Road and Bridge Construction	1c	Reconfirmed in 2009.
M 91-10	Sewer and Manhole Brick (Made from Clay or Shale)	4a	Updated to agree with ASTM C 32-09.
M 92-10	Wire-Cloth Sieves for Testing Purposes	1b	Updated to agree with ASTM E 11-09.
M 114-10	Building Brick (Solid Masonry Units Made from Clay or Shale)	4a	Updated to agree with ASTM C 62-08.
M 133-10	Preservatives and Pressure Treatment Processes for Timber	4c	Revised to include additional preservatives.
M 148-05	Liquid Membrane-Forming Compounds for Curing Concrete	3b	Discontinued in 2009.
M 156-97 (2009)	Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures	2c	Reconfirmed in 2009.
M 160M/M 160-08	General Requirements for Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use	4f	Discontinued in 2009.
M 164-05 (2008)	High-Strength Bolts for Structural Steel Joints	4f	Discontinued in 2009.
M 164M-06	High-Strength Bolts for Structural Steel Joints [Metric]	4f	Discontinued in 2009.
M 170-10	Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe	4a	Revised.
M 170M-10	Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe [Metric]	4a	Revised.
M 171-05	Sheet Materials for Curing Concrete	3b	Discontinued in 2009.
M 175M/M 175-05 (2009)	Perforated Concrete Pipe	4a	Reconfirmed in 2009.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
M 181-10	Chain-Link Fence	4d	Revised.
M 182-05 (2009)	Burlap Cloth Made from Jute or Kenaf and Cotton Mats	3b	Reconfirmed in 2009.
M 198-10	Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants	4a	Updated to agree with ASTM C 990-09.
M 199M/M 199-10	Precast Reinforced Concrete Manhole Sections	4a	Revised.
M 206M/M 206-10	Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe	4a	Revised.
M 207M/M 207-10	Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe	4a	Revised.
M 208-01 (2009)	Cationic Emulsified Asphalt	2a	Reconfirmed in 2009.
M 210-10	Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete	3a	Revised to agree with ASTM C 490-08.
M 213-01 (2010)	Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)	4e	Reconfirmed in 2010.
M 216-05 (2009)	Lime for Soil Stabilization	3a	Reconfirmed in 2009.
M 232M/M 232-10	Zinc Coating (Hot-Dip) on Iron and Steel Hardware	4h	Revised to maintain equivalency with ASTM A 153/A 153M-09.
M 237-96 (2009)	Epoxy Resin Adhesives for Bonding Traffic Markers to Hardened Portland Cement and Asphalt Concrete	4c	Reconfirmed in 2009.
M 240-10	Blended Hydraulic Cement	3a	Revised to agree with ASTM C 595-09.
M 253-05 (2008)	Structural Bolts, Alloy Steel, Heat-Treated, 150 ksi Minimum Tensile Strength	4f	Discontinued in 2009.
M 253M-05	High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints [Metric]	4f	Discontinued in 2009.
M 261-96 (2009)	Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests	5a	Reconfirmed with editorial corrections in 2009.
M 262-10	Concrete Pipe and Related Products	4a	Revised.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
M 268-10	Retroreflective Sheeting for Flat and Vertical Traffic Control Applications	4d	Revised extensively.
M 270M/M 270-10	Structural Steel for Bridges	4f	Revised to maintain equivalency with ASTM A 709/A 709M-09a.
M 286-96 (2009)	Smooth-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests	5a	Reconfirmed with editorial corrections in 2009.
M 291M-07	Carbon and Alloy Steel Nuts [Metric]	4f	Discontinued in 2009.
M 292M/M 292-10	Carbon and Alloy Steel Nuts for Bolts for High-Pressure or High-Temperature Service, or Both	4f	Revised to maintain equivalency with ASTM A 194/A 194M-09.
M 293-10	Hardened Steel Washers	4f	Revised to maintain equivalency with ASTM F 436-09.
M 293M-06	Hardened Steel Washers [Metric]	4f	Discontinued in 2009.
M 294-10	Corrugated Polyethylene Pipe, 300- to 1500-mm (12- to 60-in.) Diameter	4b	Revised, based on NCHRP Report 631.
M 297-10	Preformed Polychloroprene Elastomeric Joint Seals for Bridges	4e	Revised to maintain equivalency with ASTM D 3542-08.
M 298-10	Coatings of Zinc Mechanically Deposited on Iron and Steel	4h	Updated to agree with ASTM B 695-04 (2009).
M 299-10	Coatings of Cadmium Mechanically Deposited	4h	Updated to agree with ASTM B 696-00 (2009).
M 304-10	Poly(Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter	4b	Revised, based on NCHRP Report 631.
M 306-10	Drainage, Sewer, Utility, and Related Castings	4h	Revised according to task force recommendations.
M 320-10	Performance-Graded Asphalt Binder	2b	Revised extensively.
M 322M/M 322-10	Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement	4g	Revised to maintain equivalency with ASTM A 996/A 996M-09.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
M 328-10	Inertial Profiler	5a	Revised and adopted MP 11-08 as M 328-10.
R 4-97 (2009)	Statistical Procedures	5c	Reconfirmed in 2009.
R 9-05 (2009)	Acceptance Sampling Plans for Highway Construction	5c	Reconfirmed in 2009.
R 18-10	Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories	AMRL	Revised extensively.
R 25-00 (2009)	Technician Training and Qualification Programs	5c	Reconfirmed in 2009.
R 26-01 (2009)	Certifying Suppliers of Performance-Graded Asphalt Binders	2b	Reconfirmed in 2009.
R 38-10	Quality Assurance of Standard Manufactured Materials	5c	Revised to reference R 18.
R 40-10	Measuring Pavement Profile Using a Rod and Level	5a	Revised.
R 48-10	Determining Rut Depth in Pavements	5a	Revised.
R 51-10	Compost for Erosion/Sediment Control (Filter Berms and Filter Socks)	1a	Revised and adopted MP 9 as R 51-10.
R 52-10	Compost for Erosion/Sediment Control (Compost Blankets)	1a	Revised and adopted MP 10 as R 52-10.
R 53-10	Qualification of Deformed and Plain Reinforcing Steel Bar, Welded Wire, and Wire Producing Mills	4g	Adopted PP 45-07 as R 53-10.
R 54-10	Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems	5a	Revised and adopted MP 17 as R 54-10.
R 55-10	Quantifying Cracks in Asphalt Pavement Surfaces	5a	Revised and adopted PP 44-01 (2008) as R 55-10.
R 56-10	Certification of Inertial Profiling Systems	5a	Revised and adopted PP 49-08 as R 56-10.
R 57-10	Operating Inertial Profiling Systems	5a	Revised and adopted PP 50-07 as R 57-10.

Standard Method of Test for

Sampling of Aggregates

AASHTO Designation: T 2-91 (2006)
ASTM Designation: D 75-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling of Aggregates

AASHTO Designation: T 2-91 (2006)
ASTM Designation: D 75-03

AASHTO T 2-91 (2006) is identical to ASTM D 75-03 except that all references to ASTM C 702 contained in ASTM D 75-03 shall be replaced with T 248 in T 2.

Standard Method of Test for

Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

AASHTO Designation: T 11-05 (2009)[1]
ASTM Designation: C 117-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

AASHTO Designation: T 11-05 (2009)[1]
ASTM Designation: C 117-04

1. SCOPE

1.1. This test method covers determination of the amount of material finer than a 75-µm (No. 200) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

1.2. Two procedures are included, one using only water for the washing operation, and the other including a wetting agent to assist the loosening of the material finer than the 75-µm (No. 200) sieve from the coarser material. Unless otherwise specified, Procedure A (water only) shall be used.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:
- C 117, Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SUMMARY OF METHOD

3.1. A sample of the aggregate is washed in a prescribed manner, using either plain water or water containing a wetting agent, as specified. The decanted wash water, containing suspended and dissolved material, is passed through a 75-µm (No. 200) sieve. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a 75-µm (No. 200) sieve by washing.

4. SIGNIFICANCE AND USE

4.1. Material finer than the 75-µm (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, when accurate determinations of material finer than 75 µm in fine or coarse aggregate are desired, this test method is used on the sample prior to dry sieving in accordance with T 27. The results of this test method are included in the calculation in T 27, and the total amount of material finer than 75 µm by washing, plus that obtained by dry sieving the same sample, is reported with the results of T 27. Usually the additional amount of material finer than 75 µm obtained in the dry-sieving process is a small amount. If it is large, the efficiency of the washing operation should be checked. A large amount of material could also be an indication of the degradation of the aggregate.

4.2. Plain water is adequate to separate the material finer than 75 µm from the coarser material with most aggregates. In some cases, the finer material is adhering to the larger particles, such as some clay coatings and coatings on aggregates that have been extracted from bituminous mixtures. In these cases, the fine material will be separated more readily with a wetting agent in the water.

5. APPARATUS AND MATERIALS

5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2. *Sieves*—A nest of two sieves, the lower being a 75-µm (No. 200) sieve and the upper being a sieve with openings in the range of 2.36-mm (No. 8) to 1.18-mm (No. 16), both conforming to the requirement of M 92.

5.3. *Container*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5.4. *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 110 ± 5ºC (230 ± 9ºF).

5.5. *Wetting Agent*—Any dispersing agent, such as liquid dishwashing detergents, that will promote separation of the fine materials.

Note 1—The use of a mechanical apparatus to perform the washing operation is not precluded, provided the results are consistent with those obtained using manual operations. The use of some mechanical washing equipment with some samples may cause degradation of the sample.

6. SAMPLING

6.1. Sample the aggregate in accordance with T 2. If the same test sample is to be tested for sieve analysis according to T 27, comply with the applicable requirements of that method.

6.2. Thoroughly mix the sample of aggregate to be tested and reduce the quantity to an amount suitable for testing using the applicable methods described in T 248. If the same test sample is to be tested according to T 27, the minimum mass shall be as described in the applicable sections of that method. Otherwise, the mass of the test sample, after drying, shall conform with the following:

Nominal Maximum Size	Minimum Mass, g
4.75 mm (No. 4) or smaller	300
9.5 mm ($^3/_8$ in.)	1000
19.0 mm ($^3/_4$ in.)	2500
37.5 mm (1$^1/_2$ in.) or larger	5000

The test sample shall be the end result of the reduction. Reduction to an exact predetermined mass shall not be permitted. If the nominal maximum size of the aggregate to be tested is not listed above, the next larger size listed shall be used to determine sample size.

7. SELECTION OF PROCEDURE

7.1. Procedure A shall be used, unless otherwise specified by the specification with which the test results are to be compared, or when directed by the agency for which the work is performed.

8. PROCEDURE A—WASHING WITH PLAIN WATER

8.1. Dry the test sample to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF). Determine the mass to the nearest 0.1 percent of the mass of the test sample.

8.2. If the applicable specification requires that the amount passing the 75-µm (No. 200) sieve shall be determined on a portion of the sample passing a sieve smaller than the nominal maximum size of the aggregate, separate the sample on the designated sieve and determine the mass of the material passing the designated sieve to 0.1 percent of the mass of this portion of the test sample. Use this mass as the original dry mass of the test sample in Section 10.1.

Note 2—Some specifications for aggregates with a nominal maximum size of 50 mm or greater, for example, provide a limit for material passing the 75-µm (No. 200) sieve determined on that portion of the sample passing the 25.0-mm sieve. Such procedures are necessary since it is impractical to wash samples of the size required when the same test sample is to be used for sieve analysis by T 27.

8.3. After drying and determining the mass, place the test sample in the container and add sufficient water to cover it. No detergent, dispersing agent, or other substance shall be added to the water. Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. The use of a large spoon or other similar tool to stir and agitate the aggregate in the wash water has been found satisfactory. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

8.4. Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

Note 3—If mechanical washing equipment is used, the charging of water, agitating, and decanting may be a continuous operation.

Note 4—A spray nozzle or a piece of rubber tubing attached to a water faucet may be used to rinse any of the material that may have fallen onto the sieves. The velocity of water, which may be increased by pinching the tubing or by use of a nozzle, should not be sufficient to cause any splashing of the sample over the sides of the sieve.

8.5. Return all material retained on the nested sieves by flushing to the washed sample. Dry the washed aggregate to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF) and determine the mass to the nearest 0.1 percent of the original mass of the sample.

Note 5—Following the washing of the sample and flushing any materials retained on the 75-µm (No. 200) sieve back into the container, no water should be decanted from the container except through the 75-µm sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

9. PROCEDURE B—WASHING USING A WETTING AGENT

9.1. Prepare the sample in the same manner as for Procedure A.

9.2. After drying and determining the mass, place the test sample in the container. Add sufficient water to cover the sample, and add wetting agent to the water (Note 6). Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. The use of a large spoon or other similar tool to stir and agitate the aggregate in the wash water has been found satisfactory. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

Note 6—There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water and the quality of the detergent. Excessive suds may overflow the sieves and carry some material with them.

9.3. Add a second charge of water (without wetting agent) to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

9.4. Complete the test as for Procedure A.

10. CALCULATION

10.1. Calculate the amount of material passing a 75-µm (No. 200) sieve by washing as follows:

$$A = \left[(B - C) / B \right] \times 100 \qquad (1)$$

where:

A = percentage of material finer than a 75-µm (No. 200) sieve by washing;

B = original dry mass of sample, g; and

C = dry mass of sample after washing, g.

11. REPORT

11.1. Report the percentage of material finer than the 75-µm (No. 200) sieve by washing to the nearest 0.1 percent, except if the result is 10 percent or more, report the percentage to the nearest whole number.

11.2. Include a statement as to which procedure was used.

12. PRECISION AND BIAS

12.1. *Precision*—The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and ASTM C 117. The significant differences between the methods at the time the data were acquired is that T 11 required, and ASTM C 117 prohibited, the use of a wetting agent. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

Table 1—Precision

	Standard Deviation (1s),[a] percent	Acceptable Range of Two Results (d2s),[a] percent
Coarse aggregate:[b]		
Single-operator precision	0.10	0.28
Multilaboratory precision	0.22	0.62
Fine aggregate:[c]		
Single-operator precision	0.15	0.43
Multilaboratory precision	0.29	0.82

[a] These numbers represent the (1s) and (d2s) limits as described in ASTM C 670.

[b] Precision estimates are based on aggregates having a nominal maximum size of 19.0 mm ($^3/_4$ in.) with less than 1.5 percent finer than the 75-μm (No. 200) sieve.

[c] Precision estimates are based on fine aggregates having 1.0 to 3.0 percent finer than the 75-μm (No. 200) sieve.

12.1.1. The precision values for fine aggregate in Table 1 are based on nominal 500-g test samples. Revision of this test method in 1996 permits the fine aggregate test sample size to 300-g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 2, which indicates only minor differences due to test sample size.

Table 2—Precision Data for 300-g and 500-g Test Samples

Fine Aggregate Proficiency Sample				Within Laboratory		Between Laboratory	
Test Result	Sample Size	No. Labs	Avg	1s	d2s	1s	d2s
AASHTO T 11/ASTM C 117 (Total material passing the	500 g	270	1.23	0.08	0.24	0.23	0.66
No. 200 sieve by washing, percent)	300 g	264	1.20	0.10	0.29	0.24	0.68

Note 7—The values for fine aggregate in Table 1 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

12.2. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is made.

13. KEYWORDS

13.1. Aggregate; size analysis; wash loss; 75μm (No. 200) sieve.

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[1] Except for Sections 5.1 and 6.2, and Note 4, this test method is identical with ASTM C 117-04.

Standard Method of Test for

Bulk Density ("Unit Weight") and Voids in Aggregate

AASHTO Designation: T 19M/T 19-09
ASTM Designation: C 29/C 29M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Bulk Density ("Unit Weight") and Voids in Aggregate

AASHTO Designation: T 19M/T 19-09
ASTM Designation: C 29/C 29M-07

1. SCOPE

1.1. This test method covers the determination of bulk density ("unit weight") of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination. This test method is applicable to aggregates not exceeding 125 mm (5 in.) in nominal maximum size.

Note 1—Unit weight is the traditional terminology used to describe the property determined by this test method, which is weight per unit volume (more correctly, mass per unit volume or density).

1.2. The values stated in either inch-pound units or acceptable metric units are to be regarded separately as standard, as appropriate for a specification with which this test method is used. An exception is with regard to sieve sizes and nominal size of aggregate, in which the metric values are the standard as stated in M 92. Within the text, inch–pound units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:
- C 29/C 29M, Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate
- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 123, Standard Terminology Relating to Textiles
- E 11, Standard Specification for Woven Wire Test Sieve Cloth Standard Test Sieves

3. TERMINOLOGY

3.1. *definitions*—definitions are in accordance with ASTM C 125 unless otherwise indicated.

3.1.1. *bulk density, n*—of aggregate, the mass of a unit volume of bulk aggregate material, in which the volume includes the volume of the individual particles and the volume of the voids between the particles. Expressed in kg/m^3(lb/ft^3).

3.1.1.1. *discussion*—units of mass are the kilogram (kg), the pound (lb), or units derived from these. Mass may also be visualized as equivalent to inertia, or the resistance offered by a body to change of motion (acceleration). Masses are compared by weighing the bodies, which amounts to comparing the forces of gravitation acting on them. ASTM D 123.

3.1.2. *unit weight, n*—weight (mass) per unit volume. (Deprecated term—used preferred term bulk density.)

3.1.2.1. *discussion*—the term weight means the force of gravity acting on the mass.

3.1.3. *weight, n*—the force exerted on a body by gravity. (See also mass.)

3.1.3.1. *discussion*—weight is equal to the mass of the body multiplied by the acceleration due to gravity. Weight may be expressed in absolute units (newtons, poundals) or in gravitational units (kgf, lbf), for example: on the surface of the earth, a body with a mass of 1 kg has a weight of 1 kgf (approximately 9.81 N), or a body with a mass of 1 lb has a weight of 1 lbf (approximately 4.45 N or 32.2 poundals). Since weight is equal to mass times the acceleration due to gravity, the weight of a body will vary with the location where the weight is determined, while the mass of the body remains constant. On the surface of the earth, the force of gravity imparts to a body that is free to fall an acceleration of approximately 9.81 m/s^2 (32.2 ft/s^2). ASTM D 123.

3.2. *Descriptions of Terms*:

3.2.1. *voids, n*—in unit volume of aggregate, the space between particles in an aggregate mass not occupied by solid mineral matter.

3.2.1.1. *discussion*—voids within particles, either permeable or impermeable, are not included in voids as determined by T 19M/T 19.

4. SIGNIFICANCE AND USE

4.1. This test method is often used to determine bulk density values that are necessary for use for many methods of selecting proportions for concrete mixtures.

4.2. The bulk density also may be used for determining mass/volume relationships for conversions in purchase agreements. However, the relationship between degree of compaction of aggregates in a hauling unit or stockpile and that achieved in this method is unknown. Further, aggregates in hauling units and stockpiles usually contain absorbed and surface moisture (the latter affecting bulking), while this method determines the bulk density on a dry basis.

4.3. A procedure is included for computing the percentage of voids between the aggregate particles based on the bulk density determined by this method.

5. APPARATUS

5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2. *Tamping Rod*—A round, straight steel rod, 16 mm ($^5/_8$ in.) in diameter and approximately 600 mm (24 in.) in length, having one end rounded to a hemispherical tip of the same diameter as the rod.

5.3. *Measure*—A cylindrical metal measure, preferably provided with handles. It shall be watertight, with the top and bottom true and even, and sufficiently rigid to retain its form under rough usage. The measure should have a height approximately equal to the diameter, but in no case shall the height be less than 80 percent nor more than 150 percent of the diameter. The capacity of the measure shall conform to the limits in Table 1 for the aggregate size to be tested. The thickness of metal in the measure shall be as described in Table 2. The top rim shall be smooth and plane within 0.25 mm (0.01 in.) and shall be parallel to the bottom within 0.5º (Note 2). The interior wall of the measure shall be a smooth and continuous surface.

Table 1—Capacity of Measures

Nominal Maximum Size of Aggregate		Capacity of Measure[a]	
mm	in.	L (m^3)	ft^3
12.5	$^1/_2$	2.8 (0.0028)	$^1/_{10}$
25.0	1	9.3 (0.0093)	$^1/_3$
37.5	$1^1/_2$	14 (0.014)	$^1/_2$
75	3	28 (0.028)	1
100	4	70 (0.070)	$2^1/_2$
125	5	100 (0.100)	$3^1/_2$

[a] The indicated size of measure shall be used to test aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 percent of the nominal volume listed.

Note 2—The top rim is satisfactorily plane if a 0.25 mm (0.01 in.) feeler gauge cannot be inserted between the rim and a piece of 6 mm ($^1/_4$ in.) or thicker plate glass laid over the measure. The top and bottom are satisfactorily parallel if the slope between pieces of plate glass in contact with the top and bottom does not exceed 0.87 percent in any direction.

5.3.1. If the measure also is to be used for testing for bulk density of freshly mixed concrete according to T 121, the measure shall be made of steel or other suitable metal not readily subject to attack by cement. Reactive materials, such as aluminum alloys are permitted, where as a consequence of an initial reaction, a surface film is formed which protects the metal against further corrosion.

5.3.2. Measures larger than nominal 28-L (1-ft^3) capacity shall be made of steel for rigidity, or the minimum thicknesses of metal listed in Table 2 should be suitably increased.

Table 2—Requirements for Measures

Capacity of Measure	Thickness of Metal, Min Bottom	Thickness of Metal, Min Upper $1^1/_2$ in. or 38 mm of Wall[a]	Thickness of Metal, Min Remainder of Wall
Less than 11 L	5.0 mm	2.5 mm	2.5 mm
11 to 42 L, incl	5.0 mm	5.0 mm	3.0 mm
Over 42 to 80 L, incl	10.0 mm	6.4 mm	3.8 mm
Over 80 to 133 L, incl	13.0 mm	7.6 mm	5.0 mm
Less than 0.4 ft^3	0.20 in.	0.10 in.	0.10 in.
0.4 ft^3 to 1.5 ft^3, incl	0.20 in.	0.20 in.	0.12 in.
Over 1.5 to 2.8 ft^3, incl	0.40 in.	0.25 in.	0.15 in.
Over 2.8 to 4.0 ft^3, incl	0.50 in.	0.30 in.	0.20 in.

[a] The added thickness in the upper portion of the wall may be obtained by placing a reinforcing band around the top of the measure.

5.4. *Shovel or Scoop*—A shovel or scoop of convenient size for filling the measure with aggregate.

5.5. *Calibration Equipment*

5.5.1. *Plate Glass*—A piece of plate glass, preferably at least 6 mm ($^1/_4$ in.) thick and at least 25 mm (1 in.) larger than the diameter of the measure to be calibrated.

5.5.2. *Grease*—A supply of water insoluble grease.

Note 3—Petrolatum, vacuum grease, water pump grease, or chassis grease are examples of suitable material used to form a seal between the glass plate and measure.

5.5.3. *Thermometer*—A thermometer having a range of at least 10 to 32°C (50 to 90°F) and that is readable to at least 0.5 °C (1 °F).

5.5.4. *Balance*—A balance as described in Section 5.1.

6. SAMPLING

6.1. Obtain the sample in accordance with T 2, and reduce to test sample size in accordance with T 248.

7. SAMPLE

7.1. The size of sample shall be approximately 125 to 200 percent of the quantity required to fill the measure and shall be handled in a manner to avoid segregation. Dry the sample of aggregate to constant mass, preferably in an oven at 110 ± 5ºC (230 ± 9ºF).

8. CALIBRATION OF MEASURE

8.1. Measures shall be recalibrated at least once a year or whenever there is reason to question the accuracy of the calibration.

8.2. Place a thin layer of grease on the rim of the measure to prevent leakage of water from the measure.

8.3. Determine the mass of the plate glass and measure to the nearest 0.05 kg (0.1 lb).

8.4. Fill the measure with water that is at room temperature and cover with the plate glass in such a way as to eliminate bubbles and excess water. Remove any water that may have overflowed onto the measure or plate glass.

8.5. Determine the mass of the water, plate glass, and measure to the nearest 0.05 kg (0.1 lb).

8.6. Measure the temperature of the water to the nearest 0.5 °C (1 °F) and determine its density from Table 3, interpolating if necessary.

Table 3—Density of Water

Temperature			
°C	°F	kg/m^3	lb/ft^3
15.6	60	999.01	62.366
18.3	65	998.54	62.336
21.1	70	997.97	62.301
(23.0)	(73.4)	(997.54)	(62.274)
23.9	75	997.32	62.261
26.7	80	996.59	62.216
29.4	85	995.83	62.166

8.7. Calculate the volume, V, of the measure. Alternatively, calculate the factor, F, for the measure.

$$V = (B - C)/D \qquad (1)$$

$$F = D/(B - C) \qquad (2)$$

where:

V = volume of the measure, m^3 (ft^3)

B = mass of the water, plate glass, and measure, kg (lb)

C = mass of the plate glass and measure, kg (lb)

D = density of the water for the measured kg/m^3 (lb/ft^3), and

F = factor for the measure, 1/m^3 (1/ft^3)

Note 4—For the calculation of bulk density, the volume of the measure in acceptable metric units should be expressed in cubic meters, or the factor as 1/m^3. However, for convenience the size of the measure may be expressed in liters (equal to m^3/1000).

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9. SELECTION OF PROCEDURE

9.1. The shoveling procedure for loose bulk density shall be used only when specifically stipulated. Otherwise, the compact bulk density shall be determined by the rodding procedure for aggregates having a nominal maximum size of 37.5 mm ($1^1/_2$ in.) or less, or by the jigging procedure for aggregates having a nominal maximum size greater than 37.5 mm ($1^1/_2$ in.) and not exceeding 125 mm (5 in.).

10. RODDING PROCEDURE

10.1. Fill the measure one-third full and level the surface with the fingers. Rod the layer of aggregate with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure two-thirds full and again level and rod as above. Finally, fill the measure to overflowing and rod again in the manner previously mentioned. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

10.2. In rodding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In rodding the second and third layers, use vigorous effort, but not more force than to cause the tamping rod to penetrate to the previous layer of aggregate.

Note 5—In rodding the larger sizes of coarse aggregate, it may not be possible to penetrate the layer being consolidated, especially with angular aggregates. The intent of the procedure will be accomplished if vigorous effort is used.

10.3. Determine the mass of the measure plus contents, and the mass of the measure alone and record the values to the nearest 0.05 kg (0.1 lb).

11. JIGGING PROCEDURE

11.1. Fill the measure in three approximately equal layers as described in Section 10.1, compacting each layer by placing the measure on a firm base, such as a cement-concrete floor, raising the opposite sides alternately about 50 mm (2 in.), and allowing the measure to drop in such a manner as to hit with a sharp, slapping blow. The aggregate particles, by this procedure, will arrange themselves in a densely compacted condition. Compact each layer by dropping the measure 50 times in the manner described, 25 times on each side. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

11.2. Determine the mass of the measure plus contents, and the mass of the measure alone, and record the values to the nearest 0.05 kg (0.1 lb).

12. SHOVELING PROCEDURE

12.1. Fill the measure to overflowing by means of a shovel or scoop, discharging the aggregate from a height not to exceed 50 mm (2 in.) above the top of the measure. Exercise care to prevent, so far as possible, segregation of the particle sizes of which the sample is composed. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

12.2. Determine the mass of the measure plus contents, and the mass of the measure alone, and record the values to the nearest 0.05 kg (0.1 lb).

13. CALCULATION OF RESULTS

13.1. *Bulk Density*—Calculate the bulk density for the rodding, jigging, or shoveling procedure as follows:

$$M = (G - T)/V \tag{3}$$

or,

$$M = (G - T) \times F \tag{4}$$

where:

M = bulk density of aggregate, kg/m^3 (lb/ft^3);
G = mass of aggregate plus the measure, kg (lb);
T = mass of the measure, kg (lb);
V = volume of measure, m^3 (ft^3); and
F = factor for measure, m^{-3} (ft^{-3}).

13.1.1. The bulk density determined by this method is for aggregate in an oven-dry condition. If the bulk density in terms of saturated-surface-dry (SSD) condition is desired, use the exact procedure in this method, and then calculate the SSD bulk density by the following formula:

$$M_{SSD} = M[1 + (A/100)] \tag{5}$$

where:

M_{SSD} = bulk density in SSD condition, kg/m^3 (lb/ft^3); and
A = absorption, percent, determined in accordance with T 84 or T 85.

13.2. *Void Content*—Calculate the void content in the aggregate using the bulk density determined by either the rodding, jigging, or shoveling procedure, as follows:

$$\text{Voids \%} = \frac{100[(S \times W) - M]}{S \times W} \tag{6}$$

where:

M = bulk density of aggregate, kg/m^3 (lb/ft^3);
S = bulk specific gravity (dry basis) as determined in accordance with T 84 or T 85; and
W = density of water, 998 kg/m^3 (62.3 lb/ft^3).

14. REPORT

14.1. Report the results for bulk density to the nearest 10 kg/m^3 (1 lb/ft^3) as follows:

14.1.1. Bulk density by rodding,

14.1.2. Bulk density by jigging, or

14.1.3. Loose bulk density.

14.2. Report the results for void content to the nearest one percent as follows:

14.2.1. Voids in aggregate compacted by rodding, percent, 14.2.2. Voids in aggregate compacted by jigging, percent, or

14.2.3. Voids in loose aggregate, percent.

14.3. Indicate the procedure used.

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15. PRECISION AND BIAS

15.1. The following estimates of precision for this method are based on results from the AASHTO Materials Reference Laboratory (AMRL) Proficiency Sample Program, with testing conducted by this method and ASTM C 29. There are no significant differences between the two methods. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

15.2. *Coarse Aggregate (bulk density)*:

15.2.1. *Single-Operator Precision*—The single-operator standard deviation has been found to be 14 kg/m^3 (0.88 lb/ft^3) (1s). Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 40 kg/m^3 (2.5 lb/ft^3) (d2s).

15.2.2. *Multi-Laboratory Precision*—The multi-laboratory standard deviation has been found to be 30 kg/m^3 (1.87 lb/ft^3) (1s). Therefore, results of two properly conducted tests from two different laboratories on similar material should not differ by more than 85 kg/m^3 (5.3 lb/ft^3) (d2s).

15.2.3. These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of AMRL proficiency sample data for bulk density by rodding of normal-weight aggregates having a nominal maximum aggregate size of 25.0 mm (1 in.), and using a 14-L ($^1/_2$-ft^3) measure.

15.3. *Fine Aggregate (bulk density)*:

15.3.1. *Single-Operator Precision*—The single-operator standard deviation has been found to be 14 kg/m^3 (0.88 lb/ft^3) (1s). Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 40 kg/m^3 (2.5 lb/ft^3) (d2s).

15.3.2. *Multi-Laboratory Precision*—The multi-laboratory standard deviation has been found to be 44 kg/m^3 (2.76 lb/ft^3) (1s). Therefore, results of two properly conducted tests from two different laboratories on similar material should not differ by more than 125 kg/m^3 (7.8 lb/ft^3) (d2s).

15.3.3. These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of AMRL proficiency sample data for loose bulk density from laboratories using a 2.8-L ($^1/_{10}$-ft^3) measure.

15.4. No precision data on void content are available. However as the void content in aggregate is calculated from bulk density and bulk specific gravity, the precision of the voids content reflects the precision of these measured parameters given in Sections 15.2 and 15.3 of this method and in T 84 and T 85.

15.5. *Bias*—The procedure in this test method for measuring bulk density and void content has no bias because the values for bulk density and void content can be defined only in terms of a test method.

Standard Method of Test for

Organic Impurities in Fine Aggregates for Concrete

AASHTO Designation: T 21-05 (2009)[1]
ASTM Designation: C 40-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Organic Impurities in Fine Aggregates for Concrete

AASHTO Designation: T 21-05 (2009)[1]

ASTM Designation: C 40-04

1. SCOPE

1.1. This test method covers two procedures for an approximate determination of the presence of injurious organic compounds in fine aggregates that are to be used in hydraulic cement mortar or concrete. One procedure uses a standard color solution and the other uses a glass color standard.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 2, Sampling of Aggregates
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standard*:

- D 1544, Standard Test Method for Color of Transparent Liquids (Gardner Color Scale)

3. SIGNIFICANCE AND USE

3.1. This test method is of significance in making a preliminary determination of the acceptability of fine aggregates with respect to the requirements of M 6.

3.2. The principal value of this test method is to furnish a warning that organic impurities may be present. When a sample subjected to this test produces a color darker than the standard color, it is advisable to perform the test for the effect of organic impurities on the strength of mortar in accordance with T 71.

4. APPARATUS

4.1. *Glass Bottles*—Colorless glass graduated bottles, approximately 240 to 470-mL (8 to 16-oz) nominal capacity, equipped with watertight stoppers or caps, not soluble in the specified reagents. In no case shall the maximum outside dimension of the bottles, measured along the line of sight used for the color comparison, be greater than 60 mm (2.5 in.) or less than 40 mm (1.5 in.). The graduations on the bottles shall be in milliliters or ounces (U.S. fluid), except that unmarked bottles may be calibrated and scribed with graduations by the user. In such case, graduation marks are required at only three points as follows:

4.1.1. *Standard Color Solution Level*—75 mL, ($2^1/_2$ oz) (U.S. fluid);

4.1.2. *Fine Aggregate Level*—130 mL, ($4^1/_2$ oz) (U.S. fluid); and

4.1.3. *NaOH Solution Level*—200 mL, (7 oz) (U.S. fluid).

4.2. *Glass Color Standard*:

4.2.1. Glass standard colors shall be used as described in Table 1 of ASTM D 1544.

Note 1—A suitable instrument consists of five glass color standards mounted in a plastic holder. Only the glass identified as Gardner Color Standard No. 11 is to be used as the Glass Color Standard in Section 9.2.

5. REAGENT AND STANDARD COLOR SOLUTION

5.1. *Reagent Sodium Hydroxide Solution (3 percent)*—Dissolve 3 parts by mass of sodium hydroxide (NaOH) in 97 parts of water.

5.2. *Standard Color Solution*—Dissolve reagent grade potassium dichromate ($K_2Cr_2O_7$) in concentrated sulfuric acid (sp gr 1.84) at the rate of 0.250 g/100 mL of acid. The solution must be freshly made for the color comparison using gentle heat if necessary to effect solution. Preparation of the reference standard color solution is unnecessary when the Glass Color Standard procedure is used to determine the color value.

6. SAMPLING

6.1. The sample shall be selected in general accordance with T 2.

7. TEST SAMPLE

7.1. Obtain a test sample of fine aggregate of about 450 grams (approximately 1 pound) in accordance with T 248. Sample drying prior to testing, if necessary, shall be done by air drying only.

8. PROCEDURE

8.1. Fill a glass bottle to the 130-mL (approximately $4^1/_2$-fluid oz) level with the sample of the fine aggregate to be tested.

8.2. Add a three-percent NaOH solution in water until the volume of the fine aggregate and liquid, indicated after shaking, is 200 mL (approximately 7 fluid oz).

8.3. Stopper the bottle, shake vigorously, and then allow to stand for 24 hours.

9. DETERMINATION OF COLOR VALUE

9.1. *Standard Color Solution Procedure*—At the end of the 24-hour standing period, fill a glass bottle to the 75-mL (approximately $2^1/_2$-fluid oz) level with the fresh standard color solution, prepared not longer than two hours previously, as prescribed in Section 5.2. Hold the bottle with the test sample and the bottle with the standard color solution side by side and compare the color of light transmitted through the supernatant liquid above the test sample with the color of light transmitted through the standard color solution. Record whether it is lighter, darker, or of equal color to that of the reference standard.

9.2. *Glass Color Standard Procedure*—To define more precisely the color of the liquid of the test sample, five glass standard colors may be used as described in Table 1 of ASTM D 1544, using the following colors:

Gardener Color Standard No.	Organic Plate No.
5	1
8	2
11	3 (standard)
14	4
16	5

The comparison procedure described in Section 9.1 shall be used, except that the organic plate number which is nearest the color of the supernatant liquid above the test specimen shall be reported. When using this procedure it is not necessary to prepare the standard color solution.

10. INTERPRETATION OF RESULTS

10.1. If the color of the supernatant liquid is darker than that of the standard color solution or the glass color standard organic plate No. 3 (Gardner Color Standard No. 11), the fine aggregate under test shall be considered to possibly contain injurious organic compounds, and further tests should be made before approving the fine aggregate for use in concrete.

11. PRECISION AND BIAS

11.1. Since this test produces no numerical values, determination of the precision and bias is not necessary.

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[1] This method agrees with ASTM C 40-04, except for shifting of text between Sections 9.2 and 5.2.

Standard Method of Test for

Sieve Analysis of Fine and Coarse Aggregates

AASHTO Designation: T 27-06[1]
ASTM Designation: C 136-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sieve Analysis of Fine and Coarse Aggregates

AASHTO Designation: T 27-06[1]
ASTM Designation: C 136-05

1. SCOPE

1.1. This method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2. Some specifications for aggregates, which reference this method, contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3. The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information purposes only.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory regulations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms used in this standard, refer to ASTM C 125.

4. SUMMARY OF METHOD

4.1. A sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

5. SIGNIFICANCE AND USE

5.1. This method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

5.2. Accurate determination of material finer than the 75-μm (No. 200) sieve cannot be achieved by use of this method alone. Test Method T 11 for material finer than the 75-μm (No. 200) sieve by washing should be employed.

6. APPARATUS

6.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

6.2. *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve frames shall conform to the requirements of M 92. Nonstandard sieve frames shall conform to the requirements of M 92 as applicable.

Note 1—It is recommended that sieves mounted in frames larger than standard 203.2 mm (8 in.) diameter be used for testing coarse aggregate to reduce the possibility of overloading the sieves. See Section 8.3.

6.3. *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 8.4 is met in a reasonable time period.

Note 2—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg (44 lb) or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 minutes) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a smaller sample of coarse aggregate or fine aggregate.

6.4. *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of 110 ± 5ºC (230 ± 9ºF).

7. SAMPLING

7.1. Sample the aggregate in accordance with T 2. The mass of the field sample shall be the mass shown in T 2 or four times the mass required in Sections 7.4 and 7.5 (except as modified in Section 7.6), whichever is greater.

7.2. Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in T 248. The sample for test shall be the approximate mass desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined mass shall not be permitted.

Note 3—Where sieve analysis, including determination of material finer than the 75-µm (No. 200) sieve, is the only testing proposed, the size of the sample may be reduced in the field to avoid shipping excessive quantities of extra material to the laboratory.

7.3. *Fine Aggregate*—The size of the test sample of aggregate, after drying, shall be 300 g minimum.

7.4. *Coarse Aggregate*—The mass of the test sample of coarse aggregate shall conform with the following:

Nominal Maximum Size Square Openings, mm (in.)	Minimum Mass of Test Sample, kg (lb)
9.5 ($^3/_8$)	1 (2)
12.5 ($^1/_2$)	2 (4)
19.0 ($^3/_4$)	5 (11)
25.0 (1)	10 (22)
37.5 (1$^1/_2$)	15 (33)
50 (2)	20 (44)
63 (2$^1/_2$)	35 (77)
75 (3)	60 (130)
90 (3$^1/_2$)	100 (220)
100 (4)	150 (330)
125 (5)	300 (660)

7.5. *Coarse and Fine Aggregates Mixtures*—The mass of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate in Section 7.4.

7.6. *Samples of Large-Size Coarse Aggregate*—The size of sample required for aggregate with 50-mm (2-in.) nominal maximum size or larger is such as to preclude convenient sample reduction and testing as a unit except with large mechanical splitters and sieve shakers. As an option when such equipment is not available, instead of combining and mixing sample increments and then reducing the field sample to testing size, conduct the sieve analysis on a number of approximately equal sample increments such that the total mass tested conforms to the requirements of Section 7.4.

7.7. In the event that the amount of material finer than the 75-µm (No. 200) sieve is to be determined by T 11, use the procedure described in Section 7.7.1 or 7.7.2, whichever is applicable.

7.7.1. For aggregates with a nominal maximum size of 12.5 mm ($^1/_2$ in.) or less, use the same test sample for testing by T 11 and this method. First test the sample in accordance with T 11 through the final drying operation, then dry sieve the sample as stipulated in Sections 8.2 through 8.7 of this method.

7.7.2. For aggregates with a nominal maximum size greater than 12.5 mm ($^1/_2$ in.), a single test sample may be used as described in Section 7.7.1 or separate test samples may be used for T 11 and this method.

7.7.3. Where the specification requires determination of the total amount of material finer than the 75-µm (No. 200) sieve by washing and dry sieving, use the procedure described in Section 7.7.1.

8. PROCEDURE

8.1. If the test sample has not been subjected to testing by T 11, dry it to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF) and determine the mass of it to the nearest 0.1 percent of the total original dry sample mass.

Note 4—For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless (1) the nominal maximum size is smaller than about 12.5 mm ($^1/_2$ in.), (2) the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4), or (3) the coarse aggregate is highly absorptive (a lightweight aggregate, for example). Also, samples may be dried at the higher temperature associated with the use of hot plates without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles, and temperatures are not so great as to cause chemical breakdown of the aggregate.

8.2. Select sieves with suitable openings to furnish the information required by the specifications covering the material to be tested. Use additional sieves as desired or necessary to provide other information, such as fineness modulus, or to regulate the amount of material on a sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample, or portion of the sample if it is to be sieved in more than one increment, on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy of sieving described in Section 8.4.

8.3. Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75-mm (No. 4), the quantity retained on any sieve at the completion of the sieving operation shall not exceed 7 kg/m^2 (4 g/in.^{2}) of sieving surface area (Note 5). For sieves with openings 4.75 mm (No. 4) and larger, the quantity retained in kg shall not exceed the product of 2.5 × (sieve opening, mm × (effective sieving area, m^2)). This quantity is shown in Table 1 for five sieve-frame dimensions in common use. In no case shall the quantity retained be so great as to cause permanent deformation of the sieve cloth.

8.3.1. Prevent an overload of material on an individual sieve by one or a combination of the following methods:

8.3.1.1. Insert an additional sieve with opening size intermediate between the sieve that may be overloaded and the sieve immediately above that sieve in the original set of sieves.

8.3.1.2. Split the sample into two or more portions, sieving each portion individually. Combine the masses of the several portions retained on a specific sieve before calculating the percentage of the sample on the sieve.

8.3.1.3. Use sieves having a larger frame size and providing greater sieving area.

Note 5—The 7 kg/m^2 amounts to 200 g for the usual 203.2-mm (8-in.) diameter sieve (with effective sieving surface diameter of 190.5 mm (7.5 in.)).

8.3.1.4. In the case of coarse and fine aggregate mixtures, the portion of the sample finer than the 4.75-mm (No. 4) sieve may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

8.3.1.5. Alternatively, the portion finer than the 4.75-mm (No. 4) sieve may be reduced in size using a mechanical splitter according to T 248. If this procedure is followed, compute the mass of each size increment of the original sample as follows:

$$A = \frac{W_1}{W_2} \times B \qquad (1)$$

where:

A = mass of size increment on total sample basis,

W_1 = mass of fraction finer than 4.75-mm (No. 4) sieve in total sample,

W_2 = mass of reduced portion of material finer than 4.75-mm (No. 4) sieve actually sieved, and

B = mass of size increment in reduced portion sieved.

Table 1—Maximum Allowable Quantity of Material Retained on a Sieve, kg

Sieve Opening Size	Nominal Dimensions of Sieve[a]				
	203.2-mm, dia[b]	254-mm, dia[b]	304.8-mm, dia[b]	350 by 350, mm	372 by 580, mm
	Sieving Area, m^2				
	0.0285	0.0457	0.0670	0.1225	0.2158
125 mm (5 in.)	[c]	[c]	[c]	[c]	67.4
100 mm (4 in.)	[c]	[c]	[c]	30.6	53.9
90 mm (3 $^{1}/_{2}$ in.)	[c]	[c]	15.1	27.6	48.5
75 mm (3 in.)	[c]	8.6	12.6	23.0	40.5
63 mm (2 $^{1}/_{2}$ in.)	[c]	7.2	10.6	19.3	34.0
50 mm (2 in.)	3.6	5.7	8.4	15.3	27.0
37.5 mm (1 $^{1}/_{2}$ in.)	2.7	4.3	6.3	11.5	20.2
25.0 mm (1 in.)	1.8	2.9	4.2	7.7	13.5
19.0 mm ($^{3}/_{4}$ in.)	1.4	2.2	3.2	5.8	10.2
12.5 mm ($^{1}/_{2}$ in.)	0.89	1.4	2.1	3.8	6.7
9.5 mm ($^{3}/_{8}$ in.)	0.67	1.1	1.6	2.9	5.1
4.75 mm (No. 4)	0.33	0.54	0.80	1.5	2.6

[a] Sieve frame dimensions in inch units: 8.0-in. diameter; 10.0-in. diameter; 12.0-in. diameter; 13.8 by 13.8 in. (14 by 14 in. nominal); 14.6 by 22.8 in. (16 by 24 in. nominal).

[b] The sieve area for round sieve is based on an effective diameter 12.7 mm ($^{1}/_{2}$ in.) less than the nominal frame diameter, because M 92 permits the sealer between the sieve cloth and the frame to extend 6.35 mm ($^{1}/_{4}$ in.) over the sieve cloth. Thus the effective sieving diameter for a 203.2-mm (8.0-in.) diameter sieve frame is 190.5 mm (7.5 in.). Sieves produced by some manufacturers do not infringe on the sieve cloth by the full 6.35 mm ($^{1}/_{4}$ in.).

[c] Sieves indicated have less than five full openings and should not be used for sieve testing.

8.4. Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by mass of the total sample passes any sieve during 1 minute of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one-sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203.2-mm (8-in.) diameter sieves to verify the sufficiency of sieving.

8.5. Unless a mechanical sieve shaker is used, hand sieve particles obtained on the 75 mm (3 in.) by determining the smallest sieve opening through which each particle will pass by rotating the particles, if necessary, in order to determine whether they will pass through a particular opening; however, do not force particles to pass through an opening.

8.6. Determine the mass of each size increment on a scale or balance conforming to the requirements specified in Section 6.1 to the nearest 0.1 percent of the total original dry sample mass. The total mass of the material after sieving should check closely with original mass of sample placed on the sieves. If the amounts differ by more than 0.3 percent, based on the original dry sample mass, the results should not be used for acceptance purposes.

8.7. If the sample has previously been tested by T 11, add the mass finer than the 75-µm (No. 200) sieve determined by that method to the mass passing the 75-µm (No. 200) sieve by dry sieving of the same sample in this method.

9. CALCULATION

9.1. Calculate percentages passing, total percentages retained, or percentages in various size fractions to the nearest 0.1 percent on the basis of the total mass of the initial dry sample. If the same test sample was first tested by T 11, include the mass of material finer than 75-µm (No. 200) sieve by washing in the sieve analysis calculation; and use the total dry sample mass prior to washing in T 11 as the basis for calculating all the percentages.

9.1.1. When sample increments are tested as provided in Section 7.6, total the masses of the portion of the increments retained on each sieve, and use these masses to calculate the percentage as in Section 9.1.

9.2. Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100; 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm ($^3/_8$ in.), 19.0 mm ($^3/_4$ in.), 37.5 mm ($1^1/_2$ in.), and larger, increasing the ratio of 2 to 1.

10. REPORT

10.1. Depending upon the form of the specifications for use of the material under test, the report shall include one of the following:

10.1.1. Total percentage of material passing each sieve, or

10.1.2. Total percentage of material retained on each sieve, or

10.1.3. Percentage of material retained between consecutive sieves.

10.2. Report percentages to the nearest whole number, except if the percentage passing the 75-µm (No. 200) sieve is less than 10 percent, it shall be reported to the nearest 0.1 percent.

10.3. Report the fineness modulus, when required, to the nearest 0.01.

11. PRECISION AND BIAS

11.1. *Precision*—The estimates of precision for this test method are listed in Table 2. The estimates are based on the results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by T 27 and ASTM C 136. The data are based on the analyses of the test results from 65 to 233 laboratories that tested 18 pairs of coarse aggregate proficiency test samples and test results from 74 to 222 laboratories that tested 17 pairs of fine aggregate proficiency test samples (Samples No. 21 through 90). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

Table 2—Estimates of Precision

	Total Percentage of Material Passing		Standard Deviation (1s), Percent[a]	Acceptable Range of Two Results (d2s), Percent[a]
Coarse Aggregate:b	100	≥95	0.32	0.9
Single-operator precision	<95	≥85	0.81	2.3
	<85	≥80	1.34	3.8
	<80	≥60	2.25	6.4
	<60	≥20	1.32	3.7
	<20	≥15	0.95	2.7
	<15	≥10	1.00	2.8
	<10	≥5	0.75	2.1
	<5	≥2	0.53	1.5
	<2	0	0.27	0.8
Multilaboratory precision	100	≥95	0.35	1.0
	<95	≥85	1.37	3.9
	<85	≥80	1.92	5.4
	<80	≥60	2.82	8.0
	<60	≥20	1.97	5.6
	<20	≥15	1.60	4.5
	<15	≥10	1.48	4.2
	<10	≥5	1.22	3.4
	<5	≥2	1.04	3.0
	<2	0	0.45	1.3
Fine Aggregate:				
Single-operator precision	100	≥95	0.26	0.7
	<95	≥60	0.55	1.6
	<60	≥20	0.83	2.4
	<20	≥15	0.54	1.5
	<15	≥10	0.36	1.0
	<10	≥2	0.37	1.1
	<2	0	0.14	0.4
Multilaboratory precision	100	≥95	0.23	0.6
	<95	≥60	0.77	2.2
	<60	≥20	1.41	4.0
	<20	≥15	1.10	3.1
	<15	≥10	0.73	2.1
	<10	≥2	0.65	1.8
	<2	0	0.31	0.9

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

[b] The precision estimates are based on aggregates with nominal maximum size of 19.0 mm ($^{3}/_{4}$ in.).

11.1.1. The precision values for Fine Aggregate in Table 2 are based on nominal 500-g test samples. Revision of ASTM C 136 in 1994 permitted the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 3, which indicate only minor differences due to test sample size.

Note 6—The values for Fine Aggregate in Table 2 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

Table 3—Precision Data for 300-g and 500-g Fine Aggregate Test Samples

Fine Aggregate Proficiency Sample Test Result	Sample Size	Number of Labs	Average	Within Laboratory 1s	Within Laboratory d2s	Among Laboratories 1s	Among Laboratories d2s
AASHTO T 27/ASTM C 136:							
Total material passing the 4.75-mm (No. 4) sieve (%)	500 g	285	99.992	0.027	0.066	0.037	0.104
	300 g	276	99.990	0.021	0.060	0.042	0.117
Total material passing the 2.36-mm (No. 8) sieve (%)	500 g	281	84.10	0.43	1.21	0.63	1.76
	300 g	274	84.32	0.39	1.09	0.69	1.92
Total material passing the 1.18-mm (No. 16) sieve (%)	500 g	286	70.11	0.53	1.49	0.75	2.10
	300 g	272	70.00	0.62	1.74	0.76	2.12
Total material passing the 600-µm (No. 30) sieve (%)	500 g	287	48.54	0.75	2.10	1.33	3.73
	300 g	276	48.44	0.87	2.44	1.36	3.79
Total material passing the 300-µm (No. 50) sieve (%)	500 g	286	13.52	0.42	1.17	0.98	2.73
	300 g	275	13.51	0.45	1.25	0.99	2.76
Total material passing the 150-µm (No. 100) sieve (%)	500 g	287	2.55	0.15	0.42	0.37	1.03
	300 g	270	2.52	0.18	0.52	0.32	0.89
Total material passing the 75-µm (No. 200) sieve (%)	500 g	278	1.32	0.11	0.32	0.31	0.85
	300 g	266	1.30	0.14	0.39	0.31	0.85

11.2. *Bias*—Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

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[1] Similar but not identical to ASTM C 136-05.

Standard Method of Test for

Mechanical Analysis of Extracted Aggregate

AASHTO Designation: T 30-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Mechanical Analysis of Extracted Aggregate

AASHTO Designation: T 30-10

1. SCOPE

1.1 This method covers a procedure for the determination of the particle-size distribution of fine and coarse aggregates extracted from hot mix asphalt (HMA), using sieves with square openings.

1.2 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

2.2 *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SIGNIFICANCE AND USE

3.1 This method is used to determine the grading of aggregates extracted from HMA. The results are used to determine compliance of the particle-size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregates to be used in HMA.

4. APPARATUS

4.1 The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to M 231.

4.2 *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve frames shall conform to the requirements of M 92. Nonstandard sieve frames shall conform to the requirements of M 92 as applicable.

4.3 *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 6.7 is met in a reasonable time period.

Note 1—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg (44 lb) or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 min) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a smaller size of coarse aggregate or fine aggregate.

4.4 *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 110 ± 5ºC (230 ± 9ºF).

4.5 *Wetting Agent*—Any dispersing agent, such as Calgon, Joy, or other detergent that will promote separation of the fine materials.

4.6 *Containers and Utensils*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5. SAMPLE

5.1 The sample shall consist of the entire lot or sample of aggregate obtained according to T 164 or T 308 from which the binder material has been extracted.

6. PROCEDURE

6.1 *Sample*:

6.1.1 The sample shall be dried, if necessary, until further drying at 110 ± 5ºC (230 ± 9ºF) does not alter the mass by more than 0.1 percent, the precision of weighing. The total mass of aggregate in the HMA being tested is the sum of the mass of the dried aggregates and the mineral matter contained in the extracted asphalt binder. The latter is to be taken as the sum of the mass of ash in the extract and the increase in mass of the filter element as determined in T 164.

6.1.2 Determine and record the mass of the sample to the nearest 0.1 g. This mass shall agree with the mass of aggregate remaining after ignition (M_f from T 308) within 0.1 percent of M_f for an aggregate sample obtained from T 308. If the variation exceeds 0.1 percent, the results of this test should not be used for acceptance purposes.

6.2 The test sample shall be placed in a container and covered with water. Add a sufficient amount of wetting agent to assure a thorough separation of the material finer than the 75-µm (No. 200) sieve from the coarser particles. There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water, the quality of the detergent, and the agitation process. Excessive suds may overflow the sieves and carry some material with them. The contents of the container shall be agitated vigorously and the wash water immediately poured over a nest of two sieves consisting of a 2.00- or 1.18-mm (No. 10 or No. 16) sieve superimposed on a 75-µm (No. 200) sieve. The use of a large spoon to stir and agitate the aggregate in the wash water has been found to be satisfactory.

The use of a mechanical apparatus to perform the washing operation is allowable, providing mechanical wash does not degrade the sample. When mechanical washing equipment is used, the introduction of water, agitating, and decanting may be a continuous operation. Use care not to overflow or overload the 75-µm (No. 200) sieve.

6.3 The agitation shall be sufficiently vigorous to result in the complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarse particles and bring them into suspension in order that they may be removed by decantation of the wash water. Care should be taken to avoid, as much as possible, the decantation of the coarse particles of the sample. The operation shall be repeated until the wash water is clear.

6.4 All material retained on the nested sieves shall be returned to the container. The washed aggregate in the container shall be dried to constant mass per T 255, and weighed to the nearest 0.1 percent.

6.5 The aggregate shall then be sieved over sieves of various sizes required by the specification covering the HMA, including the 75-µm (No. 200) sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by a mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy of sieving described in Section 6.7.

6.6 Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75 mm (No. 4), the mass retained on any sieve at the completion of the sieving operation shall not exceed 6 kg/m^2 (4 g/in.^{2}) of sieving surface. For sieves with openings 4.75 mm (No. 4) and larger, the mass in kg shall not exceed the product of 2.5 × (sieve opening in mm) × (the sieving surface area in m^2). In no case shall the mass be so great as to cause permanent deformation of the sieve cloth.

Note 2—The 6 kg/m^2 (4 g/in.^{2}) amounts to 200 g for the usual 203-mm (8-in.) diameter sieve. The amount of material retained on a sieve may be regulated by (1) the introduction of a sieve with larger openings immediately above the given sieve or (2) testing the sample in a number of increments.

6.7 Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by mass of the total sample passes any sieve during 60 s of continuous hand-sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turning the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining the adequacy of sieving for sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203-mm (8-in.) diameter sieves to verify the adequacy of sieving.

7. CALCULATIONS

7.1 The mass of material passing each sieve and retained on the next and the amount passing the 75-µm (No. 200) sieve shall be recorded. The summation of these various masses must check the dried mass after washing within 0.2 percent of the total mass. The mass of dry material passing the 75-µm (No. 200) sieve by dry sieving shall be added to the mass removed by washing, and if applicable, the mass of mineral matter in the asphalt binder, in order to obtain the total passing the 75-µm (No. 200) sieve. The masses of fractions retained on the various sieves and the total passing the 75-µm (No. 200) sieve shall be converted to percentages by dividing each by the total mass of aggregate in the HMA from Section 6.1.

7.2 For aggregate samples obtained from T 308, apply the aggregate correction factor, as required in T 308, to obtain the final total passing percentages.

8. REPORT

8.1 The results of the sieve analysis shall be reported as follows: (a) total percentages passing each sieve; or (b) total percentages retained on each sieve; or (c) percentages retained between consecutive sieves, depending upon the form of the specifications for the use of the material being tested. Percentages shall be reported to the nearest whole number, except for the percentage passing the 75-μm (No. 200) sieve, which shall be reported to the nearest 0.1 percent.

9. PRECISION AND BIAS

9.1 *Precision*—The estimates of precision for this test method are listed in Table 1. The estimates are based on the results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by T 30. The data are based on the analyses of the test results from 47 to 190 laboratories that tested 17 pairs of proficiency test samples (Samples No. 1 through 34). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

Table 1—Precision

	Total Percentage of Material Passing a Sieve	Standard Deviation (1s) Percent[a]	Acceptable Range of Two Results—(d2s) Percent[a]
Extracted aggregate:[b]			
Single-Operator Precision	95 to 100	0.49	1.4
	40 to 94	1.06	3.0
	25 to 39	0.65	1.8
	10 to 24	0.46	1.3
	5to 9	0.29	0.8
	2 to 4	0.21	0.6
	0 to 1	0.17	0.5
Multilaboratory Precision	95 to 100	0.57	1.6
	40 to 94	1.24	3.5
	25 to 39	0.84	2.4
	10 to 24	0.81	2.3
	5 to 9	0.56	1.6
	2 to 4	0.43	1.2
	0 to 1	0.32	0.9

[a] These numbers represent, respectively, the (1s) and (d2s) limits described in ASTM C 670.

[b] The precision estimates are based on aggregates with nominal maximum sizes of 19.0 mm ($^3/_4$ in.) to 9.5 mm ($^3/_8$ in.).

9.2 *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

Standard Method of Test for

Sieve Analysis of Mineral Filler for Hot Mix Asphalt (HMA)

AASHTO Designation: T 37-07[1]
ASTM Designation: D 546-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sieve Analysis of Mineral Filler for Hot Mix Asphalt (HMA)

AASHTO Designation: T 37-07[1]
ASTM Designation: D 546-05

1. SCOPE

1.1. This method of test covers the sieve analysis of mineral fillers used in hot mix asphalt (HMA).

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 17, Mineral Filler for Bituminous Paving Mixtures
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 88, Particle Size Analysis of Soils
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SIGNIFICANCE AND USE

3.1. The method is used to determine compliance of mineral fillers with the grading requirements of M 17.

4. APPARATUS

4.1. *Weighing Device*, conforming to the requirements of M 231, Class G 2.

4.2. *Sieves*, conforming to M 92, square-hole, woven wire cloth, with nominal opening sizes of 75-µm (No. 200), 300-µm (No. 50), and 600-µm (No. 30) sieves.

4.3. *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 110 ± 5ºC (230 ± 9ºF).

5. TEST SAMPLE

5.1. Obtain the sample for test in accordance with the requirements of M 17 and reduce to testing size in accordance with T 248. Use a minimum of 100 g of dry material for each sieve analysis.

6. PROCEDURE

6.1. Dry the test sample to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF) and determine the mass to the nearest 0.1 g.

6.2. After drying and determining the mass, place the dry test sample on the 600-µm (No. 30) sieve, which shall be nested above the 300-µm (No. 50) and 75-µm (No. 200) sieves. Wash the material by means of a stream of water from a faucet (Note 1). Continue the washing until the water coming through the 75-µm (No. 200) sieve is clear (Note 2). Remove the material retained on each of the three sieves into individual pans, washing the sieves as necessary to remove all material. If desired, excess water may be decanted from the pans prior to drying (Note 3). Dry the residue from each sieve to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF) (Note 4). Calculate the mass of material retained on each sieve as a percentage of the original sample.

Note 1—A spray nozzle or a piece of rubber tubing attached to a water faucet may be used for the washing. The velocity of the water, which may be increased by pinching the tubing, must be controlled to prevent loss of any sample by splashing over the sides of the sieves.

Note 2—Take care to avoid accumulation of water on the 75-µm (No. 200) sieve, because it may become clogged and the operation cannot be completed within a reasonable period.

Note 3—If excess water is decanted from the pan containing the washed aggregate prior to drying, care should be taken to avoid the loss of fines. The excess water should be decanted through a 75-µm (No. 200) sieve and any material on the sieve should be returned to the sample with minimal washing.

Note 4—Some material passes the 75-µm (No. 200) sieve on dry sieving that did not pass during the washing operation. When desired, additional information may be obtained by dry sieving the portion of the sample retained on the 75-µm (No. 200) sieve, in accordance with T 88.

7. REPORT

7.1. Report the results of the sieve analysis as the total percentage passing each sieve, expressed to the nearest 0.5 percent.

8. PRECISION AND BIAS

8.1. *Precision*—The estimates of precision for this test method are shown in Table 1. They are based on results of an interlaboratory testing program where replicable samples of four different mineral fillers were tested in 20 laboratories using this test method. The materials tested ranged from a coarse mineral filler, that had about 93 percent passing the 600-µm (No. 30) sieve and 51 percent passing the 75-µm (No. 200) sieve, to finer mineral fillers that had about 99 percent passing the 300-µm (No. 50) sieve and 95 percent passing the 75-µm (No. 200) sieve.

Table 1—Average Precision

Precision	Test Result Value, Percent in Size Fraction[a]	Standard Deviation, (1s), Percent[b]	Acceptable Range of Test Results, (d2s), Percent[c]
Single operator	Less than 2	0.14	0.5[c]
	More than 2	0.7	2.0
Multilaboratory	Less than 2	0.17	0.5
	More than 2	1.0	2.8

[a] The percent between consecutive sieves, or percent retained on the largest sieve, 600-µm (No. 30), or percent passing the smallest sieve, 75-µm (No. 200).

[b] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

[c] The minimum d2s is 0.5 percent in this case since results of the test are expressed to the nearest 0.5 percent.

8.2. *Bias*—Research to determine the bias of this test method has not been conducted. Therefore, no statement on bias is made.

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[1] Except for the title, requirements for the weighing device, precision of weighing, and SI units, this method essentially corresponds to ASTM D 546-05.

Standard Method of Test for

Effect of Organic Impurities in Fine Aggregate on Strength of Mortar

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AASHTO Designation: T 71-08[1]
ASTM Designation: C 87-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Effect of Organic Impurities in Fine Aggregate on Strength of Mortar

AASHTO Designation: T 71-08[1]
ASTM Designation: C 87-04

1. SCOPE

1.1. This test method covers the determination of the effect on mortar strength of the organic impurities in fine aggregate, whose presence is indicated by tests with T 21. Comparison is made between compressive strengths of mortar made with washed and unwashed fine aggregate.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 152M/M 152, Flow Table for Use in Tests of Hydraulic Cement
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 2, Sampling of Aggregates
- T 21, Organic Impurities in Fine Aggregates for Concrete
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SIGNIFICANCE AND USE

3.1. This test method is of significance in making a final determination of the acceptability of fine aggregates with respect to the requirements of M 6 concerning organic impurities.

3.2. This test method is only applicable to those samples which, when tested in accordance with T 21, have produced a supernatant liquid with a color darker than that of the reference standard color Plate No. 3 or color solution.

4. BASIS FOR COMPARISON

4.1. The fine aggregate that produced a color darker than the standard in T 21 shall be compared in mortar, as described in this test method, with a sample of the same aggregate that has been washed in a solution of sodium hydroxide followed by thorough rinsing in water. The washing shall be repeated a sufficient number of times until the supernatant liquid obtained in T 21 has a color lighter than standard (Note 1).

4.2. Unless otherwise specified or permitted, strength comparisons shall be made at seven days in accordance with the following conditions:

4.2.1. Mix three batches of mortar with the aggregate washed in sodium hydroxide and three batches with the unwashed aggregate on the same day. All batches shall have the same quantity of fine aggregate. Mix the batches for the two conditions alternately.

4.2.2. Mold three 50-mm or 2-in. cubes from each batch.

4.2.3. Test the three cubes from each batch at the age specified.

Note 1—T 21 describes a standard procedure and an alternative procedure for the determination of color value. In the standard procedure, there is a single reference standard color. In the alternative procedure, five glass color standards are used. The reference standard color is equivalent to color Plate No. 3.

5. SAMPLING AND SAMPLE PREPARATION

5.1. Sample portions of fine aggregate for this test shall be obtained from the same sample used for T 21. Needed reduction of samples to obtain test portions shall be in accordance with T 248.

5.2. Secure an additional field sample if needed from the aggregate supply in accordance with T 2.

5.3. In the event that the fine aggregate being used includes particles so large that the adjustment bracket (as described in T 162) cannot provide adequate clearance, the oversized particles shall be removed by sieving on the 4.75-mm (No. 4) or 2.36-mm (No. 8) sieve. If this procedure is employed, the report shall so state and shall indicate the percentage of material so removed.

Note 2—**Caution**: The clearances between the paddle and the bowl specified in T 162 are suitable when using the standard mortar made with graded sand. To permit the mixer to operate freely and to avoid serious damage to the paddle and bowl when coarser aggregates are used, it may be necessary to set the clearance adjustment bracket to provide greater clearances than specified. A clearance of approximately 4.0 mm is required in T 162; a clearance of approximately 5.0 mm has been found to be satisfactory for this method when used with fine aggregate from which the material retained on the 4.75-mm (No. 4) sieve has been removed.

5.4. Split the fine aggregate to be used for these tests into two approximately equal portions, using Test Method T 248. Set one portion aside to be used in the unwashed condition. The second portion is to be washed before use.

5.5. *Preparing Washed Fine Aggregate*:

5.5.1. Perform the washing and the rinsing of the fine aggregate with care to minimize the loss of fines, so that the aggregate after washing and rinsing has a fineness modulus within 0.10 of that of the unwashed aggregate.

5.5.2. *Establishing a Standard for Thoroughness of Rinsing*—Place a small amount of the water to be used for washing and rinsing in a clean, clear container, and determine the pH of the water by use of pH paper, pH meter, or add a drop of phenolphthalein to the wash water and retain for later comparison.

5.5.3. *Washing the Aggregate*—Place sufficient quantity of fine aggregate for three batches in a suitable container, flood with the sodium hydroxide solution, and agitate thoroughly with a spoon or trowel. At the end of the washing and after allowing the fines to settle, siphon off as much of the sodium hydroxide as possible, without removing any of the aggregate fines. Aggregates containing particles that float may be elutriated onto a No. 200 sieve to capture any floating particles.

5.5.4. *Rinsing the Aggregate*—Add a large quantity of water to the washed aggregate, agitate, allow to stand for fines to settle, and then siphon off the rinse water. Repeat this operation several times, until the water used for rinsing has a pH equal to or lower than the pH of the water prior to contact with the fine aggregate. If phenolphthalein was used as an indicator, the color of the wash water is to equal or lighter in color than the solution prepared in Section 5.5.2.

5.5.5. *Verifying Removal of Organic Impurities*—Repeat the Test Method T 21 procedure to determine if the washing has removed sufficient organic impurities to produce a satisfactory result (color lighter than the standard). If the fine aggregate continues to produce an unsatisfactory result (color darker than the standard), repeat the washing and rinsing procedure (described in Sections 5.5.3 and 5.5.4) as many times as necessary until a satisfactory result is obtained by Test Method T 21.

6. REAGENTS AND MATERIALS

6.1. Portland cement shall be Type I or Type II, meeting the requirements of M 85.

6.2. *Sodium Hydroxide Solution (3 percent)*—Dissolve three parts by mass of sodium hydroxide (NaOH) in 97 parts water.

6.3. *Phenolphthalein*—Dissolve 1 g of reagent grade phenolphthalein in 1 L of 95 percent reagent grade ethyl alcohol.

7. APPARATUS

7.1. *Flow Table, Flow Mold, and Caliper*, as described in M 152M/M 152.

7.2. *Tamper, Trowel, Cube Molds, and Testing Machine*, as described in T 106.

7.3. *Mixer, Bowl, and Paddle*, as described in T 162.

7.4. *Balance*, conforming to M 231 for Class G 5.

7.5. *pH paper*, 0–14.

7.6. *pH meter*, capable of reading 0.1 pH units or better.

8. TEMPERATURE

8.1. The temperature of the mixing water, moist closet, and storage tank shall be maintained at 23.0 ± 1.7ºC (73.4 ± 3ºF).

9. PREPARATION OF MORTAR

9.1. *Number of Test Batches*—Prepare three batches of mortar using the washed aggregates and three batches of mortar using the unwashed aggregate, on the same day. Mix the batches, alternating between the washed and the unwashed aggregate.

9.2. Use water and cement in quantities that will yield a water–cement ratio of 0.6 by mass. It has been found that 600 g of cement and 360 mL of water will usually be adequate for a six-cube batch.

Note 3—Use of cement, water, and an appropriate amount of aggregate for a six-cube batch, or larger, is recommended to assure uniform mixing of the mortar.

9.3. Using fine aggregate that has been brought to a saturated surface dry condition as described in T 84, prepare a quantity of aggregate estimated to provide slightly more than needed to produce a batch of the desired consistency.

Note 4—If the absorption has been determined in accordance with T 84, the aggregate may be prepared for test by adding to a known mass of dry aggregate the amount of water it will absorb, mixing thoroughly, and permitting the aggregate to stand in a covered pan for 60 minutes before use. The washed and unwashed aggregate may be presumed to have the same absorption.

Note 5—The mass of the prepared aggregate should be determined so that the amount actually used in a batch may be calculated as described in Section 10.1.3. Experience indicates that the quantity of fine aggregate used in a six-cube batch will range from approximately 1200 g for fine-graded material to approximately 2200 g for coarse-graded material.

9.3.1. The mortar shall be proportioned to produce a consistency of 110 ± 5 in 25 drops of the flow table, as determined by the flow test described in T 106.

9.4. Prepare the mortar in a mechanical mixer in accordance with the procedure for mixing mortars described in T 162, as modified below.

Note 6—Unwashed aggregate should be used in the initial batch, so that washed aggregate is not wasted in case the batch must be discarded.

9.4.1. During the period from 30 to 60 seconds from the start of mixing, and while still mixing at slow speed, slowly add a measured quantity of aggregate estimated to provide the proper consistency.

9.4.2. During the final 1 minute of mixing at medium speed, if the flow appears to be too high, additional aggregate may be added after the first 30 seconds of this mixing period. To do so, stop the mixer briefly, add the aggregate, and then complete the additional 30 seconds of mixing.

10. PROCEDURE

10.1. Make a determination of the flow as described in T 106.

10.1.1. Should the flow be too great, return the mortar to the mixing bowl, add additional aggregate, mix for 30 seconds at medium speed, and make another determination of the flow. If more than two trials must be made to obtain a flow of 110 ± 5, consider the mortar as a trial mortar, and prepare test specimens from a new batch.

10.1.2. If the mortar is too dry, discard the batch.

10.1.3. Determine the quantity of aggregate used by subtracting the mass of the portion remaining after mixing from the mass of the initial sample. Use this quantity of aggregate in all subsequent batches for the aggregate under test.

10.2. *Molding Test Specimens*—Immediately following completion of a flow test indicating acceptable consistency, return the mortar from the flow table to the mixing bowl, scrape down the bowl, and then remix the entire batch 15 seconds at medium speed. Upon completion of mixing, shake the excess mortar from the paddle into the bowl. Place the mortar in cube molds in two layers in accordance with the procedures described in T 106.

10.3. For subsequent batches, use washed and unwashed aggregate alternately and the quantity of aggregate determined in Section 10.1.3. Follow the procedure for mixing mortars described in T 162. Following the final 1-minute mixing in T 162, do not perform a flow test but instead allow the mortar to stand in the mixing bowl 90 seconds without covering. During the last 15 seconds of this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl. Then remix for 15 seconds at medium speed. Upon completion of mixing, shake the excess mortar from the paddle into the mixing bowl. Place the mortar in the cube molds in two layers in accordance with the procedure described in T 106.

10.4. Store the test specimens and determine compressive strength in accordance with T 106.

11. CALCULATION AND REPORT

11.1. Calculate the compressive strength of each specimen by dividing the maximum load it carried during the test by the cross-sectional area. Average the strengths of the three specimens from each batch. Calculate three-strength ratios by dividing the average strength for a batch containing unwashed aggregate by the average strength for the corresponding (in respective order of mixing) batch containing washed aggregate.

11.2. Report the average of the three ratios, expressed as a percentage, as the relative strength for the aggregate under test.

11.3. If the fine aggregate was sieved to remove particles coarser than the 4.75-mm (No. 4) sieve (as described in Section 5.3), so state in the report and indicate the quantity of material removed as a percentage of the original sample mass.

12. PRECISION AND BIAS

12.1. The following precision statement is applicable when a test result is the average ratio, as defined by this test method, of three pairs of mortar batch strength tests with all the batches mixed on the same day and tested at the same age.

12.2. The single laboratory coefficient of variation has been determined to be 5.4 percent (Note 7). Therefore, results of two properly conducted tests in the same laboratory should not differ from each other by more than 15.3 percent (Note 7) of their average. The maximum range (difference between highest and lowest) of the three individual ratios used in calculating the average should not exceed 17 percent (Note 8).

Note 7—These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670.

Note 8—Calculated as described in the section on precision of individual measurements averaged to obtain a test result in ASTM C 670.

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[1] This method is similar to but not technically identical to ASTM C 87-04.

Standard Method of Test for

Specific Gravity and Absorption of Fine Aggregate

AASHTO Designation: T 84-10[1]
ASTM Designation: C 128-07a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Specific Gravity and Absorption of Fine Aggregate

AASHTO Designation: T 84-10[1]
ASTM Designation: C 128-07a

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1. SCOPE

1.1. This method covers the determination of bulk and apparent specific gravity, 23/23ºC (73.4/73.4ºF), and absorption of fine aggregate.

1.2. This method determines (after 15 hours in water) the bulk specific gravity and the apparent specific gravity, the bulk specific gravity on the basis of mass of saturated surface-dry aggregate, and the absorption.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 100, Specific Gravity of Soils
- T 133, Density of Hydraulic Cement
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

2.2. *ASTM Standards*:

- C 128, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

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3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *absorption*—the increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5ºC for sufficient time to remove all uncombined water by reaching a constant mass.

3.1.2. *specific gravity*—the ratio of the mass (or weight in air) of a unit volume of a material to the mass of the same volume of gas-free distilled water at stated temperatures. Values are dimensionless.

3.1.2.1. *apparent specific gravity*—the ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.2. *bulk specific gravity*—the ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.3. *bulk specific gravity (SSD)*—the ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

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4. SIGNIFICANCE AND USE

4.1. Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used in the computation of voids in aggregate in T 19M/T 19. Bulk specific gravity determined on the saturated surface-dry basis is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity determined on the oven-dry basis is used for computations when the aggregate is dry or assumed to be dry.

4.2. Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles that is accessible to water. This value is not widely used in construction aggregate technology.

4.3. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption when used, if not allowed to dry. Conversely, some aggregates when used may contain an amount of absorbed moisture less than the 15 hours soaked condition: For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by T 255 by drying.

5. APPARATUS

5.1. *Balance*, conforming to the requirements of M 231, Class G 2.

5.2. *Pycnometer*—A flask or other suitable container into which the fine aggregate test sample can be readily introduced and in which the volume content can be reproduced with ±100 mm^3. The volume of the container filled to mark shall be at least 50 percent greater than the space required to accommodate the test sample. A volumetric flask of 500-mL capacity or a fruit jar fitted with a pycnometer top is satisfactory for a 500-g test sample of most fine aggregates. A Le Chatelier flask as described in T 133 is satisfactory for an approximately 55-g test sample.

5.3. *Mold*—A metal mold in the form of a frustum of a cone with dimensions as follows: 40 ± 3 mm inside diameter at the top, 90 ± 3 mm inside diameter at the bottom, and 75 ± 3 mm in height, with the metal having a minimum thickness of 0.8 mm.

5.4. *Tamper*—A metal tamper having a mass of 340 ± 15 g and having a flat circular tamping face 25 ± 3 mm in diameter.

6. SAMPLING

6.1. Sampling shall be accomplished in general accordance with T 2.

7. PREPARATION OF TEST SPECIMEN

7.1. Obtain approximately one kilogram of the fine aggregate from the sample using the applicable procedures described in T 248.

7.1.1. Dry it in a suitable pan or vessel to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF). Allow it to cool to comfortable handling temperature, cover with water, either by immersion or by the addition of at least 6 percent moisture to the fine aggregate and permit to stand for 15 to 19 hours.

7.1.2. As an alternative to Section 7.1.1, where the absorption and specific gravity values are to be used in proportioning concrete mixtures with aggregates used in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated and, if the surfaces of the particles have been kept wet, the 15-hour soaking may also be eliminated.

Note 1—Values for absorption and for specific gravity in the saturated surface-dry condition may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with Section 7.1.1.

7.2. Decant excess water with care to avoid loss of fines, spread the sample on a flat, nonabsorbent surface exposed to a gently moving current of warm air, and stir frequently to secure homogeneous drying. If desired, mechanical aids such as tumbling or stirring may be employed to assist in achieving the saturated surface-dry condition. As the material begins to dry sufficiently, it may be necessary to work it with the hands in a rubbing motion to break up any conglomerations, lumps, or balls of material that develop. Continue this operation until the test specimen approaches a free-flowing condition. Follow the procedure in Section 7.2.1 to determine whether or not surface moisture is present on the constituent fine aggregate particles. It is intended that the first trial of the cone test will be made with some surface water in the specimen. Continue drying with constant stirring, and if necessary, work the material with a hand-rubbing motion, and test at frequent intervals until the test indicates that the specimen has reached a surface-dry condition. If the first trial of the surface moisture test indicates that moisture is not present on the surface, it has been dried past the saturated surface-dry condition. In this case, thoroughly mix a few milliliters of water with the fine aggregate and permit the specimen to stand in a covered container for 30 minutes. Then resume the process of drying and testing at frequent intervals for the onset of the surface-dry condition.

7.2.1. *Cone Test for Surface Moisture*—Hold the mold firmly on a smooth nonabsorbent surface with the large diameter down. Place a portion of the partially dried fine aggregate loosely in the mold by filling until overflow occurs and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each drop should start about 5 mm (0.2 in.) above the top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops over the surface. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the molded shape. When the fine aggregate slumps slightly, it indicates that it has reached a surface-dry condition. Some angular fine aggregate or material with a high proportion of fines may not slump in the cone test upon reaching a surface-dry condition. This may be the case if fines become airborne upon dropping a handful of the sand from the cone test 100 to 150 mm onto a surface. For these materials, the saturated surface-dry condition should be considered as the point that one side of the fine aggregate slumps slightly upon removing the mold.

Note 2—The following criteria have also been used on materials that do not readily slump:

1. *Provisional Cone Test*—Fill the cone mold as described in Section 7.2.1 except only use 10 drops of the tamper. Add more fine aggregate and use 10 drops of the tamper again. Then add material two more times using three and two drops of the tamper, respectively. Level off the material even with the top of the mold; remove loose material from the base; and lift the mold vertically.
2. *Provisional Surface Test*—If airborne fines are noted when the fine aggregate is such that it will not slump when it is at a moisture condition, add more moisture to the sand, and at the onset of the surface-dry condition, with the hand lightly pat approximately 100 g of the material on a flat, dry, clean, dark, or dull nonabsorbent surface such as a sheet of rubber, a worn oxidized, galvanized, or steel surface, or a black-painted metal surface. After one to three seconds, remove the fine aggregate. If noticeable moisture shows on the test surface for more than one to two seconds, then surface moisture is considered to be present on the fine aggregate.
3. Colorimetric procedures described by Kandhal and Lee, *Highway Research Record No. 307*, p. 44.
4. For reaching the saturated surface-dry condition on a single-size material that slumps when wet, hard-finish paper towels can be used to surface dry the material until the point is just reached where the paper towel does not appear to be picking up moisture from the surfaces of the fine aggregate particles.

8. PROCEDURE

8.1. Make and record all mass determinations to 0.1 g.

8.2. Partially fill the pycnometer with water. Immediately introduce into the pycnometer 500 ± 10 g of saturated surface-dry fine aggregate prepared as described in Section 7, and fill with additional water to approximately 90 percent of capacity. Manually roll, invert, and agitate or use a combination of these actions to eliminate all air bubbles in the pycnometer (Note 3). Accomplish mechanical agitation by external vibration of the pycnometer in a manner that will not degrade the sample. A level of agitation adjusted to just set individual particles in motion is sufficient to promote de-airing without degradation. A mechanical agitator shall be considered acceptable for use if comparison tests for each six-month period of use show variations less than the acceptable range of two results (d2s) indicated in Table 1 from results of manual agitation on the same material. Adjust its temperature to 23.0 ± 1.7ºC (73.4 ± 3ºF), if necessary by immersion in circulating water, and bring the water level in the pycnometer to its calibrated capacity. Determine total mass of the pycnometer, specimen, and water.

Note 3—It normally takes about 15 to 20 minutes to eliminate air bubbles by manual methods. Dipping the tip of a paper towel into the pycnometer has been found to be useful in dispersing the foam that sometimes builds up when eliminating the air bubbles, or adding a few drops of isopropyl alcohol, after removal of air bubbles and just prior to bringing the water level to its calibrated capacity, has also been found useful in dispersing foam on the water surface. Do not use isopropyl alcohol when using the alternative method described in Section 8.2.1.

Table 1—Precision

	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]
Single-operator precision:		
Bulk specific gravity (dry)	0.011	0.032
Bulk specific gravity (SSD)	0.0095	0.027
Apparent specific gravity	0.0095	0.027
Absorption,[b] percent	0.11	0.31
Multilaboratory precision:		
Bulk specific gravity (dry)	0.023	0.066
Bulk specific gravity (SSD)	0.020	0.056
Apparent specific gravity	0.020	0.056
Absorption,[b] percent	0.23	0.66

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15- to 19-hour saturation times and other laboratories using 24 ± 4 hours of saturation time. Testing was performed on aggregates of normal specific gravities, and started with aggregates in the oven-dry condition.

[b] Precision estimates are based on aggregates with absorptions of less than 1 percent and may differ for manufactured fine aggregates having absorption values greater than 1 percent.

8.2.1. *Alternative to Determining the Mass in Section 8.2*—The quantity of added water necessary to fill the pycnometer at the required temperature may be determined volumetrically using a buret accurate to 0.15 mL. Compute the total mass of the pycnometer, specimen, and water as follows:

$$C = 0.9975\,V_a + S + W \qquad (1)$$

where:

C = mass of pycnometer with specimen and water to calibration mark, g;
V_a = volume of water added to pycnometer, mL;
S = mass of saturated surface-dry specimen, g; and
W = mass of the pycnometer empty, g.

8.2.2. *Alternative to the Procedure in Section 8.2*—Use a Le Chatelier flask initially filled with water to a point on the stem between the 0 and the 1-mL mark. Record this initial reading with the flask and contents within the temperature range of 23.0 ± 1.7ºC (73.4 ± 3ºF). Add 55 ± 5 g of fine aggregate in the saturated surface-dry condition (or other mass as necessary to result in raising the water level to some point on the upper series of graduation). After all fine aggregate has been introduced, place the stopper in the flask and roll the flask in an inclined position, or gently whirl it in a horizontal circle so as to dislodge all entrapped air, continuing until no further bubbles rise to the surface (Note 4). Take a final reading with the flask and contents within 1ºC (1.8ºF) of the original temperature.

Note 4—When using the Le Chatelier flask method, slowly adding a small measured amount (not to exceed 1 mL) of isopropyl alcohol, after removal of air bubbles, has been found useful in dispersing foam appearing on the water surface. The volume of alcohol used must be subtracted from the final reading (R_2).

8.3. Remove the fine aggregate from the pycnometer, dry to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF), cool in air at room temperature for 1.0 ± 0.5 hours and determine the mass.

Note 5—In lieu of drying and determining the mass of the sample which has been removed from the pycnometer, a second portion of the saturated surface-dry sample may be used to determine the oven-dry mass. This sample must be obtained at the same time and be within 0.2 grams of the mass of the sample which is introduced into the pycnometer.

8.3.1. If the Le Chatelier flask method is used, a separate sample portion is needed for the determination of absorption. Weigh a separate 500 ± 10 g portion of the saturated surface-dry fine aggregate, dry to constant mass, and reweigh. This sample must be obtained at the same time as the sample that is introduced into the Le Chatelier flask.

8.4. Determine the mass of the pycnometer filled to its calibration capacity with water at 23.0 ± 1.7ºC (73.4 ± 3ºF).

8.4.1. *Alternative to Determining the Mass in Section 8.4*—The quantity of water necessary to fill the empty pycnometer at the required temperature may be determined volumetrically using a buret accurate to 0.15 mL. Calculate the mass of the pycnometer filled with water as follows:

$$B = 0.9975\,V + W \qquad (2)$$

where:

B = mass of flask filled with water, g;
V = volume of flask, mL; and
W = mass of the flask empty, g.

9. BULK SPECIFIC GRAVITY

9.1. Calculate the bulk specific gravity, 23/23ºC (73.4/73.4ºF) as follows:

$$\text{Bulk sp gr} = A/\left(B + S - C\right) \qquad (3)$$

where:

A = mass of oven-dry specimen in air, g;
B = mass of pycnometer filled with water, g;
S = mass of saturated surface-dry specimen, g; and
C = mass of pycnometer with specimen and water to calibration mark, g.

9.1.1. If the Le Chatelier flask method was used, calculate the bulk specific gravity, 23/23ºC, as follows:

$$\text{Bulk sp gr} = \frac{S_1\left(A/S\right)}{0.9975\left(R_2 - R_1\right)} \qquad (4)$$

where:

S_1 = mass of saturated surface-dry specimen used in Le Chatelier flask, g;

R_2 = final reading of water level in Le Chatelier flask; and

R_1 = initial reading of water level in Le Chatelier flask.

10. BULK SPECIFIC GRAVITY (SATURATED SURFACE-DRY BASIS)

10.1. Calculate the bulk specific gravity, 23/23ºC (73.4/73.4ºF), on the basis of mass of saturated surface-dry aggregate as follows:

$$\text{Bulk sp gr}\left(\text{saturated surface-dry basis}\right) = S/(B+S-C) \qquad (5)$$

10.1.1. If the Le Chatelier flask method was used, calculate the bulk specific gravity, 23/23ºC, on the basis of saturated surface-dry aggregate as follows:

$$\text{Bulk sp gr}\left(\text{saturated surface-dry basis}\right) = \frac{S_1}{0.9975\left(R_2 - R_1\right)} \qquad (6)$$

11. APPARENT SPECIFIC GRAVITY

11.1. Calculate the apparent specific gravity, 23/23ºC (73.4/73.4ºF) as follows:

$$\text{Apparent sp gr} = A/\left(B+A-C\right) \qquad (7)$$

12. ABSORPTION

12.1. Calculate the percentage of absorption as follows:

$$\text{Absorption, percent} = \left[\left(S-A\right)/A\right] \times 100 \qquad (8)$$

13. REPORT

13.1. Report specific gravity results to the nearest 0.001 (Fine Aggregate meeting M 6 requirements may be reported to the nearest 0.01) and absorption to the nearest 0.1 percent. The Appendix gives mathematical interrelationships among the three types of specific gravities and absorption. These may be useful in checking the consistency of reported data or calculating a value that was not reported by using other reported data.

13.2. If the fine aggregate was tested in a naturally moist condition other than the oven dried and 15-hour soaked condition, report the source of the sample and the procedures used to prevent drying prior to testing.

14. PRECISION AND BIAS

14.1. The estimates of precision of this test method (listed in Table 1) are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted by this test method and ASTM C 128. The significant difference between the methods is that ASTM C 128 requires a saturation period of 24 ± 4 hours, and T 84 requires a saturation period of 15 to 19 hours. This difference has been found to have an insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

14.2. Since there is no accepted reference material suitable for determining the bias for the procedure in T 84 for measuring specific gravity and absorption of fine aggregate, no statement on bias is being made.

APPENDIX

(Nonmandatory Information)

X1. POTENTIAL DIFFERENCES IN BULK SPECIFIC GRAVITY AND ABSORPTION DUE TO PRESENCE OF MATERIAL FINER THAN 75 μm (No. 200)

X1.1. It has been found that there may be significant differences in bulk specific gravity and absorption between fine aggregate samples tested with the material finer than 75 μm (No. 200) present and not present in the samples. Samples from which the material finer than 75 μm is not removed usually give a higher absorption and a lower bulk specific gravity compared with testing the same fine aggregate from which the material finer than 75 μm is removed following the procedures of Test Method T 11. Samples with material finer than 75 μm may build up a coating around the coarser fine aggregate particles during the surface drying process. The resultant specific gravity and absorption that is subsequently measured is that of the agglomerated and coated particles and not that of the parent material. The difference in absorption and specific gravity determined between samples from which the material finer than 75 μm have not been removed and samples from which the material finer than 75 μm have been removed depends on both the amount of the material finer than 75 μm present and the nature of the material. When the material finer than 75 μm is less than about 4 percent by mass, the difference in specific gravity between washed and unwashed samples is less than 0.03. When the material finer than 75 μm is greater than about 8 percent by mass, the difference in specific gravity obtained between washed and unwashed samples may be as great as 0.13.

X1.2. The material finer than 75 μm, which is removed, can be assumed to have the same specific gravity as the fine aggregate. Alternatively, the specific gravity of the material finer than 75 μm may be further evaluated using T 100; however, this test determines the apparent specific gravity and not the bulk specific gravity.

X2. INTERRELATIONSHIPS BETWEEN SPECIFIC GRAVITIES AND ABSORPTION AS DEFINED IN T 84 AND T 85

X2.1. Let:

S_d = bulk specific gravity (dry-basis),
S_s = bulk specific gravity (SSD-basis),
S_a = apparent specific gravity, and
A = absorption in percent.

Then:

$$S_s = (1 + A/100)\,S_d \tag{X1.1}$$

$$S_a = \frac{1}{\frac{1}{S_d} - \frac{A}{100}} = \frac{S_d}{1 - \frac{AS_d}{100}} \tag{X1.2}$$

Or:

$$S_a = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} = \frac{S_s}{1 - \frac{A}{100}(S_s - 1)} \tag{X1.3}$$

$$A = \left(\frac{S_s}{S_d} - 1\right)100 \tag{X1.4}$$

$$A = \left(\frac{S_a - S_s}{S_a(S_s - 1)}\right)100 \tag{X1.5}$$

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[1] This method is technically equivalent to ASTM C 128-07a.

Standard Method of Test for

Specific Gravity and Absorption of Coarse Aggregate

AASHTO Designation: T 85-10[1]
ASTM Designation: C 127-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Specific Gravity and Absorption of Coarse Aggregate

AASHTO Designation: T 85-10[1]
ASTM Designation: C 127-04

1. SCOPE

1.1. This method covers the determination of specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity (saturated-surface-dry (SSD)), or apparent specific gravity. The bulk specific gravity (SSD) and absorption are based on aggregate after 15 hours soaking in water. This method is not intended to be used with lightweight aggregates.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 43, Sizes of Aggregate for Road and Bridge Construction
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

2.2. *ASTM Standard*:
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

2.3. *IEEE/ASTM Standard*:
- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *absorption*—the increase in the mass of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered "dry" when it has been maintained at a temperature of 110 ± 5ºC for sufficient time to remove all uncombined water by reaching a constant mass.

3.1.2. *specific gravity*—the ratio of the mass (or weight in air) of a unit volume of a material to the mass of the same volume of gas-free distilled water at stated temperatures. Values are dimensionless.

3.1.2.1. *apparent specific gravity*—the ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.2. *bulk specific gravity*—the ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

3.1.2.3. *bulk specific gravity (SSD)*—the ratio of the mass in air of a unit volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for approximately 15 hours (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

4. SUMMARY OF METHOD

4.1. A sample of aggregate is immersed in water for approximately 15 hours to essentially fill the pores. It is then removed from the water, the water dried from the surface of the particles, and weighed. Subsequently the sample is weighed while submerged in water. Finally the sample is oven-dried and weighed a third time. Using the mass and weight measurements thus obtained and formulas in the method, it is possible to calculate three types of specific gravity and absorption.

5. SIGNIFICANCE AND USE

5.1. Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used in the computation of voids in aggregate in T 19M/T 19. Bulk specific gravity (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity (oven-dry) is used for computations when the aggregate is dry or assumed to be dry.

5.2. Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles which is accessible to water.

5.3. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption, when used, if not allowed to dry. Conversely, some aggregates when used may contain an amount of absorbed moisture less than the 15-hour soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by T 255.

5.4. The general procedures described in this method are suitable for determining the absorption of aggregates that have had conditioning other than the 15-hour soak, such as boiling water or vacuum saturation. The values obtained for absorption by other methods will be different than the values obtained by the prescribed 15-hour soak, as will the bulk specific gravity (SSD).

5.5. The pores in lightweight aggregates may or may not become essentially filled with water after immersion for 15 hours. In fact, many such aggregates can remain immersed in water for several days without satisfying most of the aggregates' absorption potential. Therefore, this method is not intended for use with lightweight aggregate.

6. APPARATUS

6.1. *Balance*—Conforming to the requirements of M 231, Class G 5. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the center of the weighing platform or pan of the balance.

6.2. *Sample Container*—A wire basket of 3.35 mm (No. 6) or finer mesh, or a bucket of approximately equal breadth and height, with a capacity of 4 to 7 L for 37.5-mm ($1^1/_2$-in.) nominal maximum size aggregate or smaller, and a larger container as needed for testing larger maximum size aggregate. The container shall be constructed so as to prevent trapping air when the container is submerged.

6.3. *Water Tank*—A watertight tank into which the sample and container are placed for complete immersion while suspended below the balance, equipped with an overflow outlet for maintaining a constant water level.

6.4. *Suspended Apparatus*—Wire suspending the container shall be of the smallest practical size to minimize any possible effects of a variable immersed length.

6.5. *Sieves*—A 4.75-mm (No. 4) sieve or other sizes as needed (Sections 7.2, 7.3, and 7.4), conforming to M 92.

7. SAMPLING

7.1. Sample the aggregate in accordance with T 2.

7.2. Thoroughly mix the sample of aggregate and reduce it to the approximate quantity needed using the applicable procedures in T 248. Reject all material passing a 4.75-mm (No. 4) sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface. If the coarse aggregate contains a substantial quantity of material finer than the 4.75-mm (No. 4) sieve (such as for Size No. 8 and 9 aggregates in M 43), use the 2.36-mm (No. 8) sieve in place of the 4.75-mm (No. 4) sieve. Alternatively, separate the material finer than the 4.75-mm (No. 4) sieve and test the finer material according to T 84.

7.3. The minimum mass of test sample to be used is given below. In many instances it may be desirable to test a coarse aggregate in several separate size fractions; and if the sample contains more than 15 percent retained on the 37.5-mm ($1^1/_2$-in.) sieve, test the material larger than 37.5 mm in one or more size fractions separately from the smaller size fractions. When an aggregate is tested in separate size fractions, the minimum mass of test sample for each fraction shall be the difference between the masses prescribed for the maximum and minimum sizes of the fraction.

Nominal Maximum Size, mm (in.)	Minimum Mass of Test Sample, kg (lb)
12.5 ($^1/_2$) or less	2 (4.4)
19.0 ($^3/_4$)	3 (6.6)
25.0 (1)	4 (8.8)
37.5 ($1^1/_2$)	5 (11)
50 (2)	8 (18)
63 ($2^1/_2$)	12 (26)
75 (3)	18 (40)
90 ($3^1/_2$)	25 (55)
100 (4)	40 (88)
112 ($4^1/_2$)	50 (110)
125 (5)	75 (165)
150 (6)	125 (276)

7.4. If the sample is tested in two or more size fractions, determine the grading of the sample in accordance with T 27, including the sieves used for separating the size fractions for the determinations in this method. In calculating the percentage of material in each size fraction, ignore the quantity of material finer than the 4.75-mm (No. 4) sieve or 2.36-mm (No. 8) sieve when that sieve is used in accordance with Section 7.2.

8. PROCEDURE

8.1. Dry the test sample to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF), cool in air at room temperature for 1 to 3 hours for test samples of 37.5 mm ($1^1/_2$-in.) nominal maximum size, or longer for larger sizes until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50ºC). Subsequently immerse the aggregate in water at room temperature for a period of 15 to 19 hours.

Note 1—When testing coarse aggregate of large nominal maximum size requiring large test samples, it may be more convenient to perform the test on two or more subsamples, and the values obtained combined for the computation described in Section 9.

8.2. Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-hour soaking may also be eliminated.

Note 2—Values for absorption and bulk specific gravity (SSD) may be significantly higher for aggregate not oven dried before soaking than for the same aggregate treated in accordance with Section 8.1. This is especially true of particles larger than 75 mm (3 in.) since the water may not be able to penetrate the pores to the center of the particle in the prescribed soaking period.

8.3. Remove the test sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. A moving stream of air may be used to assist in the drying operation. Take care to avoid evaporation of water from aggregate pores during the operation of surface-drying. Determine the mass of the test sample in the saturated surface-dry condition. Record this and all subsequent masses to the nearest 1.0 g or 0.1 percent of the sample mass, whichever is greater.

8.4. After determining the mass, immediately place the saturated-surface-dry test sample in the sample container and determine its mass in water at 23.0 ± 1.7ºC (73.4 ± 3ºF), having a density of 997 ± 2 kg/m^3. Take care to remove all entrapped air before determining the mass by shaking the container while immersed.

Note 3—The container should be immersed to a depth sufficient to cover it and the test sample during mass determination. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

8.5. Dry the test sample to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF), cool in air at room temperature 1 to 3 hours, or until the aggregate has cooled to a temperature that is comfortable to handle (approximately 50ºC), and determine the mass. Use this weight for A in the calculations in Section 9.

9. CALCULATIONS

9.1. *Specific Gravity*:

9.1.1. *Bulk Specific Gravity*—Calculate the bulk specific gravity, 23/23ºC (73.4/73.4ºF), as follows:

$$\text{Bulk sp gr} = A/(B-C) \tag{1}$$

where:

A = mass of oven-dry test sample in air, g;

B = mass of saturated-surface-dry test sample in air, g; and

C = mass of saturated test sample in water, g.

9.1.2. *Bulk Specific Gravity (Saturated-Surface-Dry)*—Calculate the bulk specific gravity, 23/23ºC (73.4/73.4ºF), on the basis of mass of saturated-surface-dry aggregate as follows:

$$\text{Bulk sp gr}\,(\text{saturated - surface - dry}) = B/(B-C) \tag{2}$$

9.1.3. *Apparent Specific Gravity*—Calculate the apparent specific gravity, 23/23ºC (73.4/73.4ºF), as follows:

$$\text{Apparent sp gr} = A/(A-C) \tag{3}$$

9.2. *Average Specific Gravity Values*—When the sample is tested in separate size fractions, the average value for bulk specific gravity, bulk specific gravity (SSD), or apparent specific gravity can be computed as the weighted average of the values as computed in accordance with Section 9.1 using the following equation:

$$G = \frac{1}{\frac{P_1}{100\,G_1} + \frac{P_2}{100\,G_2} + \cdots \frac{P_n}{100\,G_n}} \tag{4}$$

where:

G = average specific gravity (All forms of expression of specific gravity can be averaged in this manner.);

$P_1, P_2 \ldots P_n$ = mass percentages of each size fraction present in the original sample; and

$G_1, G_2 \ldots G_n$ = appropriate specific gravity values for each size fraction depending on the type of specific gravity being averaged.

Note 4—Some users of this method may wish to express the results in terms of density. Density may be determined by multiplying the bulk specific gravity, bulk specific gravity (SSD), or apparent specific gravity by the density of water (997.5 kg/m^3 or 0.9975 Mg/m^3 or 62.27 lb/ft^3 at 23ºC). Some authorities recommend using the density of water at 4ºC (1000 kg/m^3 or 1.000 Mg/m^3 or 62.43 lb/ft^3) as being sufficiently accurate. The density terminology corresponding to bulk specific gravity, bulk specific gravity (SSD), and apparent specific gravity has not been standardized.

9.3. *Absorption*—Calculate the percentage of absorption, as follows:

$$\text{Absorption, percent} = [(B - A)/A] \times 100 \tag{5}$$

9.4. *Average Absorption Value*—When the sample is tested in separate size fractions, the average absorption value is the average of the values as computed in Section 9.3, weighted in proportion to the mass percentages of the size fractions in the original sample as follows:

$$A = (P_1 A_1/100) + (P_2 A_2/100) + \cdots (P_n A_n/100) \tag{6}$$

where:

A = average absorption, percent;

$P_1, P_2 \ldots P_n$ = mass percentages of each size fraction present in the original sample; and

$A_1, A_2 \ldots A_n$ = absorption percentages for each size fraction.

10. REPORT

10.1. Report specific gravity results to the nearest 0.001(Coarse Aggregate meeting M 80 requirements may be reported to the nearest 0.01), and indicate the type of specific gravity, whether bulk, bulk (saturated-surface-dry), or apparent.

10.2. Report the absorption result to the nearest 0.1 percent.

10.3. If the specific gravity and absorption values were determined without first drying the aggregate, as permitted in Section 8.2, it shall be noted in the report.

11. PRECISION AND BIAS

11.1. The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Reference Sample Program, with testing conducted by this test method and ASTM C 127. The significant difference between the methods is that ASTM C 127 requires a saturation period of 24 ± 4 hours, while T 85 requires a saturation period of 15 hours minimum. This difference has been found to have insignificant effect on the precision indices. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

Table 1—Precision

	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]
Single-operator precision:		
Bulk specific gravity (dry)	0.009	0.025
Bulk specific gravity (SSD)	0.007	0.020
Apparent specific gravity	0.007	0.020
Absorption,[b] percent	0.088	0.25
Multilaboratory precision:		
Bulk specific gravity (dry)	0.013	0.038
Bulk specific gravity (SSD)	0.011	0.032
Apparent specific gravity	0.011	0.032
Absorption,[b] percent	0.145	0.41

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670. The precision estimates were obtained from the analysis of combined AASHTO Materials Reference Laboratory reference sample data from laboratories using 15-hour minimum saturation times and other laboratories using 24 ± 4-hour saturation time. Testing was performed on aggregates of normal specific gravities and started with aggregates in the oven-dry condition.

[b] Precision estimates are based on aggregates with absorptions of less than 2 percent.

11.2. *Bias*—Since there is no accepted reference material for determining the bias for the procedure in this test method, no statement on bias is being made.

APPENDIXES

(Nonmandatory Information)

X1. DEVELOPMENT OF EQUATIONS

X1.1. The derivation of the equation is apparent from the following simplified cases using two solids. Solid 1 has a mass W_1 in grams and a volume V_1 in milliliters; its specific gravity (G_1) is therefore W_1/V_1. Solid 2 has a mass W_2 and volume V_2, and $G_2 = W_2/V_2$. If the two solids are considered together, the specific gravity of the combination is the total mass in grams divided by the total volume in milliliters:

$$G = (W_1 + W_2)/(V_1 + V_2) \qquad (X1.1)$$

Manipulation of this equation yields the following:

$$G = \frac{1}{\dfrac{V_1 + V_2}{W_1 + W_2}} = \frac{1}{\dfrac{V_1}{W_1 + W_2} + \dfrac{V_2}{W_1 + W_2}} \qquad (X1.2)$$

$$G = \frac{1}{\dfrac{W_1}{W_1 + W_2}\left(\dfrac{V_1}{W_1}\right) + \dfrac{W_2}{W_1 + W_2}\left(\dfrac{V_2}{W_2}\right)} \qquad (X1.3)$$

However, the mass fractions of the two solids are:

$$W_1/(W_1 + W_2) = P_1/100 \qquad (X1.4)$$

and:

$$W_2/(W_1+W_2)=P_2/100 \qquad (X1.5)$$

and:

$$1/G_1=V_1/W_1 \text{ and } 1/G_2=V_2/W_2 \qquad (X1.6)$$

therefore:

$$G=1/[(P_1/100)(1/G_1)+(P_2/100)(1/G_2)] \qquad (X1.7)$$

An example of the computation is given in Table X1.1.

Table X1.1—Example Calculation of Average Values of Specific Gravity and Absorption for a Coarse Aggregate Tested in Separate Sizes

Size Fraction, mm (in.)	Percent in Original Sample	Bulk Specific Gravity (SSD)[a]	Sample Mass Used in Test, g	Absorption, percent
4.75 to 12.5 (No. 4 to $^1/_2$)	44	2.72	2213.0	0.4
12.5 to 37.5 ($^1/_2$ to $1^1/_2$)	35	2.56	5462.5	2.5
37.5 to 63 ($1^1/_2$ to $2^1/_2$)	21	2.54	12593.0	3.0

[a] Average Specific Gravity (SSD)

$$G_{SSD}=\frac{1}{\dfrac{0.44}{2.72}+\dfrac{0.35}{2.56}+\dfrac{0.21}{2.54}}=2.62 \qquad (X1.8)$$

Average Absorption:

$$A=(0.44)\ (0.4)+(0.35)\ (2.5)+(0.21)\ (3.0)=1.7\% \qquad (X1.9)$$

X2. INTERRELATIONSHIPS BETWEEN SPECIFIC GRAVITIES AND ABSORPTION AS DEFINED IN METHODS T 85 AND T 84

X2.1. Let:

S_d = bulk specific gravity (dry basis),

S_s = bulk specific gravity (SSD basis),

S_a = apparent specific gravity, and

A = absorption in percent.

Then:

$$S_s=(1+A/100)\,S_d \qquad (X2.1)$$

$$S_a=\frac{1}{\dfrac{1}{S_d}-\dfrac{A}{100}}=\frac{S_d}{1-\dfrac{AS_d}{100}} \qquad (X2.2)$$

$$S_d = \frac{1}{\frac{1 + A/100}{S_s} - \frac{A}{100}} \qquad (X2.3)$$

$$= \frac{S_s}{1 - \left(\frac{A}{100}\left(S_s - 1\right)\right)}$$

$$A = \left(\frac{S_s}{S_d} - 1\right)100 \qquad (X2.4)$$

$$A = \left(\frac{S_a - S_s}{S_a\left(S_s - 1\right)}\right)100 \qquad (X2.5)$$

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[1] This method is technically equivalent to ASTM C 127-04.

Standard Method of Test for

Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

AASHTO Designation: T 96-02 (2006)
ASTM Designation: C 131-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

AASHTO Designation: T 96-02 (2006)
ASTM Designation: C 131-01

AASHTO T 96-02 (2006) is identical to ASTM C 131-01 except for the following provisions:

1. All references to the ASTM standards contained in ASTM C 131-01, listed in the following table, shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO
C 136	T 27
C 702	T 248
D 75	T 2
E 11	M 92

2. Add a new Section after Section 3.1 of ASTM C 131-01 as follows:

   3.2 DESCRIPTION OF TERMS

   Constant Mass—Test samples dried at a temperature of 110 ± 5ºC (230 ± 9ºF) to a condition such that it will not lose more than 0.1 percent moisture after an additional 2 hours of drying at 110 ± 5ºC (230 ± 9ºF). Such a condition of dryness can be verified by determining the mass of the sample before and after successive 2 hours of drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5ºC (230 ± 9ºF) for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.

3. Add the phrase to the first sentence in Section 6.1 of ASTM C 131-01 as follows:

   …machine "equipped with a counter and" conforming…

   Also replace the seventh sentence of this section as follows:

   "A removable steel shelf shall extend along the length of the cylinder to within 5 mm (0.2 in.) of the full inside length of the cylinder, project inward 89 ± 2 mm (3.5 ± 0.1 in.) and shall be mounted on the interior cylindrical surface of the cylinder, or on the inside surface of the cover, in such a way that a plane centered between the large faces coincides with an axial plane."

   Also the third from the last sentence of Section 6.1 of ASTM C 131-01 is not included in AASHTO T 96-02 (2006).

4. Changes to Figure 1 of ASTM C 131-01 are as follows:

a. The phrase "NOT LESS THAN 1270 mm MEASURED ON OUTSIDE OF DRUM" is not included in AASHTO T 96-02 (2006).

b. The steel wall thickness shall be changed from "12.7 mm THICK" to "12.7 ± 3.2 mm ($^1/_2$ ± $^1/_8$ in.) THICK."

5. Add the following note after Note 2 in ASTM C 131-01:

   "NOTE—Due to its mass, the location of the shelf relative to the opening influences the "at rest" position of the opening. The shelf location should be chosen to provide a convenient position of the opening to facilitate the loading of aggregate and spheres and to avoid impact of the charge on the cover."

6. Add the following new section after Section 6.3 of ASTM C 131-01:

   "*Oven*—The oven shall be capable of maintaining a uniform temperature of 110 ± 5ºC (230 ± 9ºF)."

7. Replace Section 6.3 of ASTM C 131-01 with the following:

   "*Balance*—The balance shall conform to AASHTO M 231, Class G 5."

Standard Method of Test for

Soundness of Aggregates by Freezing and Thawing

AASHTO Designation: T 103-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Soundness of Aggregates by Freezing and Thawing

AASHTO Designation: T 103-08

1. SCOPE

1.1. This method describes three procedures to be followed in testing aggregates to determine their resistance to disintegration by freezing and thawing. It furnishes information helpful in judging the soundness of aggregates subjected to weathering, particularly when adequate information is not available from service records of the behavior of the aggregate.

1.2. The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with the rounding-off of E 29.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 27, Sieve Analysis of Fine and Coarse Aggregates

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *The apparatus shall consist of the following*:

3.1.1. *Freezing Equipment*—No specific requirements for the type or size of the freezing equipment are given as many laboratories have adequate equipment but variable in type and size. The freezing and thawing apparatus shall consist of a suitable chamber or chambers in which the sample may be subjected to the specified freezing and thawing cycle, together with the necessary refrigerating and heating equipment and controls to produce continuously and automatically, reproducible cycles within the specified temperature requirements. In the event that the equipment does not operate automatically, provision shall be made for either its continuous manual operation on a 24-hour-a-day basis or for the storage of all samples in a thawed condition when the equipment is not in operation. All equipment shall be capable of being operated at a temperature not higher than

–26º ± 3°C (–15º ± 5.4ºF) to 21°C ± 3°C (70°F ± 5.4°F) at any point in the freezing chamber. The equipment shall be equipped with an automatic temperature-recording device with an approximate temperature range of –40ºC (–40ºF) to 50ºC (122ºF), readable and accurate to 0.5ºC (1ºF).

3.1.2. *Sample Containers*—The sample containers shall be of plastic, rubber, or other materials suitable for the procedure to be followed. The containers shall be flexible to not cause undue stress on the aggregate being tested in water in the freezing cycle. The sample containers shall be of sufficient size to hold required sample and solution as well as being compatible with the freeze/thaw apparatus.

3.1.3. *Sieves*—The sieves used shall meet the requirements of M 92.

3.1.4. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

3.1.5. *Drying Oven*—The drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 110º ± 5ºC (230º ± 9ºF).

3.1.6. *Temperature–Measuring Equipment*—Shall consist of thermometers, resistance thermometers, or thermocouples, capable of measuring the temperature at various points within the testing chamber and at the centers of each sample container. The thermometers, resistance thermometers, or thermocouples shall have an approximate range from –26ºC to 50ºC (–15° to 120ºF), readable and accurate to 0.5ºC (1ºF).

4. SAMPLES

4.1. *Fine Aggregate*—Fine aggregate for the test shall be passed through a 9.5-mm ($^3/_8$-in.) sieve. The sample shall be of such size that it will yield a minimum 100 g of each of the following sieves:

Table 1—Sieve Size

Passing Sieve	Retained on Sieve
9.5 mm ($^3/_8$ in.)	4.75 mm (No. 4)
4.75 mm (No. 4)	2.36 mm (No. 8)
2.36 mm (No. 8)	1.18 mm (No. 16)
1.18 mm (No. 16)	600 µm (No. 30)
600 µm (No. 30)	300 µm (No. 50)

4.1.1. Should the sample contain less than five percent of any of the sizes specified in Section 4.1., that size shall not be tested.

4.2. *Coarse Aggregate*—Coarse aggregate for the test shall consist of +4.75-mm (No. 4) sieve size material. The sample shall be of such a size that it will yield the following minimum:

Table 2—Grading Requirements

Fraction Size Range (Note 1)	Mass, g
Larger sizes by 25.0-mm (1-in.) spread in sieve size, each fraction	7000 ± 1000
63-mm to 50-mm ($2^1/_2$-in. to 2-in.) material	3000 ± 300
50-mm to 37.5-mm (2- in. to $1^1/_2$-in.) material	2000 ± 200
37.5-mm to 25.0-mm ($1^1/_2$-in. to 1-in.) material	1000 ± 50
25.0-mm to 19.0-mm (1-in. to $^3/_4$-in.) material	700 ± 30
19.0-mm to 12.5-mm ($^3/_4$-in. to $^1/_2$-in.) material	670 ± 10
12.5-mm to 9.5-mm ($^1/_2$-in. to $^3/_8$-in.) material	330 ± 5
9.5-mm to 4.75-mm ($^3/_8$-in. to No. 4) material	300 ± 5

Note 1—The number and size range of fraction sizes, which are shown in Table 2, may be changed to reduce the number of size fractions being tested; however, the total sample mass for the number of size fractions being tested should equal the sample mass for the size as shown in Table 2.

4.3. Should the samples contain less than 5 percent of the sizes specified in Section 4.1 or 4.2, that size shall not be tested. For the purpose of calculating the test results, it shall be considered to have the same loss in treatment as the average of the next smaller and the next larger size. If one of these sizes is absent, it shall be considered to have the same loss as the next larger or next smaller size, whichever is present. When the 19- to 9.5-mm ($^3/_4$- to $^3/_8$-in.), 37.5- to 19.0-mm ($^3/_4$- to $1^1/_2$-in.), or 63- to 37.5-mm ($2^1/_2$- to $1^1/_2$-in.) test samples specified in Section 4.2 cannot be prepared due to absence of one of the two sizes of aggregate shown for each, the size available shall be used to prepare the sample tested.

4.4. When a sample to be tested with more than 10 percent coarser than the 9.5-mm ($^3/_8$-in.) sieve and, also, more than 10 percent finer than the 4.75-mm (No. 4) sieve, the sample shall be divided into a minus 4.75-mm fraction and a plus 4.75-mm fraction. The resulting fractions shall be tested in accordance with the procedures for fine aggregate and coarse aggregate, respectively. Report the results separately for the fine aggregate fraction and the coarse aggregate fraction, giving the percentages of the coarse and fine size fractions in the initial grading.

Table 3—Grading Requirements

Size (Square-Opening Sieves)	Mass, g
9.5 mm to 4.75 mm ($^3/_8$ in. to No. 4)	300 ± 5
19.0 mm to 9.5 mm ($^3/_4$ in. to $^3/_8$ in.)	1000 ± 10
Consisting of:	
12.5-mm to 9.5-mm ($^1/_2$-in. to $^3/_8$-in.) material	330 ± 5
19.0-mm to 12.5-mm ($^3/_4$-in. to $^1/_2$-in.) material	670 ± 10
37.5-mm to 19.0-mm ($1^1/_2$-in. to $^3/_4$-in.) material	1500 ± 50
Consisting of:	
25.0-mm to 19.0-mm (1-in. to $^3/_4$-in.) material	500 ± 30
37.5-mm to 25.0-mm ($1^1/_2$-in. to 1-in.) material	1000 ± 50
63-mm to 37.5-mm ($2^1/_2$-in. to $1^1/_2$-in.) material	5000 ± 300
Consisting of:	
50-mm to 37.5-mm (2-in. to $1^1/_2$-in.) material	2000 ± 200
63-mm to 50-mm ($2^1/_2$-in. to 2-in.) material	3000 ± 300
Larger sizes by 25.0-mm (1-in.) spread in sieve size, each fraction	7000 ± 1000

5. PREPARATION OF TEST SAMPLE

5.1. *Fine Aggregate*—The sample shall be thoroughly washed on a 150-µm (No. 100) sieve and dried to constant mass at a temperature of 110 ± 5ºC (230º ± 9ºF). The sample shall be separated into the different sizes by sieving, as follows:

5.1.1. Separate each fraction of mineral aggregate by sieving over required nest of the standard sieves specified in Section 4.1. From the fractions obtained in this manner select samples of sufficient size to yield 100 g after sieving to refusal per AASHTO T 27. Fine aggregate sticking in the meshes of the sieves shall not be used in preparing the samples. Samples consisting of 100 g shall be weighed out of each of the separated fractions after final sieving and placed in separate containers for the test.

5.2. *Coarse Aggregate*—The sample of coarse aggregate shall be thoroughly washed and dried to constant mass at a temperature of 110º ± 5ºC (230º ± 9ºF). It shall be separated into the different sizes shown in Section 4.2 by sieving to refusal per AASHTO T 27. The proper mass of sample for each fraction shall be weighed out and placed in separate containers for the test. In the case of fractions coarser than the 19.0-mm ($^3/_4$-in.) sieve, the number of particles shall be counted.

5.3. *Ledge Rock*—For testing ledge rock, the sample shall be prepared by breaking it into fragments reasonably uniform in size and shape and having a mass of approximately 100 g each. The test sample shall have a mass of 5000 g ± 100 g. The sample shall be thoroughly washed and dried previous to test as described in Section 5.2.

Table 4—Suggested Form for Recording Test Data (with Illustrative Test Values)

Sieve Size			Grading of Original Sample, Percent	Mass of Test Fractions Before Test, g	Percentage Passing Designated Sieve After Test	Weighted Percentage Loss
			Soundness Test of Fine Aggregate			
Minus 150 µm			5			
300 µm to 150 µm			12			
600 µm to 300 µm			26	100	4.2	1.1
1.18 mm to 600 µm			25	100	4.8	1.2
2.36 mm to 1.18 mm			17	100	8.0	1.4
4.75 mm to 2.36 mm			11	100	11.2	1.2
9.5 mm to 4.75 mm			4		11.2[a]	0.4
Totals			100			5
			Soundness Test of Coarse Aggregate			
63 mm to 50 mm	2825 g	63 to 37.5 mm	20	4783	4.8	1.0
50 mm to 37.5 mm	1958 g					
37.5 mm to 25.0 mm	1012 g	37.5 to 19.0 mm	45	1525	8.0	3.6
25.0 mm to 19.0 mm	513 g					
19.0 mm to 12.5 mm	675 g	19.0 to 9.5 mm	23	1008	9.6	2.2
12.5 mm to 9.5 mm	333 g					
9.5 mm to 4.75 mm			12	298	11.2	1.3
Totals			100			8

[a] The percentage loss (11.2 percent) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5 percent of the original sample as received. See Section 4.3.

6. PROCEDURES

6.1. *Procedure A—Total Immersion*:

6.1.1. Each sample fraction obtained per Section 5 shall be placed in a freeze/thaw container. Sufficient quantity of water, 3 percent NaCl and water solution, or 0.5 percent methyl alcohol and water solution shall be added to the sample container to completely immerse the sample in the solution. Allow the immersed sample to soak for 24 ± 4 hours at a temperature of 23° ± 3°C (73° ± 5°F) prior to the start of the freeze cycle.

6.1.2. Each sample fraction container shall be placed in the freeze apparatus. A thermometer or thermocouple shall be placed in the center of one of the samples. The sample shall be cooled until the temperature at the center of the sample reaches –23° ± 3°C (–9° ± 5°F). The temperature shall be held for a minimum 2 hours prior to the start of the thaw cycle. Upon completion of a freeze cycle, the temperature at the center of the sample shall be raised to 21° ± 3°C (70° ± 5°F). The temperature shall be held for a minimum 30 minutes.

6.2. *Procedure B—Partial Immersion in Alcohol–Water Solution*:

6.2.1. In this procedure, the samples shall be placed in a vacuum chamber and saturated by subjecting them to an air pressure of not over 3.4 kPa (25.4 mm of mercury), and breaking the vacuum with a sufficient amount of a 0.5 percent (by mass) solution of ethyl alcohol in water to completely cover the samples. The samples shall be left in the solution for 15 minutes.

6.2.2. The samples shall then be removed from the vacuum chamber. Coarse aggregates shall be placed one layer deep in shallow pans containing 6.4 mm ($^1/_4$ in.) of the alcohol–water solution and frozen in this condition. Samples of fine aggregate can most conveniently be handled by placing them in 250-µm (No. 60) or finer wire cloth sieves which in turn are held in shallow trays, and the samples frozen in a surface-wet condition.

6.2.3. Samples shall be frozen and thawed as required in Procedure A.

6.3. *Procedure C—Partial Immersion in Water*:

6.3.1. This procedure is the same as Procedure B except that water is used instead of the alcohol–water solution.

7. CYCLES

7.1. Alternate freezing and thawing shall be repeated until the required number of cycles is obtained. One test cycle consists of one freeze cycle and one thaw cycle. Repeat the procedure of alternate freezing and thawing for 25 cycles. Aggregate type and history may require additional cycles to accurately evaluate aggregate performance. One complete cycle shall not exceed 24 hours. If the test is interrupted, the sample shall remain covered in a thawed state until testing is resumed. The sample shall remain immersed during the test.

Some authorities have required 50, 16, and 25 cycles for Procedures A, B, and C, respectively.

8. QUANTITATIVE EXAMINATION

8.1. *The quantitative examination shall be made as follows*:

8.1.1. After the completion of the final cycle, each sample shall be dried to constant mass at 110º ± 5ºC (230º ± 9ºF) weighed, and except in the case of fine aggregate or ledge rock, sieved over the sieve shown for the appropriate size of particle in Table 4. The material retained on the sieve shall be weighed and the mass recorded. Larger sizes by 25-mm spread in sieve size shall be sieved over the original retaining sieve to determine their loss. The material retained on each sieve shall be weighed and the mass recorded.

Table 5—Sieve Size

Size of Aggregate	Sieve Used to Determine Loss
63 mm to 37.5 mm ($2_1/_2$ to $1^1/_2$ in.)	31.5 mm ($1^1/_4$ in.)
37.5 mm to 19.0 mm ($1^1/_2$ to $^3/_4$ in.)	16.0 mm ($^5/_8$ in.)
19.0 mm to 9.5 mm ($^3/_4$ to $^3/_8$ in.)	8.0 mm ($^5/_{16}$ in.)
9.5 mm to 4.75 mm ($^3/_8$ in. to No. 4)	4.0 mm (No. 5)

8.1.2. Samples of fine aggregate shall be sieved over the original retaining sieve to determine their loss. The material retained on each sieve shall be weighed and the mass recorded.

8.1.3. In the case of ledge rock, the loss in mass shall be determined by subtracting from the original mass of the sample the final mass of all fragments that have not broken into three or more pieces.

9. REPORT

9.1. *The report shall include the following data*:

Note 2—Table 4 in Section 5, shown with test values inserted for purpose of illustration, is a suggested form for recording test data. The test values shown might be appropriate for any procedure, depending on the quality of the aggregates.

9.1.1. Mass of each fraction of each sample before test.

9.1.2. Except in the case of ledge rock, the actual loss of each fraction of the sample expressed as a percentage of the original mass of the fraction.

9.1.3. Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative. In these calculations, sizes finer than the 300-μm (No. 50) sieve shall be assumed to have zero-percent loss.

9.1.4. For an aggregate containing appreciable amounts of both fine and coarse material tested as two separate samples as required in Section 4.4, compute the weighted average losses separately for the minus 4.75-mm and plus 4.75-mm fractions based on recomputed gradings considering the fine fraction as 100 percent and the coarse fraction as 100 percent. Report the results separately giving the percentage of the minus 4.75-mm and plus 4.75-mm material in the initial grading.

9.1.5. In the case of ledge rock, the loss as determined in Section 8.1.3 shall be reported as a percentage of the original mass.

9.1.6. If considered desirable or when requested, the type of failure of the discrete particles in the sample shall be reported.

9.1.7. Procedure used.

9.1.8. For Procedure A, solution used.

Standard Method of Test for

Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

AASHTO Designation: T 104-99 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

AASHTO Designation: T 104-99 (2007)

1. SCOPE

1.1. This method covers the procedure to be followed in testing aggregates to determine their resistance to disintegration by saturated solutions of sodium sulfate or magnesium sulfate. This is accomplished by repeated immersion in saturated solutions of sodium or magnesium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing. This test method furnishes information helpful in judging the soundness of aggregates subject to weathering action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions. Attention is called to the fact that test results by the use of the two salts differ considerably and care must be exercised in fixing proper limits in any specifications that may include requirements for these tests.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 27, Sieve Analysis of Fine and Coarse Aggregates

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 100, Standard Specification for ASTM Hydrometers

3. APPARATUS

3.1. *Sieves*—With square openings of the following sizes conforming to M 92, for sieving the samples in accordance with Sections 5, 6, and 8:

4.75 mm	(No. 4)	63 mm	($2^1/_2$ in.)
4.00 mm	(No. 5)	50 mm	(2 in.)
2.36 mm	(No. 8)	37.5 mm	($1^1/_2$ in.)
1.18 mm	(No. 16)	31.5 mm	($1^1/_4$ in.)
600 µm	(No. 30)	25.0 mm	(1 in.)
300 µm	(No. 50)	19.0 mm	($^3/_4$ in.)
150 µm	(No. 100)	16.0 mm	($^5/_8$ in.)
		12.5 mm	($^1/_2$ in.)
		9.5 mm	($^3/_8$ in.)
		8.0 mm	($^5/_{16}$ in.)

3.2. *Containers for Samples*—Sieves 203.2 mm (8 in.) in diameter for each separate size fractions of aggregate during test. Used, out-of-tolerance sieves according to M 92, in acceptable condition, may be used as containers (Note 1).

3.2.1. *Coarse Aggregate*—2.36-mm (No. 8) Size.

3.2.2. *Fine Aggregate*—250-µm (No. 60) Size.

Note 1—Sieves 203.2 mm (8 in.) in diameter may be substituted with containers which permit free access of solution to the sample and drainage of the solution from the sample without loss of aggregate. Substitution with such containers may affect results. Referee testing, comparison testing, or testing of aggregate to be used in critical applications must be performed using sieves 203.2 mm (8 in.) in diameter.

3.3. *Apparatus for Immersing Samples in Solution (optional)*—When necessary, apparatus for holding the sieves containing the sample for immersing into the solution shall be constructed in such a manner to permit free access of the solution to the sample and drainage of the solution from the sample.

3.4. *Temperature Regulation*—Suitable means for regulating the temperature of the samples during immersion in the sodium sulfate or magnesium sulfate solution shall be provided.

3.5. *Thermometer*—A thermometer covering the recommended temperature range for solutions during test and readable to 0.1ºC (0.2ºF).

3.6. *Temperature Recorder*—A unit capable of recording solution temperature a minimum of once every 10 minutes for the duration of the test with an accuracy of 0.3ºC (0.5ºF).

3.7. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

3.8. *Drying Oven*—The oven shall be capable of being heated continuously at 110º ± 5ºC (230º ± 9ºF) and the rate of evaporation, at this range of temperature, shall be at least 25 g/h for 4 hours, during which period the doors of the oven shall be kept closed. This rate shall be determined by the loss of water from 1-liter Griffin low-form beakers, each initially containing 500 g of water at a temperature of 21º ± 2ºC (70º ± 3ºF), placed at each corner and the center of each shelf of the oven. The evaporation requirement is to apply to all test locations when the oven is empty except for the beakers of water.

3.9. *Specific Gravity Measurement*—Hydrometers conforming to the requirements of ASTM E 100, or a suitable combination of graduated glassware and balance, capable of measuring the solution specific gravity within ±0.001.

4. SPECIAL SOLUTIONS REQUIRED

4.1. Prepare the solution for immersion of test samples from either sodium or magnesium sulfate in accordance with Section 4.1.1 or 4.1.2 (Note 2). The volume of the solution shall be at least five times the solid volume of all samples immersed at any one time.

Note 2—Some aggregates containing carbonates of calcium or magnesium are attacked chemically by fresh sulfate solution, resulting in erroneously high-measured losses. If this condition is encountered or is suspected, repeat the test using a filtered solution that has been used previously to test the same type of carbonate rock, provided that the solution meets the requirements of Sections 4.1.1 and 4.1.2 for specific gravity.

4.1.1. *Sodium Sulfate Solution*—Prepare a saturated solution of sodium sulfate by dissolving a reagent grade of the salt in water (Note 5) at a temperature of 25ºC (77ºF) minimum. Add sufficient salt (Note 3) of the anhydrous (Na_2SO_4) form to ensure not only saturation but also the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool to 20.3 to 21.9ºC (68.5 to 71.5ºF). Again stir, and allow the solution to remain at the designated temperature for at least 48 hours before use. Prior to each use, break up the salt cake, if any, in the container, stir the solution thoroughly, and determine the specific gravity of the solution. When used, the solution shall have a specific gravity not less than 1.154 nor more than 1.171. Discard a discolored solution, or filter it and check for specific gravity.

Note 3—For the solution, 215 g of anhydrous salt per liter of water are sufficient for saturation at 22ºC (71.6ºF). However, since this salt is not completely stable and since it is desirable that an excess of crystals be present, the use of not less than 225 g of the anhydrous salt per liter of water is recommended.

4.1.2. *Magnesium Sulfate Solution*—Prepare a saturated solution of magnesium sulfate by dissolving a reagent grade of the salt in water (Note 5) at a minimum temperature of 25ºC (77ºF) (Note 4). Add sufficient salt (Note 4) of either the anhydrous ($MgSO_4$) or the crystalline ($MgSO_4 \cdot 7H_2O$) (Epsom salt) form, to ensure saturation and the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool to 20.3 to 21.9ºC (68.5 to 71.5ºF). Again stir, and allow the solution to remain at the designated temperature for at least 48 hours before use. Prior to each use, break up the salt cake, if any, in the container, stir the solution thoroughly, and determine the specific gravity of the solution. When used, the solution shall have a specific gravity not less than 1.297 nor more than 1.306. Discard a discolored solution, or filter it and check for specific gravity.

Note 4—For the solution, 350 g of anhydrous salt or 1230 g of the heptahydrate per liter of water are sufficient for saturation at 23ºC (73.4ºF). However, since these salts are not completely stable, with the hydrous salt being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate salt be used and in an amount of not less than 1400 g/L of water.

When preparing the saturated solution of magnesium sulfate, the salt crystals will dissolve more readily if the crystals are added in small amounts and the water temperature is higher than 35ºC (95ºF) due to the chemical cooling effect during preparation.

Note 5—Distilled water shall be used in referee or comparison testing.

4.2. *Barium Chloride Solution*—A 0.2 molar solution of barium chloride (41.6 g of $BaCl_2$ per liter of solution) to determine the presence of sodium or magnesium sulfate in the wash water.

5. SAMPLES

5.1. *Fine Aggregate*—Fine aggregate for the test shall be passed through a 9.5-mm ($^3/_8$-in.) sieve. The sample shall be of such size that it will yield not less than 100 g of each of the following sizes, expressed in terms of the following sieves:

Passing Sieve	Retained on Sieve
9.5 mm ($^3/_8$ in.)	4.75 mm (No. 4)
4.75 mm (No. 4)	2.36 mm (No. 8)
2.36 mm (No. 8)	1.18 mm (No. 16)
1.18 mm (No. 16)	600 µm (No. 30)
600 µm (No. 30)	300 µm (No. 50)

5.1.1. Should the sample contain less than 5 percent of any of the sizes specified in Section 5.1, that size shall not be tested.

5.2. *Coarse Aggregate*—Coarse aggregate for the test shall consist of material from which the sizes finer than the 4.75-mm (No. 4) sieve have been removed. The sample shall be of such a size that it will yield the amounts indicated in Table 1.

Table 1—Coarse Aggregate Sample

Sieve Size	Mass, g
63 mm to 37.5 mm ($2^1/_2$ in. to $1^1/_2$ in.)	5000 ± 300
Consisting of:	
50-mm to 37.5-mm (2-in. to $1^1/_2$-in.) material	2000 ± 200
63-mm to 50-mm ($2^1/_2$-in. to 2-in.) material	3000 ± 300
37.5 mm to 19.0 mm ($1^1/_2$ in. to $^3/_4$ in.)	1500 ± 50
Consisting of:	
25.0-mm to 19.0-mm (1-in. to $^3/_4$ -in.) material	500 ± 30
37.5-mm to 25.0-mm ($1^1/_2$-in. to 1-in.) material	1000 ± 50
19.0 mm to 9.5 mm ($^3/_4$ in. to $^3/_8$ in.)	1000 ± 10
Consisting of:	
12.5-mm to 9.5-mm ($^1/_2$-in. to $^3/_8$-in.) material	330 ± 5
19.0-mm to 12.5-mm ($^3/_4$-in. to $^1/_2$-in.) material	670 ± 10
9.5 mm to 4.75 mm ($^3/_8$ in. to No. 4)	300 ± 5

5.2.1. Should the sample contain less than 5 percent of any of the sizes specified in Section 5.2, that size shall not be tested. When a combination of sizes is specified for the test portion and one of the sizes specified is less than 5 percent of the sample, reduce the test portion by the applicable mass specified in Section 5.2 for the size not available.

5.2.2. When testing large rock (broken stone, ledge rock, cobbles, and boulders for use as riprap, channel lining, etc.), obtain the test portion by crushing, splitting, or sawing the larger sample pieces. Test only those pieces in the 37.5 to 19.0 mm ($1^1/_2$ to $^3/_4$ in.) and 63 to 37.5 mm ($2^1/_2$ to $1^1/_2$ in.) size fractions when size reduction is by crushing or splitting. Test pieces in the 63 to 37.5 mm ($2^1/_2$ to $1^1/_2$ in.) size fraction when size reduction is by sawing.

Note 6—When the rock contains bedding planes, crushing or splitting will usually cause the rock to break on those bedding planes. Sawing will usually leave the bedding planes intact, and thus more likely to split the particles due to growth of the salt crystals in the soundness test.

5.2.3. When testing large rock (to evaluate a potential source) which will be subsequently crushed to produce aggregate, obtain the test portion by crushing the larger sample pieces. Test pieces only in those sizes that will be included in the produced aggregate, but ignoring any material finer than 4.75-mm (No. 4) sieve or coarser than 63-mm ($2^1/_2$-in.) sieve.

5.2.4. When the finished aggregate material will contain particles coarser than 63 mm ($2^1/_2$ in.), such as aggregate for use in mass concrete, crush the material coarser than 63 mm ($2^1/_2$ in.) and distribute the material among that in the range of 63-mm ($2^1/_2$ in.) to 4.75-mm (No. 4) sieves. Discard material finer than 4.75-mm (No. 4) sieve.

5.3. When an aggregate to be tested contains appreciable amounts of both fine and coarse material, having a grading with more than 10 percent coarser than the 9.5-mm ($^3/_8$-in.) sieve and, also, more than 10 percent finer than the 4.75-mm (No. 4) sieve, test separate samples of the minus 4.75 mm (No. 4) fraction and the plus 4.75 mm (No. 4) fraction in accordance with the procedures for fine aggregate and coarse aggregate, respectively. Report the results separately for the fine aggregate fraction and the coarse aggregate fraction, giving the percentages of the coarse and fine size fractions in the initial grading.

6. PREPARATION OF TEST SAMPLE

6.1. *Fine Aggregate*—Thoroughly wash the sample of fine aggregate on a 300-µm (No. 50) sieve, dry to constant mass at 110º ± 5ºC (230º ± 9ºF), and separate into the different sizes by sieving, as follows: Make a rough separation of the graded sample by means of a nest of the standard sieves specified in Section 5.1. From the fractions obtained in this manner, select samples of sufficient size to yield 100 g after sieving to refusal. (In general, a 110-g sample will be sufficient.) Do not use fine aggregate sticking in the meshes of the sieves in preparing the samples. Weigh samples consisting of 100 ± 0.1 g out of each of the separated fractions after final sieving, record the masses of the test samples, and place in separate containers for the test.

6.2. *Coarse Aggregate*—Thoroughly wash and dry the sample of coarse aggregate to constant mass at 110º ± 5ºC (230º ± 9ºF) and separate it into the different sizes shown in Section 5.2 by sieving to refusal. Weigh out quantities of the different sizes within the tolerances of Section 5.2 and combine them to the designated total mass (Note 7). Record the masses of the test samples and their fractional components. In the case of sizes larger than 19.0 mm ($^3/_4$ in.), record the number of particles in the test samples.

Note 7—The fractional components of each sample may be placed in separate containers if so desired but is not required. If separate containers are used, the two sizes must be combined for the calculations for Section 8.1.2 (Table 2).

Table 2—Suggested Form for Recording Test Data (with Illustrative Test Values)

Sieve Size			Grading of Original Sample, Percent	Mass of Test Fractions Before Test, g	Percentage Passing Designated Sieve After Test	Weighted Percentage Loss
			Soundness Test of Fine Aggregate			
Minus 150 µm			5			
300 µm to 150 µm			12			
600 µm to 300 µm			26	100	4.2	1.1
1.18 mm to 600 µm			25	100	4.8	1.2
2.36 mm to 1.18 mm			17	100	8.0	1.4
4.75 mm to 2.36 mm			11	100	11.2	1.2
9.5 mm to 4.75 mm			4		11.2[a]	0.4
Totals			100			5
			Soundness Test of Coarse Aggregate			
63 mm to 50 mm 50 mm to 37.5 mm	2825 g 1958 g	63 to 37.5 mm	20	4783	4.8	1.0
37.5 mm to 25.0 mm 25.0 mm to 19.0 mm	1012 g 513 g	37.5 to 19.0 mm	45	1525	8.0	3.6
19.0 mm to 12.5 mm 12.5 mm to 9.5 mm	675 g 333 g	19.0 to 9.5 mm	23	1008	9.6	2.2
9.5 mm to 4.75 mm			12	298	11.2	1.3
Totals			100			8

[a] The percentage loss (11.2 percent) of the next smaller size is used as the percentage loss for this size, since this size contains less than 5 percent of the original sample as received. See Section 10.1.3.4.

7. PROCEDURE

7.1. *Storage of Samples in Solution*—Immerse the samples in the prepared solution of sodium sulfate or magnesium sulfate for not less than 16 hours nor more than 18 hours in such a manner that the solution covers them to a depth of at least 12.5 mm ($^{1}/_{2}$ in.) (Note 8). Cover the containers to reduce evaporation and prevent the accidental addition of extraneous substances. Maintain the samples immersed in the solution at a temperature of 20.3 to 21.9ºC (68.5 to 71.5ºF) for the immersion period.

Note 8—Suitably weighted wire grids placed over the sample in the containers will permit this coverage to be achieved with very light-weight aggregates.

7.2. *Drying Samples after Immersion*—After the immersion period, remove the aggregate sample from the solution, permit it to drain for 15 ± 5 minutes, and place in the drying oven. The temperature of the oven shall have been brought previously to 110º ± 5ºC (230º ± 9ºF). Dry the samples at the specified temperature until constant mass has been achieved. Establish the time required to attain constant mass as follows: with the oven containing the maximum sample load expected, check the mass losses of test samples by removing and weighing them without cooling, at intervals of 2 to 4 hours; make enough checks to establish required drying time for the least favorable oven location (Section 3.6) and sample condition (Note 9). Constant mass will be considered to have been achieved when mass loss is less than 0.1 percent of sample mass in 4 hours of drying. After constant mass has been achieved, allow the samples to cool to 20 to 25ºC (68 to 77ºF) (Note 10), when they shall again be immersed in the prepared solution as described in Section 7.1. Cooling may be aided by the use of an air conditioner or fan. Temperature of the material shall be checked by thermometer or other acceptable means before placing the material in the soaking solution.

Note 9—Drying time required to reach constant mass may vary considerably for several reasons. Efficiency of drying will be reduced as cycles accumulate because of salt adhering to particles and, in some cases, because of increase in surface area due to breakdown. The different size fractions of aggregate will have differing drying rates. The smaller sizes will tend to dry more slowly because of their larger surface area and restricted interparticle voids, but this tendency may be altered by the effects of container size and shape.

Note 10—Experience has shown that sample temperatures significantly different than the solution temperature of 21.1ºC (70.0ºF) may change the temperature of the solution temporarily, thereby causing a change in salt saturation even though the solution returns to 21.1ºC (70.0ºF) for most of the soaking period. This may cause erroneous results.

7.3. *Number of Cycles*—Repeat the process of alternate immersion and drying until the required number of cycles is obtained. Preferably, the test shall be performed continuously until the specified number of cycles is obtained. However, if the test must be interrupted, leave the samples in the oven, at 110º ± 5ºC (230º ± 9ºF) until the testing can be resumed.

7.4. Review the temperature record from the recording unit. Verify solution temperature limits were not exceeded.

8. QUANTITATIVE EXAMINATION

8.1. *Make the quantitative examination as follows*:

8.1.1. After the completion of the final cycle and after the sample has cooled, wash the sample free from the sodium sulfate or magnesium sulfate. Wash by circulating water at 43º ± 6ºC (110º ± 10ºF) through the samples in their containers by introducing hot water near the bottom and allowing the water to pass through the samples and overflow. The thoroughness of washing shall be checked by obtaining a sample of rinse water after it has passed through the samples and checked with 0.2 molar barium chloride. Further washing is required if sample becomes cloudy upon addition of the barium chloride solution. In areas where the water gives a reaction with barium chloride other analytical means shall be used to assure thoroughness of washing. In the washing operation, the samples shall not be subjected to impact or abrasion that may tend to break up particles.

8.1.2. After the sodium sulfate or magnesium sulfate has been removed, dry each fraction of the sample to constant mass at 110º ± 5ºC (230º ± 9ºF). Sieve the fine aggregate over the same sieve on which it was retained before the test, and sieve the coarse aggregate over the sieve shown below for the appropriate size of particle. For fine aggregate, the method and duration of sieving shall be the same as were used in preparing the test samples. For coarse aggregate, sieving shall be by hand, with agitation sufficient only to assure that all undersize material passes the designated sieve. No extra manipulation shall be employed to break up particles or cause them to pass the sieves. Determine the mass of the material retained on each sieve and record each amount. The difference between each of these amounts and the initial mass of the fraction of the sample tested is the loss in the test and is to be expressed as a percentage of the initial mass for use in Table 2.

Size of Aggregate	Sieve Used to Determine Loss
63 mm to 37.5 mm ($2^1/_2$ to $1^1/_2$ in.)	31.5 mm ($1^1/_4$ in.)
37.5 mm to 19.0 mm ($1^1/_2$ to $^3/_4$ in.)	16.0 mm ($^5/_8$ in.)
19.0 mm to 9.5 mm ($^3/_4$ to $^3/_8$ in.)	8.0 mm ($^5/_{16}$ in.)
9.5 mm to 4.75 mm ($^3/_8$ in. to No. 4)	4.0 mm (No. 5)

9. QUALITATIVE EXAMINATION

9.1. *Make a qualitative examination of test samples coarser than 19.0 mm ($^3/_4$ in.) as follows (Note 11)*:

9.1.1. Separate the particles of each test sample into groups according to the action produced by the test (Note 11).

9.1.2. Record the number of particles showing each type of distress.

Note 11—Many types of action may be expected. In general, they may be classified as disintegration, splitting, crumbling, cracking, flaking, etc. While only particles larger than 19.0 mm ($^3/_4$ in.) in size are required to be examined qualitatively, it is recommended that examination of the smaller sizes be made in order to determine whether there is any evidence of excessive splitting.

10. REPORT

10.1. *The report shall include the following data (Note 12)*:

10.1.1. Mass of each fraction of each sample before test.

10.1.2. Material from each fraction of the sample finer than the sieve designated in Section 8.1.2 for sieving after test, expressed as a percentage of the original mass of the fraction.

10.1.3. Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination determined by using T 27 or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative except that:

10.1.3.1. For fine aggregates with less than 10 percent coarser than the 9.5-mm ($^3/_8$-in.) sieve, assume sizes finer than the 300-μm (No. 50) sieve to have zero-percent loss and sizes coarser than the 9.5-mm ($^3/_8$-in.) sieve to have the same loss as the next smaller size for which test data are available.

10.1.3.2. For coarse aggregate with less than 10 percent finer than the 4.75-mm (No. 4) sieve, assume sizes finer than the 4.75-mm (No. 4) sieve to have the same loss as the next larger size for which test data are available.

10.1.3.3. For an aggregate containing appreciable amounts of both fine and coarse material tested as two separate samples as required in Section 5.3, compute the weighted average losses separately for the minus 4.75-mm (No. 4) and plus 4.75-mm (No. 4) fractions based on recomputed gradings considering the fine fraction as 100 percent and the coarse fraction as 100 percent. Report the results separately giving the percentage of the minus 4.75-mm (No. 4) and plus 4.75-mm (No. 4) material in the initial grading.

10.1.3.4. For the purpose of calculating the weighted average, consider any size in Section 5.1 or 5.2 that contain less than 5 percent of the sample to have the same loss as the average of the next smaller and the next larger size, or if one of these sizes is absent, to have the same loss as the next larger or next smaller size, whichever is present.

10.1.3.5. For large rock tested according to Section 5.2.2 the weighted average (if more than one size fraction is tested) shall be the arithmetic mean of the loss on the fractions tested.

10.1.3.6. For large rock tested according to Sections 5.2.3 or 5.2.4, the weighted average shall be based on a sample grading conforming to the middle of the specification to which the aggregate will be produced, or the actual grading as produced. If the specification grading includes fractions larger than 63-mm ($2^1/_2$ in.) sieve, assume such sizes have the same percentage loss as the 63 to 37.5 mm ($2^1/_2$ to $1^1/_2$ in.) fraction.

10.1.4. Report the weighted percentage loss to the nearest whole number.

10.1.5. In the case of particles coarser than 19.0 mm ($^3/_4$ in.) before test: (1) the number of particles in each fraction before test, and (2) the number of particles affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc., as shown in Table 3.

Table 3—Suggested Form for Qualitative Examination (with Illustrative Test Values)

Qualitative Examination of Coarse Sizes									
	Particles Exhibiting Distress								Total No. of Particles before Test
	Splitting		Crumbling		Cracking		Flaking		
Sieve Size	No.	Percent	No.	Percent	No.	Percent	No.	Percent	
63 mm to 37.5 mm	2	7	—	—	2	7	—	—	29
37.5 mm to 19.0 mm	5	—	—	2	—	—	—	—	50

10.1.6. Kind of solution (sodium or magnesium sulfate) and whether the solution was freshly prepared or previously used.

10.1.7. Method of producing particles for test, when reduced from large pieces as described in Sections 5.2.2, 5.2.3, or 5.2.4.

Note 12—Table 2, shown with test values inserted for purpose of illustration, is a suggested form for recording test data. The test values shown might be appropriate for either salt, depending on the quality of the aggregate.

11. PRECISION

11.1. For coarse aggregate with weighted average sulfate soundness losses in the ranges of 6 to 16 percent for sodium and 9 to 20 percent for magnesium, the precision indexes are as indicated, in Table 4 (Note 13).

Table 4—Precision Indexes

	Coefficient of Variation (1s%), percent[a]	Difference between Two Tests (d2s%), percent of average[a]
Multilaboratory:		
Sodium sulfate	41	116
Magnesium sulfate	25	71
Single-Operator:		
Sodium sulfate	24	68
Magnesium sulfate	11	31

[a] These numbers represent, respectively, the (1s%) and (d2s%) limits as described in ASTM C 670.

Note 13—The values in the precision statement are based on testing according to this method prior to revision in 1991. The revisions in 1991 are believed to improve the precision of the method.

Standard Method of Test for

Clay Lumps and Friable Particles in Aggregate

AASHTO Designation: T 112-00 (2008)[1]
ASTM Designation: C 142-97

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Clay Lumps and Friable Particles in Aggregate

AASHTO Designation: T 112-00 (2008)[1]
ASTM Designation: C 142-97

1. SCOPE

1.1. This method covers the approximate determination of clay lumps and friable particles in natural aggregates.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

3. SIGNIFICANCE AND USE

3.1. This test method is of primary significance in determining the acceptability of aggregate with respect to the requirements of M 6 and M 80.

4. APPARATUS

4.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

4.2. *Containers*—Rust-resistant containers of a size and shape that will permit the spreading of the sample on the bottom in a thin layer.

4.3. *Sieves*—Sieves conforming to M 92.

4.4. *Oven*—An oven providing free circulation of air and capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF).

5. SAMPLES

5.1. Aggregate for this test shall consist of the material remaining after completion of T 11. To provide the quantities designated in Sections 5.3 and 5.4, it may be necessary to combine material from more than one test by T 11.

5.2. Dry the aggregate to substantially constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF).

5.3. Test samples of fine aggregate shall consist of the particles coarser than a 1.18-mm (No. 16) sieve and shall have a mass not less than 25 g.

5.4. Separate the test samples of coarse aggregate into different sizes, using the following sieves: 4.75 mm (No. 4), 9.5 mm ($^3/_8$ in.), 19.0 mm ($^3/_4$ in.), and 37.5 mm ($1^1/_2$ in.). The test sample shall weigh not less than indicated in the following table:

Size of Particles Making Up Test Sample	Weight of Test Sample, Min, g
4.75 to 9.5 mm (No. 4 to $^3/_8$ in.)	1000
9.5 to 19.0 mm ($^3/_8$ to $^3/_4$ in.)	2000
19.0 to 37.5 mm ($^3/_4$ to $1^1/_2$ in.)	3000
Over 37.5 mm ($1^1/_2$ in.)	5000

5.5. If the grading of the original sample provides less than 5 percent of any of the sizes indicated in Section 5.4, do not test that size.

5.6. In the case of aggregate which is composed of substantial amounts of both fine and coarse aggregate sizes, separate the material into two sizes at the 4.75-mm (No. 4) sieve, and prepare the samples of fine and coarse aggregate in accordance with Sections 5.3 and 5.4. Any aggregate containing 50 percent or more material retained on the 4.75-mm (No. 4) sieve is considered to be coarse aggregate.

Note 1—In most cases, only the plus 4.75-mm (No. 4) fraction of coarse aggregate needs to be evaluated by this test method, regardless of the amount of minus 4.75-mm (No. 4) material present. However, the amount of 1.18-mm (No. 16) to 4.75-mm (No. 4) material present shall be included in the weight of the test sample in Section 7.1 when calculating the percent of clay lumps and friable particles.

6. PROCEDURE

6.1. Determine the mass of the test sample to the accuracy specified in Section 4.1 and spread it in a thin layer on the bottom of the container, cover it with distilled water and soak it for a period of 24 ± 4 hours. Roll and squeeze particles individually between the thumb and forefinger to attempt to break the particle into smaller sizes. Do not use the fingernails to break up particles, or press particles against a hard surface or each other. Classify any particles that can be broken with the fingers into fines removable by wet sieving as clay lumps or friable particles. After all discernible clay lumps and friable particles have been broken, separate the undersized material from the remainder of the sample by wet sieving over the sieve prescribed in Table 1.

Table 1—Procedure

Size of Particles Making Up Sample	Size of Sieve for Removing Residue of Clay Lumps and Friable Particles
Fine aggregate (retained on 1.18-mm (No. 16) sieve)	850 µm (No. 20)
4.75 to 9.5 mm (No. 4 to $^3/_8$ in.)	2.36 mm (No .8)
9.5 to 19.0 mm ($^3/_8$ to $^3/_4$ in.)	4.75 mm (No. 4)
19.0 to 37.5 mm ($^3/_4$ to $1^1/_2$ in.)	4.75 mm (No. 4)
Over 37.5 mm ($1^1/_2$ in.)	4.75 mm (No. 4)

6.2. Perform the wet sieving by passing water over the sample through the sieve while manually agitating the sieve, until all undersize material has been removed.

6.3. Remove the retained particles carefully from the sieve, dry to substantially constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF), allow to cool, and determine the mass to the accuracy specified in Section 4.1.

7. CALCULATION

7.1. Calculate the percent of clay lumps and friable particles in fine aggregate or individual sizes of coarse aggregate as follows:

$$P = \left[\left(M - R \right) / M \right] \times 100 \qquad (1)$$

where:

P = percent of clay lumps and friable particles;

M = mass of test sample (for fine aggregate the mass of the portion coarser than the 1.18-mm (No. 16) sieve as described in Section 5.3); and

R = mass of particles retained on designated sieve, as determined in accordance with Section 6.3.

7.2. For coarse aggregates, the percent of clay lumps and friable particles shall be an average based on the percent of clay lumps and friable particles in each sieve-size fraction weighted in accordance with the grading of the original sample before separation, or, preferably, the average grading of the supply represented by the sample. For the purpose of calculating the weighted average when the sample contains less than 5 percent of the material in a given size, that size shall be considered to contain the same percent of clay lumps and friable particles as the next larger or next smaller size, whichever is present.

8. PRECISION AND BIAS

8.1. *Precision*—The estimate of the precision of this test method is provisional and is based on samples of one fine aggregate that was tested by 10 different operators at nine different laboratories. For that sample, the average "percent of clay lumps and friable particles" in the aggregate was 1.2 percent, and the standard deviation was 0.6 percent. Based on this standard deviation, the acceptable range of two test results on samples from the same aggregate sent to different laboratories is 1.7 percent.

8.2. *Bias*—Since there is no acceptable reference material for determining the bias for the procedure in this test method, no statement is being made.

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[1] Except for Sections 4.1 and 5.6, this method is identical to ASTM C 142-97.

Standard Method of Test for

Lightweight Pieces in Aggregate

AASHTO Designation: T 113-06[1]
ASTM Designation: C 123-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Lightweight Pieces in Aggregate

AASHTO Designation: T 113-06[1]

ASTM Designation: C 123-03

1. SCOPE

1.1. This method covers the determination of the percentage of lightweight pieces in aggregate by means of sink-float separation in a heavy liquid of suitable specific gravity.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard involves hazardous materials, operations, or equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For a specific hazard statement, see Note 1.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 2, Sampling of Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- D 3665, Standard Practice for Random Sampling of Construction Materials
- E 100, Standard Specification for ASTM Hydrometers

3. SIGNIFICANCE AND USE

3.1. This method is used to determine conformance with provisions of M 6 and M 80 pertaining to the amount of lightweight material in fine and coarse aggregates. A heavy liquid with a specific gravity of 2.0 is used to separate particles, which may be classified as coal or lignite. Heavier liquids are used to check the percentages of other lightweight pieces, such as chert having a specific gravity less than 2.40.

3.2. The method is useful in identifying porous aggregate particles in research activities or in petrographic analyses.

4. APPARATUS

4.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

4.2. *Containers* suitable for drying the aggregate sample, and containers suitable for holding the heavy liquid during the sink-float separation.

4.3. *Skimmer*—A piece of 300-µm (No. 50) sieve cloth, conforming to M 92, of suitable size and shape for separating the floating pieces from the heavy liquid.

4.4. *Hot Plate or Oven*—Of appropriate size capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

4.5. *Sieves*—300-µm (No. 50) and 4.75-mm (No. 4) conforming to M 92.

4.6. *Specific Gravity Measurement*—A hydrometer conforming to the requirements of Section 5 through 11 of ASTM E 100 or a suitable combination of graduated glassware and balance, capable of measuring the liquid specific gravity within ± 0.01.

5. HEAVY LIQUID

5.1. The heavy liquid shall consist of one of the following: (See Note 1.)

5.1.1. A solution of zinc chloride in water (for materials having a specific gravity less than 2.0).

5.1.2. A mixture of kerosene with 1,1,2,2 tetrabromoethane, proportioned to produce desired specific gravities (1,1,2,2-tetrabromoethane has a specific gravity of about 2.95).

5.1.3. A solution of zinc bromide in water (for materials having a specific gravity less than 2.6).

5.2. The specific gravity of the heavy liquid shall be maintained within ± 0.01 of the specified value at all times during the test.

Note 1—**Caution**: The chemicals listed in Section 5.1.2 are toxic, both by absorption through the skin and by inhalation. They shall be used only in a hood (preferably of the down-draft type) or out-of-doors, and care shall be taken to avoid inhalation or contact with the eyes or skin. There is no particular hazard from the fumes of zinc chloride solution (Section 5.1.1) or zinc bromide solution (Section 5.1.3), but goggles and gloves shall be worn to prevent contact with the eyes or skin.

1,1,2,2-tetrabromoethene is highly toxic and extremely dangerous to use and when heated emits highly toxic fumes of bromine, hydrogen bromide, and carbonyl bromide. It should be handled only by personnel trained and qualified in its use. Its storage should be in a secured location, away from noncompatible chemicals.

6. SAMPLING

6.1. Secure a field sample of the aggregate in accordance with T 2 and ASTM D 3665. Reduce the sample to test portion size in accordance with T 248.

6.2. Dry the test portion to constant mass at a temperature of 110 ± 5°C (230 ± 9°F) before testing. The minimum size of the test specimen shall be as follows:

Nominal Maximum Size of Aggregate (Square-Opening Sieves)	Minimum Mass of Sample, g
4.75 mm (No. 4)	200
9.5 mm ($^3/_8$ in.)	1500
19.0 mm ($^3/_4$ in.)	3000
37.5 mm ($1^1/_2$ in.)	5000
75 mm (3 in.)	10000

If the nominal maximum size of the aggregate to be tested is not listed above, the next largest size shall be used to determine the sample size.

7. PROCEDURE

7.1. *Fine Aggregate*—Allow the dried test specimen of fine aggregate to cool to room temperature and then sieve over a 300-µm (No. 50) sieve until less than 1 percent of the retained material passes the sieve in 1 minute of continuous sieving. Determine the mass of the material coarser than the 300-µm sieve to the nearest 0.1 g and bring this material to a saturated-surface-dry condition (Note 2) by means of the procedure specified in T 84 (Section 7.1.1), then introduce it into the heavy liquid (Note 1) in a suitable container. The volume of liquid shall be at least three times the absolute volume of the aggregate. Pour the liquid, including the floating pieces, into a second container, passing it through the skimmer, taking care that only the floating pieces are poured off with the liquid and that none of the fine aggregate which sinks is decanted onto the skimmer. Return to the first container the liquid that has been collected in the second container and, after further agitation of the sample by stirring, repeat the decanting process just described until the specimen is free of floating pieces. Wash the decanted pieces contained on the skimmer in an appropriate solvent to remove the heavy liquid. Alcohol is appropriate for 1.1.2.2-tetrabromoethane and water for the zinc chloride and zinc bromide solutions. After the decanted pieces have been washed allow them to dry (Section 7.1.2). Brush the dry decanted pieces from the skimmer onto the balance pan and determine the mass to the nearest 0.1 g. If more precise determination is required, the decanted particles shall be dried to constant mass at 110 ± 5°C to determine the value of W_1 used for the calculation in Section 8.1. (See Section 7.1.3.)

7.1.1. If the absorption as determined in accordance with T 84 is known, the fine aggregate is permitted to be prepared for test by adding to a known mass of dry sand the amount of water it will absorb, mixing thoroughly, and permitting the sand to stand in a covered pan for 30 minutes before use.

7.1.2. Drying shall take place in the hood or out-of-doors if other than zinc chloride or zinc bromide is used. An oven or hot plate is permitted to be used to accelerate the drying providing that it is done in the hood or that the oven is forced-air ventilated and that a temperature of 115°C is not exceeded.

7.1.3. Normally the discrepancy between oven-dry mass and saturated surface-dry mass of the decanted particles will not significantly affect the calculated percentage of lightweight pieces.

7.2. *Coarse Aggregate*—Allow the dried test specimen of coarse aggregate to cool to room temperature and sieve over a 4.75-mm sieve. Determine the mass of the material coarser than the No. 4 sieve to the nearest 1 g, and bring to a saturated surface-dry condition (Note 2) by means of the procedure specified in T 85; then introduce it into the heavy liquid in a suitable container. The volume of liquid shall be at least three times the absolute volume of the aggregate. Using the skimmer, remove the pieces that float to the surface, and save them. Repeatedly agitate the remaining pieces, and remove the floating pieces until no additional pieces rise to the surface. Wash the pieces that are skimmed off in an appropriate solvent to remove the heavy liquid (see Section 7.1). After the heavy liquid has been removed, allow the pieces to dry (Section 7.1.2). Determine the mass of the decanted pieces to the nearest 1 g. If a more precise determination is required, dry the particles to constant mass at 110 ± 5°C to determine the value of W_1 used for the calculation in Section 8.1. (See Section 7.1.3.)

Note 2—If material undergoes degradation in water, the material does not have to be brought to a saturated surface-dry condition.

8. CALCULATION

8.1. *Calculate the percentage of lightweight pieces (pieces floating on the heavy liquid) as follows*:

For fine aggregate:

$$L = \left(W_1/W_2\right) \times 100 \tag{1}$$

For coarse aggregate:

$$L = \left(W_1/W_3\right) \times 100 \tag{2}$$

where:

L = percentage of lightweight pieces,

W_1 = dry mass of pieces that float,

W_2 = dry mass of portion of specimen coarser than 300-µm (No. 50) sieve, and

W_3 = dry mass of portion of specimen coarser than the 4.75-mm (No. 4) sieve.

9. REPORT

9.1. *The report shall include the following*:

9.1.1. Identification of the aggregate as to source, type, and nominal maximum size.

9.1.2. Type and specific gravity of heavy liquid used for the test.

9.1.3. Percentage of lightweight pieces calculated to nearest 0.1 percent.

10. PRECISION AND BIAS

10.1. *Precision*—No interlaboratory or intralaboratory studies have been conducted using this test method to determine precision indices. The committee is seeking pertinent data from users of the test method.

10.2. *Bias*—Bias of the test method may be estimated by running separate specific gravity and absorption determinations on individual pieces of the separate sink, or float fractions, or both.

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[1] This test method is technically equivalent with ASTM C 123-03.

Standard Method of Test for

Aggregate Durability Index

AASHTO Designation: T 210-10[1]
ASTM Designation: D 3744-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Aggregate Durability Index

AASHTO Designation: T 210-10[1]
ASTM Designation: D 3744-03

1. SCOPE

1.1. This method describes the procedure for determining the durability of aggregates. The durability index is a value indicating the relative resistance of an aggregate to produce detrimental claylike fines when subjected to the prescribed mechanical methods of degradation.

1.2. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 248, Reducing Samples of Aggregate to Testing Size

3. SUMMARY OF METHOD

3.1. This method was developed to permit prequalification of aggregates proposed for use in the construction of transportation facilities. Basically, the test establishes an aggregate's resistance to generating fines when agitated in the presence of water. Separate and different test procedures are used to evaluate the coarse and the fine portions of a material.

3.2. A sample of coarse aggregate is prepared to a specific grading and then washed in a mechanical washing vessel for a 2-minute agitation time. After discarding the minus 4.75-mm (No. 4) material, the washed test sample is dried and prepared to the final test grading.

3.3. The coarse aggregate test sample is then agitated in the mechanical washing vessel for a period of 10 minutes. A representative portion of the resulting wash water and minus 75-µm (No. 200) size fines are collected and mixed with a stock calcium chloride solution and placed in a plastic cylinder. After a 20-minute sedimentation time, the level of the sediment column is read. The height of the sediment value is then used to calculate the durability index of the coarse aggregate (D_c).

3.4. The fine aggregate sample is prepared by washing a specific quantity of the material in the mechanical washing vessel for a 2-minute agitation period. All minus 75-µm (No. 200) size material is washed from the sample through a 75-µm (No. 200) sieve and discarded. The plus 75-µm (No. 200) fraction is dried.

3.5. The fine aggregate test sample is tested by T 176 except for a modification to the duration of the shaking time. The mechanical shaker method is required. A shaking time of 10 minutes instead of 45 seconds is used.

3.6. This method includes procedures for testing aggregates exhibiting a wide range in specific gravity, including lightweight and porous coarse aggregates, and also procedures for testing small maximum size aggregate that is too fine to test as a coarse aggregate and too coarse to consider as a fine aggregate, such as a pea gravel or a very coarse sand.

3.7. The durability index for coarse aggregate (D_c) or for fine aggregate (D_f) is calculated, as applicable, by appropriate equations presented in the method. The durability index of a well-graded aggregate containing both coarse and fine fractions is defined as the lowest of the two values, D_c or D_f, obtained by the test. This value is recommended to be the controlling value for specification purposes.

4. SIGNIFICANCE AND USE

4.1. This test assigns an empirical value to the relative amount, fineness, and character of claylike material that may be generated in an aggregate when subjected to mechanical degradation.

4.2. The procedure has been used in limited geographical areas of the United States and the results have been correlated with aggregate performance in various construction applications, including: aggregate base, permeable material for backfill, fine concrete aggregate, and riprap for rock slope protection.[2,3]

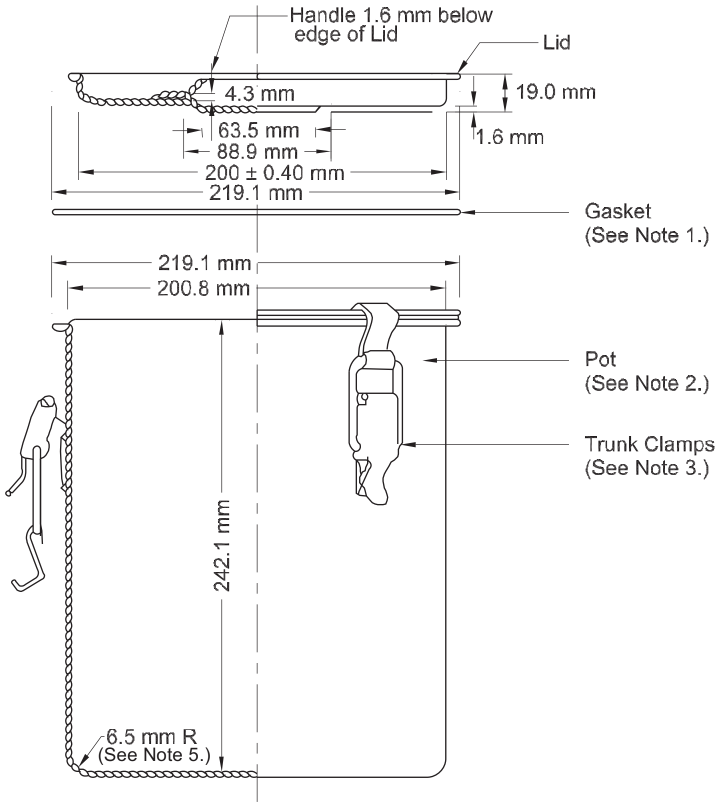
4.3. A minimum durability index is permitted to be specified to prohibit the use of an aggregate that is prone to degradation and will result in generation of claylike fines in various construction applications.

4.4. This method provides a rapid test for evaluation of the quality of a new aggregate source. Research has indicated it may also be suitable for use instead of the sodium sulfate soundness test for evaluating the durability characteristics of fine aggregate for use in portland-cement concrete, thereby reducing the need for time-consuming and expensive soundness tests.[2]

4.5. Although the application of this method has been limited to aggregates for specific construction uses, the possibility exists for expanding the application of this method to control the quality of aggregates used in other areas of construction, such as aggregates for use in bituminous paving mixtures, coarse aggregate for use in portland-cement concrete, and aggregate for use as railroad ballast.

5. APPARATUS

5.1. *Mechanical Washing Vessel (Pot)*—A flat-bottomed, straight-sided cylindrical vessel conforming to the specifications and dimensions shown in Figure 1.



Dimensional Equivalents

mm	in.	mm	in.	mm	in.
242.1	$9^{17}/_{32}$	199.2	$7^{27}/_{32}$	6.4	$^1/_4$
219.1	$8^5/_8$	88.9	$3^1/_2$	1.6	$^1/_{16}$
216.3	$8^{33}/_{64}$	63.5	$2^1/_2$	0.8	$^1/_{32}$
200.8	$7^{29}/_{32}$	19.0	$^3/_4$	0.40	$^1/_{64}$
200.0	$7^7/_8$	14.3	$^9/_{16}$		

Notes:

1. The gasket will be 3.2-mm ($^1/_8$-in.) neoprene rubber, having an inside diameter of 199.23 ± 0.40 mm ($7\ ^{27}/_{32} \pm {}^1/_{64}$ in.) and an outside diameter of 216.30 ± 0.40 mm ($8\ ^{33}/_{64} \pm {}^1/_{64}$ in.).
2. The pot shall be a flat bottom, straight-sided, cylindrical vessel with a capacity of approximately 4 L (2 gal). The top edge shall be flared outward to form a seal for the gasket and lid.
3. Three trunk clamps are required and shall be placed at one-third intervals. The clamps shall be attached to the pot by rivets or welds so that the pot remains watertight. When fitted with the 3.2-mm ($^1/_8$-in.) gasket and clamped in place, the lid shall form a watertight seal with the flared edge of the pot.
4. The vessel shall be 0.9-mm (20-gauge) stainless steel, unless otherwise noted. All dimensions shall be within ± 0.8 mm ($\pm\ ^1/_{32}$ in.), unless otherwise noted.
5. The bottom side inside radius shall be no larger than 6.4 mm ($^1/_4$ in.) with an allowable tolerance of –0.8 mm ($-^1/_{32}$ in.).

Figure 1—Mechanical Washing Vessel

5.2. *Collection Pan*—A round pan at least 250 mm (10 in.) in diameter and at least 100 mm (4 in.) deep, suitable to collect the wash water from the washed sample. The pan shall have vertical or nearly vertical sides and shall be equipped as necessary to hold the wire mesh of a 203-mm (8-in.) diameter sieve at least 76 mm (3 in.) above the bottom. An adaptor that will not allow loss of fines or wash water may be used to nest the sieve with the container, or the sieve may be nested with a blank sieve frame resting in the bottom of the pan.

5.3. *Agitator*—A mechanical device designed to hold the wash vessel in an upright position while subjecting it to a lateral reciprocating motion at a rate of 285 ± 10 complete cycles per minute. The reciprocating motion shall be produced by means of an eccentric in the base of the carrier and the length of the stroke shall be 44.5 ± 0.6 mm (1.75 ± 0.025 in.). The clearance between the cam and follower of the eccentric shall be 0.25 to 1.02 mm (0.001 to 0.004 in.).

5.4. All equipment required to perform T 176.

5.5. *Sieves*—The sieves shall conform to M 92.

5.6. *Balance*, conforming to the requirements of M 231, Class G 2.

6. REAGENTS AND MATERIALS

6.1. *Calcium Chloride Solutions*—Use stock and working calcium chloride solutions as specified in Section 7 of T 176.

6.2. *Water*—Use distilled or demineralized water for the normal performance of this method. The test results are likely to be affected by certain minerals dissolved in water. However, if it is determined that local tap water is of such purity that it does not affect the test results, the use of tap water is permissible in place of distilled or demineralized water. For referee purposes, distilled or demineralized water shall be used for all steps in the test.

7. TEMPERATURE CONTROL

7.1. This test is normally performed without strict temperature control; however, for referee purposes, retest the material with the temperature of the distilled or demineralized water and the working calcium chloride solution at 22 ± 3°C (72 ± 5°F).

8. SAMPLING

8.1. Obtain samples of the aggregate to be tested in accordance with T 2.

9. INITIAL SAMPLE PREPARATION

9.1. Dry aggregate samples sufficiently to permit a complete separation on the 4.75-mm (No. 4) sieve and to develop a free-flowing condition in the portion passing the sieve. Perform drying by any method that does not heat the aggregate in excess of 60°C (140°F) or cause degradation of the particles. The use of sunlight, ovens, or forced drafts of warm air are the most common drying methods.

9.2. If the sample contains an appreciable amount of clay, turn the aggregate frequently during the drying process to obtain even drying throughout and prevent the formation of hard clay lumps.

9.3. Break up any hard clods and remove coatings of fines from the coarse aggregate particles by any means that will not appreciably reduce the natural individual particle sizes.

9.4. Determine the sample grading by sieving in accordance with T 27 on the 19.0-, 12.5-, 9.5-, 4.75-, 2.36-, and 1.18-mm ($^3/_4$-, $^1/_2$-, $^3/_8$-in. and Nos. 4, 8, and 16) sieves. Discard any material that is retained on the 19.0-mm ($^3/_4$-in.) sieve.

9.5. Determine the test procedures to be used for establishing the durability index of the aggregate based upon the grading of the aggregate as determined in Section 9.4.

9.5.1. If less than 10 percent of the aggregate passes the 4.75-mm (No. 4) sieve, test coarse aggregate (Procedure A) only.

9.5.2. If less than 10 percent of the aggregate is coarser than the 4.75-mm (No. 4) sieve, test fine aggregate (Procedure B) only.

9.5.3. When both coarse and fine aggregate fractions are each present in quantities equal to or greater than 10 percent and if the percent passing the 1.18-mm (No. 16) sieve is greater than 10 percent, use both Procedures A and B on the appropriate aggregate sizes. If the percent passing the 1.18-mm (No. 16) sieve is less than or equal to 10 percent, use Procedure A or Procedure C.

9.5.4. If most of the aggregate (75 to 80 percent) is retained between the 9.5- and 1.18-mm ($^3/_8$-in. and No. 16) sieves, use Procedure C only.

PROCEDURE A—COARSE AGGREGATE

10. TEST SAMPLE PREPARATION

10.1. Prepare a 2550 ± 25 g (air-dry) preliminary test sample using the grading given below:

Aggregate Size	Air Dry Mass, g
19.0 to 12.5 mm ($^3/_4$ to $^1/_2$ in.)	1070 ± 10
12.5 to 9.5 mm ($^1/_2$ to $^3/_8$ in.)	570 ± 10
9.5 to 4.75 mm ($^3/_8$ in. to No. 4)	910 ± 5
	2550 ± 25

For materials with less than 10 percent in any of the fractions specified in the above table, prepare the test specimen using the actual calculated percentage for the deficient fraction and proportionally increase the weights of the remaining fractions to obtain the 2550-gram test specimen.

Example 1—Less than 10 percent of $^3/_4$- to $^1/_2$ in. (19.0- to 12.5-mm) material in aggregate.

Aggregate Sieve Size	Percent Each Size	Calculations	Air Dry Weight, g
19.0 to 12.5 mm ($^3/_4$ in. to $^1/_2$ in.)	6	0.06 × 2550	153 ± 10
12.5 to 9.5 mm ($^1/_2$ in. to $^3/_8$ in.)	36	$\frac{570\ (2550 - 153)}{570 + 910}$	923 ± 10
9.5 to 4.75 mm ($^3/_8$ in. to No. 4)	58	$\frac{910\ (2550 - 153)}{570 + 910}$	1474 ± 5
Totals	100		2550 ± 25

Example 2—Less than 10 percent of $^3/_4$- to $^1/_2$-in. (19.0- to 12.5 mm) and $^1/_2$- × $^3/_8$-in. (12.5- to 9.5-mm) material in aggregate.

Aggregate Sieve Size	Percent Each Size	Calculations	Air Dry Weight, g
19.0 to 12.5 mm ($^3/_4$ in. to $^1/_2$ in.)	4	0.04 × 2550	102 ± 10
12.5 to 9.5 mm ($^1/_2$ in. to $^3/_8$ in.)	7	0.07 × 2550	179 ± 10
9.5 to 4.75 mm ($^3/_8$ in. to No. 4)	89	2550 – (102 + 179)	2269 ± 5
Totals	100		2550 ± 25

Example 3—No $^3/_4$- to $^1/_2$-in. (19.0- to 12.5-mm) material in aggregate.

Aggregate Sieve Size	Percent Each Size	Calculations	Air Dry Weight, g
19.0 to 12.5 mm ($^3/_4$ in. to $^1/_2$ in.)	None present	0 × 2550	0
12.5 to 9.5 mm ($^1/_2$ in. to $^3/_8$ in.)	39	$\frac{570\ (2550 - 0)}{570 + 910}$	982 ± 10
9.5 to 4.75 mm ($^3/_8$ in. to No. 4)	61	$\frac{910\ (2550 - 0)}{570 + 910}$	1568 ± 10
Totals	100		2550 ± 25

Remainder of 10.1 does not change.

Dry the preliminary test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F), allow to cool, and determine the mass. Record the resulting mass, *W*.

Note 1—If an adjustment of the test specimen mass or volume of wash and test water (Section 10.3), or both, is not required, it is not necessary to oven-dry the test sample prior to the initial wash.

10.2. Place the preliminary test sample in the mechanical washing vessel, and add 1000 ± 5 mL of distilled or demineralized water.

Note 2—Sections 10.3 through 10.3.4 are only necessary if the preliminary test sample is not completely inundated after the specified amount of water is added to the washing vessel pot.

10.3. Because of the low-specific gravity or high-absorption rate, or both, of some aggregates, the proportions of aggregate to water will not provide the intended interparticle abrasion. Testing of these materials will require adjustment of the test specimen mass or volume of both wash and test water, or both.

10.3.1. Wash all materials that are not completely inundated when 1000 mL of water are added to the test sample and test with adjusted sample masses and water volumes.

10.3.2. Determine the bulk, oven-dry specific gravity, and percentage of absorption of the aggregate in accordance with T 85.

10.3.3. Adjust the total mass of the test sample using the following equation:

Adjusted sample mass,

$$g = \frac{\text{Specific Gravity of Aggregate}}{2.65} \times W \tag{1}$$

Adjust the mass of material in each size fraction proportionally to the masses specified in Section 10.7.

10.3.4. Adjust the volume of test water using the following equation:

$$\text{Adjusted Water} = 1000 + (A \times W) - 50 \tag{2}$$

where:

A = absorption of aggregate, percent (expressed as a decimal fraction); and

W = mass of oven-dried test sample, g.

10.4. Clamp the vessel lid in place, and secure the vessel in the agitator. Begin agitation after a time of 60 ± 10 seconds has elapsed from the introduction of the wash water. Agitate the vessel for 120 ± 5 seconds.

10.5. After the 2-minute agitation time is completed, remove the vessel from the agitator, unclamp the lid and pour the contents onto a 4.75-mm (No. 4) sieve. Rinse any remaining fines from the vessel onto the sieve and direct water (from a flexible hose attached to a faucet) onto the aggregate until the water passing through the sieve comes out clear.

10.6. Dry the fraction retained on the 4.75-mm (No. 4) sieve to constant mass at a temperature of 110 ± 5°C (230 ± 9°F) and determine the mass. If the loss in mass due to washing in accordance with Sections 10.2, 10.3, 10.4, and 10.5 is equal to or less than 75 g, a test sample suitable for further testing has been prepared and the procedures in Sections 10.7 through 10.12 are omitted. If the loss in mass exceeds 75 g, the preliminary test sample is permitted to be retained and used if a second sample is washed by the same procedure and the two samples are combined according to the specified masses to provide the desired test sample.

10.7. Determine the grading to be used in preparing the preliminary test sample as follows: If each of the aggregate sizes listed in the following table represents 10 percent or more of the 19.0-mm to 4.75-mm ($^3/_4$-in. to No. 4) portion, as determined from the masses recorded in Section 9.4, use the oven-dry masses of material specified below for preparing the preliminary test sample.

Aggregate Size	Air Dry Mass, g
19.0 to 12.5 mm ($^3/_4$ in. to $^1/_2$ in.)	1050 ± 10
12.5 to 9.5 mm ($^1/_2$ in. to $^3/_8$ in.)	550 ± 10
9.5 to 4.75 mm ($^3/_8$ in. to No. 4)	900 ± 5
	2500 ± 25

Note 3—For materials with less than 10 percent in any of the fractions specified in the above table, prepare the test specimen using the actual calculated percentage for the deficient fraction and proportionally increase weights of the remaining fractions using the method shown in Section 10.1.

10.8. Prepare a 2500 g preliminary test sample using the prescribed grading. Dry the test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F).

10.9. Mechanically wash the preliminary sample in the same manner as prescribed in Sections 10.2, 10.3, 10.4, and 10.5.

10.10. Repeat Sections 10.8 and 10.9, if necessary, to obtain sufficient material to yield a washed test sample of 2500 ± 25 g and contain each size fraction in the quantity specified in Section 10.7.

10.11. After allowing the oven-dried material to cool, separate the washed coarse aggregate on the 12.5-, 9.5-, and 4.75-mm ($^1/_2$-, $^3/_8$-in., and No. 4) sieves. Discard the material passing the 4.75-mm (No. 4) sieve.

10.12. Prepare the washed test sample using the masses specified in Section 10.7 from representative portions of each size of washed material. Occasionally a third preliminary test sample is needed to obtain the required mass of material of a specific size.

11. PROCEDURE FOR COARSE AGGREGATE

11.1. Place the plastic cylinder (sand equivalent test cylinder as required in T 176) on a work table, which will not be subjected to vibrations during the performance of the sedimentation phase of the test. Pour 7 mL (0.24 oz) of the stock calcium chloride solution into the cylinder. Place a 4.75-mm and 75-µm (Nos. 4 and 200) sieve on the pan or vessel provided to collect the wash water with 4.75-mm sieve on top. The 4.75-mm sieve serves only to protect the 75-µm sieve.

11.2. Place the washed test sample (as prepared in Section 10) in the mechanical washing vessel. Then add the amount of distilled or demineralized water as determined in Section 10.3, clamp the lid in place, and secure the vessel in the agitator. Begin agitation after a period of 60 seconds has elapsed from the introduction of the wash water. Agitate the vessel for 600 ± 15 seconds.

11.3. Immediately following the agitation period, take the vessel from the agitator and remove the lid. Agitate the contents of the vessel by moving the upright vessel vigorously in a horizontal circular motion five or six times in order to bring the fines into suspension. Immediately pour the contents of the vessel into the nested 4.75-mm and 75-µm (Nos. 4 and 200) sieves placed in the pan provided to collect the wash water. Discard the material retained on the 4.75-mm sieve. Collect all wash water and passing 75-µm material in the collecting pan. To assure that all material finer than 75-µm sieve is washed through the sieve, take the following steps:

11.3.1. As the wash water is draining through the 75-µm (No. 200) sieve, apply a jarring action to the sieve by lightly bumping the side of the sieve frame with the heel of a hand.

11.3.2. When a concentration of the material is retained on the 75-µm (No. 200) sieve, rerinse the fine material by pouring the wash water through the sieve again. To rerinse the material:

11.3.2.1. Allow the wash water to stand undisturbed in the collection pan for a few moments to permit the heavier particles to settle to the bottom.

11.3.2.2. Pour the upper portion of the wash water into another container.

11.3.2.3. Pour the wash water back through the 75-µm (No. 200) sieve and again collect all wash water and passing 75-µm material in the collection pan.

11.3.2.4. Repeat the rinsing procedure as necessary until all of the minus 75-µm (No. 200) material has been washed through the sieve.

11.4. Add distilled or demineralized water to bring the volume of dirty wash water to 1000 ± 5 mL. Then transfer the wash water to a vessel suitable for stirring and pouring.

11.5. Place a funnel in the graduated plastic cylinder. Stir the wash water by hand to bring the fines into suspension. While the water is still turbulent, pour enough of the wash water into the cylinder to bring the level of the liquid to the 381-mm (15-in.) mark.

11.6. Remove the funnel, place the stopper in the end of the cylinder, and prepare to mix the contents immediately.

11.7. Mix the contents of the cylinder by alternately turning the cylinder upside down and right side up, allowing the bubble to completely traverse the length of the cylinder 20 times in approximately 35 seconds.

11.8. At the completion of the mixing process, place the cylinder on the work table and remove the stopper. Allow the cylinder to stand undisturbed for 1200 ± 15 seconds. Then immediately read and record the height of the sediment column to the nearest 2.5 mm (0.1 in.).

Note 4—There are two unusual conditions that may be encountered in this phase of the test procedure. One is that a clearly defined line of demarcation may not form between the sediment and the liquid above it in the specified 20-minute period. If this should occur in a test in which distilled or demineralized water is used, allow the cylinder to stand undisturbed until the clear demarcation line does form; then immediately read and record the height of the column of sediment and the total sedimentation time. If this should occur in a test in which tap water is used, discontinue the test and retest using an untested portion of the sample with distilled or demineralized water. The second unusual condition is that the liquid immediately above the line of demarcation may still be darkly clouded at the end of 20 minutes and the demarcation line, although distinct, may appear to be in the sediment column itself. As for the first case, if tap water was used, rerun the test using a new sample with distilled or demineralized water; otherwise read and record this line of demarcation at the end of the specified 20-minute sedimentation period as usual.

PROCEDURE B—FINE AGGREGATE

12. TEST SAMPLE PREPARATION

12.1. Split or quarter a representative portion from the material passing the 4.75-mm (No. 4) sieve of sufficient mass to obtain an oven-dry mass of 500 ± 25 g.

12.2. Dry the preliminary test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). Cool to room temperature.

12.3. Place the preliminary test sample in the mechanical washing vessel, add 1000 ± 5 mL of distilled or demineralized water, and clamp the vessel lid in place. Secure the vessel in the agitator in sufficient time to begin agitation after 600 ± 30 seconds have elapsed from the introduction of the wash water. Agitate the vessel for a period of 120 ± 5 seconds.

12.4. After the 2-minute agitation period is completed, remove the vessel from the agitator, unclamp the lid, and carefully pour the contents into the protected 75-µm (No. 200) sieve described in Section 11.1. Rinse any remaining fines from the vessel onto the sieve. Direct the water (from flexible hose attached to a faucet) onto the aggregate until the water passing through the sieve comes out clear.

12.5. If necessary, flood clayey or silty samples prior to pouring them over the sieve to prevent clogging the 75-µm (No. 200) sieve. Flood by adding water to the vessel following the agitation period. Use repeated flooding as necessary before all of the contents of the vessel can be poured over the sieve.

12.6. Following the rinsing, transfer the material from the sieve to a drying pan, and dry to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). It is necessary to wash the material from the 75-µm (No. 200) sieve in order to transfer the retained material to a drying pan. Leave the pan in a slanted position until the free water that drains to the lower side becomes clear; then pour off this clear water. Use large shallow pans and spread the sample as thin as possible to speed drying.

12.7. After allowing the oven-dried material to cool, split or quarter a sufficient amount of the washed material to fill the 85-mL (3-oz) measuring tin to overflowing. While filling the tin measure, tap the bottom edge of the tin on a work table or other hard surface to cause consolidation of the material and allow the maximum amount to be placed in the measuring tin. After filling and consolidation is complete, strike off to level using a straightedge. Use extreme care in this procedure to obtain a truly representative sample.

Note 5—The use of a sample splitter meeting the requirements of T 248 is considered preferable.

13. PROCEDURE FOR FINE AGGREGATE

13.1. Conduct a sand equivalent test in accordance with T 176, except use a mechanical shaker to continuously shake the cylinder and contents for 600 ± 15 seconds.

PROCEDURE C—AGGREGATES TOO FINE TO BE TESTED AS COARSE AGGREGATE AND TOO COARSE TO BE TESTED AS FINE AGGREGATE

14. TEST SAMPLE PREPARATION

14.1. Procedure C has been developed to test aggregates, such as pea gravel, and other aggregates contained primarily between the 9.5- and 1.18-mm ($^3/_8$-in. and No. 16) sieves. Such aggregates are too fine to be tested as coarse aggregate and too coarse to be tested as sand.

14.2. Prepare a test sample using the procedure in Section 12.

15. PROCEDURE

15.1. Fill the plastic cylinder to the 102.0 ± 2.5 mm (4 ± 0.1 in.) level with distilled or demineralized water. Pour the prepared test specimen into the cylinder using a funnel to avoid spillage. Tap the bottom of the cylinder sharply with the heel of the hand, as necessary, to release air bubbles and promote thorough wetting. Allow to stand undisturbed for 10 ± 1 minutes.

15.2. Stopper the cylinder, loosen the material from the bottom, and place the cylinder in the mechanical sand equivalent shaker. Start the timer and allow the machine to shake the cylinder and contents for 30 ± 1 minute.

15.3. At the end of the shaking period, remove the cylinder from the shaker and transfer the water and passing 75-µm (No. 200) material to another cylinder containing 7 mL (0.24 oz) of stock calcium chloride solution as follows:

15.3.1. Nest the 2.36-mm and 75-µm (Nos. 8 and 200) sieves into a funnel that empties into the second cylinder. Hold the mouth of the inverted cylinder over the nested sieves and remove the stopper, permitting the sample and water to pour onto the sieves. Rinse the remaining fines from the inverted cylinder onto the sieves with a small amount of fresh distilled water. Rinse the material retained on the sieves with additional fresh distilled water to assure that all minus 75-µm (No. 200) material passes through the sieve. Take care not to fill the cylinder above the 380-mm (15-in.) mark. Allow time for the water to drain through the sieves and then add enough fresh distilled water to bring the level of the liquid to the 380-mm (15-in.) mark. Stopper the cylinder and mix the contents by inverting 20 times in 35 seconds.

15.4. Allow the cylinder to stand undisturbed for 1200 ± 15 seconds from the time of completion of mixing, then read the top of the clay suspension to the nearest 2.5 mm (0.1 in.).

CALCULATION

16. PROCEDURE A—COARSE AGGREGATE

16.1. Compute the durability index of the coarse aggregate to the nearest whole number using the following equation:

$$D_c = 30.3 + 20.8 \cot\left(0.29 + 0.0059\,H\right) \qquad (3)$$

where:

D_c = durability index;

H = height of sediment, mm, and the quantity (0.29 – 0.0059 H) is in radians.

16.2. Solutions of Equation 3 are given in Table 1.

Table 1—Durability Index of Coarse Aggregate

Sediment Height		D_c	Sediment Height		D_c	Sediment Height		D_c	Sediment Height		D_c	Sediment Height		D_c
mm	in.		mm	in.		mm	in.		mm	in.		mm	in.	
0.0	0.0	100	76.2	3.0	53	152.4	6.0	39	228.6	9.0	29	304.8	12.0	18
2.5	0.1	96	78.7	3.1	52	154.9	6.1	38	231.1	9.1	29	307.3	12.1	18
5.1	0.2	93	81.3	3.2	52	157.5	6.2	38	233.7	9.2	28	309.9	12.2	18
7.6	0.3	90	83.8	3.3	51	160.0	6.3	38	236.2	9.3	28	312.4	12.3	17
10.2	0.4	87	86.4	3.4	51	162.6	6.4	37	238.8	9.4	28	315.0	12.4	17
12.7	0.5	85	88.9	3.5	50	165.1	6.5	37	241.3	9.5	27	317.5	12.5	16
15.2	0.6	82	91.4	3.6	49	167.6	6.6	37	243.8	9.6	27	320.0	12.6	16
17.8	0.7	80	94.0	3.7	49	170.2	6.7	36	246.4	9.7	27	322.6	12.7	15
20.3	0.8	78	96.5	3.8	48	172.7	6.8	36	248.9	9.8	26	325.1	12.8	15
22.9	0.9	76	99.1	3.9	48	175.3	6.9	36	251.5	9.9	26	327.7	12.9	14
25.4	1.0	74	101.6	4.0	47	177.8	7.0	35	254.0	10.0	26	330.2	13.0	14
27.9	1.1	73	104.1	4.1	47	180.3	7.1	35	256.5	10.1	25	332.7	13.1	13
30.5	1.2	71	106.7	4.2	46	182.9	7.2	35	259.1	10.2	25	335.3	13.2	13
33.0	1.3	70	109.2	4.3	46	185.4	7.3	34	261.6	10.3	25	337.8	13.3	12
35.6	1.4	68	111.8	4.4	45	188.0	7.4	34	264.2	10.4	24	340.4	13.4	12
38.1	1.5	67	114.3	4.5	45	190.5	7.5	34	266.7	10.5	24	342.9	13.5	11
40.6	1.6	66	116.8	4.6	44	193.0	7.6	33	269.2	10.6	24	345.4	13.6	11
43.2	1.7	65	119.4	4.7	44	195.6	7.7	33	271.8	10.7	23	348.0	13.7	10
45.7	1.8	63	121.9	4.8	43	198.1	7.8	33	274.3	10.8	23	350.5	13.8	9
48.3	1.9	62	124.5	4.9	43	200.7	7.9	32	276.9	10.9	23	353.1	13.9	9
50.8	2.0	61	127.0	5.0	43	203.2	8.0	32	279.4	11.0	22	355.6	14.0	8
55.4	2.1	60	129.5	5.1	42	205.7	8.1	32	281.9	11.1	22	358.1	14.1	7
55.9	2.2	59	132.1	5.2	42	208.3	8.2	31	284.5	11.2	22	360.7	14.2	7
58.4	2.3	59	134.6	5.3	41	210.8	8.3	31	287.0	11.3	21	363.2	14.3	6
61.0	2.4	58	137.2	5.4	41	213.4	8.4	31	289.6	11.4	21	365.8	14.4	5
63.5	2.5	57	139.7	5.5	40	215.9	8.5	30	292.1	11.5	20	368.3	14.5	4
66.0	2.6	56	142.2	5.6	40	218.4	8.6	30	294.6	11.6	20	370.8	14.6	4
68.6	2.7	55	144.8	5.7	40	221.0	8.7	30	297.2	11.7	20	373.4	14.7	3
71.1	2.8	54	147.3	5.8	39	223.5	8.8	29	299.7	11.8	19	375.9	14.8	2
73.7	2.9	54	149.9	5.9	39	226.1	8.9	29	302.3	11.9	19	378.5	14.9	1
												381.0	15.0	0

Note: $D_c = 30.3 + 20.8 \cot (0.29 + 0.0059\,H)$[a].

[a] H is measured in mm.

17. PROCEDURE B—FINE AGGREGATE

17.1. Calculate the durability index of the fine aggregate to the nearest 0.1 using the following equation:

$$D_f = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100 \qquad (4)$$

17.2. If the calculated durability index is not a whole number, report it as the next higher whole number. For example, if the clay reading was recorded as 203.2 mm (8.0 in.) and the sand reading was recorded as 83.8 mm (3.3 in.), the calculated durability index would be: D_f = (83.8/203.2) × 100 or 41.2; report as 42.

17.3. If it is desired to average a series of values, average the whole number values as determined in Section 17.2. If the average of these values is not a whole number, round it to the next higher whole number as shown in the following example:

Example—Calculated D_f values are 41.2, 43.8, and 40.9, which, when rounded to the next higher whole number, become 42, 44, and 41. The average of these values is then determined: (42 + 44 + 41)/3 = 42.3; and reported as 43.

18. PROCEDURE C—AGGREGATES TOO FINE TO BE TESTED AS COARSE AGGREGATE AND TOO COARSE TO BE TESTED AS FINE AGGREGATE

18.1. Calculate the durability index in accordance with Section 16.

PRECAUTIONS

19. PRECAUTIONS

19.1. Perform the test in a location free of vibrations, because vibrations may cause the suspended material to settle at a greater rate than normal.

19.2. Do not expose the plastic cylinders to direct sunlight any longer than is necessary.

19.3. Frequently check the play between the cam and eccentric on the agitator by grasping one of the hanger rods and attempting to move the sieve base. If any play is noticed, replace the cam or bearing, or both.

19.4. Lubricate the agitator at least once every three months.

REPORT

20. REPORT

20.1. Report the "as-received" sieve analysis of the aggregate subjected to testing, the sieve analysis of the coarse sample used, and the sieve analysis of the fine sample used. Report the calculated durability index (D_c or D_f) with an indication as to whether Procedure A, B, or C was used.

20.2. Include a statement as to whether or not strict temperature control was maintained, and whether tap, distilled, or demineralized water was used.

PRECISION AND ACCURACY

21. PRECISION AND ACCURACY

21.1. Criteria for judging the acceptability of the durability index values determined by this method are very limited. The data that are tabulated herein were developed by one state agency in the western United States on materials common to that geographical area. The criteria were established by performing 48 individual tests on each of six different aggregates, two of which were coarse aggregates and four of which were fine aggregates. Two tests by two operators in 12 laboratories were performed on each material.

21.2. An indication of the precision of this method of test is presented in Table 2. The single-operator standard deviation and the multilaboratory standard deviation for both the durability index of coarse aggregate (D_c) and the durability index of fine aggregate (D_f) increases as the index decreases.

Table 2—Precision[a]

Coarse Aggregate[b]			Fine Aggregate[c]		
Durability Index	Standard Deviation	Acceptable range of two results	Durability Index	Standard Deviation	Acceptable range of two results
Single-Operator Precision			Single-Operator Precision		
60	3.58	10.1	50	2.40	6.8
65	3.07	8.7	55	2.24	6.3
70	2.56	7.2	60	2.08	5.9
75	2.04	5.8	65	1.92	5.4
80	1.53	4.3	70	1.76	5.0
85	1.01	2.9	75	1.61	4.5
Multilaboratory Precision			Multilaboratory Precision		
60	4.35	12.3	50	5.11	14.4
65	3.72	10.5	55	4.77	13.5
70	3.10	8.8	60	4.43	12.5
75	2.47	7.0	65	4.10	11.6
80	1.85	5.2	70	3.76	10.6
85	1.22	3.5	75	3.42	9.7

[a] These values represent the 1s and d2s limits described in ASTM C 670.

[b] Data for two materials.

[c] Data for four materials.

21.3. The maximum single-operator standard deviation has been found to be 3.58. Therefore, the results of two properly conducted tests by the same operator on the same material are not expected to differ by more than 10.1.

21.4. The maximum multilaboratory standard deviation has been found to be 5.11. Therefore, the results of two properly conducted tests from two different laboratories on samples of the same aggregate are not expected to differ by more than 14.4.

21.5. *Bias*—No information is presented on the bias of the procedure in this test method for measuring the durability index, because no material having an accepted reference value is available.

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[1] Similar, but not technically identical to ASTM D 3744-03.

[2] Hamilton, R. D., R. E. Smith, and G. B. Sherman, “Factors Influencing the Durability of Aggregates,” Research Report 633476, State of California, Division of Highways, Materials, and Research Department, June 1971.

[3] Hveem, F. N., and T. N. Smith, “Durability of Aggregates,” Research Report, State of California, Division of Highways, Materials and Research Department, June 1971.

Standard Method of Test for

Reducing Samples of Aggregate to Testing Size

AASHTO Designation: T 248-02 (2006)[1]
ASTM Designation: C 702-98 (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Reducing Samples of Aggregate to Testing Size

AASHTO Designation: T 248-02 (2006)[1]
ASTM Designation: C 702-98 (2003)

1. SCOPE

1.1. These methods cover the reduction of large samples of aggregate to the appropriate size for testing employing techniques that are intended to minimize variations in measured characteristics between the test samples so selected and the large sample.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 2, Sampling of Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate

2.2. *ASTM Standard*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates

3. TERMINOLOGY

3.1. *definitions*—the terms used in this standard are defined in ASTM C 125.

4. SIGNIFICANCE AND USE

4.1. Specifications for aggregates require sampling portions of the material for testing. Other factors being equal, larger samples will tend to be more representative of the total supply. These methods provide for reducing the large sample obtained in the field or produced in the laboratory to a convenient size for conducting a number of tests to describe the material and measure its quality in a manner that the smaller test sample portion is most likely to be a representation of the larger sample, and thus of the total supply. The individual test methods provide for minimum masses of material to be tested.

4.2. Under certain circumstances, reduction in size of the large sample prior to testing is not recommended. Substantial differences between the selected test samples sometimes cannot be avoided, as for example, in the case of an aggregate having relatively few large-sized particles in the sample. The laws of chance dictate that these few particles may be unequally distributed among the reduced-size test samples. Similarly, if the test sample is being examined for certain contaminants occurring as a few discrete fragments in only small percentages, caution should be used in interpreting results from the reduced-size test sample. Chance inclusion or exclusion of only one or two particles in the selected test sample may importantly influence interpretation of the characteristics of the original sample. In these cases, the entire original sample should be tested.

4.3. Failure to carefully follow the procedures in these methods could result in providing a nonrepresentative sample to be used in subsequent testing.

5. SELECTION OF METHOD

5.1. *Fine Aggregate*—Samples of fine aggregate that are drier than the saturated-surface-dry condition (Note 1) shall be reduced in size by a mechanical splitter according to Method A. Samples having free moisture on the particle surfaces may be reduced in size by quartering according to Method B, or by treating as a miniature stockpile as described in Method C.

5.1.1. If the use of Method B or Method C is desired, and the sample does not have free moisture on the particle surfaces, the sample may be moistened to achieve this condition, thoroughly mixed, and then the sample reduction performed.

Note 1—The method of determining the saturated-surface-dry condition is described in T 84. As a quick approximation, if the fine aggregate will retain its shape when molded in the hand, it may be considered to be wetter than saturated-surface-dry.

5.1.2. If use of Method A is desired and the sample has free moisture on the particle surfaces, the entire sample may be dried to at least the surface-dry condition, using temperatures that do not exceed those specified for any of the tests contemplated, and then the sample reduction performed. Alternatively, if the moist sample is very large, a preliminary split may be made using a mechanical splitter having wide chute openings 38 mm ($1^1/_2$ in.) or more to reduce the sample to not less than 5000 g. The portion so obtained is then dried, and reduction to test sample size is completed using Method A.

5.2. *Coarse Aggregates and Mixtures of Coarse and Fine Aggregates*—Reduce the sample using a mechanical splitter in accordance with Method A (preferred method) or by quartering in accordance with Method B. The miniature stockpile Method C is not permitted for coarse aggregates or mixtures of coarse and fine aggregates.

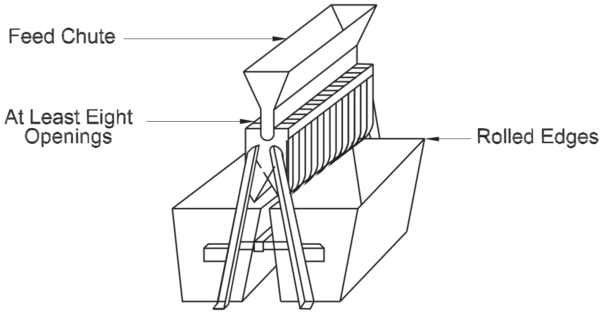
6. SAMPLING

6.1. The samples of aggregate obtained in the field shall be taken in accordance with T 2, or as required by individual test methods. When tests for sieve analysis only are contemplated, the size of field sample listed in T 2 is usually adequate. When additional tests are to be conducted, the user shall determine that the initial size of the field sample is adequate to accomplish all intended tests. Similar procedures shall be used for aggregate produced in the laboratory.

METHOD A—MECHANICAL SPLITTER

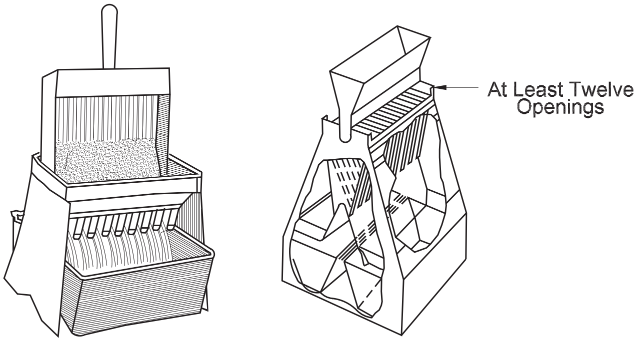
7. APPARATUS

7.1. *Sample Splitter*—Sample splitters shall have an even number of equal width chutes, but not less than a total of eight for coarse aggregate, or 12 for fine aggregate, which discharge alternatively to each side of the splitter. For coarse aggregate and mixed aggregate the minimum width of the individual chutes shall be approximately 50 percent larger than the largest particles in the sample to be split (Note 2). For dry fine aggregate in which the entire sample will pass the 9.5-mm ($^3/_8$-in.) sieve, the minimum width of the individual chutes shall be at least 50 percent larger than the largest particles in the sample and the maximum width shall be 19 mm ($^3/_4$ in.). The splitter shall be equipped with two receptacles to hold the two halves of the sample following splitting. It shall also be equipped with a hopper or straightedged pan, which has a width equal to or slightly less than the overall width of the assembly of chutes, by which the sample may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material (Figure 1).



Riffle Sample Splitter

(a) Large Sample Splitter for Coarse Aggregate



(b) Small Sample Splitters for Fine Aggregate

Note: (a) may be constructed as either closed or open type. Closed type is preferred.

Figure 1—Sample Splitters (Riffles)

Note 2—Mechanical splitters are commonly available in sizes adequate for coarse aggregate having the largest particle not over 37.5 mm ($1^1/_2$ in.).

8. PROCEDURE

8.1. Place the original sample in the hopper or pan and uniformly distribute it from edge to edge, so that when it is introduced into the chutes, approximately equal amounts will flow through each chute. The rate at which the sample is introduced shall be such as to allow free flowing through the chutes into the receptacles below. Reintroduce the portion of the sample in one of the receptacles into the splitter as many times as necessary to reduce the sample to the size specified for the intended test. The portion of the material collected in the other receptacle may be reserved for reduction in size for other tests.

METHOD B—QUARTERING

9. APPARATUS

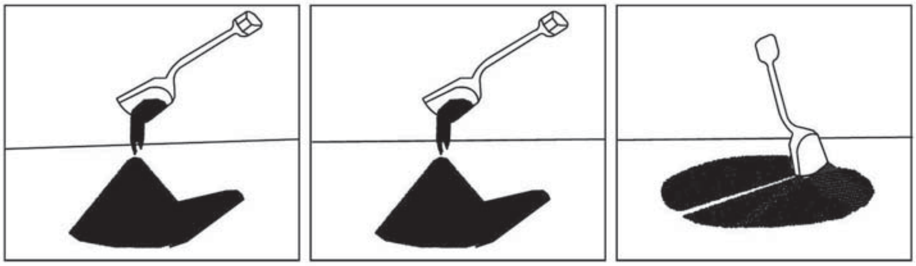
9.1. Apparatus shall consist of a straightedge; straightedged scoop, shovel, or trowel; a broom or brush; and a canvas blanket approximately 2 by 2.5 m (6 by 8 ft).

10. PROCEDURE

10.1. Use either the procedure described in Section 10.1.1 or 10.1.2, or a combination of both.

10.1.1. Place the original sample on a hard, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material. Mix the material thoroughly by turning the entire sample over three times. With the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one. Carefully flatten the conical pile to a uniform thickness and diameter by pressing down the apex with a shovel so that each quarter sector of the resulting pile will contain the material originally in it. The diameter should be approximately four to eight times the thickness. Divide the flattened mass into four equal quarters with a shovel or trowel and remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean. Successively mix and quarter the remaining material until the sample is reduced to the desired size (Figure 2).

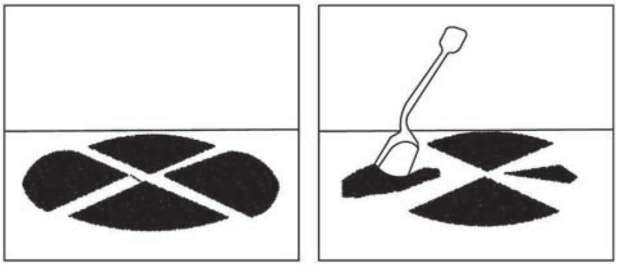
10.1.2. As an alternative to the procedure in Section 10.1.1 when the floor surface is uneven, the field sample may be placed on a canvas blanket and mixed with a shovel as described in Section 10.1.1, or by alternatively lifting each corner of the canvas and pulling it over the sample toward the diagonally opposite corner causing the material to be rolled. Flatten the pile as described in Section 10.1.1. Divide the sample as described in Section 10.1.1, or, if the surface beneath the blanket is uneven, insert a stick or pipe beneath the blanket and under the center of the pile, then lift both ends of the stick, dividing the sample into two equal parts. Remove the stick leaving a fold of the blanket between the divided portions. Insert the stick under the center of the pile at right angles to the first division and again lift both ends of the stick, dividing the sample into four equal parts. Remove two diagonally opposite quarters, being careful to clean the fines from the blanket. Successively mix and quarter the remaining material until the sample is reduced to the desired size (Figure 3).



Cone Sample on Hand Clean Surface

Mix by Forming New Cone

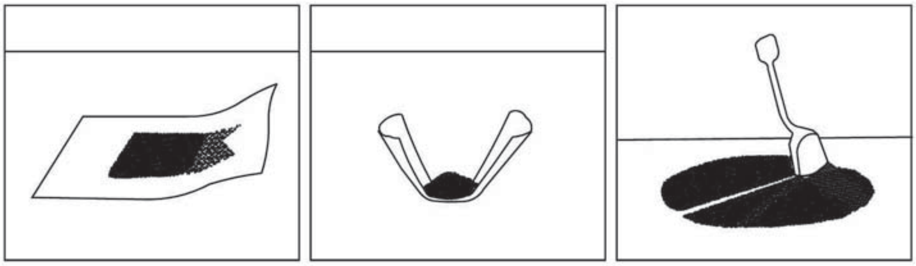
Quarter after Flattening Cone



Sample Divided into Quarters

Retain Opposite Quarters Reject the Other Two Quarters

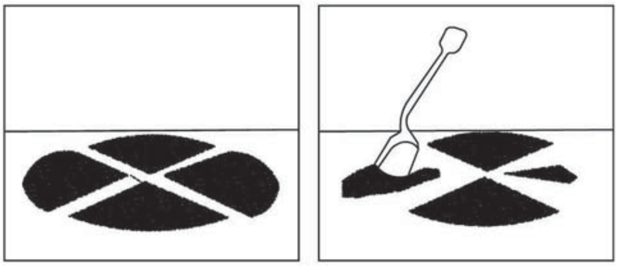
Figure 2—Quartering on a Hard, Clean, Level Surface



Mix by Rolling on Blanket

Form Cone after Mixing

Quarter after Flattening Cone



Sample Divided into Quarters

Retain Opposite Quarters Reject the Other Two Quarters

Figure 3—Quartering on a Canvas Blanket

METHOD C—MINIATURE STOCKPILE SAMPLING (DAMP FINE AGGREGATE ONLY)

11. APPARATUS

11.1. Apparatus shall consist of a straightedge; straightedged scoop, shovel, or trowel for mixing the aggregate; and either a small sampling thief, small scoop, or spoon for sampling.

12. PROCEDURE

12.1. Place the original sample of damp fine aggregate on a hard, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material. Mix the material thoroughly by turning the entire sample over three times. With the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one. If desired, the conical pile may be flattened to a uniform thickness and diameter by pressing the apex with a shovel so that each quarter sector of the resulting pile will contain the material originally in it. Obtain a sample for each test by selecting at least five increments of material at random locations from the miniature stockpile, using any of the sampling devices described in Section 11.1.

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[1] Technically equivalent but not identical to ASTM C 702-98 (2003).

Standard Method of Test for

Total Evaporable Moisture Content of Aggregate by Drying

AASHTO Designation: T 255-00 (2008)[1]
ASTM Designation: C 566-97 (2004)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Total Evaporable Moisture Content of Aggregate by Drying

AASHTO Designation: T 255-00 (2008)[1]
ASTM Designation: C 566-97 (2004)

1. SCOPE

1.1. This test method covers the determination of the percentage of evaporable moisture in a sample of aggregate by drying both surface moisture and moisture in the pores of the aggregate. Some aggregate may contain water that is chemically combined with the minerals in the aggregate. Such water is not evaporable and is not included in the percentage determined by this test method.

1.2. The values stated in SI units are to be regarded as the standard. The values stated in parentheses are provided for information only.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For specific precautionary statements, see Sections 5.3.1, 7.2.1, and 7.3.1.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 2, Sampling of Aggregates
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. For definitions of terms used in this test method, refer to ASTM C 125.

4. SIGNIFICANCE AND USE

4.1. This test method is sufficiently accurate for usual purposes such as adjusting batch quantities of ingredients for concrete. It will generally measure the moisture in the test sample more reliably than the sample can be made to represent the aggregate supply. In rare cases where aggregate itself is altered by heat, or where more refined measurement is required, the test should be conducted using a ventilated, controlled-temperature oven.

4.2. Large particles of coarse aggregate, especially those larger than 50 mm (2 in.), will require greater time for the moisture to travel from the interior of the particle to the surface. The user of this test method should determine by trial if rapid drying methods provide sufficient accuracy for the intended use when drying large-size particles.

5. APPARATUS

5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2. *Source of Heat*—A ventilated oven capable of maintaining the temperature surrounding the sample at 110 ± 5ºC (230 ± 9ºF). Where close control of the temperature is not required (see Section 4.1), other suitable sources of heat may be used, such as an electric or gas hot plate, electric heat lamps, or a ventilated microwave oven.

5.3. *Sample Container*—A container not affected by the heat, and of sufficient volume to contain the sample without danger of spilling, and of such shape that the depth of sample will not exceed one-fifth of the least lateral dimension.

5.3.1. **Precaution**—When a microwave oven is used, the container shall be nonmetallic.

Note 1—Except for testing large samples, an ordinary frying pan is suitable for use with a hot plate, or any shallow flat-bottomed metal pan with heat lamps or oven. Note precaution in Section 5.3.1.

5.4. *Stirrer*—A metal spoon or spatula of convenient size.

6. SAMPLE

6.1. Sampling shall generally be accomplished in accordance with T 2, except the sample size may be as stated in Table 1.

Table 1—Sample Size for Aggregate

Nominal Maximum Size of Aggregate, mm (in.)[a]	Mass of Normal Weight Aggregate Sample, Min., kg[b]
4.75 (0.187) (No. 4)	0.5
9.5 ($^3/_8$)	1.5
12.5 ($^1/_2$)	2
19.0 ($^3/_4$)	3
25.0 (1)	4
37.5 ($1^1/_2$)	6
50 (2)	8
63 ($2^1/_2$)	10
75 (3)	13
90 ($3^1/_2$)	16
100 (4)	25
150 (6)	50

[a] Based on sieves meeting M 92.

[b] Determine the minimum sample mass for lightweight aggregate by multiplying the value listed by the dry-loose unit mass of the aggregate in kg/m3 (determined using T 19M/T 19) and dividing by 1600.

6.2. Secure a sample of the aggregate representative of the moisture content in the supply being tested and having a mass not less than the amount listed in Table 1. Protect the sample against loss of moisture prior to determining the mass.

7. PROCEDURE

7.1. Determine the mass of the sample to the nearest 0.1 percent.

7.2. Dry the sample thoroughly in the sample container by means of the selected source of heat, exercising care to avoid loss of any particles. Very rapid heating may cause some particles to explode, resulting in loss of particles. Use a controlled temperature oven when excessive heat may alter the character of the aggregate, or where more precise measurement is required. If a source of heat other than the controlled temperature oven is used, stir the sample during drying to accelerate the operation and avoid localized overheating. When using a microwave oven, stirring of the sample is optional.

7.2.1. **Caution**—When using a microwave oven, occasionally minerals are present in aggregates that may cause the material to overheat and explode. If this occurs, it can damage the microwave oven.

7.3. When a hot plate is used, drying can be expedited by the following procedure. Add sufficient anhydrous denatured alcohol to cover the moist sample. Stir and allow suspended material to settle. Decant as much of the alcohol as possible without losing any of the sample. Ignite the remaining alcohol and allow it to burn off during drying over the hot plate.

7.3.1. **Warning**—Exercise care to control the ignition operation to prevent injury or damage from the burning alcohol.

7.4. The sample is thoroughly dry when further heating causes, or would cause, less than 0.1 percent additional loss in mass.

7.5. Determine the mass of the dried sample to the nearest 0.1 percent after it has cooled sufficiently not to damage the balance.

8. CALCULATION

8.1. Calculate total evaporable moisture content as follows:

$$p = 100(W - D)/D \qquad (1)$$

where:

p = total evaporable moisture content of sample, percent;
W = mass of original sample, g; and
D = mass of dried sample, g.

8.2. Surface moisture content is equal to the difference between the total evaporable moisture content and the absorption, with all values based on the mass of a dry sample. Absorption may be determined in accordance with T 85, Test for Specific Gravity and Absorption of Coarse Aggregate, or T 84, Test for Specific Gravity and Absorption of Fine Aggregate.

9. PRECISION AND BIAS

9.1. *Precision*:

9.1.1. The within-laboratory single operator standard deviation for moisture content of aggregates has been found to be 0.28 percent (Note 2). Therefore, results of two properly conducted tests by the same operator in the same laboratory on the same type of aggregate sample should not differ by more than 0.79 percent (Note 2) from each other.

9.1.2. The between-laboratory standard deviation for moisture content of aggregates has been found to be 0.28 percent (Note 2). Therefore, results of properly conducted tests from two laboratories on the same aggregate sample should not differ by more than 0.79 percent (Note 2) from each other.

9.1.3. Test data used to derive the above precision indices were obtained from samples dried to a constant mass in a drying oven maintained at 110 ± 5ºC. When other drying procedures are used, the precision of the results may be significantly different than that indicated above.

Note 2—These numbers represent, respectively, the 1s and d2s limits as described in ASTM C 670.

9.2. *Bias*:

9.2.1. When experimental results are compared with known values from accurately compounded specimens, the following has been derived.

9.2.1.1. The bias of moisture tests on one aggregate material has been found to have a mean of +0.06 percent. The bias of individual test values from the same aggregate material has been found with 95 percent confidence to lie between –0.07 percent and +0.20 percent.

9.2.1.2. The bias of moisture tests on a second aggregate material has been found to have a mean of less than +0.01 percent. The bias of individual test values from the same aggregate material has been found with 95 percent confidence to lie between –0.14 percent and +0.14 percent.

9.2.1.3. The bias of moisture tests overall on both aggregate materials has been found to have a mean of +0.03 percent. The bias of individual test values overall from both aggregate materials has been found with 95 percent confidence to lie between –0.12 percent and +0.18 percent.

9.2.2. Test data used to derive the above bias statement were obtained from samples dried to a constant mass in a drying oven maintained at 110 ± 5ºC. When other drying procedures are used, the bias of the results may be significantly different than that indicated above.

Note 3—These precision and bias statements were derived from aggregate moisture data provided by 17 laboratories participating in the SHRP Soil Moisture Proficiency Sample Program, which is fully described in the National Research Council Report SHRP-P-619. The samples tested that relate to these statements were well-graded mixtures of fine and coarse aggregate with moisture contents ranging from air dry to saturated surface dry.

10. KEYWORDS

10.1. Aggregate; drying; moisture content.

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[1] This method is technically equivalent with ASTM C 566-97 (2004), except for the balance statement in Section 5.1.

Standard Method of Test for

Accelerated Polishing of Aggregates Using the British Wheel

AASHTO Designation: T 279-96 (2006)
ASTM Designation: D 3319-90

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Accelerated Polishing of Aggregates Using the British Wheel

AASHTO Designation: T 279-96 (2006)
ASTM Designation: D 3319-90

1. SCOPE

1.1. This method covers a laboratory procedure by which an estimate may be made of the extent to which different coarse aggregates may polish.

1.2. The values stated in SI units are regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the users of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 261, Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests
- T 2, Sampling of Aggregates
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 278, Surface Frictional Properties Using the British Pendulum Tester

2.2. *ASTM Standards*:

- C 778, Standard Specification for Standard Sand
- D 75, Standard Practice for Sampling Aggregates
- D 1415, Standard Test Method for Rubber Property—International Hardness [1]
- E 303, Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester

3. SIGNIFICANCE AND USE

3.1. This test method simulates the polishing action of vehicular traffic on coarse aggregates used in bituminous pavements.

3.2. A polish value is determined that may be used to rate or classify coarse aggregates for their ability to resist polishing under traffic.

4. TERMINOLOGY

4.1. *Definitions*:

4.1.1. *initial friction value*—the initial British Pendulum Tester readings on the test specimens before they are polished in the accelerated polishing machine.

4.1.2. *polish value (PV)*—a measure of the state of polish reached by a test specimen subjected to accelerated polishing using the materials, equipment, and procedures described in this method. The measurement is made using the British Pendulum Tester as described in Section 5.3 and T 278.

5. APPARATUS

5.1. *Accelerated Polishing Machine*[2]—An accelerated polishing machine, also known as the British Wheel, and based upon a 1958 design by the Road Research Laboratory of Great Britain. This machine shall be mounted on a firm, rigid, and level base. The equipment shall include the following:

5.1.1. *Cylindrical Wheel*—Hereafter referred to as the road wheel, and having a flat surface periphery and of such size and shape as to permit 14 specimens described below to be clamped onto the periphery to form a continuous surface of aggregate particles, 44.5 mm ($1^3/_4$ in.) wide and 406.4 mm (16 in.) in diameter.

5.1.2. A means of rotating the road wheel about its own axis at a speed of 320 ± 5 rpm.

5.1.3. A means of bringing the surface of a rubber-tired wheel 203.2 mm (8 in.) in diameter and 50.8 mm (2 in.) wide to bear on the aggregate specimens mounted on the surface of the road wheel with a total load of 391.44 ± 4.45 N (88 ± 1 lbf). The tire shall be treated, if necessary, to obtain a true running surface. The tire shall be free to rotate about on its own axis, which shall be parallel to the axis of the road wheel. The plane of rotation of the tire shall coincide with that of the road wheel. Before a new tire is used on a test, it should be conditioned by a preliminary run of 6 hours with a 150-grit silicon carbide using dummy specimens (extra or used) on the road wheel.

5.1.3.1. *Alternate Tire No. 1*—An industrial 8 × 2 pneumatic smooth-tread hand-truck tire (Note 1). The tire rubber hardness shall be 55 ± 5 IRHD measured in accordance with ASTM D 1415. The tire shall be inflated to a pressure of 310.26 ± 13.79 kPa (45 ± 2 psi).

Note 1—This is the tire originally supplied with the Accelerated Polishing Machine[2] and known by the tire manufacturer's designation Dunlop® RLI 8 × 2. Dunlop discontinued manufacturing this tire in February 1979. It is retained as an alternate in this test method for those users who may still have a supply and in the event that Dunlop should resume manufacturing it in the future.

5.1.3.2. *Alternate Tire No. 2*—An industrial 8-in. OD × 4-in. ID (2.80 × 4), 4 NHS-4 ply, cross-hatch pattern tread hand-truck tire (Note 2). The tire shall be inflated to a pressure of 241.32 ± 13.79 kPa (35 ± 2 psi).

Note 2—When it became known that the Dunlop® tire (Section 5.1.3.1) was no longer being manufactured, the necessity of finding a replacement tire for the test method was evident. A search and study by the Texas State Department of Highways and Public Transportation culminated in finding this tire, a Goodyear® Industrial All Weather Hand-Truck tire size 2.80 × 4 (Goodyear Product Code 202-008-002), to give polish values equal to those obtained with the Dunlop® tire.[3] A suitable inner-tube such as Goodyear® G250-4 (Product Code 199-010-700) is necessary. It was also found necessary to modify the 4-in. wheel furnished with the Accelerated Polish Machine to facilitate mounting the Goodyear® tire. Approximately 0.10 in. should be removed from the wheel diameter and a larger hole provided for the valve stem. This did not affect mounting and use of the Dunlop® tire.

5.1.4. A means to feed the 150-grit silicon carbide abrasive at the rate given in Section 8.5. The grit shall be fed continuously and with a uniform distribution across the width of the specimens. The grit shall be applied directly onto the road wheel surface ahead of the point of contact with the rubber-tired wheel.

5.1.5. A means to feed the water at the rate given in Section 8.5 in such a way that the water is spread continuously and uniformly over the surface of the road wheel ahead of the point of contact with the rubber-tired wheel.

5.2. *Metal Molds*—A number of accurately machined metal molds for preparing specimens. The specimen formed is 88.9 by 44.45 by 16.0 mm (3.5 by 1.75 by 0.63 in.) and shall be curved to fit on a surface having a 203.2-mm (8-in.) radius of curvature.

5.3. *British Pendulum Tester*—A friction measuring device. The British Pendulum Tester used shall conform to T 278.

5.3.1. The slider contact path shall be 76.2 ± 1.6 mm (3 ± $^1/_{16}$ in.).

5.3.2. The slider width shall be 31.8 mm ($1^1/_4$ in.).

5.3.3. The rubber that is bonded to the slider shall be 6.4 by 25.4 by 31.8 mm ($^1/_4$ by 1 by $1^1/_4$ in.).

5.3.4. The rubber shall meet the requirements of M 261.

5.3.5. The zero adjustment shall be checked before and after testing the specimens and as often as the operator deems necessary.

5.3.6. The calibration procedures of T 278 shall be used. However, after calibration, the small slider shall be inserted.

6. MATERIALS AND SUPPLIES

6.1. *Water*—A supply of tap water for use where water is required for any purpose in this method.

6.2. *Fine Sand*—A supply of fine sand for sifting into the interstices of the aggregate prior to placing of the bonding material. Standard sand conforming to the requirements of ASTM C 778 has been found suitable for this purpose.

6.3. *Mold-Release Agent*—The use of a mold-release agent is optional. A mold-release agent may be used to prevent bonding between the mold and the bonding material. Silicon release agent and paste wax, as used for automobiles and floors, have been found suitable. The user should use care to prevent this agent from being absorbed by the aggregate as it could affect the measured polish value.

6.4. *Silicon Carbide Grit*—A supply of silicon carbide grit (150-grit size) to be used as the polishing agent. Grit should be checked for gradation using 150-µm (No. 100), 75-µm (No. 200) sieves and separated and recombined if necessary to maintain a uniform gradation for all testing.

6.5. *Bonding Agent*—A supply of polyester resin and catalyst (or another suitable bonding material, such as an epoxy resin) having a pot life of 20 to 30 minutes and a curing time of 3 to 6 hours. This bonding agent shall not be so fluid as to flow through the fine sand.

6.5.1. An optional bonding agent may be used to eliminate use of the fine sand. This bonding agent must be quite viscous so that it will not flow completely around the aggregate particles and become part of the surface of the test specimen. Examples of suitable materials are given in Appendix X1.

6.5.2. Follow the manufacturer's precautions concerning storage and use of resin and catalyst.

6.6. *Coarse Aggregate*—Approximately a 0.014 m^3 ($^1/_2$ ft^3) supply of coarse aggregate to be tested and sampled in accordance with T 2. The aggregate shall be normal plant-run, but laboratory-crushed material may be tested, if so identified.

7. TEST AND CONTROL SPECIMENS

7.1. At least five test specimens for each coarse aggregate shall be tested. (See Section 10.2.)

7.2. Laboratories evaluating only a few coarse aggregates each year shall include standard laboratory control specimens in each run. Two sets containing five test specimens each will allow the inclusion of four control specimens. With an accumulation of polish value history, the control specimens may be eliminated. This will allow an increase in the number of the coarse aggregate test specimens for the two sets.

7.3. The aggregate to be tested shall pass the 12.7-mm ($^1/_2$-in.) sieve and shall be retained on a 9.53-mm ($^3/_8$-in.) sieve.

Note 3—Aggregate gradation may be varied to meet the needs of the user if reported with the test results. However, aggregates larger than 12.7 mm ($^1/_2$ in.) may not be accommodated by the mold, and aggregates smaller than 9.53 mm ($^3/_8$ in.) may not be adequately bonded in the specimen molding process to be retained for the duration of the test.

7.4. Thoroughly wash and dry the aggregate to be tested at 100 to 110ºC to essentially constant mass.

7.5. Coat the mold with mold-release agent.

7.6. Each specimen shall contain a single layer of dry aggregate placed by hand as densely as possible with a flat surface down to cover the bottom 89.9 by 44.45 mm (3.5 by 1.75 in.) surface of the mold.

Note 4—Particles selected should be representative of the material to be evaluated. Flat, elongated, or unusually shaped particles can cause difficulty in placement and bonding. Misleading polish values can result from inadequate surface area for polishing.

7.7. Fill the interstices between the aggregate with the fine sand, described in Section 6.2, from one-fourth to one-half of the aggregate depth.

7.7.1. An optional method eliminates the sand by using a viscous polyester resin. This material is described in Section 6.5.

7.8. Prepare the bonding agent described in Section 6.5 and in accordance with the manufacturer's instructions. The consistency of the bonding agent shall be such that it will flow freely between the aggregate particles but not so thin as to impregnate the sand or to bond this sand to the specimen surface, later preventing its removal. An ideal consistency would be such that the bonding agent must be forced into the voids between the aggregate particles by gentle hand pressure with a spatula.

7.8.1. The optional bonding agent requires a heavier consistency such that it will not flow except with the aid of a spatula.

7.9. Fill the prepared mold to overflow with the bonding material.

Note 5—Care should be used to ensure that the bonding agent is not allowed to penetrate near the aggregate surface to be polished in such a way that the rubber slider may contact it.

7.10. When the bonding material has stiffened sufficiently, strike off the excess material even with the curved sides of the mold.

7.11. When the bonding material has cured properly (3 to 6 hours) remove the specimen from the mold.

7.12. If sand was used, remove all free and excess sand from the face of the specimen.

7.13. If warping prevents proper placement on the road wheel, dress the bottom of the test specimens with a grinding wheel or belt sander to ensure proper fit. Respirators shall be used to prevent breathing the dust.

8. PROCEDURE

8.1. Determine the initial friction value of each prepared test specimen in accordance with T 278 using the slider specified in Section 5.3. Take all readings from the permanent scale.

8.2. Clamp 14 specimens around the periphery of the road wheel (using rubber O-rings near the edge of the specimens) to form a continuous strip of particles upon which the pneumatic-tired wheel shall ride freely without bumping or slipping.

8.3. Maintain the temperature of the specimens, water, and apparatus at 23.9 ± 2.8ºC (75 ± 5ºF) during the entire time of the test.

8.4. Bring the road wheel to a speed of 320 + 5 rpm, and bring the pneumatic-tired wheel to bear on the surface of the specimen with a total load of 391.44 ± 4.45 N (88 ± 1 lbf).

8.5. Feed the No. 150 silicon carbide grit at a rate of 6 ± 2 g/min for the desired testing time (Note 6). Feed the water at the rate of 50 to 75 mL per minute.

Note 6—Aggregates should be subjected to a polishing action of 10 hours, unless maximum polish is achieved in a shorter time. Maximum polish is achieved when no change is detected on successive measurements.

8.6. Remove the specimens from the road wheel and wash thoroughly to remove grit.

8.7. After cleaning, test each specimen to determine the polish value in accordance with T 278 using the slider specified in Section 5.3. Take all readings from the permanent scale.

8.8. If control specimens are used, determine adjustments to the polish value by comparing the polish value obtained for control specimens to the established value for the control aggregate as follows:

PV adjusted = PV Control (Standard)/PV Control (run) – PV Specimen (run)

8.9. If the rate of polish is desired, repeat the procedure in Sections 8.2 to 8.7 at regular intervals of machine time such as 1, 2, 4, 6, 8, and 10 hours.

9. REPORT

9.1. *Report the following information as is appropriate to the needs of the user*:

9.1.1. Identification of the coarse aggregate tested (and the control aggregate, if used) including gradation of aggregate,

9.1.2. Initial friction value for specimens containing aggregates to be evaluated and for control specimens, if used,

9.1.3. Polish values for specimens containing aggregates evaluated and for control specimens, if used,

9.1.4. Length of time and interim polish value of specimens tested for rate-of-polish determination,

9.1.5. Temperature during testing period, and

9.1.6. Dates of testing period.

10. PRECISION AND BIAS

10.1. The only measurement in this method that may be evaluated for precision and bias is the polish value. Refer to Section 7, Precision and Bias, of T 278 for information on precision and number of test specimens.

10.2. If no control specimen is used, it is recommended that seven specimens of the aggregate to be evaluated be tested in order to reduce random testing errors and to increase the confidence level of the test.

APPENDIX

(Nonmandatory Information)

X1. SUITABLE BONDING AGENT

X1.1. The formulation in Table X1.1 entitled “Polyester Bonding Agent” is a polyester bonding agent that has been found to successfully eliminate the need for sand as described in Section 7.

Table X1.1—Polyester Bonding Agent

Parts by Weight	Component	Supplier
100	Polylite 32-773 Polyester Resin[a]	Reichhold Chemical Co.
30	Wollastonite NYAD 400 Extender Pigment[b]	Interpace Corp.[b]
5 to 6	Santocel Z Silica Aerogel,[c]	Monsanto Chemical Co.
	Aerosil 200,[d] or Cab-O-Sil	Degussa, Inc.
	M-5 Colloidal Silica[e]	Godfrey L. Cabot, Inc.
0.5	6 percent Cobalt Naphthenate Solution[a]	Reichhold Chemical Co.

[a] Available from Reichhold Chemical Co., 523 N. Broadway, White Plains, NY 10603.
[b] Available from Interpace Corp., Customer Service Division, Willsboro, NY 12996.
[c] Available from Monsanto Chemical Co., 800 N. Lindberg Blvd, St. Louis, MO 63166.
[d] Available from Degussa, Inc., Route 46 at Hollister Rd., Teterboro, NJ 07608.
[e] Available from Cabot Corp., Cab-O-sil Division, Tuscole, IL 61953.

X1.2. Prepare the grout as follows:

X1.2.1. Add the Wollastonite NYAD 400 to the polyester resin and disperse with a laboratory model Cowles Disperser or similar equipment that will give a good, uniform mix. Then add the Santocel Z or Cab-O-Sil M-5 and grind in with the Cowles Dispenser until a good gel is obtained. The amount of gelling agent may be varied depending upon the stiffness desired. The thixotropy or gel can also be increased by stirring in glycerine at a maximum of 0.1 part by mass following dispersal of the gelling agent. Stir in the cobalt naphthenate.

X1.2.2. Just prior to use, add approximately 0.7 percent mass of 60 percent methyl ethyl ketone peroxide catalyst to the basic polyester grout and stir well. The amount of catalyst may also be varied depending upon the pot life or working time and the speed of cure desired.

X1.3. The working time of a 200-g batch of the catalyzed material is 15 to 20 minutes at 25ºC (77ºF). The cast specimens will cure adequately in 12 hours at 25ºC (77ºF) to perform the accelerated polish test.

Note X1—Other formulations may also be suitable and easily obtained locally. One such material is Preco, Gold Label, Non-Sagging Resin and Powder.[4]

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[1] *Annual Book of ASTM Standards*, Part 37.
[2] Available from Wessex Engineering and Metal Craft C., Ltd., Merchants Barton, Frome, Somerset, England.
[3] Copy of the report on the evaluation of this tire is available at ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.
[4] Available from Preco Industries, Ltd., 55 Skyline Dr., Plainview, NY 11803.

Standard Method of Test for

Uncompacted Void Content of Fine Aggregate

AASHTO Designation: T 304-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Uncompacted Void Content of Fine Aggregate

AASHTO Designation: T 304-08

1. SCOPE

1.1. This method describes the determination of the loose uncompacted void content of a sample of fine aggregate. When measured on any aggregate of a known grading, void content provides an indication of that aggregate's angularity, sphericity, and surface texture compared with other fine aggregates tested in the same grading. When void content is measured on an as-received fine aggregate grading, it can be an indicator of the effect of the fine aggregate on the workability of a mixture in which it may be used.

1.2. Three procedures are included for the measurement of void content. Two use graded fine aggregate (standard grading or as-received grading), and the other uses several individual size fractions for void content determinations:

1.2.1. *Standard Graded Sample (Method A)*—This method uses a standard fine aggregate grading that is obtained by combining individual sieve fractions from a typical fine aggregate sieve analysis. See the section on Preparation of Test Samples for the Grading.

1.2.2. *Individual Size Fractions (Method B)*—This method uses each of three fine aggregate size fractions: (a) 2.36-mm (No. 8) to 1.18-mm (No. 16); (b) 1.18-mm (No. 16) to 600-µm (No. 30); and (c) 600-µm (No. 30) to 300 µm (No. 50). For this method, each size is tested separately.

1.2.3. *As-Received Grading (Method C)*—This method uses that portion of the fine aggregate finer than a 4.75-mm (No. 4) sieve.

1.2.4. See the section on Significance and Use for Guidance on the method to be used.

1.3. The values stated in SI units shall be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates

- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- B 88, Standard Specification for Seamless Copper Water Tube
- B 88M, Standard Specification for Seamless Copper Water Tube (Metric)
- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 778, Standard Specification for Standard Sand

2.3. *ACI Document*:

- ACI 116R, Cement and Concrete Terminology[1]

3. TERMINOLOGY

3.1. Terms used in this standard are defined in ASTM C 125 or ACI 116R.

4. SUMMARY OF TEST METHOD

4.1. A nominal 100-mL calibrated cylindrical measure is filled with fine aggregate of prescribed grading by allowing the sample to flow through a funnel from a fixed height into the measure. The fine aggregate is struck off, and its mass is determined by weighing. Uncompacted void content is calculated as the difference between the volume of the cylindrical measure and the absolute volume of the fine aggregate collected in the measure. Uncompacted void content is calculated using the bulk dry specific gravity of the fine aggregate. Two runs are made on each sample and the results are averaged.

4.1.1. For a graded sample (Method A or Method C) the percent void content is determined directly, and the average value from two runs is reported.

4.1.2. For the individual size fractions (Method B), the mean percent void content is calculated using the results from tests of each of the three individual size fractions.

5. SIGNIFICANCE AND USE

5.1. Methods A and B provide percent void content determined under standardized conditions that depend on the particle shape and texture of a fine aggregate. An increase in void content by these procedures indicates greater angularity, less sphericity, or rougher surface texture, or some combination of the three factors. A decrease in void content results is associated with more rounded, spherical, smooth surfaced fine aggregate, or a combination of these factors.

5.2. Method C measures the uncompacted void content of the minus 4.75-mm (No. 4) portion of the as-received material. This void content depends on grading as well as particle shape and texture.

5.3. The void content determined on the standard graded sample (Method A) is not directly comparable with the average void content of the three individual size fractions from the same sample tested separately (Method B). A sample consisting of single size particles will have a higher void content than a graded sample. Therefore, use either one method or the other as a comparative measure of shape and texture, and identify which method has been used to obtain the reported data. Method C does not provide an indication of shape and texture directly if the grading from sample to sample changes.

5.3.1. The standard graded sample (Method A) is most useful as a quick test that indicates the particle shape properties of a graded fine aggregate. Typically, the material used to make up the standard graded sample can be obtained from the remaining size fractions after performing a single sieve analysis of the fine aggregate.

5.3.2. Obtaining and testing individual size fractions (Method B) is more time consuming and requires a larger initial sample than using the graded sample. However, Method B provides additional information concerning the shape and texture characteristics of individual sizes.

5.3.3. Testing samples in the as-received grading (Method C) may be useful in selecting proportions of components used in a variety of mixtures. In general, high void content suggests that the material could be improved by providing additional fines in the fine aggregate or more cementitious material may be needed to fill voids between particles.

5.3.4. The bulk dry specific gravity of the fine aggregate is used in calculating the void content. The effectiveness of these methods of determining void content and its relationship to particle shape and texture depends on the bulk specific gravity of the various size fractions being equal, or nearly so. The void content is actually a function of the volume of each size fraction. If the type of rock or minerals, or its porosity, in any of the size fractions varies markedly it may be necessary to determine the specific gravity of the size fractions used in the test.

5.4. Void content information from Methods A, B, or C will be useful as an indicator of properties such as: the mixing water demand of hydraulic cement concrete; flowability, pumpability, or workability factors when formulating grouts or mortars; or, in bituminous concrete, the effect of the fine aggregate on stability and voids in the mineral aggregate; or the stability of the fine aggregate portion of a base course aggregate.

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6. APPARATUS

6.1. *Cylindrical Measure*—A right cylinder of approximately 100 mL capacity having an inside diameter of approximately 39 mm and an inside height of approximately 86 mm made of drawn copper water tube meeting ASTM Specification B 88 Type M, or B 88 M Type C. The bottom of the measure shall be metal at least 6 mm thick, shall be firmly sealed to the tubing, and shall be provided with means for aligning the axis of the cylinder with that of the funnel. (See Figure 1.)

6.2. *Funnel*—The lateral surface of the right frustum of a cone sloped 60 ± 4º from the horizontal with an opening of 12.7 ± 0.6 mm diameter. The funnel section shall be a piece of metal, smooth on the inside and at least 38 mm high. It shall have a volume of at least 200 mL or shall be provided with a supplemental glass or metal container to provide the required volume. (See Figure 2.)

Note 1—Pycnometer top C9455 sold by Hogentogler and Co., Inc., 9515 Gerwig, Columbia, MD 21046, 410-381-2390 is satisfactory for the funnel section, except that the size of the opening has to be enlarged and any burrs or lips that are apparent should be removed by light filing or sanding before use. This pycnometer top must be used with a suitable glass jar with the bottom removed (Figure 2).

6.3. *Funnel Stand*—A three- or four-legged support capable of holding the funnel firmly in position with the axis of the funnel colinear (within a 4-degree angle and a displacement of 2 mm) with the axis of the cylindrical measure. The funnel opening shall be 115 ± 2 mm above the top of the cylinder. A suitable arrangement is shown in Figure 2.

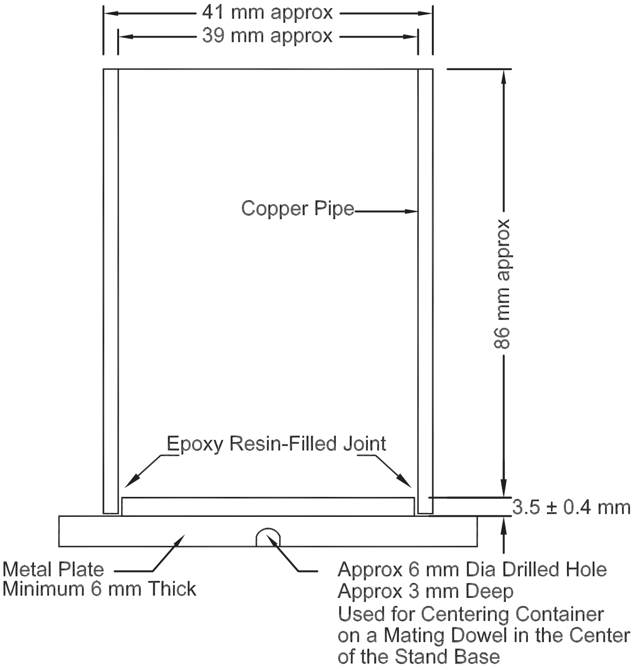

Figure 1—Nominal 100-mL Cylindrical Measure

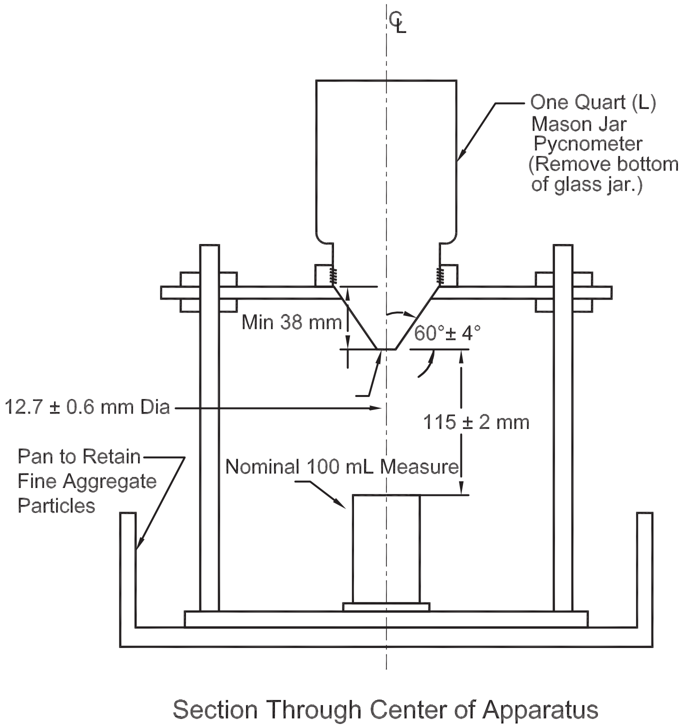

Figure 2—Suitable Funnel Stand Apparatus with Cylindrical Measure in Place

6.4. *Glass Plate*—A square glass plate approximately 60 mm by 60 mm with a minimum 4-mm thickness used to calibrate the cylindrical measure.

6.5. *Pan*—A metal or plastic pan of sufficient size to contain the funnel stand and to prevent loss of material. The purpose of the pan is to catch and retain fine aggregate particles that overflow the measure during filling and strike off.

6.6. Metal spatula with a blade approximately 100 mm long, and at least 20 mm wide, with straight edges. The end shall be cut at a right angle to the edges. The straight edge of the spatula blade is used to strike off the fine aggregate.

6.7. Scale or balance accurate and readable to ±0.1 g within the range of use, capable of weighing the cylindrical measure and its contents.

7. SAMPLING

7.1. The sample(s) used for this test shall be obtained using T 2 and T 248, or from sieve analysis samples used for T 27, or from aggregate extracted from a bituminous concrete specimen. For Methods A and B, the sample is washed over a 150-µm (No. 100) or 75-µm (No. 200) sieve in accordance with T 11 and then dried and sieved into separate size fractions according to T 27 procedures. Maintain the necessary size fractions obtained from one (or more) sieve analysis in a dry condition in separate containers for each size. For Method C, dry a split of the as-received sample in accordance with the drying procedure in T 27.

8. CALIBRATION OF CYLINDRICAL MEASURE

8.1. Apply a light coat of grease to the top edge of the dry, empty cylindrical measure. Weigh the measure, grease, and glass plate. Fill the measure with freshly boiled, deionized water at a temperature of 18 to 24ºC. Record the temperature of the water. Place the glass plate on the measure, being sure that no air bubbles remain. Dry the outer surfaces of the measure and determine the combined mass of measure, glass plate, grease, and water by weighing. Following the final weighing, remove the grease, and determine the mass of the clean, dry, empty measure for subsequent tests.

8.2. Calculate the volume of the measure as follows:

$$V = 1000\ \frac{M}{D} \tag{1}$$

where:

V = volume of cylinder, mL;

M = net mass of water, g; and

D = density of water (See table in T 19M/T 19 for density at the temperature used.), kg/m^3.

Determine the volume to the nearest 0.1 mL.

Note 2—If the volume of the measure is greater than 100.0 mL, it may be desirable to grind the upper edge of the cylinder until the volume is exactly 100.0 mL, to simplify subsequent calculations.

9. PREPARATION OF TEST SAMPLES

9.1. *Method A—Standard Graded Sample*—Weigh out and combine the following quantities of fine aggregate, which has been dried and sieved in accordance with T 27.

Individual Size Fraction	Mass, g
2.36 mm (No. 8) to 1.18 mm (No. 16)	44
1.18 mm (No. 16) to 600 µm (No. 30)	57
600 µm (No. 30) to 300 µm (No. 50)	72
300 µm (No. 50) to 150 µm (No. 100)	17
	190

The tolerance on each of these amounts is ±0.2 g.

9.2. *Method B—Individual Size Fractions*—Prepare a separate 190-g sample of fine aggregate, dried and sieved in accordance with T 27, for each of the following size fractions:

Individual Size Fraction	Mass, g
2.36 mm (No. 8) to 1.18 mm (No. 16)	190
1.18 mm (No. 16) to 600 µm (No. 30)	190
600 µm (No. 30) to 300 µm (No. 50)	190

The tolerance on each of these amounts is ±1 g. Do not mix these samples together. Each size is tested separately.

9.3. *Method C—As-Received Grading*—Pass the sample (dried in accordance with T 27) through a 4.75-mm (No. 4) sieve. Obtain a 190 ± 1-g sample of the material passing the 4.75-mm (No. 4) sieve for test.

9.4. *Specific Gravity of Fine Aggregate*—If the bulk dry specific gravity of fine aggregate from the source is unknown, determine it on the minus 4.75-mm (No. 4) material according to T 84. Use this value in subsequent calculations unless some size fractions differ by more than 0.05 from the specific gravity typical of the complete sample, in which case the specific gravity of the fraction (or fractions) being tested must be determined. An indicator of differences in specific gravity of various particle sizes is a comparison of specific gravities run on the fine aggregate in different gradings. Specific gravity can be run on gradings with and without specific size fractions of interest. If specific gravity differences exceed 0.05, determine the specific gravity of the individual 2.36-mm (No. 8) to 150-µm (No. 100) sizes for use with Method A or the individual size fractions for use with Method B either by direct measurement or by calculation using the specific gravity data on gradings with and without the size fraction of interest. A difference in specific gravity of 0.05 will change the calculated void content about one percent.

10. PROCEDURE

10.1. Mix each test sample with the spatula until it appears to be homogeneous. Position the jar and funnel section in the stand and center the cylindrical measure as shown in Figure 2. Use a finger to block the opening of the funnel. Pour the test sample into the funnel. Level the material in the funnel with the spatula. Remove the finger and allow the sample to fall freely into the cylindrical measure.

10.2. After the funnel empties, strike-off excess heaped fine aggregate from the cylindrical measure by a rapid single pass of the spatula with the width of the blade vertical, keeping the straight part of its edge horizontal and in light contact with the top of the measure. Until this operation is complete, exercise care to avoid vibration or any disturbance that could cause compaction of the fine aggregate in the cylindrical measure (Note 3). Brush adhering grains from the outside of the container and determine the mass of the cylindrical measure and contents to the nearest 0.1 g. Retain all fine aggregate particles for a second test run.

Note 3—After strike-off, the cylindrical measure may be tapped lightly to compact the sample to make it easier to transfer the container to scale or balance without spilling any of the sample.

10.3. Recombine the sample from the retaining pan and cylindrical measure and repeat the procedure. The results of two runs are averaged. See the Calculation section.

10.4. Record the mass of the empty measure. Also, for each run, record the mass of the measure and fine aggregate.

11. CALCULATION

11.1. Calculate the uncompacted voids for each determination as follows:

$$U = \frac{V - (F/G)}{V} \times 100 \qquad (2)$$

where:

V = volume of cylindrical measure, mL;

F = net mass, g, of fine aggregate in measure (gross mass minus the mass of the empty measure);

G = bulk dry specific gravity of fine aggregate; and

U = uncompacted voids, percent, in the material.

11.2. *For the Standard Graded Sample* (Method A), calculate the average uncompacted voids for the two determinations and report the result as U_s.

11.3. *For the Individual Size Fractions* (Method B), calculate:

11.3.1. First, the average uncompacted voids for the determination made on each of the three size-fraction samples:

U_1 = uncompacted voids, 2.36 mm (No. 8) to 1.18 mm (No. 16), percent;

U_2 = uncompacted voids, 1.18 mm (No. 16) to 600 μm (No. 30), percent; and

U_3 = uncompacted voids, 600 μm (No. 30) to 300 μm (No. 50), percent.

11.3.2. Second, the mean uncompacted voids (U_m) including the results for all three sizes:

$$U_m = (U_1 + U_2 + U_3)/3 \qquad (3)$$

11.4. *For the As-Received Grading* (Method C), calculate the average uncompacted voids for the two determinations and report the result as U_R.

12. REPORT

12.1. *For the Standard-Graded Sample* (Method A), report:

12.1.1. The Uncompacted Voids (U_s) in percent to the nearest one-tenth of a percent (0.1 percent).

12.1.2. The specific gravity value used in the calculations.

12.2. *For the Individual-Size Fractions* (Method B), report the following percent voids to the nearest one-tenth of a percent (0.1 percent):

12.2.1. Uncompacted Voids for Size Fractions: (a) 2.36 mm (No. 8) to 1.18 mm (No. 16) (U_1); (b) 1.18 mm (No. 16) to 600 μm (No. 30) (U_2); and (c) 600 μm (No. 30) to 300 μm (No. 50) (U_3).

12.2.2. Mean Uncompacted Voids (U_m).

12.2.3. Specific gravity value(s) used in the calculations, and whether the specific gravity value(s) were determined on a graded sample or the individual size fractions used in the test.

12.3. *For the As-Received Sample* (Method C), report:

12.3.1. The uncompacted voids (U_R) in percent to the nearest one-tenth of a percent (0.1 percent).

12.3.2. The specific gravity value used in the calculation.

13. PRECISION AND BIAS

13.1. *Precision*:

13.1.1. The single-operator standard deviation has been found to be 0.13 percent voids (1s), using the graded standard silica sand as described in ASTM C 778. Therefore, results of two properly conducted tests by the same operator on similar samples should not differ by more than 0.37 percent (d2s).

13.1.2. The multilaboratory standard deviation has been found to be 0.33 percent (1s) using the standard fine aggregate as described in ASTM C 778. Therefore, results of two properly conducted tests by different laboratories on similar samples should not differ by more than 0.93 percent (d2s).

13.1.3. The above statements pertain to void contents determined on "graded standard sand" as described in ASTM C 778, which is considered rounded, and is graded from 600 μm (No. 30) to 150 μm (No. 100), and may not be typical of other fine aggregates. Additional precision data are needed for tests of fine aggregates having different levels of angularity and texture tested in accordance with this test method.

13.2. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedures in this test method, bias has not been determined.

14. KEYWORDS

14.1. Angularity; fine aggregate; particle shape; sand; surface texture; void content.

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[1] Copies may be obtained from the American Concrete Institute, Box 19150, Detroit, MI 48219.

Standard Method of Test for

Uncompacted Void Content of Coarse Aggregate (As Influenced by Particle Shape, Surface Texture, and Grading)

AASHTO Designation: T 326-05 (2009)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Uncompacted Void Content of Coarse Aggregate (As Influenced by Particle Shape, Surface Texture, and Grading)

AASHTO Designation: T 326-05 (2009)[1]

1. SCOPE

1.1. This method describes the determination of the loose uncompacted void content of a sample of coarse aggregate. When measured on any aggregate of a known grading, void content provides an indication of the aggregate's angularity, sphericity, and surface texture compared with other coarse aggregates tested in the same grading.

1.2. Three procedures are included for the measurement of void content. Two use graded coarse aggregate (standard grading or as-received grading), and the other uses several individual size fractions for void content determinations:

1.2.1. *Standard Graded Sample (Method A)*—This method uses a standard coarse aggregate grading that is obtained by combining individual sieve fractions from the maximum density curve drawn from the maximum coarse aggregate size. See the section on Preparation of Test Samples for the grading.

1.2.2. *Individual Size Fractions (Method B)*—This method uses each of three coarse aggregate size fractions: (a) 19 mm ($^3/_4$ in.) to 12.5 mm ($^1/_2$ in.); (b) 12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.); (c) 9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4). For this method, each size is tested separately.

1.2.3. *As-Received Grading (Method C)*—This method uses that portion of the coarse aggregate retained on the 4.75-mm (No. 4) sieve.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulation limitations prior to its use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates

- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size

3. SUMMARY OF TEST METHODS

3.1. A calibrated cylindrical measure is filled with coarse aggregate of prescribed grading by allowing the sample to flow through a funnel from a fixed height into the measure. The coarse aggregate is struck off, and its mass is determined by weighing. Uncompacted void content is calculated as the difference between the volume of the cylindrical measure and the absolute volume of the coarse aggregate collected in the measure. Uncompacted void content is calculated using the bulk dry specific gravity of the coarse aggregate as received without special grading except as noted in Section 4.3.1. Two runs are made on each sample and the results are averaged.

3.1.1. For a graded sample (Test Method A or C) the percent void content is determined directly, and the average value from two runs is reported.

3.1.2. For the individual size fractions (Test Method B), the mean percent void content is calculated using the results from tests of each of the three individual size fractions.

4. SIGNIFICANCE AND USE

4.1. Methods A and B provide percent void content determined under standardized conditions, which depends on the particle shape and texture of a coarse aggregate. An increase in void content by these procedures indicates greater angularity, less sphericity, or rougher surface texture, or some combination of the three factors. A decrease in void content results is associated with more rounded, spherical, or smooth-surfaced coarse aggregates, or a combination of these factors.

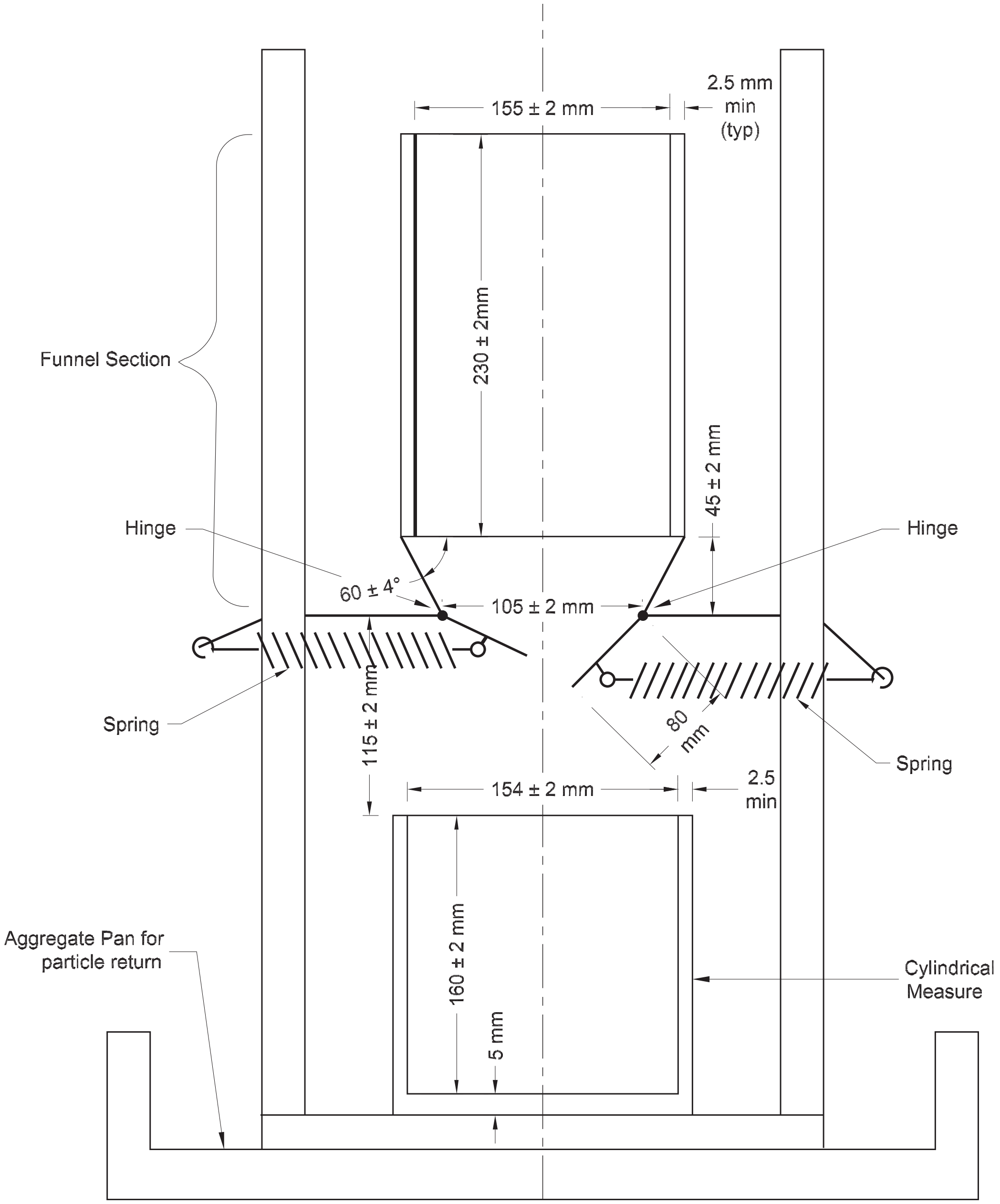
4.2. Method C measures the uncompacted void content of the fraction retained on a 4.75-mm (No. 4) sieve of the as-received material. This void content depends on grading as well as particle shape and texture.

4.3. The void content determined on the standard graded sample (Method A) is not directly comparable with the average void content of the three individual size fractions from the same sample tested separately (Method B). A sample consisting of single size particles will have a higher void content than a graded sample. Therefore, use either one method or the other as a comparative measure of shape and texture, and identify which method has been used to obtain the reported data. Method C does not provide an indication of shape and texture directly if the grading from sample to sample changes.

4.3.1. The bulk dry specific gravity of the coarse aggregate determined by T 85 is used in calculating the void content. The effectiveness of these methods of determining void content and its relationship to particle shape and texture depends on the bulk specific gravity of various size fractions being equal, or nearly so. The void content is actually a function of the volume of each size fraction. If the type of rock or minerals, or its porosity, in any of the size fractions varies markedly, it may be necessary to determine the specific gravity of the size fractions used in the test.

5. APPARATUS

5.1. *Cylindrical Measure*—A cylindrical metal measure shall be watertight, with the top and bottom true and even, preferably machined to accurate dimensions on the inside and sufficiently rigid to retain its form under rough usage. The top rim shall be smooth and plane within 0.25 mm and shall be parallel to the bottom within 0.5 degrees. The inside diameter shall be 154 ± 2 mm and the inside height shall be 160 ± 2 mm. See Figure 1 for nominal dimensions.



Note: Figure is not to scale.

Figure 1—Test Apparatus

5.2. *Funnel*—The lateral surface of the right frustum of a cone sloped 60 ± 4 degrees from the horizontal with an opening of 105 ± 2-mm diameter. The funnel section shall be a piece of metal, smooth on the inside. It shall have a volume of at least two times the volume of the cylindrical measure or shall be provided with a supplemental metal container to provide the required volume. (See Figure 1.)

5.3. *Funnel Stand*—A support capable of holding the funnel firmly in position with the axis of the funnel colinear (within a four degree angle and a displacement of 2 mm) with the axis of the cylindrical measure. The funnel opening shall be 115 ± 2 mm above the top of the cylinder.

5.4. *Glass Plate*—A square glass plate approximately 170 mm × 170 mm with a minimum thickness of 4 mm used to calibrate the cylindrical measure.

5.5. *Pan*—A metal or glass pan of sufficient size to contain the funnel stand and to prevent loss of material. The purpose of the pan is to catch and retain aggregate particles that overflow the measure during filling and strike off.

5.6. *Flat Metal Straightedge*—A flat metal straightedge of 300 ± 5 mm length, 40 ± 2 mm in width and 3 mm thickness is used to strike off the top of the container.

5.7. *Scale* or balance conforming to M 231 and capable of weighing the cylindrical measure and its contents.

6. SAMPLING

6.1. The samples used for this test shall be obtained using T 2 and T 248, or from sieve analysis samples used for T 27. For Methods A and B, the sample is washed over a 75-µm (No. 200) sieve in accordance with T 11 and then dried and sieved into separate size fractions according to T 27. Maintain the necessary size fractions obtained from one (or more) sieve analysis in a dry condition in separate containers for each size. For Method C, dry and split the as-received sample in accordance with T 27 drying procedure.

7. CALIBRATION OF CYLINDRICAL MEASURE

7.1. Apply a light coat of grease to the top edge of the dry, empty cylindrical measure. Weigh the measure, grease, and glass plate. Fill the measure with freshly boiled, deionized water at a temperature of 18 to 24°C. Record the temperature of the water. Place the glass plate on the measure, being sure that no air bubbles remain. Dry the outer surfaces of the measure and determine the combined mass of measure, glass plate, grease, and water by weighing. Following the final weighing, remove the grease, and determine the mass of the clean, dry, empty measure for subsequent tests.

7.2. Calculate the volume of measure as follows:

$$V = 1000\left(M/D\right) \qquad (1)$$

where:

V = volume of cylinder, mL;

M = net mass of water, g; and

D = density of water (see Table 3 in T 19M/T 19 for density at the temperature used), kg/m^3.

Determine the volume to the nearest 0.1 mL.

8. PREPARATION OF TEST SAMPLES

8.1. *Method A—Standard Graded Sample*—weigh and combine the following quantities of coarse aggregate (based on the maximum size of the aggregate) which has been dried and sieved in accordance with T 27. (See Table 1.) The total sample weight should be 5000 g ± 10 g.

Table 1—Standard Gradations for Method A

Maximum Size of Aggregate	Sieve Size (mm)	Mass, g
19 mm	19 mm ($^3/_4$ in.) to 12.5 mm ($^1/_2$ in.)	1740
	12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.)	1090
	9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4)	2170
12.5 mm	12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.)	1970
	9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4)	3030

8.2. *Method B—Individual Size Fractions*—Prepare a separate 5000 g sample of coarse aggregate, dried and sieved in accordance with T 27, for each of the following size fractions (see Table 2):

Table 2—Size Fractions for Method B

Sieve Size (mm)	Mass, g
19 mm ($^3/_4$ in.) to 12.5 mm ($^1/_2$ in.)	5000
12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.)	5000
9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4)	5000

8.3. *Method C—As-Received Grading*—Pass the sample (dried in accordance with T 27) over a 4.75-mm (No. 4) sieve. Obtain a 5000 g ± 10 g sample of the material. The tolerance on each of the amounts in Table 2 is 10 g. Do not mix these samples together. Each size is tested separately.

8.4. *Specific Gravity of Coarse Aggregate*—If the bulk dry specific gravity of coarse aggregate from the source is unknown, determine it on the plus 4.75 mm (No. 4) sample according to T 85.

9. PROCEDURE

9.1. Mix each sample until it appears to be homogeneous. Center the cylindrical measure under the funnel section as shown in Figure 1. Close the doors at the bottom of the funnel section and latch them shut. Pour the test sample into the funnel section. Hold the doors shut with one finger and open the latch on the doors. Remove the finger from the doors, allowing the doors to swing open and the aggregate to fall freely into the cylindrical measure.

Note 1—A latch may be placed on the doors for the convenience of the operator or the operator may hold the doors closed with a finger during the filling of the funnel section, in which case the latch on the doors would not be necessary.

9.2. After the funnel empties, strike off excess heaped aggregate from the cylindrical measure. Until this operation is complete, exercise care to avoid vibration or any disturbance that could cause compaction of the coarse aggregate in the cylindrical measure. Remove any aggregate that may have fallen on the outside of the container and determine the mass of the cylindrical measure and contents to the nearest 0.1 g. Retain all aggregate particles for a second test run.

9.3. Recombine the sample from the retaining pan and cylindrical measure and repeat the procedure. The results of two runs are averaged. (See Section 10.)

9.4. Record the mass of the empty measure. Also, for each run, record the mass of the measure and coarse aggregate.

10. CALCULATION

10.1. Calculate uncompacted voids for each determination as follows:

$$U = \frac{V - \left(F / G\right)}{V} \times 100 \qquad (2)$$

where:

V = volume of cylindrical measure, mL;

F = net mass, g, of coarse aggregate in measure (gross mass minus the mass of the empty measure);

G = bulk dry specific gravity of coarse aggregate; and

U = uncompacted voids, percent, in the material.

10.2. For the Standard Graded Sample (Method A), calculate the average uncompacted voids for the two determinations and report the result as U_s.

10.3. For the Individual Size Fractions (Method B), calculate:

10.3.1. First, the average uncompacted voids for the determination made on each of the three size-fraction samples:

U_1 = uncompacted voids, 19 mm ($^3/_4$ in.) to 12.5 mm ($^1/_2$ in.), percent;

U_2 = uncompacted voids, 12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.), percent; and

U_3 = uncompacted voids, 9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4), percent.

10.3.2. Second, the mean uncompacted voids (U_m) including the results for all three sizes:

$$U_m = (U_1 + U_2 + U_3)/3 \qquad (3)$$

10.4. For the As-Received Grading (Method C), calculate the average uncompacted voids for the two determinations and report the results as U_R.

11. REPORT

11.1. For the Standard Graded Sample (Method A), report the following:

11.1.1. The Uncompacted Voids (U_s) in percent to the nearest one-tenth of a percent.

11.1.2. The specific gravity value used in the calculation.

11.2. For the Individual Size Fractions (Method B), report the following percent voids to the nearest one tenth of a percent:

11.2.1. Uncompacted Voids for Size Fraction:

11.2.1.1. 19 mm ($^3/_4$ in.) to 12.5 mm ($^1/_2$ in.) (U_1).

11.2.1.2. 12.5 mm ($^1/_2$ in.) to 9.5 mm ($^3/_8$ in.) (U_2).

11.2.1.3. 9.5 mm ($^3/_8$ in.) to 4.75 mm (No. 4) (U_3).

11.2.2. Mean Uncompacted Voids (U_m).

11.2.3. Specific gravity value(s) used in the calculations, and whether the specific gravity value(s) were determined on a graded sample or the individual size fractions used in the test.

11.3. For the As-Received Sample (Method C), report the following:

11.3.1. The Uncompacted Voids (U_R) in percent to the nearest one-tenth of a percent.

11.3.2. The specific gravity value used in the calculation.

12. PRECISION AND BIAS

12.1. *Precision*—No precision has been established.

12.2. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedures in these test methods, bias has not been determined.

13. KEYWORDS

13.1. Angularity; coarse aggregate; particle shape; surface texture; void content.

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[1] Formerly TP 56.

Standard Method of Test for

Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

AASHTO Designation: T 327-09[1]
ASTM Designation: D 6928-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

AASHTO Designation: T 327-09[1]
ASTM Designation: D 6928-03

1. SCOPE

1.1. This method covers a procedure for testing coarse aggregate for resistance to abrasion using the Micro-Deval apparatus.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. The text of this method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the test method.

1.4. *This procedure may involve hazardous materials, operations, and equipment. This procedure does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitation prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 27, Sieve Analysis of Fine and Coarse Aggregates

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SUMMARY OF TEST METHOD

3.1. The Micro-Deval Test is a measure of abrasion resistance and durability of mineral aggregates resulting from a combination of actions including abrasion and grinding with steel balls in the presence of water. A sample with standard grading is initially soaked in water for not less than 1 hour. The sample is then placed in a jar mill with 2.0 liters of water and an abrasive charge consisting of 5000 grams of 9.5-mm diameter steel balls. The jar, aggregate, water, and charge are revolved at 100 rpm for 2 hours depending on the particle size. The sample is then washed and oven-dried. The loss is the amount of material passing the 1.18-mm sieve, expressed as a percent by mass of the original sample.

4. SIGNIFICANCE AND USE

4.1. The Micro-Deval abrasion test is a test of coarse aggregates to determine abrasion loss in the presence of water and an abrasive charge. Many aggregates are more susceptible to abrasion when wet than dry, and the use of water in this test incorporates this reduction in resistance in degradation, in contrast to some other tests that are conducted on dry aggregate. The test results are helpful in evaluating the toughness/abrasion resistance of coarse aggregate subject to abrasion when adequate information is not available from service records.

4.2. The Micro-Deval abrasion test is a useful test for detecting changes in properties of aggregate produced from an aggregate source as part of a quality control or quality assurance process.

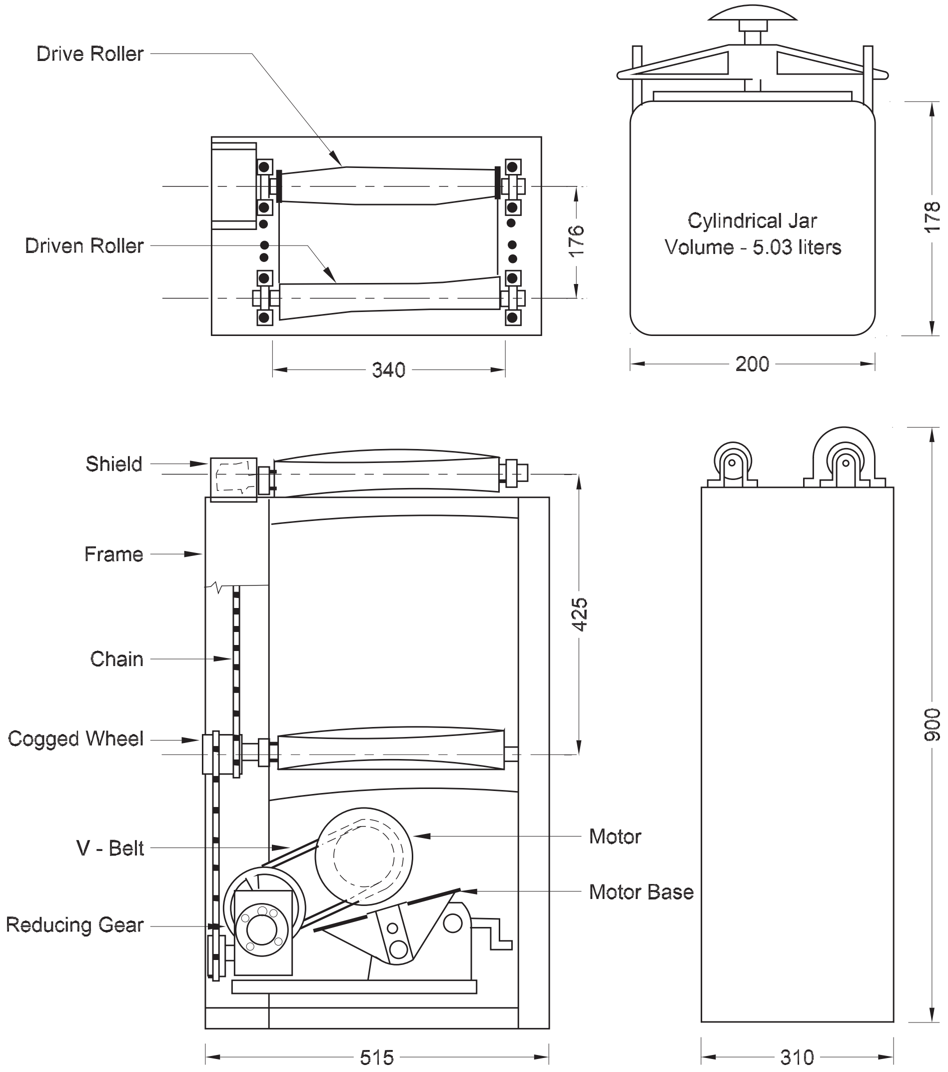
5. TERMINOLOGY

5.1. *constant mass*—test samples dried at a temperature of 110 ± 5°C to a condition such that it will not lose more than 0.1 percent moisture after 2 hours of drying. Such a condition of dryness can be verified by weighing the sample before and after successive 2 hours drying periods. In lieu of such a determination, samples may be considered to have reached constant mass when they have been dried at a temperature of 110 ± 5°C for an equal or longer period than that previously found adequate for producing the desired constant mass condition under equal or heavier loading conditions of the oven.

6. APPARATUS

6.1. *Micro-Deval Abrasion Machine*—A jar rolling mill capable of running at 100 ± 5 rpm (Figure 1).

Note 1—Micro-Deval abrasion machine fitted with a counter may be used if the test is conducted on the basis of number of revolutions (Section 9.4).



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 1—Micro-Deval Abrasion Machine and Container

6.2. *Containers*—Stainless steel Micro-Deval abrasion jars having a 5-L capacity with a rubber ring in the rotary locking cover; an external diameter of 194 to 202 mm, and an internal height of 170 to 177 mm. The inside and outside surfaces of the jars shall be smooth and have no observable ridges or indentations (Figure 1).

6.3. *Abrasion Charge*—Magnetic stainless steel balls are required. These shall have a diameter of 9.5 ± 0.5 mm. Each jar requires a charge of 5000 ± 5 g of balls.

6.4. *Sieves*—Sieves with square openings, and of the following sizes conforming to M 92 specifications: 19.0 mm, 16.0 mm, 12.5 mm, 9.5 mm, 6.3 mm, 4.75 mm, 1.18 mm.

6.5. *Oven*—The oven shall be capable of maintaining a temperature of 110 ± 5°C.

6.6. *Balance*—A balance or scale accurate to 1.0 g.

7. REFERENCE AGGREGATE

7.1. *Laboratory Reference Aggregate*—A supply of standard "Brechin Quarry No. 2" coarse aggregate available from the Soils and Aggregates Section, Materials Engineering and Research Office, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario, Canada M3M 1J8.

7.2. *Calibration Aggregate*—An adequate supply of aggregate, established by the laboratory to use for calibration of the test method (see Section 11.1).

8. TEST SAMPLE

8.1. The test sample shall be washed and oven-dried at 110 ± 5°C to constant mass, separated into individual size fractions in accordance with T 27, and recombined to meet the grading as shown in Section 8.2.

8.2. Aggregate for the test shall normally consist of material passing the 19.0-mm sieve, retained on the 9.5-mm sieve. An oven-dried sample of 1500 ± 5 g shall be prepared as in Table 1 (suggested revisions to Micro-Deval Test Method, July 13, 1998, AASHTO Technical Subcommittee 1c).

Table 1—Preparation of an Oven-Dried Sample of 19.0 mm

Passing	Retained	Mass
19.0 mm	16.0 mm	375 g
16.0 mm	12.5 mm	375 g
12.5 mm	9.5 mm	750 g

8.3. In a case where the nominal maximum size of the coarse aggregate is 12.5 mm or less, a sample of 1500 ± 5 g shall be prepared as in Table 2:

Table 2—Preparation of an Oven-Dried Sample of Less Than 16.0 mm

Passing	Retained	Mass
12.5 mm	9.5 mm	750 g
9.5 mm	6.3 mm	375 g
6.3 mm	4.75 mm	375 g

8.4. In a case where the nominal maximum size of the coarse aggregate is 9.5 mm or less, a sample 1500 ± 5 g shall be prepared as in Table 3:

Table 3—Preparing an Oven-Dried Sample of Less Than 12.5 mm

Passing	Retained	Mass
9.5 mm	6.3 mm	750 g
6.3 mm	4.75 mm	750 g

9. TEST PROCEDURE

9.1. Prepare a representative 1500 ± 5 g sample. Determine the Mass "A" and record to the nearest 1.0 g.

9.2. Immerse the sample in 2.0 ± 0.05 liters of tap water at a temperature of 20 ± 5°C for a minimum of 1 hour either in the Micro-Deval container or some other suitable container.

9.3. Place the sample in the Micro-Deval abrasion container with 5000 ± 5 g of steel balls and the water used in Section 9.2 to saturate the sample. Install the cover and place the Micro-Deval container on the machine.

9.4. Run the machine at 100 ± 5 rpm for 12,000 ± 100 revolutions for the grading shown in Section 8.2; for 10,500 ± 100 revolutions for the grading shown in Section 8.3; and for 9,500 ± 100 revolutions for the grading shown in Section 8.4.

Note 2—Some equipment is not capable of measuring the total number of revolutions of the drum. If desired, instead of using revolutions, time can be used as follows:

Run the machine at 100 ± 5 rpm for 120 ± 1 minutes for the grading shown in Section 8.2. For the grading shown in Section 8.3, run the machine for 105 ± 1 minutes. For the grading shown in Section 8.4, run the machine for 95 ± 1 minutes.

9.5. Carefully pour the sample and steel balls over a 4.75-mm sieve superimposed on a 1.18-mm sieve. Take care to remove the entire sample from the stainless steel jar. Wash and manipulate the retained material on the sieve with water using a hand held water hose and the hand until the washings are clear and all material smaller than 1.18 mm passes that sieve. Remove the stainless steel balls using a magnet or other suitable means. Discard material smaller than 1.18 mm.

9.6. Combine the material retained on the 4.75-mm and 1.18-mm sieves, being careful not to lose any material.

9.7. Oven-dry the sample to constant mass at 110 ± 5°C.

9.8. Weigh the sample to the nearest 1.0 g. Record the Mass "B."

10. CALCULATIONS

10.1. Calculate the Micro-Deval abrasion loss, as follows, to the nearest 0.1 percent.

$$\text{Percent Loss} = (A - B)/A \times 100 \quad (1)$$

where:

A = mass, as determined in Section 9.1; and

B = mass, as determined in Section 9.8.

11. USE OF THE CALIBRATION AGGREGATE

11.1. *Calibration Aggregate*—The laboratory will establish an adequate supply of material to use for calibration of the test method. A suitable material with a loss of between 15 and 25 percent shall be established. From this material, 10 samples shall be taken randomly and tested. At the same time, 10 samples of reference aggregate from Brechin Quarry No. 2 (see Section 7.1) shall also be tested. Provided the mean loss and variation of the Brechin Quarry No. 2 aggregate is within allowed tolerance of Section 11.1.1, the mean value obtained with the supply of the in-house calibration aggregate shall be used thereafter. At any time a new supply is required, the calibration procedure shall be conducted.

11.1.1. The mean loss of the Brechin Quarry No. 2 reference aggregate (see Section 7.1) in multilaboratory study of the Micro-Deval Test is 19.1 percent. For continued acceptance of data, individual reference material test data must fall within the range 17.5 to 20.7 percent loss for 95 percent of the time.

11.1.2. When test data of the calibration aggregate is outside the limits, an investigation as to the probable cause shall be conducted. The equipment shall be re-calibrated and the testing technique re-examined to detect nonconformance with the test procedure.

11.2. Every 10 samples, but at least every week in which a sample is tested, a sample of the calibration aggregate shall be tested. The material shall be taken from a stock supply and prepared according to Section 8. When 20 samples of calibration material have been tested, and the results show satisfactory variation, the frequency of testing may be changed to a minimum of one sample every month.

11.3. *Trend Chart Use*—The percent loss of the last 20 samples of calibration material shall be plotted on a trend chart in order to monitor the variation in results (Figure 2).

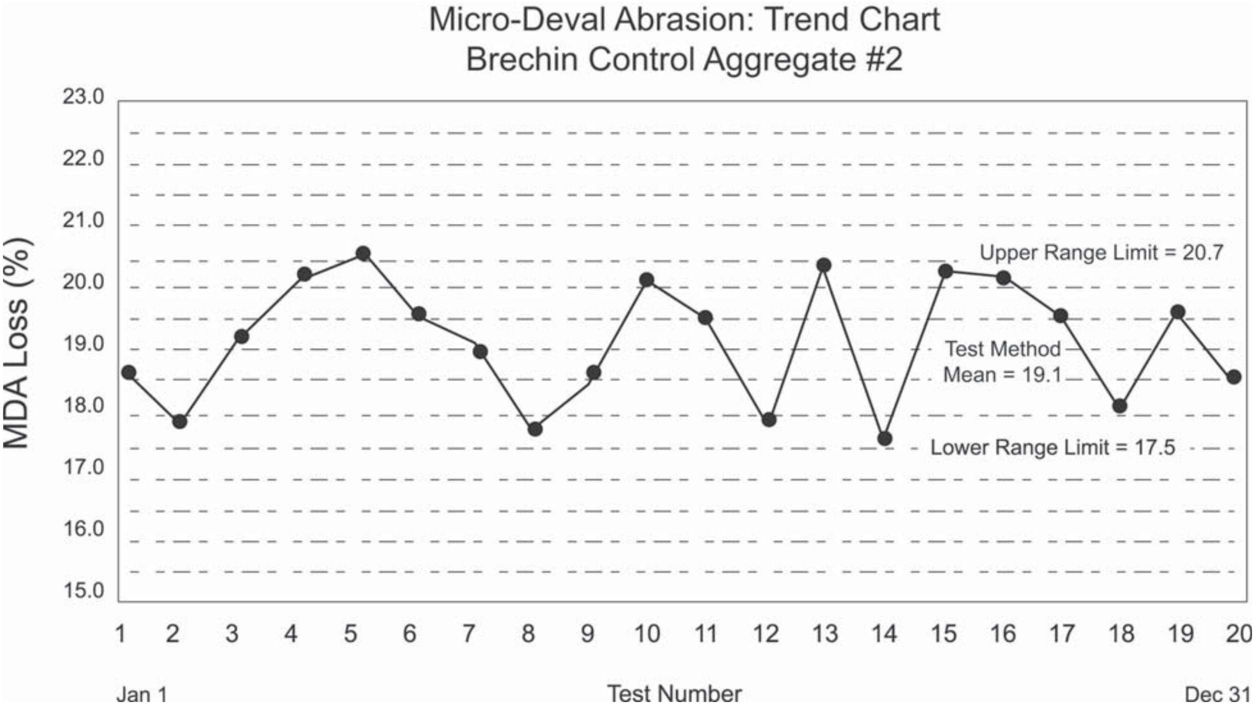


Figure 2—Micro-Deval Abrasion Trend Chart for Brechin Quarry No. 2 Aggregates Sample

12. REPORT

12.1. *The report shall include the following*:

12.1.1. The maximum size of the aggregate tested and the grading used;

12.1.2. The percent loss of the test sample to one decimal place;

12.1.3. The percent loss of the calibration aggregate, tested closest to the time at which the aggregate was tested, to the nearest 0.1 percent; and

12.1.4. The percent loss of the last 20 samples of calibration material on a trend chart.

13. PRECISION AND BIAS

13.1. *Precision*—The multilaboratory precision has been found to vary over the range of values obtained in this test. The figures given in Column 2 are the coefficients of variation that have been found to be appropriate for the materials described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests on the same sample expressed as a percent of their mean, 95 percent of the time.

Table 4—Multilaboratory Precision

Aggregate Abrasion Loss, Percent	Coefficient of Variation, Percent of Mean[a]	Acceptable Range of Two Results, Percent of Mean[a]
5	10.0	28
12	6.4	18
17	5.6	16
21	5.3	15

[a] These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670.

13.2. *Bias*—The procedure in this test method for measuring resistance to abrasion has no bias because the resistance to abrasion can only be defined in terms of the test method.

14. KEYWORDS

14.1. Abrasion resistance; coarse aggregate; Micro-Deval.

15. REFERENCES

15.1. Rogers, C. Canadian Experience with the Micro-Deval Test for aggregates. In *Advances in Aggregates and Armourstone Evaluation*. Latham, J. P. (ed). Geological Society, London, Engineering Geology Special Publications, 13, 1998, *pp*. 139–147.

15.2. Kandhal, P. S. and F. Parker, Jr. “Aggregate Tests Related to Asphalt Concrete Performance in Pavements.” Final Report prepared for National Cooperative Highway Research Program, Transportation Research Board, Washington, May 1997.

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF TEST RESULTS

X1.1. In studies of the performance of aggregates in this test (Rogers 1998; Kandhal and Parker 1997), the limits in Table X1.1 have been found useful for separating aggregates of satisfactory performance from those of fair or poor performance.

Table X1.1—Limits of Satisfactory Performance of Aggregates

Application	Maximum Micro-Deval Abrasion Loss, %
Granular subbase	30[a]
Granular base	25[a]
Open graded base course	17[a]
Asphalt concrete base course and secondary surface course	21[a]
Asphalt concrete surface course	17[a] 18[b]

[a] Rogers, 1998 (See Section 15.1.)

[b] Kandhal and Parker, 1997 (See Section 15.2.)

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[1] Except for Sections 6.1 and 9.4, this test method is identical to ASTM D 6928-03.

Standard Method of Test for

The Qualitative Detection of Harmful Clays of the Smectite Group in Aggregates Using Methylene Blue

AASHTO Designation: T 330-07[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

The Qualitative Detection of Harmful Clays of the Smectite Group in Aggregates Using Methylene Blue

AASHTO Designation: T 330-07[1]

1. SCOPE

1.1. The purpose of this standard is to identify the presence of harmful clays of the smectite group (poor minus 75-µm material) and to provide an indication of the surface activity of the aggregate.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 231, Weighing Devices Used in the Testing of Materials

3. SUMMARY OF TEST METHOD

3.1. Methylene Blue solution is titrated in increments into distilled water containing sample material passing the 75-µm (No. 200) sieve in increments. A small amount of water containing the sample material and titrated Methylene Blue is removed via a glass rod and dropped onto filter paper. When the clay fraction of the sample aggregate can no longer absorb more Methylene Blue, a blue ring is formed on the filter paper.

4. SIGNIFICANCE AND USE

4.1. The Methylene Blue Value determined by this standard can be used to estimate the amount of harmful clays and organic matter present in an aggregate. A high value for Methylene Blue Value indicates a large amount of clay or organic material present in the sample.

Note 1—Research (Aschenbrener, 1992) has developed the following relationship of methylene blue values and anticipated hot mix asphalt pavement performance as related to moisture susceptibility. (See Table 1.)

Table 1—Expected Performance of Methylene Blue

Methylene Blue (mg/g)	Expected Performance
≤6	Excellent
7–12	Marginally acceptable
13–19	Problems/possible failures
≥20	Failure

5. APPARATUS

5.1. Amber-colored burette of at least 50-mL capacity with 0.1-mL graduations.

5.2. Magnetic mixer with stir bar.

5.3. Balance complying with M 231, Class G1.

5.4. Glass rod of approximately 250-mm (10-in.) length and approximately 8-mm (0.3-in.) diameter.

5.5. Timer or stopwatch.

5.6. Pan and 75-µm (No. 200) sieve.

5.7. Volumetric flask of 1000-mL capacity.

5.8. Whatman No. 2 filter paper.

5.9. Three 500-mL griffin beakers.

5.10. Methylene Blue, reagent grade-dated and stored for no more than four months in a brown bottle wrapped with foil in a dark cabinet at lab temperature.

Note 2—One gram of Methylene Blue is dissolved in enough distilled water to produce 200 mL of solution, with each one mL of solution containing 5 mg of Methylene Blue.

5.11. Distilled water at lab temperature.

5.12. Oven capable of maintaining 110 ± 5°C (230 ± 9°F).

Note 3—For the purposes of this procedure, lab temperature is defined as 15–25°C (60–77°F).

6. SAMPLE PREPARATION

6.1. This test shall be performed on a sample of material passing the 75-µm (No. 200) sieve, taken from the washed portion of a representative sample of individual or combined material (as required). The material shall be washed through the 75-µm (No. 200) sieve and collected in a clean container. This container shall be large enough to hold several gallons of water and material passing the 75-µm (No. 200) sieve. Allow the material to settle and remove the excess water. The portion passing the 75-µm (No. 200) sieve is collected, transferred to a smaller container, and dried for testing. The collected material is mixed thoroughly prior to testing. The minimum oven-dry mass of the collected material shall be at least 30 g to ensure enough material for a possible retest.

7. PROCEDURE

7.1. Place 10.0 g (±0.05 g) of the minus 75-µm (No. 200) material that has been dried to constant mass in a 500-mL griffin beaker.

7.2. Add 30 mL of distilled water and stir with the mixer to make a slurry.

7.3. With the slurry still mixing, fill the burette with the Methylene Blue solution, add 0.5 mL of the solution to the slurry, and stir for 1 minute.

7.4. Remove a drop of the slurry, using the glass stirring rod, and place on the filter paper.

7.5. Observe the appearance of the drop on the filter paper. The end point is indicated by the formation of a light blue halo around the drop. Continue adding the Methylene Blue solution to the slurry in 0.5-mL increments with 1-minute stirring after each addition, then testing, until the end point is reached.

7.6. After the end point is reached, continue stirring for 5 minutes and retest.

Note 4—With experience, the person performing the test can reach the end point more quickly by skipping early increments.

8. CALCULATION

8.1. *Example*:

$$M = CV/W \qquad (1)$$

where:

M = Methylene Blue Value in mg of solution per g of the minus 75-µm (No. 200) material;

C = mg of Methylene Blue/mL of solution;

V = mL of Methylene Blue solution required for titration; and

W = grams of dry material.

8.2. The calculation may be simplified by inserting the mg of Methylene Blue per mL of solution and the grams of dry material.

$$M = (5 \times V)/10 \qquad (2)$$

$$M = 0.5V \qquad (3)$$

9. REPORT

9.1. *The report shall include the following*:

9.1.1. Type and source of the material tested; and

9.1.2. Methylene Blue value to the nearest 0.1 mg/g.

10. PRECISION AND BIAS

10.1. *Precision*—No precision has been established for this test.

10.2. *Bias*—No bias can be established because no reference material is available for this test.

11. KEYWORDS

11.1. Clay and organic material; fine aggregate; methylene blue; moisture susceptibility.

12. REFERENCES

12.1. Aschenbrener, T. Comparison of Colorado Component Hot Mix Asphalt Materials with some European Specifications. In *Research Report CDOT-DTD-R-92-14.* Colorado Department of Transportation, Denver, CO, December 1992, *p*. 65.

12.2. Aschenbrener, T. and R. Zamora. Evaluation of Specialized Tests for Aggregates Used in Hot Mix Asphalt Pavements in Colorado. In *Transportation Research Record 1486*. Transportation Research Board Business Office, Washington, DC, January 1995, *pp*. 130–136.

12.3. Aschenbrener, T., R. Terrel, and R. Zamora. Comparison of the Hamburg Wheel Tracking Device and the Environmental Conditioning System to Pavements of Known Stripping Performance. In *Research Report CDOT-DTD-R-94-1*. Colorado Department of Transportation, Denver, CO, January 1994, *p*. 110.

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[1] Formerly TP 57.

Standard Method of Test for

Determining the Percentage of Fracture in Coarse Aggregate

AASHTO Designation: T 335-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Percentage of Fracture in Coarse Aggregate

AASHTO Designation: T 335-09[1]

1. SCOPE

1.1. This test method covers the determination of the percentage, by mass, of a coarse aggregate sample that consists of fractured particles meeting specified requirements.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3. The text of the standard reference notes provides explanatory material. These notes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

3. SUMMARY OF TEST METHOD

3.1. A sample of aggregate is separated using the designated size of screen conforming to the specification controlling the determination of coarse and fine aggregate. The coarse aggregate particles are visually evaluated to determine their conformance to the defined fracture. The percentage of conforming particles, by mass, is determined for comparison to standard specifications.

4. APPARATUS

4.1. *Balance*—Meeting the requirements of M 231 for general-purpose balance required for the principal sample mass being tested.

4.2. *Sieves*—Meeting the requirements of M 92.

4.3. *Splitter*—Meeting the requirements of T 248.

5. TERMINOLOGY

5.1. *fractured face*—an angular, rough, or broken surface of an aggregate particle created by crushing, or by other means. A face is considered a "fractured face" whenever one-half or more of the projected area, when viewed normal to that face, is fractured with sharp and well-defined edges (this excludes small nicks).

5.2. *fractured particle*—a particle of aggregate having at least the minimum number of fractured faces specified (usually one or two).

6. SAMPLING

6.1. Sample the aggregate in accordance with T 2 and reduce the sample in accordance with T 248.

7. SAMPLE PREPARATION

7.1. Where the specifications list only a total fracture percentage, the sample shall be prepared in accordance with Method 1. When the specifications require that the fracture be counted and reported on each sieve, the sample shall be prepared in accordance with Method 2.

7.2. *Method 1—Combined Fracture Determination*:

7.2.1. Dry the sample sufficiently to obtain a clean separation of fine and coarse material in the sieving operation. Sieve the sample in accordance with T 27 over the 4.75-mm (No. 4) sieve, or the appropriate sieve listed in the agency specifications for this material.

Note 1—Where necessary, wash the sample over the sieve or sieves designated for the determination of fractured particles to remove any remaining fine material and dry the sample to a constant mass in accordance with T 255.

7.2.2. Reduce the sample using a splitter in accordance with T 248 to the appropriate size for test. This size of test sample should be slightly larger in mass than that shown in Table 1 to account for additional loss of fines after washing.

Table 1—Sample Size (Method 1, Combined Sieve Fracture)

Nominal Maximum Particle Size	Minimum Sample Mass Retained 4.75-mm (No. 4) Sieve
37.5 mm ($1^1/_2$ in.)	2500 g (6 lb)
25.0 mm (1 in.)	1500 g (3.5 lb)
19.0 mm ($^3/_4$ in.)	1000 g (2.2 lb)
12.5 mm ($^1/_2$ in.)	700 g (1.5 lb)
9.5 mm ($^3/_8$ in.)	400 g (0.9 lb)
4.75 mm (No. 4)	200 g (0.5 lb)

7.3. *Method 2—Individual Sieve Fracture Determination*:

7.3.1. Dry the sample sufficiently to obtain a clean separation of fine and coarse material in the sieving operation. A washed sample from the gradation determination (T 11 and T 27) may be used. If not, sieve the sample in accordance with T 27 over the appropriate sieves listed in the specifications for this material. Select a representative portion from each sieve by splitting or quartering in accordance with T 248 to the appropriate size for testing. This size of test sample for each sieve should be at least as large as shown in Table 2.

Table 2—Sample Size (Method 2, Individual Sieve Fracture)

Nominal Maximum Particle Size	Minimum Sample Mass Retained 4.75-mm (No. 4) Sieve
31.5 mm ($1^1/_4$ in.)	1500 g (3.5 lb)
25.0 mm (1 in.)	1000 g (2.2 lb)
19.0 mm ($^3/_4$ in.)	700 g (1.5 lb)
16.0 mm ($^5/_8$ in.)	500 g (1.0 lb)
12.5 mm ($^1/_2$ in.)	300 g (0.7 lb)
9.5 mm ($^3/_8$ in.)	200 g (0.5 lb)
6.3 mm ($^1/_4$ in.)	100 g (0.2 lb)
4.75 mm (No. 4)	100 g (0.2 lb)
2.36 mm (No. 8)	25 g (0.1 lb)
2.00 mm (No. 10)	25 g (0.1 lb)

Note 2—Where necessary, wash the sample over the sieve or sieves designated for the determination of fractured particles to remove any remaining fine material and dry the sample to a constant mass in accordance with T 255.

Note 3—If fracture is determined on a sample obtained for gradation, use the mass retained on the individual sieves unless less than 5 percent of the total mass is retained on that sieve. In that case, place the material with that retained on the next smaller sieve size. If a smaller specification sieve does not exist, this material shall not be included in the fracture determination.

8. PROCEDURE

8.1. Spread the dried, cooled test sample on a clean flat surface large enough to permit careful inspection of each particle. To verify that a particle meets the fracture criteria, hold the aggregate particle so that the face is viewed directly. (See Section 5.1.)

8.2. To aid in making the fracture determination, separate the sample into three categories: (1) fractured particles meeting the above criteria, (2) particles not meeting specification criteria, and (3) questionable or borderline particles.

8.3. Determine the mass of particles in the fractured category, the mass of questionable particles, and the mass of the unfractured particles.

8.4. If on any of the determinations more than 15 percent of the total mass of the sample is placed in the questionable category, repeat the determination until no more than 15 percent is present in that category.

9. REPORT

9.1. *Report the following information*:

9.1.1. Calculate the mass percentage of fracture faces to the nearest 1 percent as follows:

$$P = [(F + Q/2)/(F + Q + N)] \times 100 \qquad (1)$$

where:

P = percentage of fracture,
F = mass of fractured particles,
Q = mass of questionable or borderline particles, and
N = mass of unfractured particles.

10. PRECISION AND BIAS

10.1. No precision data is available using this method.

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[1] Formerly AASHTO Provisional Standard TP 61.

Standard Method of Test for

Sampling Bituminous Materials

AASHTO Designation: T 40-02 (2006)
ASTM Designation: D 140-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling Bituminous Materials

AASHTO Designation: T 40-02 (2006)
ASTM Designation: D 140-01

AASHTO T 40-02 (2006) is identical to ASTM D 140-01 except for the following provisions:

1. Insert an additional sentence in Section 1.1 as follows:

   Samples may be taken from tanks, stockpiles, vehicles, or containers used for the storage or shipping of bituminous materials.
2. Section 5 is not included.
3. Replace Section 6.1.2 with the following:

   6.1.2 From bulk storage, 1 L (1 qt) for each sampling valve, or
4. Replace Sections 7.1.1, 7.1.2, and 7.1.3 with the following:

   7.1.1 Containers for liquid bituminous material samples, except emulsions, shall be double-seal friction-top cans, square cans with screw tops, or small-mouth cans with screw caps.

   7.1.2 Containers for anionic emulsified asphalt samples shall be wide-mouth jars or bottles made of glass or plastic.

   7.1.3 Containers for cationic emulsified asphalt samples shall be wide-mouth jars or bottles made of plastic or wide-mouth cans with screw caps.
5. Add a note at the end of Section 7.1 as follows:

   Note—Wide-mouth jars or bottles made of glass may be permitted if previous experience has shown them to be satisfactory.
6. Replace Section 8.5 with the following:

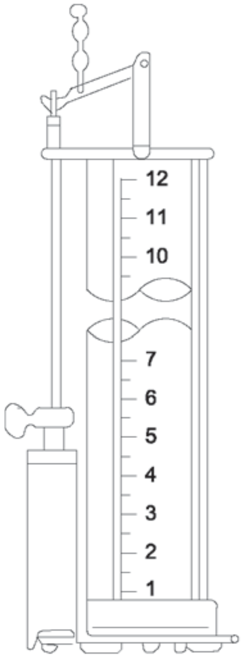
   8.5 Transferring samples from one container to another shall be avoided if possible, as the characteristics of the materials could be altered during transfer, and there is a possibility of contamination.
7. Replace Section 9.1 with the following:

   9.1 *Bulk Storage Tanks Not Equipped with Mechanical Agitators (Liquid Materials or Materials Made Liquid by Heating)*—Samples shall be obtained by one of the three following methods:
8. Replace Section 9.1.1 with the following:

   9.1.1 *Tank Tap Method*—Using valves or taps at the top, middle, and lower locations of the tank, draw a 1- to 4-L (1-qt to 1-gal) sample from each location after clearing the line by drawing and discarding a minimum of 4 L (1 gal) of the material.
9. Sections 9.1.1.1 and 9.1.1.2 are not included.

10. Replace Section 9.1.2 with the following:

    9.1.2 *Thief Sampler Method* (not suitable for asphalt cements)—Samples shall be taken at the top, middle, and lower levels of the tank by lowering a thief sampler into the material. A satisfactory type with instructions for use is shown in Figure 2.



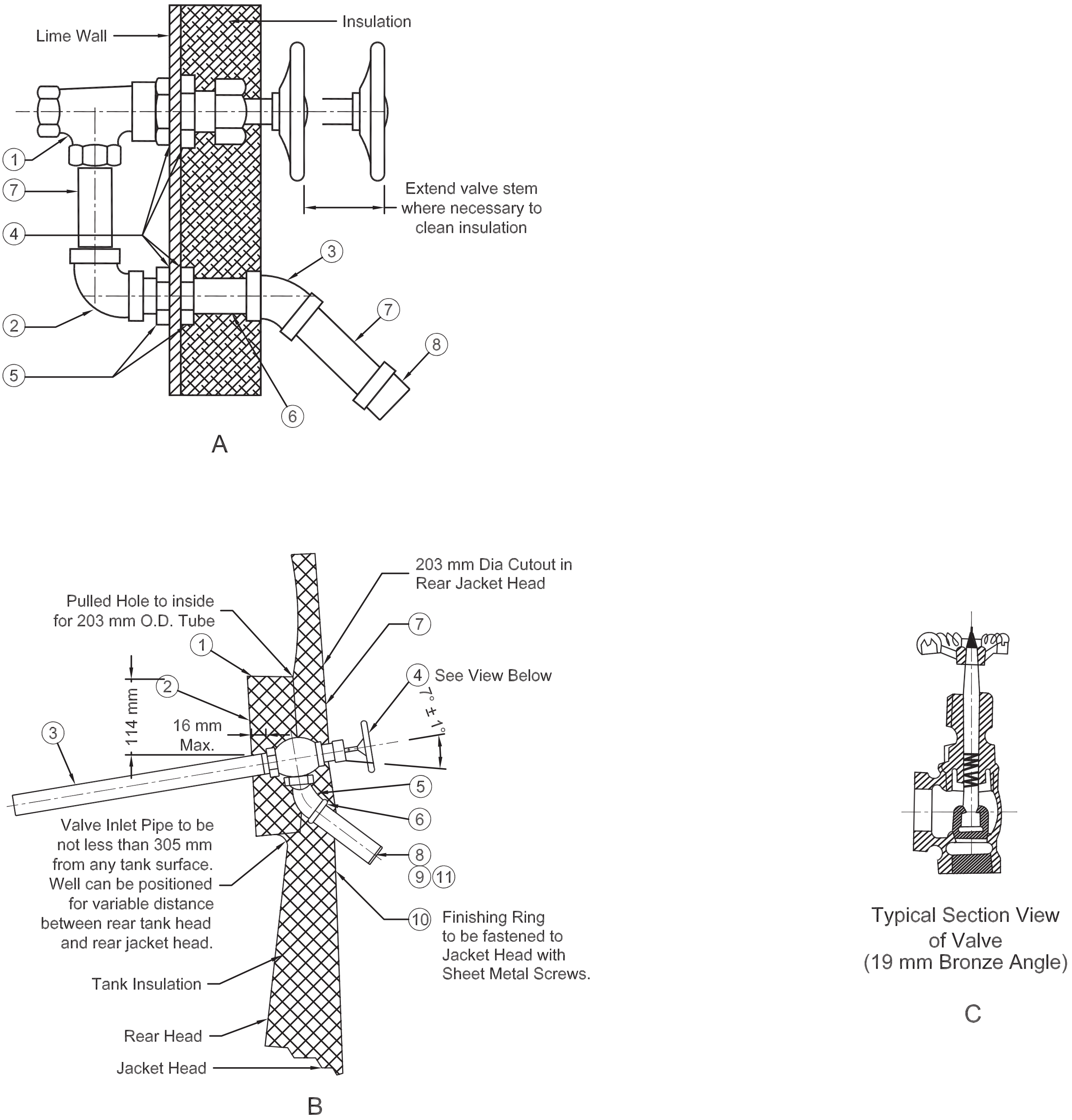
Note: This type of sampler is lowered into the tank with the bottom valve open (there is no top closure). When the desired depth is reached, the lowering chain is given a snap tug which closes the bottom valve. The sampler is then withdrawn from the tank and the contents transferred to the sample container. This sampler may be used for repetitive sampling in the same tank.

Figure 2—Thief Sampler

11. Note 3 contained in Section 9.1.2 is not included.
12. Replace Section 10.1 with the following:

    10.1 Each delivery vehicle or distributor shall be equipped with a sampling valve similar in design to those shown in Figure 1. It shall be installed at least 305 mm (1 ft) from the shell and clearly labeled as a “Sampling Valve.” Before the sample is taken from the sample valve, a minimum of 4 L (1 gal) shall be drawn from the sample valve and discarded.
13. Insert an additional section between Sections 10.1 and 10.2 as follows:

    When permitted by the purchaser, the following methods may be used to obtain representative samples.
14. Replace Figure 1 with the following figure:



Typical Section View of Valve (19 mm Bronze Angle)

Figure 1—Typical Submerged Asphalt Sampling Devices

Dimensional Equivalents

16 mm	19 mm	25 mm	76 mm	89 mm	102 mm	114 mm	203 mm	305 mm	330 mm
$^{5}/_{8}$ in.	$^{3}/_{4}$ in.	1 in.	3 in.	3.5 in.	4 in.	4.5 in.	8 in.	12 in.	13 in.

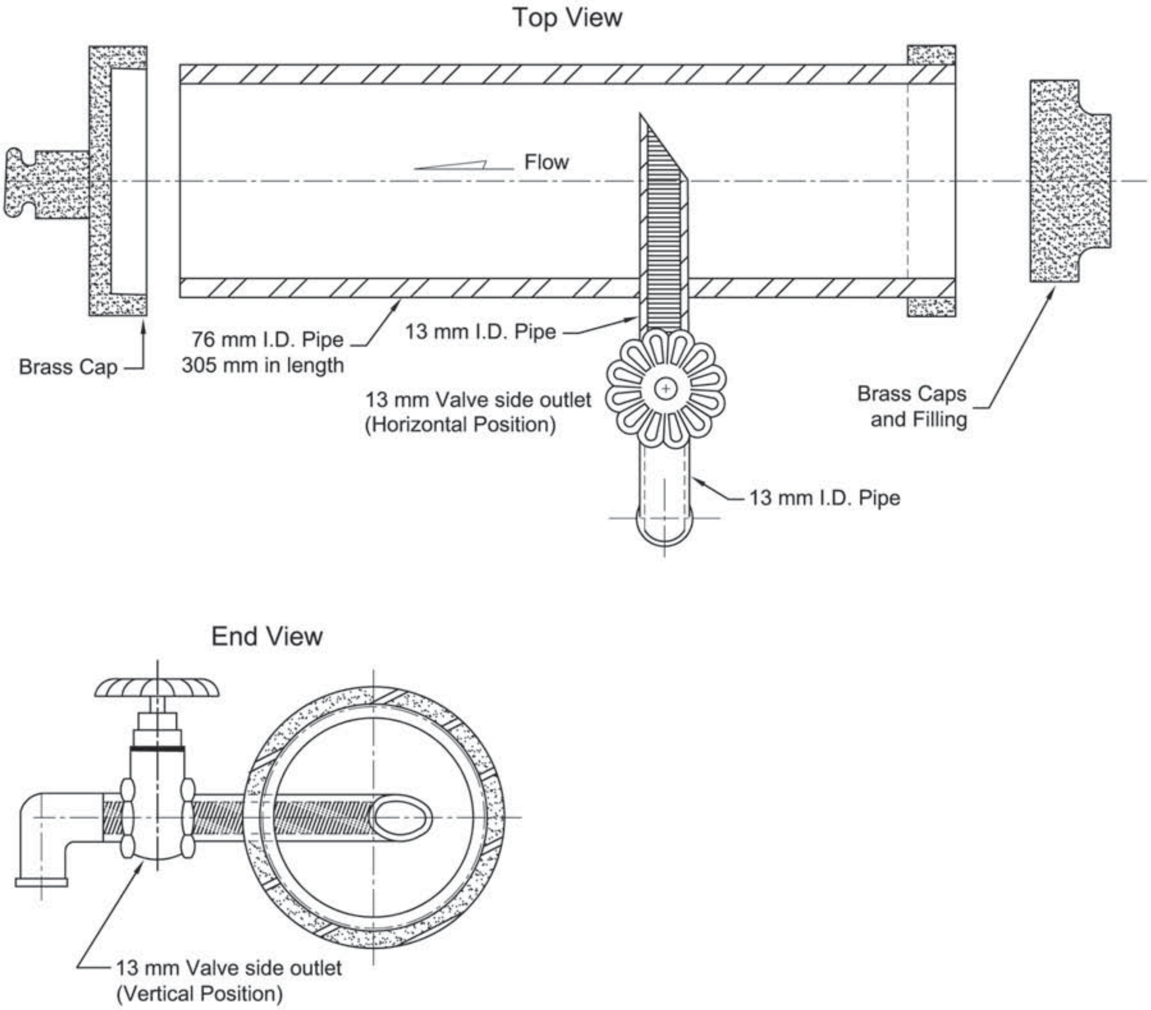
Figure 1A Table

Ref No.	Description	No. Req
1	19 mm "YoGT" P–9944 STEEL ANGLE VALVE OR SIMILAR, PANEL-MOUNTED	1
2	19 mm STEEL OR MALL IRON 90° ELBOW	1
3	19 mm STEEL OR MALL IRON 45° ELBOW	1
4	ASBESTOS GASKETS SNUG ON THREAD WOUND WITH YARN	4
5	19 mm 150 lb SCREWED M.I. LOCKNUT	2
6	19 mm × 89 mm ± PARALLEL-THREADED STEEL PIPE NIPPLE (CUT FROM 19 mm STD. TANK NIPPLE IF OTHERWISE UNOBTAINABLE)	1
7	19 mm × 76 mm THREADED STEEL PIPE NIPPLE	2
8	19 mm MALL IRON PIPE CAP	1

Figure 1B Table

Ref No.	No. Req.	Description
1	1	COLLAR-RECESS, SAMPLE VALVE
2	1	PLATE-END, RECESS, SAMPLE VALVE
3	1	PIPE-INLET, 19 mm × 330 mm LG., T.O.E.
4	1	VALVE, 19 mm, ANGLE, CRANE, #2
5	1	ELBOW-45°, STREET, 19 mm
6	1	RING-FIN, THERM. WELL
7	1	RING-FIN, RECESS, SAMPLE VALVE
8	1	NIPPLE-PIPE, 19 mm × 102 mm LG.
9	1	CAP ASM.-SAMPLING VALVE
10	12	SCREW-PARKER KALON, #14
11	2	RIVET-SOUTHCO, #38-106-05, 3/16, 9/32 LG.

15. Replace Figure 5 with the following figure:



Dimensional Equivalents

13 mm	76 mm	305 mm
$^1/_2$ in.	3 in.	12 in.

Notes:
1. The outlet valve may be attached in either a horizontal or vertical position; the vertical position is preferred.
2. This device is to be furnished by the asphalt plant operator and should remain in the custody of the inspector until the completion of the job.
3. The device is to be inserted in the discharge line between the unloading pipe and the hose.
4. If the transport operator so elects, the 13-mm outlet assembly may be permanently attached to the outlet pipe, as near to the end as is practicable.
5. Drain off sufficient material through the spigot prior to taking a sample to ensure removal of any contaminants.
6. The sample should be taken after one-third and not more than two-thirds of the load has been removed. Take the sample slowly to ensure it is representative of the material being unloaded.

Figure 5—Typical Device for Sampling of Liquid Asphalt from Transports

Standard Method of Test for

Solubility of Bituminous Materials

AASHTO Designation: T 44-03 (2007)[1]
ASTM Designation: D 2042-01

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Solubility of Bituminous Materials

AASHTO Designation: T 44-03 (2007)[1]
ASTM Designation: D 2042-01

1. SCOPE

1.1. This method covers the determination of the degree of solubility in trichloroethylene or 1,1,1 trichloroethane of asphalt materials having little or no mineral matter. The portion that is soluble in trichloroethylene or 1,1,1 trichloroethane represents the active cementing constituents.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests

3. SUMMARY OF METHOD

3.1. The sample is dissolved in trichloroethylene or 1,1,1 trichloroethane and filtered through a filter mat. The insoluble material is washed, dried, and weighed.

4. APPARATUS AND MATERIALS

4.1. The assembly of the filtering apparatus is illustrated in Figure 1. Details of the component parts are as follows:

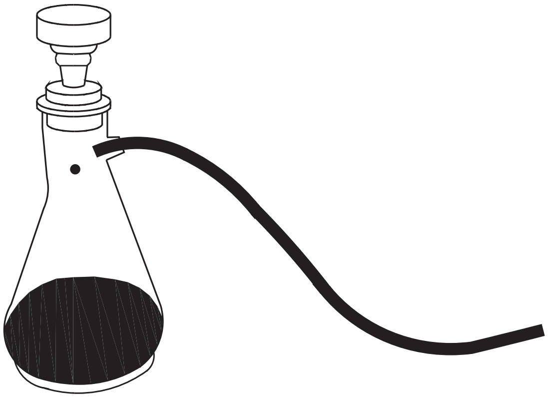


Figure 1—Filtering Apparatus Assembly

4.1.1. *Gooch Crucible*—glazed inside and outside with the exception of outside bottom surface. The approximate dimensions shall be a diameter of 44 mm at top, tapering to 36 mm at bottom, and a depth of 24 to 28 mm.

4.1.2. *Glass Fiber Pad*—32, 35, or 37 mm in diameter.[2]

4.1.3. *Filter Flask*—heavy-wall, with side tube, 250-mL capacity or larger.

4.1.4. *Filter Tube*—40 to 42 mm inside diameter.

4.1.5. *Rubber Tubing or Adapter*—for holding the Gooch crucible on the filter tube.

Note 1—Other suitable assemblies permitting vacuum filtration with a Gooch crucible may be used.

4.2. *Erlenmeyer Flask*—125 mL, or other suitable container.

4.3. *Oven*—capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF).

4.4. *Desiccator*—of suitable size, charged with an effective desiccant.

4.5. *Analytical Balance*—Class A conforming to the requirements of AASHTO Specification M 231.

5. SOLVENT

5.1. Technical grade, Type I, tricholorethylene or technical grade 1,1,1 tricholorethane.

6. SAFETY PRECAUTIONS

6.1. Trichloroethylene and 1,1,1 trichloroethane are toxic materials and strict adherence to instructions in Material Safety Data Sheets are to be followed. *Caution*: Trichloroethylene and 1,1,1 trichloroethane in the presence of heat and moisture may form acids that are extremely corrosive.

7. PREPARATION OF GOOCH CRUCIBLE

7.1. Assemble the filtering apparatus as shown in Figure 1. Place filter pad into the Gooch crucible, moisten the pad with solvent, and seat firmly in the bottom of the crucible with light suction. Dry the crucible and contents at 110 ± 5ºC (230 ± 9ºF) for at least 20 minutes. Cool the crucible and contents in a desiccator for at least 20 minutes and determine the mass. Repeat this procedure until constant mass (±0.3 mg) is obtained. Store in a desiccator until ready for use.

8. SAMPLE PREPARATION

8.1. If the sample is not fluid, heat the sample with care to prevent local overheating until it has become sufficiently fluid to pour, occasionally stirring the sample to aid heat transfer and to assure uniformity. Avoid the entrapment of air.

9. PROCEDURE

9.1. Note safety precautions in Section 6. Transfer approximately 2 g of the sample into a tared 125-mL Erlenmeyer flask or other suitable container. Allow the container and its contents to cool to ambient temperatures and determine the mass to the nearest 1 mg. Add 100 mL of the trichloroethylene or 1,1,1 trichloroethane to the container, stopper flask and agitate as necessary until the sample is dissolved and no undissolved material adheres to the container. Check for undissolved material after a period of at least 15 minutes.

Normally the temperature at which this test is run is not critical, and it may be performed at the laboratory air temperature. For referee tests, however, the flask and sample in solution shall be placed in a water bath maintained at 37.8 ± 0.25ºC (100 ± 0.5ºF) for one hour before filtering.

9.2. Place the previously prepared and tared Gooch crucible in the filtering tube.

Wet the filter pad with a small portion of clean solvent and decant the solution through the filter pad of the crucible with light suction.

When the insoluble matter is appreciable, retain as much of it as possible in the container until the solution has drained through the filter pad. Wash the container with a small amount of solvent and, using a stream of solvent from a wash bottle, transfer all insoluble matter to the crucible. Use a "policeman" if necessary to remove any insoluble matter adhering to the container, rinse the policeman and the container, thoroughly wash the insoluble matter in the crucible with solvent until the filtrate is substantially colorless, then apply strong suction to remove the remaining solvent. Remove the crucible from the tube and wash the bottom free of any dissolved matter. Dry the crucible and contents at 110 ± 5ºC (230 ± 9ºF) for at least 20 minutes. Cool the crucible and contents in a desiccator for at least 20 minutes and determine the mass. Repeat this procedure until constant mass (±0.3 mg) is obtained.

Fiberglass filter pads should be used only one time.

10. CALCULATIONS AND REPORT

10.1. Calculate either the total percentage of insoluble matter or the percentage of the sample soluble in the solvent used as follows:

$$\text{Insoluble, percent} = \frac{C - A}{B} \times 100 \qquad (1)$$

$$\text{Soluble, percent} = \left(\frac{B - (C - A)}{B} \right) \times 100 \qquad (2)$$

where:

A = mass of crucible and filter;

B = total mass of sample; and

C = mass of crucible, filter, and insoluble material.

10.1.1. Report the percentage of insoluble material to the nearest 0.1 percent.

11. PRECISION

11.1. Estimates of standard deviations for this procedure and the criteria for judging the acceptability of results (95 percent confidence level) are indicated in Table 1.

Table 1—Standard Deviations

	Standard Deviations			
	Within-Laboratory Variability[a]		Between-Laboratory Variability[a]	
	Standard Deviation[b]	Repeatability[c]	Standard Deviation[b]	Reproducibility[d]
Asphalts solubility more than 99 percent (trichloroethylene or 1,1,1 trichloroethane)	0.035	0.10	0.090	0.26

[a] For definition of terms and recommended use of precision indexes, see the Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material (ASTM E 177).

[b] The standard deviations shown represent the estimated standard deviation of the measurement process for the stated conditions. They are calculated by multiplying the standard deviations of the applicable data by the factor:

$$1 + \frac{1}{4(N-1)}$$

where N is the number of tests in the set of data.

[c] Two results obtained by an operator on the same sample should be considered suspect if they differ by more than the stated amount. As defined in Recommended Practice E 177, this is the difference two-sigma limits for single-laboratory-operator-machine-multiday precision.

[d] Two results obtained by operators in different laboratories should be considered suspect if they differ by more than the stated amount. As defined in Recommended Practice E 177, this is the "difference two-sigma" limits for multilaboratory-operator-machine-day precision.

The estimates of standard deviation are based on the following:

	Asphalts
Materials	4
Replications	3
Solvents	4
Laboratories	26
Degrees of freedom:	
Within-laboratory variability	159
Between-laboratory variability	81
Standard deviation(s) of data:	
Within-laboratory variation	0.035
Between-laboratory variation	0.090

11.2. AASHTO Materials Reference Laboratory (AMRL) data for T 44 and ASTM D 2042 were analyzed in 2001. These data represent approximately 13,200 repetitions of the test conducted on 132 samples having solubility values between 99.5 percent and 100 percent. For samples within this range, the analysis suggests the following precision values are appropriate:

Multilaboratory Standard Deviation (1s) = 0.01 + (0.75 × % Insoluble)
Single-Operator Standard Deviation (1s) = 0.01 + (0.25 × % Insoluble)

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[1] Similar, but not technically identical to ASTM D 2042-01.

[2] Whatman Grade 934 AH glass microfiber filter pad, available from Reeves Angel & Co., Clifton, NJ, has been found suitable.

Standard Method of Test for

Flash and Fire Points by Cleveland Open Cup

AASHTO Designation: T 48-06
ASTM Designation: D 92-05a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Flash and Fire Points by Cleveland Open Cup

AASHTO Designation: T 48-06
ASTM Designation: D 92-05a

AASHTO T 48-06 is identical to ASTM D 92-05a except for the following provisions:

1. All references to the ASTM standards listed in the following table shall be replaced with the corresponding AASHTO standard:

Referenced Standards

ASTM	AASHTO
D 93	T 73
D 140	T 40
D 1310	T 79

2. Add the following reference to Section 2.1:

   C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. Replace the dimensions in Figure 1 with the following:

	Millimeters		Inches	
	Min	Max	Min	Max
A—Diameter	3.8	5.4	0.15	0.21
C—Diameter	1.6	5.0	0.06	0.20
D	5.0		0.20	
E	6.4, approximately		0.25, approximately	

4. Replace the dimensions in Figure 2 with the following:

	Millimeters		Inches	
	Min	Max	Min	Max
A	6.4, nominal		0.25, nominal	
C	6.4, nominal		0.25, nominal	
D—Diameter	54.5	56.5	2.15	2.22
F—Diameter	150, nominal		6, nominal	

5. Replace the dimensions in Figure 3 with the dimensions below. Do not include a dimension "G" as shown in Figure 3. However, include a dimension for the thickness of the flange of the test cup that is not included in Figure 3. This dimension for the thickness of the flange shall be designated "K" with the dimensional requirements as in the following table:

	Millimeters		Inches	
	Min	Max	Min	Max
B	62.5	64.0	2.46	2.52
C	2.8	3.6	0.11	0.14
D—Radius	4, approximately		0.16, approximately	
H	2.8	3.6	0.11	0.14
J	97	101	3.8	4.0
K	1.8	3.4	0.07	0.13

6. Add the following sentence after the first sentence in Section 11.1.1:

   To aid in this operation, a Filling Level Gauge (A1.7) may be used.

7. Add an additional note that immediately follows Section 11.1.1 as follows:

   Note—The sample cup may be filled away from the apparatus provided the thermometer is preset with the cup in place and the sample level is correct at the beginning of the test. A shim 6.4-mm (0.25-in.) thick is useful in obtaining the correction distance from the bottom of the bulb to the bottom of the cup.

8. Replace the first sentence of Section 11.1.3 with the following:

   Light the test flame, and adjust it to a diameter of 3.8 to 5.4 mm (0.15 to 0.21 in.).

9. Replace Section 11.1.4 with the following:

   11.1.4 Apply heat initially at such a rate that the temperature indicated by the temperature-measuring device increases 10 to 20ºC (18 to 36ºF)/min. When the test specimen temperature is approximately 56ºC (100ºF) below the expected flash point, decrease the heat so that the rate of temperature rise during the last 28ºC (50ºF) before the flash point is 4 to 7ºC (7 to 13ºF)/min.

10. Replace the fourth sentence of Section 11.1.5 with the following:

    The center of the test flame must move in a horizontal plane not more than 2.5 mm (0.10 in.) above the plane of the upper edge of the cup and pass in one direction only.

11. Replace the last sentence of Section 11.1.9 with the following:

    Continue heating the test specimen at 4 to 7ºC (7 to 13ºF)/min and testing the material every 2ºC (5ºF) as described in Section 11.1.5 until the flash point is obtained.

12. Replace Section 14 with the following:

    14. **Precision and Bias**

    14.1 *Precision*—Criteria for judging the acceptability of test results for the flash point of asphalt binders obtained by this method are given in Table 1. Criteria for judging the acceptability of fire point test results can be found in ASTM D 92.

    14.1.1 *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the values given in Table 1, Column 3.

    14.1.2 *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the values given in Table 1, Column 3.

Table 1—Precision Estimates

Condition	Acceptable Standard Deviation (1s)[a]	Range of Two Results (d2s)[a]
Single-Operator Precision:		
Flash Point (°C)	3	8
Multilaboratory Precision:		
Flash Point (°C)	10	28

[a] These values represent the 1s and d2s limits described in ASTM Practice C 670.

Note: The precision estimates for Flash Point given in Table 1 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 98 to 148 laboratories for each of the eight pairs of samples. The analysis included four binder grades: PG 52-34, PG 64-16, PG 64-22, and PG 70-22. Average flash points ranged from 268.5 to 353.5°C. The details of the analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

14.2 *Bias*—The procedure of this test method has no bias because flash point and fire point can only be defined in terms of this test method.

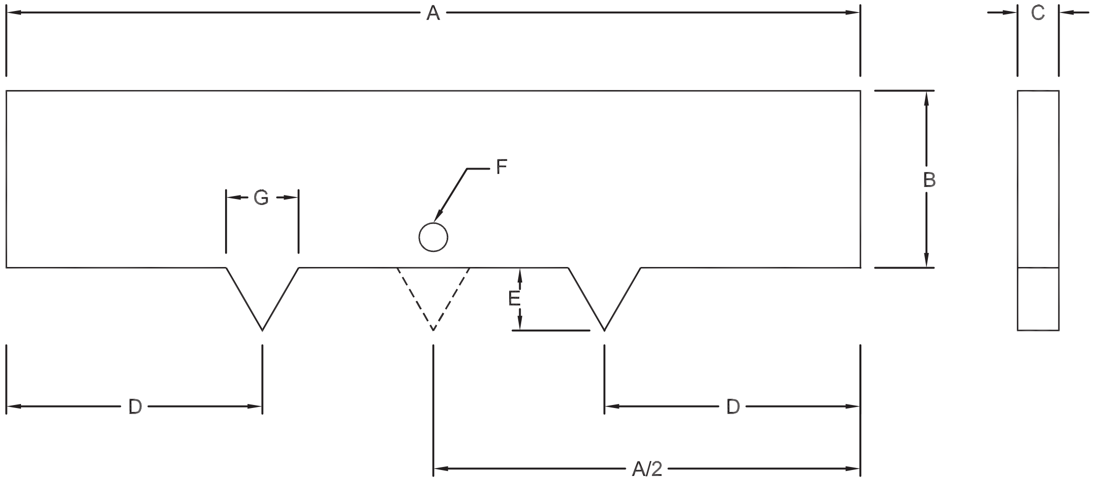
13. Replace Section A1.3 with the following:

    A1.3 *Ignition Source Applicator*—The device for applying the test flame may be of any suitable design, but the tip shall be 1.6 to 5.0 mm (0.06 to 0.20 in.) in diameter at the end and the orifice shall have an approximate diameter of 0.8 mm (0.031 in.). The device for applying the test flame shall be so mounted to permit automatic duplication of the sweep of the test flame, the radius of swing being not less than 150 mm (6 in.) and the center of the orifice moving in a plane not more than 2.5 mm (0.10 in.) above the cup. A bead having a diameter of 3.8 to 5.4 mm (0.15 to 0.21 in.) shall be mounted in a convenient position on the apparatus so the size of the test flame can be compared to it.

14. Add an additional Section A1.7 after Section A1.6 as follows:

    A1.7 *Filling Level Gauge*—A device to aid in the proper adjustment of the sample level in the cup. It may be made of suitable metal with at least one projection, but preferably two for adjusting the sample level in the test cup to 9 to 10 mm (0.35 to 0.39 in.) below the top edge of the cup. A hole 0.8 mm (0.031 in.) in diameter, the center of which is located not more than 2.5 mm (0.10 in.) above the bottom edge of the gauge, shall be provided for use in checking the center position of the orifice of the test flame applicator with respect to the rim of the cup. (Figure 4 shows a suitable version.)

15. Add a Figure 4 after Section A1.7.



	Millimeters	Inches	
A	100	4	Nominal
B	20	¾	Nominal
C	3.2	⅛	Nominal
D	30	1¼	Nominal
E	9–10	0.35–0.39	
F	0.8 Dia (2.5 mm above bottom edge)	1/32 Dia (0.10 in. above bottom edge)	Nominal Maximum
G	10	⅜	Nominal

Figure 4—Filling Level Gauge

Standard Method of Test for

Penetration of Bituminous Materials

AASHTO Designation: T 49-07
ASTM Designation: D 5-06$^{\in 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Penetration of Bituminous Materials

AASHTO Designation: T 49-07
ASTM Designation: D 5-06$^{\epsilon 1}$

AASHTO T 49-07 is identical to ASTM D 5-06$^{\epsilon 1}$ except for the following provisions:

1. Replace all references to ASTM D 36 with AASHTO T 53.
2. Add the following to Section 2:
   2.4 *AASHTO Standard*:
   R 16, Regulatory Information for Chemicals Used in AASHTO Tests
3. Replace the last sentence of Section 6.1 with the following:
   The weight of the spindle shall be checked.

Standard Method of Test for

Float Test for Bituminous Materials

AASHTO Designation: T 50-09
ASTM Designation: D 139-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Float Test for Bituminous Materials

AASHTO Designation: T 50-09
ASTM Designation: D 139-07

AASHTO T 50-09 is identical to ASTM D 139-07 except as follows:

1. Insert a new section immediately before Section 2.1 to contain the following:

   All references to the ASTM standards listed in the following table shall be replaced with the corresponding AASHTO standard.

Referenced Standards

ASTM	AASHTO
D 244	T 59
D 6997	T 59

2. Add two new sentences at the end of Section 7.3 to contain the following:

   "The residue may also be poured from the still directly into a tin or small container which shall be maintained at the proper temperature for pouring. The temperature of the residue shall be verified during pouring by inserting the 30 AWG gauge thermocouple probe into the residue while it is poured out of the container into the collar."

Standard Method of Test for

Ductility of Asphalt Materials

AASHTO Designation: T 51-09
ASTM Designation: D 113-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Ductility of Asphalt Materials

AASHTO Designation: T 51-09

ASTM Designation: D 113-07

AASHTO T 51-09 is identical to ASTM D 113-07 except for the following provisions:

1. Replace all references to the ASTM standards listed in the following table with the corresponding AASHTO standard:

Referenced Standards

ASTM	AASHTO
D 5	T 49
D 1754	T 179
D 2872	T 240
E 11	M 92

2. Add the following sentences to Section 4.2:

   The volume of water shall be not less than 10 L. The depth of water shall not be less than 50 mm and such that the mold can be immersed to a depth of 25 mm. The water in the bath shall be substantially free from oil and slime or other organic growth.

3. Add the following sentence to Section 4.4:

   If a thermometer conforming to ASTM E 1 is used, calibrate the thermometer according to ASTM E 77.

4. Replace 4.5 with the following:

   4.5 *Release Agent* —Mixtures of glycerin and dextrin or talc (3 g of glycerin to about 5 g of dextrin or talc has been used satisfactorily), Dow-Corning Silicone Stop-Cock Grease, or a mixture of castor oil and Versamid 900 [100:1 mixture by weight heated to 204 to 232ºC (400 to 450ºF) and stirred until homogeneous] have been proven suitable. Other release agents may be used provided results obtained are comparable to those obtained when using one of the above.

5. Delete Note 2, which recommends sieving some samples.

Standard Method of Test for

Softening Point of Bitumen (Ring-and-Ball Apparatus)

AASHTO Designation: T 53-09
ASTM Designation: D 36-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Softening Point of Bitumen (Ring-and-Ball Apparatus)

AASHTO Designation: T 53-09
ASTM Designation: D 36-06

AASHTO T 53-09 is identical to ASTM D 36-06 except for the following provisions:

1. Replace all references to the ASTM standards listed in the following table with the corresponding AASHTO standard:

Referenced Standards

ASTM	AASHTO
D 92	T 48
D 140	T 40

2. Replace Section 5.2 with the following:

   Pouring Plate—A flat, smooth brass plate.

3. Add an additional subsection to Section 5.7 that reads as follows:

   An ASTM Wide Range Softening Point Thermometer, having a range from –1 to +175°C or 30 to 350°F and conforming to the requirements for Thermometer 113C or 113F as prescribed in ASTM E 1. As an alternative, other thermometric devices may be used provided they: (1) have a maximum scale error no greater than that of the thermometer specified in ASTM E 1, and (2) are capable of indicating temperature within 0.5°C (1.0°F).

4. Replace the last sentence of Section 5.7.1 with the following:

   As an alternative, other thermometric devices may be used provided they: (1) have a maximum scale error no greater than that of the thermometer specified in ASTM E 1, and (2) are capable of indicating temperature within 0.2°C (0.5°F).

5. Replace the last sentence of Section 5.7.2 with the following:

   As an alternative, other thermometric devices may be used provided they: (1) have a maximum scale error no greater than that of the thermometer specified in ASTM E 1, and (2) are capable of indicating temperature within 0.5°C (1.0°F).

6. Delete the final two sentences of Section 5.7.3.
7. Replace Figure 1 with the figure on the next page.
8. Replace the first sentence of Section 6.1.3 with the following:

   Ethylene Glycol, with a boiling point between 193 and 204°C (379 and 399°F).

9. Replace the first sentence of Section 9.1.1 with the following:

   Freshly boiled distilled water for softening points between 30 and 80°C (86 and 176°F); use Thermometer 15C or 15F or an alternative thermometric device as specified in Section 5.7.1.

10. Replace the first sentence of Section 9.1.2 with the following:

    USP glycerin for softening points above 80°C (176°F) and up to 157°C (315°F); use Thermometer 16C or 16F or an alternative thermometric device as specified in Section 5.7.2.

11. Replace the first sentence of Section 9.1.3 with the following:

    Ethylene glycol for softening points between 30 and 110°C (86 and 230°F); use Thermometer 113C or 113F, or an alternative thermometric device as specified in Section 5.7.2.

12. Replace Section 11.1 with the following:

    When using Thermometer 15C or 15F, or an alternative thermometric device as specified in Section 5.7.1, report the mean or corrected mean of the temperatures recorded in Section 9.6 to the nearest 0.2°C (0.5°F) as the softening point.

13. Replace Section 11.2 with the following:

    When using Thermometer 16C, 16F, 113C, or 113F, or an alternative thermometric device as specified in Section 5.7.2, report the mean or corrected mean of the temperatures recorded in Section 9.6 to the nearest 0.5°C (1.0°F) as the softening point.

Standard Method of Test for

Water in Petroleum Products and Bituminous Materials by Distillation

AASHTO Designation: T 55-02 (2006)
ASTM Designation: D 95-05$^{\epsilon 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

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AASHTO T 55-02 (2006) is identical to ASTM D 95-05$^{\in 1}$ except that all references to the ASTM standards contained in ASTM D 95-05$^{\in 1}$, listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standards	
ASTM	AASHTO
D 244	T 59

Standard Method of Test for
Emulsified Asphalts

AASHTO Designation: T 59-09

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Standard Method of Test for

Emulsified Asphalts

AASHTO Designation: T 59-09

1. SCOPE

1.1 These test methods, given under the headings titled Composition, Consistency, Stability, Examination of Residue, Identification Tests, Coating Tests on Emulsified Asphalts, and Density of Emulsified Asphalts, cover the examination of Emulsified Asphalt composed principally of a semisolid or liquid asphalt base, water, and an emulsifying agent. The methods cover the following tests:

Test	Section(s)
Composition:	
Water Content	4
Residue and Oil Distillate by Distillation	5
Emulsified Asphalt Residue by Evaporation	6
Particle Charge of Cationic Emulsified Asphalts	7
Consistency:	
Viscosity (Saybolt Furol)	8
Stability:	
Demulsibility	9
Settlement	10
Cement Mixing	11
Sieve Test	12
Coating Test	13
Miscibility with Water	14
Freezing Test	15
Coating Ability and Water Resistance	16
Storage Stability of Emulsified Asphalt	17
Examination of Residue	18 to 25
Identification Tests:	
Identification Test for Cationic Rapid-Setting (CRS) Emulsified Asphalts	26
Identification Test for Cationic Slow-Setting (CSS) Emulsified Asphalts	27
Coating Tests on Emulsified Asphalts:	
Field Coating Test	28
Emulsified Asphalt/Job Aggregate Coating Test	29
Density of Emulsified Asphalts:	
Test to Determine Mass per Liter (Gallon)	30

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 85, Portland Cement
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 140, Emulsified Asphalt
- M 208, Cationic Emulsified Asphalt
- M 231, Weighing Devices Used in the Testing of Materials
- M 316, Polymer-Modified Cationic Emulsified Asphalt
- T 40, Sampling Bituminous Materials
- T 44, Solubility of Bituminous Materials
- T 49, Penetration of Bituminous Materials
- T 50, Float Test for Bituminous Materials
- T 51, Ductility of Asphalt Materials
- T 72, Saybolt Viscosity
- T 228, Specific Gravity of Semi-Solid Asphalt Materials

2.2 *ASTM Standards*:

- C 778, Standard Specification for Standard Sand
- D 86, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D 128, Standard Test Methods for Analysis of Lubricating Grease
- D 3289, Standard Test Method for Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method)
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 145, Standard Specification for Gravity-Convection and Forced-Ventilation Ovens

3. SAMPLE CONDITIONING FOR TESTING

3.1 All emulsified asphalt with viscosity requirements of 50°C (122°F) should be heated to 50 ± 3°C (122 ± 5°F) in the original sample container in a 71°C (160°F) water bath or oven. The container should be vented to relieve pressure. After the sample reaches 50 ± 3°C (122 ± 5°F), stir the sample to achieve homogeneity.

COMPOSITION

4. WATER CONTENT

4.1 *Scope*:

4.1.1 This test method covers the procedure for determining the water content of emulsified asphalt by reflux distillation using a water trap.

4.2 *Significance and Use*:

4.2.1 This test method measures the amount of water present in the emulsified asphalt, as distinguished from either asphalt material or petroleum solvent.

4.3 *Apparatus and Materials*:

4.3.1 *Metal Distillation Pot*—The metal distillation pot [Figure 1(a)] shall be a vertical cylindrical vessel, preferably made of copper, having a faced flange at the top to which the head is tightly attached by means of a clamp. The head shall be made of metal, preferably brass or copper, and shall be provided with a tubulation 25.4 mm (1 in.) in inside diameter.

4.3.2 *Glass Distillation Pot*—The glass distillation pot [Figure 1(b)] shall be a short-neck, round-bottom flask, made of well-annealed glass, and having an approximate capacity of 500 mL.

4.3.3 *Heat Source*—The heat source used with the metal distillation pot shall be a ring gas burner of 100-mm (4-in.) inside diameter or an electric mantle heater. The heat source for the glass distillation pot shall be either an ordinary gas burner or electric heater.

4.3.4 *Condenser*—The condenser shall be a water-cooled, reflux glass-tube type, having a jacket not less than 400 mm ($15^3/_4$ in.) in length, with an inner tube 9.5 to 12.7 mm ($^3/_8$ to $^1/_2$ in.) in outside diameter. The end of the condenser shall be ground to an angle of 30 ± 5° from the vertical axis of the condenser.

4.3.5 *Trap*—The trap shall be made of annealed glass constructed in accordance with Figure 1(c) and graduated in 0.10-mL divisions from 0 to 2 mL and in 0.20-mL divisions from 2 to 25 mL.

4.3.6 *Solvent*—Xylol or other petroleum distillate conforming to the following distillation requirements: 98 percent distills between 120 and 250°C (248 and 482°F). This distillation shall be conducted in accordance with ASTM D 86.

4.3.7 *Balance*—Conforming to the requirements of M 231, Class G 2.

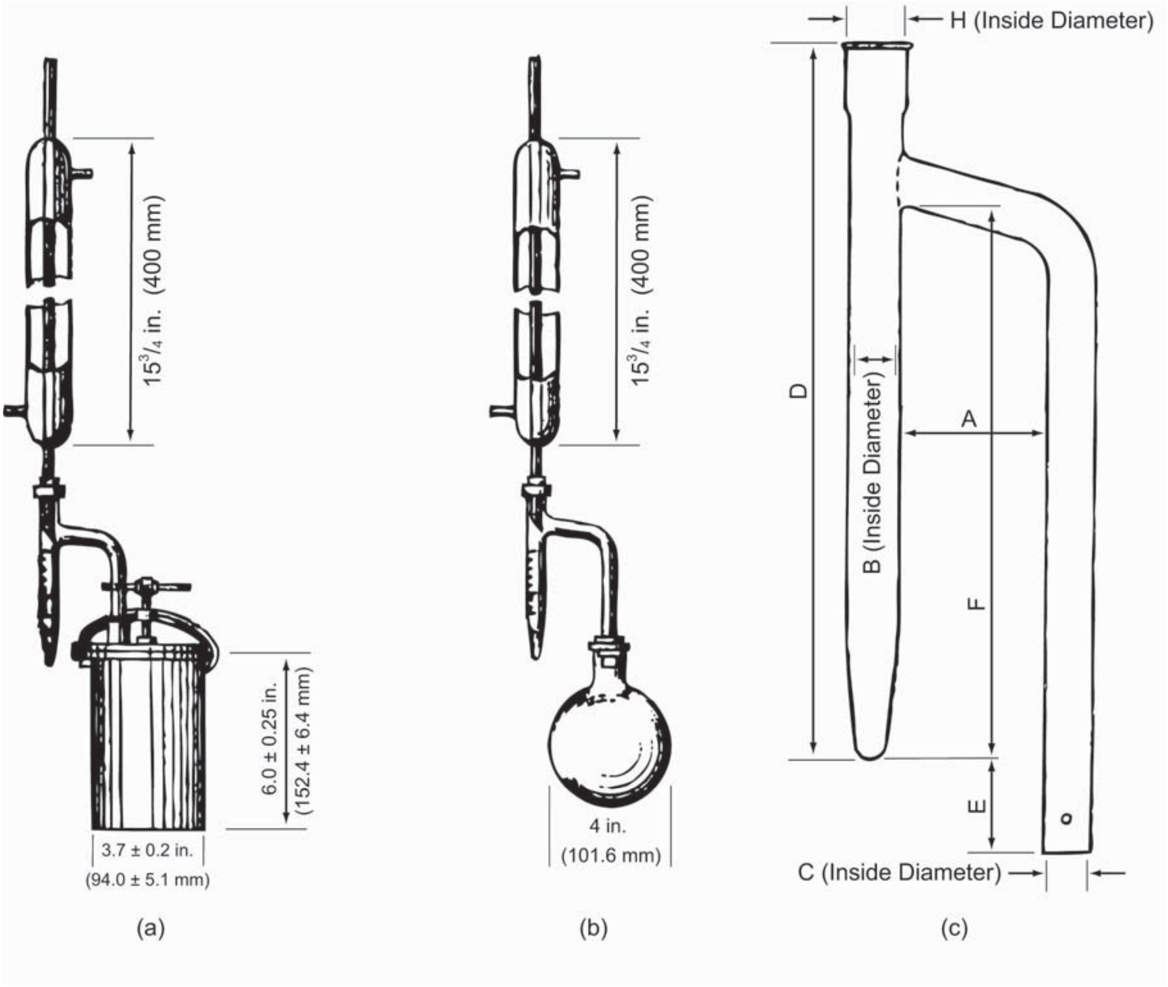
4.4 *Sample*:

4.4.1 Obtain a representative sample of the material as specified in T 40.

Note 1—The difficulties in obtaining representative samples for this determination are unusually great, so the importance of proper sampling cannot be too strongly emphasized.

4.5 *Procedure*:

4.5.1 When the material to be tested contains 25 percent or less water, place 100 ± 0.1 g of the sample in the distillation pot. When the material contains more than 25 percent water, use a 50 ± 0.1-g sample. Thoroughly mix the sample to be tested with 200 mL of solvent by swirling, taking proper care to avoid any loss of material.



Metric Equivalents

A = 45 to 55 mm (1.8 to 2.2 in.)
B = 14 to 16 mm (0.55 to 0.62 in.)
C = 12 to 16 mm (0.47 to 0.62 in.)
D = 235 to 255 mm (9.3 to 10.0 in.)
E = 25 to 38 mm (1.0 to 1.5 in.)
F = 186 to 194 mm (7.3 to 7.6 in.)
H = 18 to 19 mm (0.71 to 0.75 in.)

Figure 1—Apparatus for Determining Water Content

4.5.2 Connect the distillation pot, trap, and condenser by means of tight-fitting corks as shown in Figure 1(a) or 1(b). Adjust the end of the condenser in the trap to a position which will allow the end to be submerged to a depth of not more than 1 mm (0.04 in.) below the surface of the liquid in the trap after distillation conditions have been established. When using the metal distillation pot, insert a heavy paper gasket, moistened with the solvent, between the lid and flange before attaching the clamp. Insert a loose cotton plug in the top of the condenser tube to prevent condensation of atmospheric moisture.

4.5.3 When the ring burner is used with the metal distillation pot, place it about 75 mm (3 in.) above the bottom of the distillation pot at the beginning of the distillation, and gradually lower it as the distillation proceeds. Regulate the heat so that the condensate falls from the end of the condenser at a rate of 2 to 5 drops per second. Continue the distillation at the specified rate until no water is visible on any part of the apparatus and a constant volume of water is obtained in the trap (V_{wt}).

Remove any persistent ring of condensed water in the condenser tube by increasing the rate of distillation for a few minutes.

4.6 *Calculation and Report*:

4.6.1 Calculate the water content as follows:

$$\text{Water Content, \%} = (V_{wt}/M_s) \times 100 \qquad (1)$$

where:

V_{wt} = volume of water in the trap, mL; and

M_s = original mass of the sample, g.

4.6.2 Report the result as "water mass percent."

4.7 *Precision and Bias*:

4.7.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

4.7.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Water Content, mass %	Repeatability, mass %
30 to 50	0.8

4.7.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Water Content, mass %	Reproducibility, mass %
30 to 50	2.0

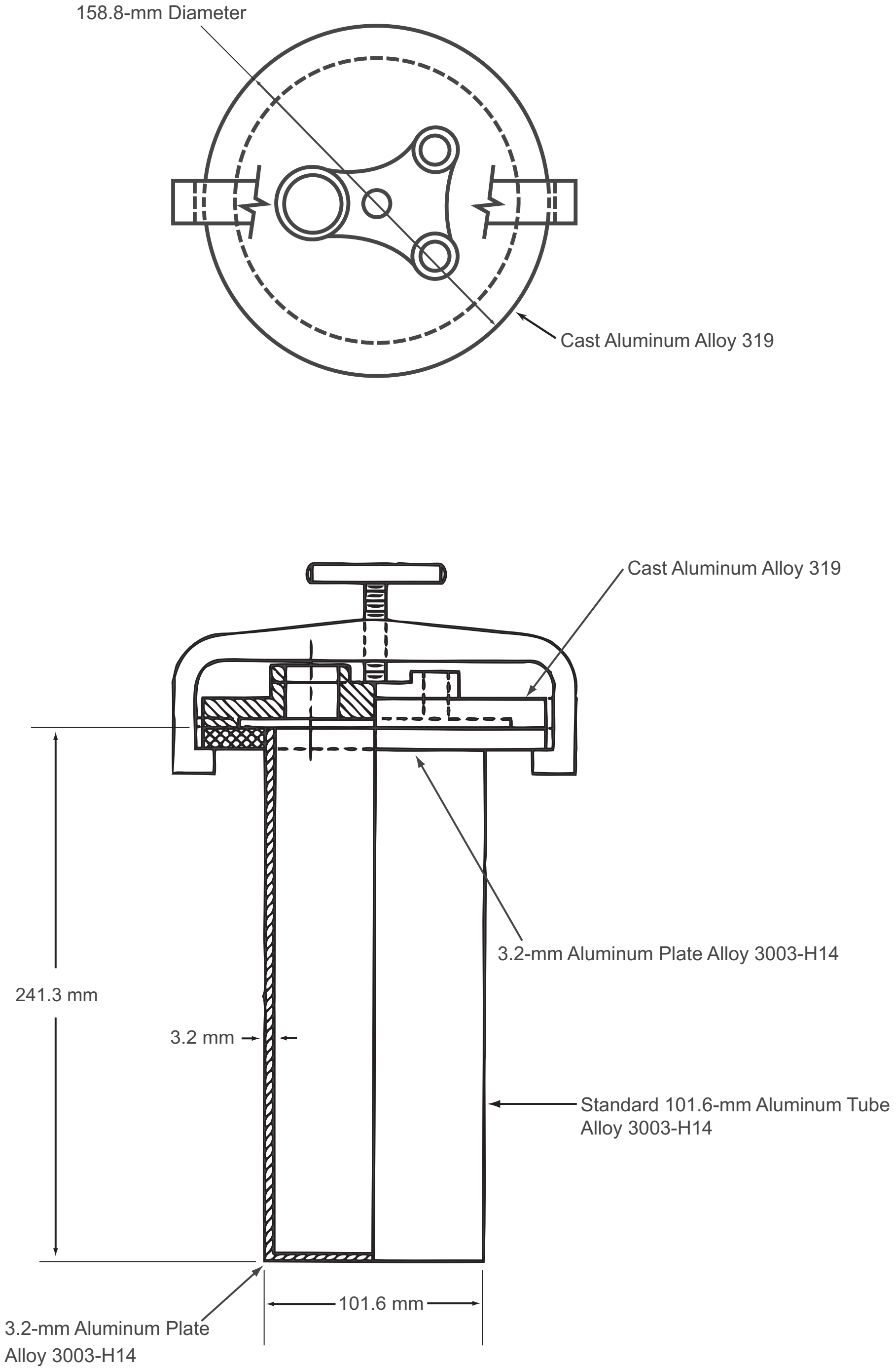
5. RESIDUE AND OIL DISTILLATE BY DISTILLATION

5.1 *Scope*:

5.1.1 This test method covers the quantitative determination of residue and oil distillate in emulsified asphalt composed principally of a semisolid or liquid asphalt base, water, and an emulsifying agent.

5.2 *Significance and Use*:

5.2.1 This test method can be used for quantitative determination of residue and oil distillate in emulsified asphalt for specification acceptance, service evaluation, control, and research. This method can also be used to obtain residue and oil distillate for further testing.



Metric Equivalents	
in.	mm
$^1/_8$	3.2
4	101.6
$6^1/_4$	158.8
$9^1/_2$	241.3

NOTE—The distillation pot cover may be machined from Rolled Aluminum Plate Alloy 3003-H14.

Figure 2—Example of an Aluminum-Alloy Distillation Pot

5.3 *Apparatus*:

5.3.1 *Aluminum-Alloy Distillation Pot*[1]*and Heat Source*—Approximately 240 mm ($9^1/_2$ in.) in height by 95 mm ($3^3/_4$ in.) in inside diameter (Figure 2) with one 121-mm ($4^3/_4$ -in.) inside diameter ring burner,[2] having holes on the inner periphery and having three spacers to ensure centering of the burner around the distillation pot (Figure 3).

Note 2—Residue by distillation results obtained with iron stills in accordance with T 59-65 are acceptable. Similarly, results obtained with a 127-mm (5-in.) ring burner as in subsequent issues of T 59 are acceptable.

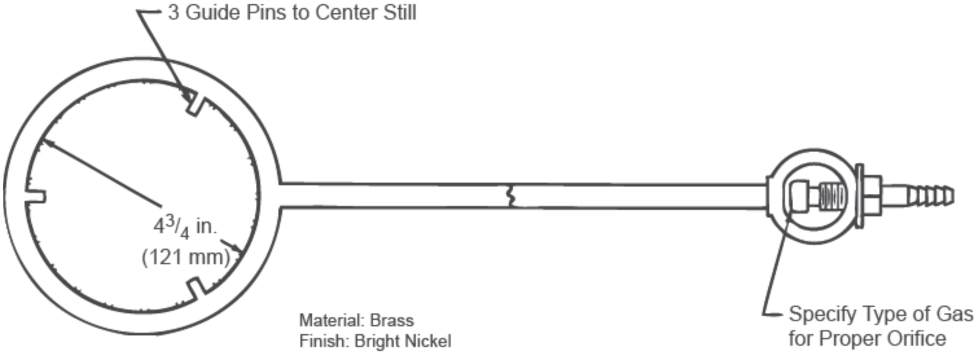


Figure 3—Ring Burner with 121-mm ($4^3/_4$-in.) Inside Diameter

5.3.2 *Connection Apparatus*—Consisting of a glass connecting tube, tin shield, and water-cooled glass condenser of the West or Leibig type with a borosilicate glass or metal jacket and a suitable adapter between the condenser and a 100-mL graduated cylinder, all with dimensions as shown in Figure 4.

5.3.3 *Graduated Cylinder*—100-mL capacity with graduation intervals of 1.0 mL.

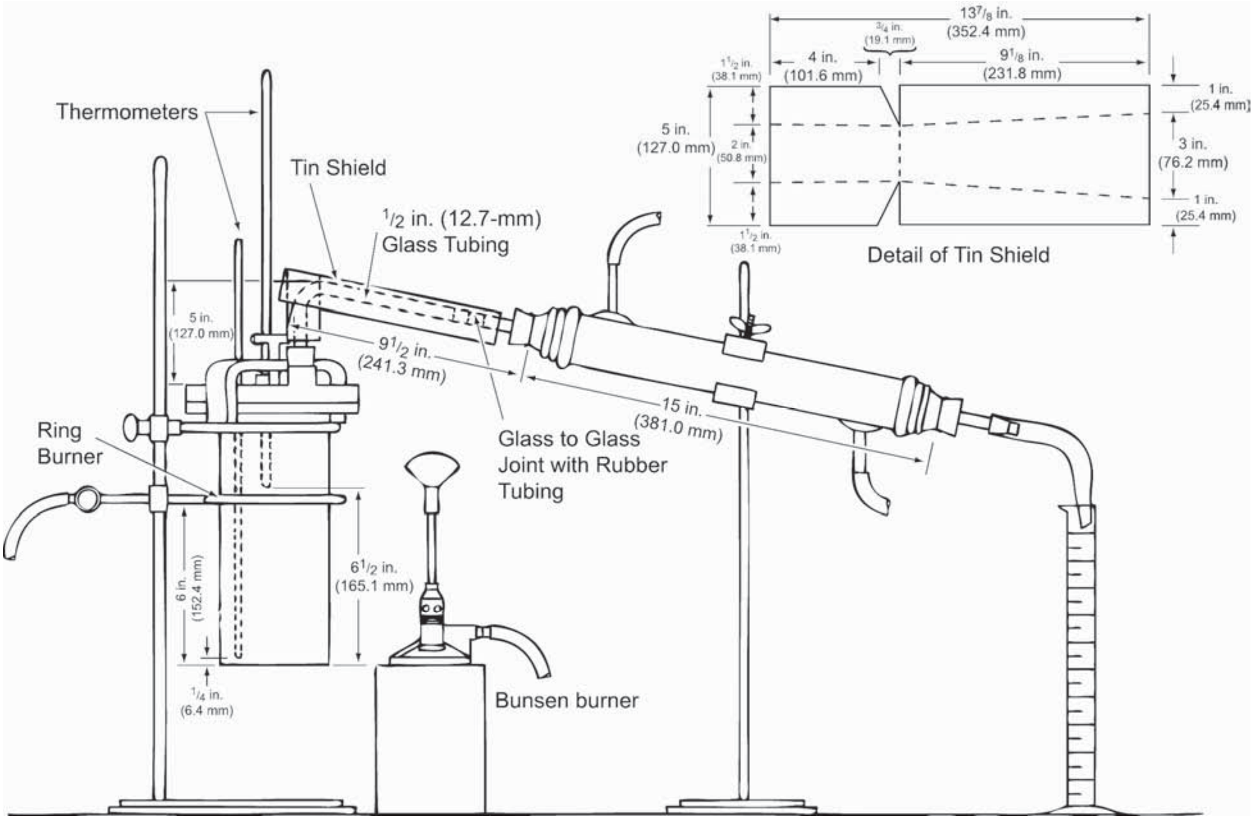
5.3.4 *Thermometers*—Two ASTM Low-Distillation Thermometers, graduated either in Celsius or Fahrenheit degrees as specified, having a range from –2 to +300°C or 30 to 580°F, respectively, and conforming to the requirements for Thermometer 7C or 7F as prescribed in ASTM E 1.

Note 3—For details of the assembly of the apparatus for the distillation test, see Figure 4.

5.3.5 *Balance*—Conforming to the requirements of M 231, Class G 2.

5.3.6 *Sieve*—A 0.300-mm (No. 50) sieve conforming to M 92.

5.3.7 *Bunsen Burner.*



Metric Equivalents															
mm	6.5	13	19	25	38	51	76	102	127	152	165	232	241	352	381
in.	$^1/_4$	$^1/_2$	$^3/_4$	1	$1^1/_2$	2	3	4	5	6	$6^1/_2$	$9^1/_8$	$9^1/_2$	$13^7/_8$	15

Figure 4—Apparatus Assembly for Distillation Test of Emulsified Asphalt

5.4 *Procedure*:

5.4.1 Determine the mass of the aluminum-alloy distillation pot (including the lid, clamp, cork, thermometers, and gaskets, if a gasket is used.) Pour 200 ± 0.1 g of a representative sample of the emulsified asphalt into the distillation pot.

5.4.2 Use a gasket of oiled paper between the distillation pot and its cover, or grind the joint to a tight fit. Securely clamp the cover on the distillation pot.

5.4.3 Insert a thermometer through a cork, in each of the small holes provided in the cover. Adjust these thermometers so that the end of the bulb of one is approximately 6 mm ($^1/_4$ in.) from the bottom of the distillation pot and the bulb of the other is approximately 165 mm ($6^1/_2$ in.) from the bottom of the distillation pot.

5.4.4 Place the ring burner around the distillation pot about 150 mm (6 in.) from the bottom of the distillation pot. Apply heat by lighting this burner and adjusting it to a low flame. Also apply just enough heat from a burner to the connecting tube to prevent condensation of water in this tube.

5.4.5 Move the ring burner approximately level with the bottom of the distillation pot when the temperature on the lower thermometer is approximately 215°C (420°F). Increase the temperature to 260 ± 5°C (500 ± 10°F), as read on the lower thermometer, maintaining it at this temperature for 15 minutes. Complete the total distillation in 60 ± 15 minutes from the first application of heat.

Note 4—The location of the burner at the start of the test is flexible. It may be raised to decrease the chance of "foam-over" or lowered to the middle of the distillation pot for emulsified asphalt containing no solvent. A sudden change in the temperature reading of the upper thermometer indicates foam on the bulb. Remove heat until the foaming ceases. (The ring burner may be gradually lowered as the distillation proceeds to ensure that the time requirements of this test are satisfied.)

5.4.6 Immediately at the expiration of the heating period, determine the mass of the distillation pot and accessories again as described in Section 5.4.1. Calculate and report the percentage of residue by distillation according to Equation 2. Record the volume of oil distillate to the nearest $^1/_2$ mL (V_{od}). Calculate and report the oil distillate as a volume percentage of the total emulsified asphalt according to Equation 3. Save this oil distillate if identification is desired.

Note 5—The mass of the aluminum-alloy distillation pot at room temperature (Section 5.4.1) is 1.5 g higher than at 260°C (500°F). Correct for this error by adding 1.5 g to the gross mass obtained in Section 5.4.6 prior to calculating the percentage of residue by distillation (M_{pr} as provided in Equation 2.)

5.4.7 Remove the cover from the distillation pot; stir, and immediately pour appropriate portions of the residue into a 236-mL (8-oz) tin or other suitable molds and containers for performing the required tests. Handle or condition molds and containers for the desired examination of the residue as described in Sections 20 to 25, and proceed as required by the appropriate method from the points that follow the pouring stage. If there is foreign matter in the residue, the material shall be poured through a 300-µm (No. 50) sieve prior to pouring it into the test molds and containers.

5.5 *Calculation and Report*:

5.5.1 Calculate the percentage of residue in the sample as follows:

$$P_{or} = (M_{pr} - M_p)/2 \qquad (2)$$

where:

P_{or} = percentage of oil residue;

M_{pr} = mass of the distillation pot, accessories, and residue after the test (+ 1.5 g), g; and

M_p = mass of the distillation pot and accessories before the test, g.

5.5.2 Calculate the percentage of oil distillate as follows:

$$P_{od} = V_{od}/2 \qquad (3)$$

where:

P_{od} = percentage of oil distillate (by volume of emulsified asphalt); and

V_{od} = volume of oil distillate, to the nearest 0.5 mL.

5.5.3 Report both the percentage of asphalt residue and percentage of asphalt distillate to the nearest 0.1 percent.

5.6 *Precision and Bias*:

5.6.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

5.6.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Residue by Distillation, mass %	Repeatability, mass %
50 to 70	1.0

5.6.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Residue by Distillation, mass %	Reproducibility, mass %
50 to 70	2.0

6. EMULSIFIED ASPHALT RESIDUE BY EVAPORATION

6.1 *Scope*:

6.1.1 This test method covers the quantitative determination of emulsified asphalt residue in emulsified asphalt composed principally of a semisolid or liquid asphalt base, water, and an emulsifying agent.

6.2 *Significance and Use*:

6.2.1 The test may be used to indicate compositional characteristics of emulsified asphalt. Evaporation residue may also be subjected to other characterization tests outlined under the "examination of residue" portions of this method (Sections 20 to 25). However, properties of the residue from the evaporation procedure may differ from those from the distillation residue (see Section 6.4.2.1).

6.3 *Apparatus*:

6.3.1 *Beakers*—Low form, l000-mL capacity, made of glass or metal, or a container of similar capacity.

6.3.2 *Glass Rods*—With flame-polished ends, approximately 6 mm ($^1/_4$ in.) in diameter and 180 mm (7 in.) in length.

6.3.3 *Balance*—Conforming to the requirements of M 231, Class G 2.

6.3.4 *Oven*—Conforming to ASTM E 145, Type lB.

6.3.5 *Sieve*—A 0.300-mm (No. 50) sieve conforming to M 92.

6.4 *Procedure*:

6.4.1 Determine the mass of each beaker containing a glass rod to the nearest 0.1 g (M_{br}). Pour 50 ± 0.1g of thoroughly mixed emulsified asphalt into each of four beakers. Place the beakers containing the rods and sample in the oven, the temperature of which has been adjusted to 163 ± 3°C (325 ± 5°F), for 2 hours. At the end of this period, remove each beaker, and stir the residue thoroughly. Replace the beakers in the oven for 1 hour; then remove the beakers from the oven. Allow them to cool to room temperature, and determine the mass of each beaker (containing a rod and the residue from the sample). Designate this mass as M_{brr}.

Note 6—Care must be taken to prevent the loss of asphalt from the beaker through foaming or spattering. Also, the placing of the beakers and emulsified asphalt samples in the oven and bringing the oven and sample to a temperature of 163°C (325°F) together is permissible. If preferred, preliminary evaporation of water may be accomplished by careful heating on a hot plate, followed by oven heating at 163°C (325°F) for 1 hour.

6.4.2 When tests on the residue from the emulsified asphalt are required, replace the beakers in the oven until the asphalt residue is sufficiently fluid to pass through a 0.300-mm (No. 50) sieve (usually requiring 15 to 30 minutes). Pour the residue through the 0.300-mm (No. 50) sieve into suitable containers and molds for performing such tests as desired, as described in Sections 20 to 25.

6.4.2.1 The method for residue by evaporation described in Section 6 tends to give an asphalt residue lower in penetration and ductility than the distillation method described in Section 5. Material may be accepted but shall not be rejected as failing to meet specifications containing requirements for determination of residue by distillation on data obtained by evaporation. If residue by evaporation fails to meet the requirements for properties specified for residue by distillation, the tests shall be repeated using the distillation method.

6.5 *Calculation and Report*:

6.5.1 Calculate the percentage of residue for each beaker as follows:

$$\text{Residue, \%} = 2(M_{brr} - M_{br}) \qquad (4)$$

where:

M_{brr} = mass of the beaker, rod, and residue, g; and

M_{br} = tare mass of the beaker and rod, g.

6.5.2 Report the percentage of residue by evaporation as the average of the four results.

6.6 *Precision and Bias*:

6.6.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

6.6.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Residue by Evaporation, mass %	Repeatability, mass %
50 to 70	0.4

6.6.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Residue by Evaporation, mass %	Reproducibility, mass %
50 to 70	0.8

7. PARTICLE CHARGE OF CATIONIC EMULSIFIED ASPHALTS

7.1 *Scope*:

7.1.1 This test method is used to identify cationic emulsified asphalt. Positively charged particles are classified as cationic.

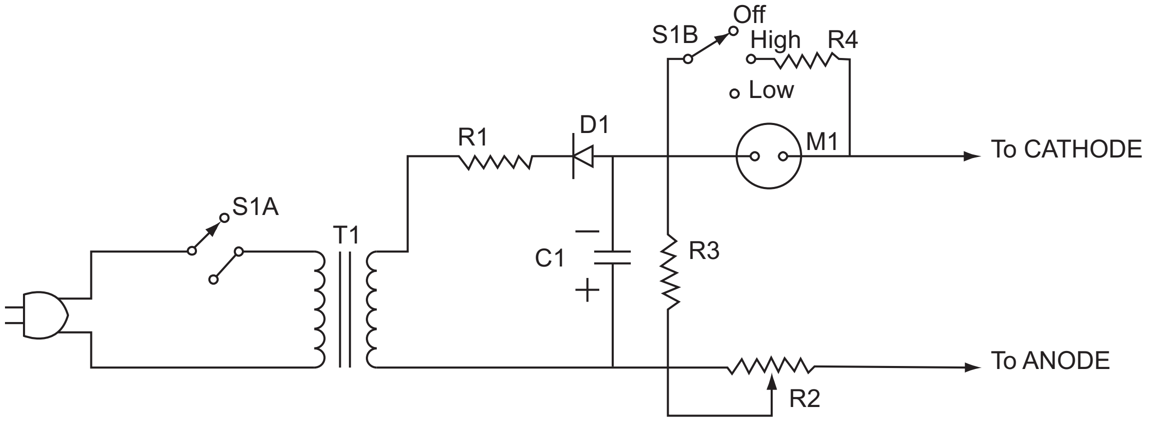
7.2 *Significance and Use*:

7.2.1 Cationic emulsified asphalt is identified by the migration of the particles to a negatively charged electrode (cathode) by means of a direct current.

7.3 *Apparatus*:

7.3.1 *Current Source*—Consisting of 12-V DC, a milliammeter, and a variable resistor (Figures 5 and 6).

Figure 5—Particle Charge Tester



C1—500-µF 25-V capacitor
D1—silicon diode
M1—0- to 10-mA milliammeter
R1—47 Ω, 1-W resistor
R2—5000 Ω potentiometer
R3—6800 Ω $^1/_4$W resistor
R4—meter shunt (determined by type of meter used)
S1—2-pole, 3-position rotary switch
T1—12.6-V filament transformer

Figure 6—Particle Charge Tester Circuit Diagram

7.3.2 *Electrodes*—Two stainless steel plates, 25.4 mm by 101.6 mm (1 in. by 4 in.) insulated from each other and rigidly held parallel 12.7 mm ($^1/_2$ in.) apart (Figure 7).

7.3.3 *Insulator*—Polytetraflouroethylene resin square rod, virgin electrical grade, 12.7 mm ($^1/_2$ in.) thick (see Figure 7). An insulator made from other suitable material may be used.

7.3.4 *Beaker*—250 mL capacity.

7.3.5 *Glass Rod*—101.6 mm (4 in.) long and 6.35 mm ($^1/_4$ in.) thick or other suitable material or device that is capable of insulating and suspending the electrode assembly in the emulsified asphalt.

7.3.6 *Water Bath*—Capable of maintaining the required testing temperature within the limits specified.

7.3.7 *Thermometer*—ASTM No. 19C or 19F conforming to the requirements of ASTM E 1.

7.3.8 *Timer*—Graduated in 0.1 second and accurate within 0.1 percent when tested over a 15-minute interval.

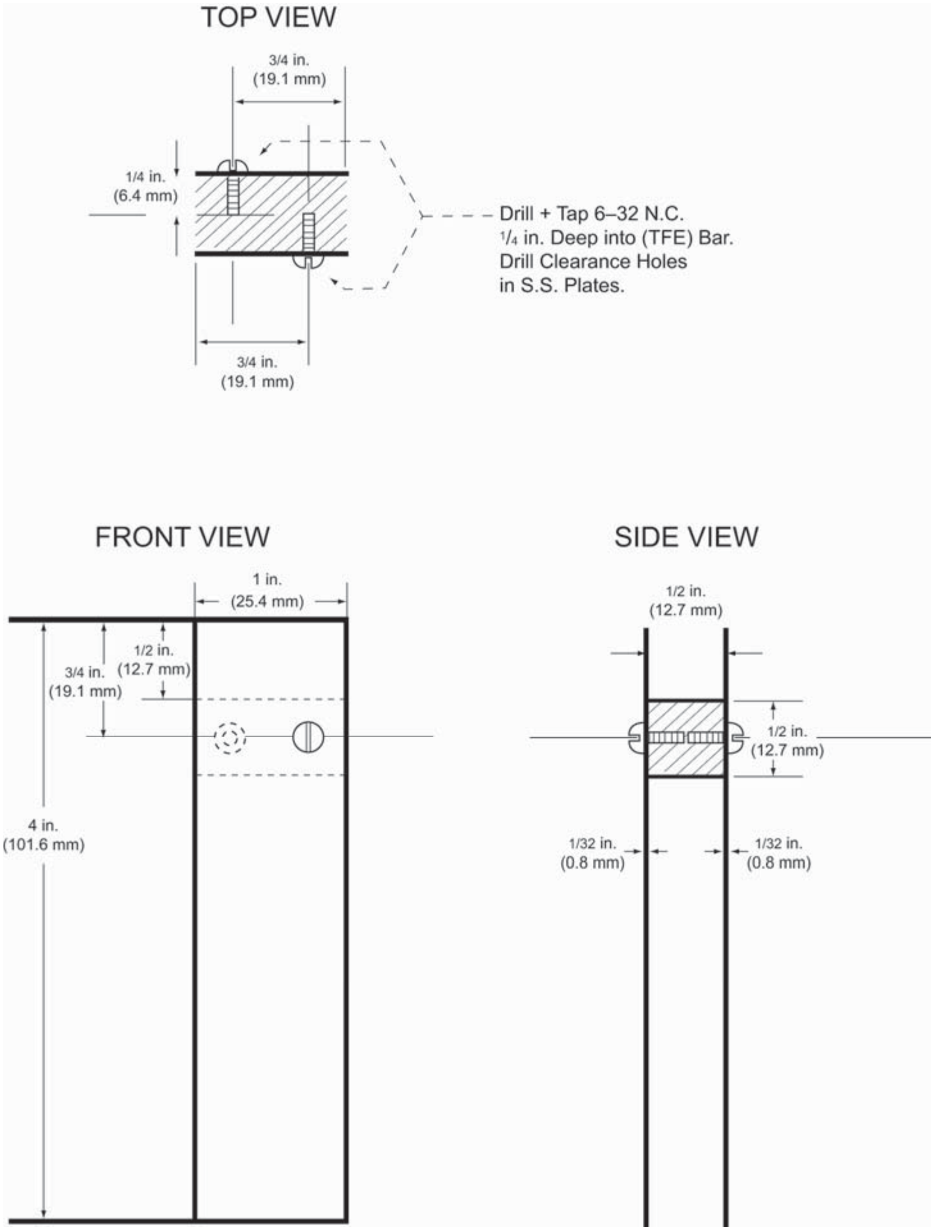


Figure 7—Insulator

7.4 *Procedure*:

7.4.1 Heat the emulsified asphalt to be tested to 50 ± 3°C (122 ± 5°F) in a 71 ± 3°C (160 ± 5°F) water bath. Stir the emulsified asphalt thoroughly to ensure uniformity of temperature.

7.4.2 Pour the emulsified asphalt to be tested into the 250-mL beaker to a height that will allow the electrodes to be suspended 25.4 mm (1 in.) in the emulsified asphalt. To facilitate suspension of the electrodes, insert the glass rod or equivalent between the two electrodes under the insulator. Place the ends of the glass rod or equivalent on the two opposite top edges of the beaker. An apparatus capable of manual height adjustment to insulate and suspend the electrode assembly in the emulsified asphalt may be used if desired.

7.4.3 Connect the electrodes, properly cleaned according to Section 7.4.3.1, to the DC source.

7.4.3.1 New electrodes and electrodes to be reused should be cleaned in the following sequence:

1. Wash with distilled water;
2. Wash with a suitable asphalt solvent;
3. Wash with isopropyl or ethyl alcohol; and
4. Wash with distilled water.

7.4.4 Adjust the current to a minimum of 8 mA with the variable resistor, and start timing with a suitable timing device.

Note 7—Higher current levels may be specified, but the current used shall be reported.

7.4.5 When the current drops to 2 mA or at the end of 30 minutes, whichever occurs first, disconnect the current source, and gently wash the electrodes with a smooth, thin stream of distilled water.

7.4.6 Observe the asphalt deposit on the electrodes. A cationic emulsified asphalt will deposit a discernible amount of asphalt on the cathode (negative electrode) while the anode (positive electrode) will be relatively clean. Any evidence of a clearly discernible asphalt deposit on the cathode when compared with the anode is considered to be passing. If the particle charge test does not produce conclusive results for cationic slow-setting (CSS) emulsified asphalt, proceed to Section 27.

7.5 *Report*:

7.5.1 Report the following information:

7.5.1.1 Level of current used; and

7.5.1.2 Whether the tested emulsified asphalt passes or fails as defined in Section 7.4.6.

7.6 *Precision and Bias*:

7.6.1 This test method, requiring subjective evaluation of test results and reporting of only two possible conditions, does not lend itself readily to a conventional statistical round-robin exercise. At present, there is no precision and bias statement for this test method.

CONSISTENCY

8. VISCOSITY (SAYBOLT FUROL)

8.1 *Scope*:

8.1.1 This test method utilizes the Saybolt Furol viscometer to measure the consistency of emulsified asphalt. It is applicable to all the emulsified asphalt specified in M 140, M 208, and M 316.

8.2 *Significance and Use*:

8.2.1 Viscosity has significance in the use of emulsified asphalt because it is a property that affects utility. When used in application types of construction, the material must be thin enough to be uniformly applied through the spray bar of a distributor, yet thick enough so that it will not flow from the crown or grade of the road. For mixing-grade emulsified asphalt, the viscosity may affect the mixability and resulting thickness of film on the aggregate. The viscosity of emulsified asphalt may be affected by shear. Therefore, strict adherence to this test procedure is necessary to achieve precision.

8.3 *Apparatus*:

8.3.1 *Viscometer*—A Saybolt Furol viscometer conforming to the requirements specified in T 72.

8.3.2 *Sieve*—An 0.850-mm (No. 20) sieve or a 20-mesh strainer of wire cloth, framed or unframed.

8.3.3 *Thermometers*—ASTM No. l7C or 17F for tests at 25°C (77°F) and ASTM No. l9C or l9F for tests at 50°C (l22°F), conforming to the requirements of ASTM E 1.

8.3.4 *Water Bath*—Capable of maintaining the required testing temperature within the limits specified in T 72.

8.3.5 *Beaker*—Glass beaker, 400-mL capacity

8.3.6 *Timer*—Graduated in 0.1 second and accurate within 0.1 percent when tested over a 15-minute interval.

8.4 *Procedure*:

8.4.1 *Tests at 25°C (77°F)*—Stir the sample thoroughly without incorporating bubbles, and pour it into a 118-mL (4-oz) bottle. Place the bottle in the water bath at 25°C (77°F) for 30 minutes and mix the sample in the bottle by inverting it several times, slowly enough to prevent bubble formation. Pour the sample into the viscometer through the 0.850-mm (No. 20) sieve or 20-mesh strainer, allowing a small portion to flow through the outlet tube to waste. Place the cork in position; fill the viscometer, and without stirring the sample again, determine the viscosity as prescribed in T 72.

8.4.2 *Tests at 50°C (122°F)*—Clean and dry the viscometer and insert the cork. Heat the emulsified asphalt sample to 50 ± 3°C (122 ± 5°F) in a 71 ± 3°C (160 ± 5°F) water bath or oven. Stir the sample thoroughly without incorporating bubbles, and then pour approximately 100 mL into a 400-mL glass beaker. Immerse the bottom of the beaker containing the emulsified asphalt approximately 50.8 mm (2 in.) below the level of a 71 ± 3°C (160 ± 5°F) water bath. Hold the beaker upright and stir the emulsified asphalt with a wide circular motion at a rate of 60 r/min with the thermometer to obtain uniform temperature distribution. Avoid incorporation of bubbles. Heat the emulsified asphalt in the water bath to 51.4 ± 0.3°C (124.5 ± 0.5°F). Immediately pour the emulsified asphalt through the 0.850-mm (No. 20) sieve or 20-mesh strainer into the viscometer until it is above the overflow rim. Stir the emulsified asphalt in the viscometer at 60 r/min with the thermometer until the test temperature is attained, avoiding bubble formation. Adjust the bath temperature until the emulsified asphalt temperature remains constant for 1 minute at 50 ± 0.05°C (122 ± 0.1°F). Withdraw the thermometer. Quickly remove the excess emulsified asphalt from the gallery with a suction pipet. Determine the viscosity as described in T 72. Report the results to the nearest 1 second.

Note 8—While the Saybolt Furol viscometer is not used for petroleum products and lubricants when the time of flow is less than 25 seconds, this instrument is satisfactory for testing emulsified asphalt when the time of flow is not less than 20 seconds.

8.5 *Precision and Bias*:

8.5.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

8.5.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Test Temperature, °C (F)	Viscosity, s	Repeatability, % of the mean
25 (77)	20 to 100	5
50 (122)	75 to 400	9.6

8.5.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Test Temperature, °C (F)	Viscosity, s	Reproducibility, % of the mean
25 (77)	20 to 100	15
50 (122)	75 to 400	21

STABILITY

9. DEMULSIBILITY

9.1 *Scope*:

9.1.1 This test method, applicable to anionic and cationic emulsified asphalt of the rapid-setting (RS) and medium-setting (MS) types, measures the chemical breaking of the emulsified asphalt.

9.2 *Significance and Use*:

9.2.1 This test method is used to identify or classify an emulsified asphalt as an RS or MS type by measuring the amount of available asphalt that is broken from the emulsified asphalt by utilizing specified amounts and concentrations of calcium chloride solution for anionic emulsified asphalt and dioctyl sodium sulfosuccinate for cationic emulsified asphalt.

9.3 *Apparatus and Reagents*:

9.3.1 *Wire Cloth*—Three pieces of 1.40-mm (No. 14) wire cloth approximately 125 mm (5 in.) square, unframed, having wire diameters and openings that conform to M 92.

9.3.2 *Beakers*—Three metal beakers of 600-mL capacity each.

9.3.3 *Rods*—Three metal rods with rounded ends, approximately 8 mm ($^5/_{16}$ in.) in diameter.

9.3.4 *Buret*—A 50-mL glass buret graduated in 0.1-mL intervals.

9.3.5 *Calcium Chloride Solution (1.11 g/L)*—Dissolve 1.11 g of calcium chloride ($CaCL_2$) in distilled water and dilute it to 1 L. The 1.11 g/L calcium chloride solution shall be standardized to be a 0.02 ± 0.001-N solution of calcium chloride in water. Although this solution will remain stable, it shall be stored in an airtight container when not in use.

9.3.6 *Calcium Chloride Solution (5.55 g/L)*—Dissolve 5.55 g of $CaCl_2$, in distilled water, and dilute it to 1 L. The 5.55 g/L calcium chloride solution shall be standardized to be a 0.1 ± 0.001-N solution of calcium chloride in water. Although this solution will remain stable, it shall be stored in an airtight container when not in use.

9.3.7 *Dioctyl Sodium Sulfosuccinate Solution (0.8 percent)*—Dissolve 8.00 g of dioctyl sodium sulfosuccinate in 992 mL of distilled water. This solution will degrade over time; it shall be stored in a dark glass, airtight container in a cool, dark location when not in use. This solution shall not be used for testing purposes if more than 90 days have elapsed since it was prepared.

9.3.8 *Balance*—Conforming to the requirements of M 231, Class G 2.

9.3.9 *Oven*—Capable of maintaining a temperature of 163 ± 3°C (325 ± 5°F).

9.3.10 *Timer*—Graduated in 0.1 second and accurate within 0.1 percent when tested over a 15-minute interval.

9.4 *Procedure*:

9.4.1 Determine the percentage of residue by distillation as described in Section 5.

9.4.2 Record the mass of each assembly of beaker, rod, and wire cloth.

9.4.3 Pour 100 ± 0.1 g of the emulsified asphalt into each of three 600-mL beakers in the assemblies. Heat the sample of emulsified asphalt and proper reagent to a temperature of 25 ± 0.5°C (77 ± 1.0°F).

9.4.4 Over a period of approximately 2 minutes, add to each beaker, from a buret, one of the following:

9.4.4.1 35 mL of $CaCl_2$ solution (1.11 g/L) for anionic RS emulsified asphalt:

9.4.4.2 50 mL of $CaC1_2$ solution (5.55 g/L) for MS or mixing-type emulsified asphalt; or

9.4.4.3 35 mL of dioctyl sodium sulfosuccinate solution (0.8 percent) for cationic RS emulsified asphalt.

9.4.5 While adding the $CaC1_2$ solution in Section 9.4.4.1, 9.4.4.2, or 9.4.4.3, stir the contents of the beaker continuously and vigorously, kneading any lumps against the sides of the beaker to ensure thorough mixing of the reagent with the emulsified asphalt.

9.4.6 Continue kneading any lumps for an additional 2 minutes after all of the solution has been added.

9.4.7 Decant the mixture of any unbroken emulsified asphalt and reagent onto the wire cloth. Rinse the beaker containing the sample and metal rod with distilled water, pouring the rinse water through the wire cloth. Knead and break up all lumps, and continue washing the beaker, rod, and wire cloth until the rinse water drains clear.

9.4.8 Place the wire cloth containing the asphalt residue in the beaker with the metal rod. Place the assembly in a 163 ± 3°C (325 ± 5°F) drying oven for 1 hour. Preliminary heating at lower temperatures to prevent spattering is permissible. Allow the beaker and contents to cool, and determine the mass. Repeat the heating and mass determination until successive masses differ by no more than 0.1 g.

9.5 *Calculation*:

9.5.1 Subtract the tare mass of the beaker, rod, and wire cloth from the mass of the dried assembly to obtain the demulsibility residue. Calculate the demulsibility as follows:

$$\text{Demulsibility, \%} = (M_{der}/M_{dir}) \times 100 \qquad (5)$$

where:

M_{der} = average mass of demulsibility residue from the three tests of each sample of emulsified asphalt, g (Section 9.4.8); and

M_{dir} = mass of residue by distillation in 100 g of the emulsified asphalt, g (Section 9.4.1).

9.6 *Precision and Bias*:

9.6.1 The following criteria should be used for judging the acceptability of results of tests on RS emulsified asphalt (95 percent probability):

Note 9—Precision does not apply when using dioctyl sodium sulfosuccinate solution in the testing of cationic emulsified asphalt for demulsibility.

9.6.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Demulsibility, mass %	Repeatability, % of the mean
30 to 100	5

9.6.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Demulsibility, mass %	Reproducibility, % of the mean
30 to l00	30

10. SETTLEMENT

10.1 *Scope*:

10.1.1 This test method measures the settlement of emulsified asphalt that occurs in a cylindrical container.

10.2 *Significance and Use*:

10.2.1 This test method is a measure of the uniformity of emulsified asphalt dispersion in storage over a period of time.

10.3 *Apparatus*:

10.3.1 *Cylinders*—Two 500-mL glass cylinders, with pressed or molded glass bases and cork or glass stoppers, having an outside diameter of 50 ± 5 mm (2 ± 0.2 in.). The cylinders should have 5-mL graduations.

Note 10—Cylinders with side arms may be used so that samples can be withdrawn without the use of pipets.

10.3.2 *Glass Pipet*—A 60-mL siphon glass-tube pipet of optional form.

10.3.3 *Balance*—Conforming to the requirements of M 231, Class G 2.

10.3.4 *Beakers*—Low form, 1000-mL capacity, made of glass or metal, or a container of similar capacity.

10.4 *Procedure*:

10.4.1 Place a 500-mL representative sample in each of the two glass cylinders. Stopper the cylinders and allow them to stand undisturbed at laboratory air temperature for 5 days. After standing for this period, remove approximately the top 55 mL of emulsified asphalt by means of a pipet or siphon without disturbing the balance. Mix each portion thoroughly. Pour 50 g of each sample into separate 1000-mL beakers, and determine the asphalt residue by evaporation in accordance with Section 6.

10.4.2 After removal of the top portion of the sample, siphon off approximately the next 390 mL from each of the cylinders. Thoroughly mix the emulsified asphalt remaining in the cylinders, and pour 50 g into separate 1000-mL beakers. Determine the asphalt residue by evaporation of these samples in accordance with Section 6.

Note 11—If the emulsified asphalt contains appreciable amounts of oil distillate as determined by distillation (see Section 5), the settlement value may be calculated from the difference in the percentage of water content between the top and bottom portion of the samples as determined by the procedure described in Section 4.

Note 12—If cylinders with side arms are used, siphoning is not required. Obtain a 55-mL sample from the upper arm. Drain off 390 mL from the lower arm.

10.5 *Calculation and Report*:

10.5.1 Calculate the settlement for each cylinder as follows:

$$\text{Settlement, \% (5 days)} = P_{rb} - P_{rt} \qquad (6)$$

where:

P_{rb} = the percentage of residue from the top portion of the sample; and

P_{rt} = the percentage of residue from the bottom portion of the sample.

Note 13—If the settlement values between the two cylinders differ by more than the stated repeatability, the result is considered suspect and the test shall be repeated. If for individual cylinders the percent residue of both the top and bottom samples is less than the percent residue of the emulsified asphalt, the result is considered suspect and the test shall be repeated. If for individual cylinders the percent residue of both the top and bottom portion of the samples is greater than the percent residue of the emulsified asphalt, the result is considered suspect, and the test shall be repeated.

10.5.2 Report the settlement as the average of the two individual cylinder results.

10.6 *Precision and Bias*:

10.6.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

10.6.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Settlement, mass %	Repeatability
0 to 1.0	0.4 mass %
Above 1.0	5% of the mean

10.6.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Settlement, mass %	Reproducibility
0 to 1.0	0.8 mass %
Above 1.0	10% of the mean

11. CEMENT MIXING

11.1 *Scope*:

11.1.1 This test method is a mixing test used to identify or classify a slow-setting, SS or CSS, type of emulsified asphalt.

11.2 *Significance and Use*:

11.2.1 The result of this test indicates the ability of an SS emulsified asphalt to mix with a finely divided, high surface area material (i.e., high early strength, Type III, portland cement) without breaking the emulsified asphalt.

11.3 *Apparatus and Material*:

11.3.1 *Sieves*—A 0.180-mm (No. 80) sieve and a 76.2-mm (3-in.) diameter 1.40-mm (No. 14) sieve, made of wire cloth conforming to M 92.

11.3.2 *Dish*—A round-bottom iron dish or kitchen saucepan of approximately 500-mL capacity.

11.3.3 *Stirring Rod*—A steel rod with rounded ends, approximately 13 mm ($^1/_2$ in.) in diameter.

11.3.4 *Graduate*—A l00-mL graduated cylinder.

11.3.5 *Balance*—Conforming to the requirements of M 231, Class G 2.

11.3.6 *Oven*—Conforming to ASTM E 145, Type 1B.

11.3.7 *Cement*:

11.3.7.1 High-early-strength portland cement conforming to the requirements for Type III portland cement in M 85 and having a minimum specific surface area of 1900 cm^2/g (928 ft^2/lb) as measured by the Wagner Turbidimeter.

11.4 *Procedure*:

11.4.1 Dilute the emulsified asphalt with distilled water to a residue of 55 percent, as determined by distillation or by evaporation for 3 h at 163°C (325°F), according to Section 5 or 6 as appropriate.

11.4.2 Sieve a portion of the cement through the 0.180-mm (No. 80) sieve. Add 50 ± 0.1 g of the cement passing the 0.180-mm (No. 80) sieve into the dish.

11.4.3 Ensure the ingredients and apparatus are at a temperature of approximately 25°C (77°F) before mixing. Add 100 mL of the diluted emulsified asphalt to the cement and stir the mixture at once with the steel rod, using a circular motion at a rate of 60 r/pm. At the end of the 1-min mixing period, add 150 mL of distilled water, and continue stirring for 3 min.

11.4.4 Pour the mixture through a weighed 1.40-mm (No. 14) sieve. Use repeated washings to completely remove the material from the mixing bowl. Pour these washings over the sieve, and rinse the sieve using distilled water held at a height of approximately 150 mm (6 in.) until the water running through the sieve is clear. Place the sieve in a shallow pan; heat it at 163°C (325°F) in an oven, and determine the mass. Repeat the heating and mass determination until successive masses differ by no more than 0.1 g.

11.5 *Calculation and Report*:

11.5.1 Calculate the mass of the sample retained on the sieve and in the pan as follows:

$$\text{Mass retained} = M_{spr} - M_{sp} \qquad (7)$$

where:

M_{spr} = mass of the sieve, pan, and residue, g; and

M_{sp} = mass of the sieve and pan, g.

11.5.2 Report the mass, in grams, of the material retained on the sieve and in the pan as the percentage of break in the cement mixing test.

11.6 *Precision and Bias*:

11.6.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

11.6.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Cement Mixing, mass %	Repeatability, mass %
0 to 2	0.2

11.6.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Cement Mixing, mass %	Reproducibility, mass %
0 to 2	0.4

12. SIEVE TEST

12.1 *Scope*:

12.1.1 This test method measures the degree to which an emulsified asphalt may contain particles of asphalt or other discreet solids retained on a 0.850 mm (No. 20) mesh sieve.

12.2 *Significance and Use*:

12.2.1 The retention of an excessive amount of particles on the sieve indicates that problems may occur in handling and application of the material. Particles of asphalt retained on the sieve often are caused by agglomeration of the dispersed phase. Storage, pumping, handling, and temperature can all contribute to the formation of particles. Contamination from the tank, transport, or hose is another factor affecting particle formation.

12.3 *Apparatus and Reagents*:

12.3.1 *Sieve*—A sieve having a 76.2-mm (3-in.) frame and an 0.850-mm (No. 20) wire sieve cloth conforming to M 92.

12.3.2 *Pan*—A tin box cover or shallow metal pan of appropriate size to fit over the bottom of the standard sieve.

12.3.3 *Sodium Oleate Solution (2 percent)*—Dissolve 20 g of pure sodium oleate in distilled water and dilute it to 1 L.

Note 14—Replace sodium oleate solution with distilled water when testing cationic emulsified asphalt.

12.3.4 *Balances*—Conforming to the requirements of M 231, Class G 5 for determining the mass of the emulsified asphalt, and M 231, Class G 2 for determining the mass of the sieve and residue.

12.3.5 *Oven*—Capable of maintaining a temperature of 105 ± 5°C (220 ± 9°F).

12.3.6 *Desiccator*.

12.3.7 *Oven or Water Bath*—Capable of maintaining a temperature of 50 ± 3°C (122 ±5°F), if it is necessary to heat the emulsified asphalt before testing.

12.4 *Procedure*:

12.4.1 The temperature at which the sieve test should be performed is related to the viscosity of the emulsified asphalt. For those materials whose viscosity is 100 seconds or less at 25°C (77°F), perform the test at room temperature. For those materials whose viscosity is more than 100 seconds at 25°C (77°F) and those whose viscosity is specified at 50°C (122°F), use a test temperature of 50 ± 3°C (122 ± 5°F). If heating is necessary, the emulsified asphalt may be placed in a closed container in an oven or water bath, followed by stirring to achieve homogeneity.

12.4.2 Record the mass of the sieve and pan and wet the wire cloth with the 2-percent sodium oleate solution. Transfer 1000 g of the emulsified asphalt into a suitable container, and pour it through the sieve. Wash the container and residue on the sieve with the sodium oleate solution until the washings run clear. Place the pan under the sieve and heat them for 2 h in a 105°C (220°F) drying oven. Cool them in a desiccator, and determine the mass of the sieve, pan, and residue.

12.5 *Calculation*:

12.5.1 Calculate the percentage of sample retained on the sieve as follows:

Sample retained, % = $(M_{spr} - M_{sp})/10$ (8)

where:

M_{spr} = mass of the sieve, pan, and residue, g; and
M_{sp} = mass of the sieve and pan, g.

12.6 *Precision*:

12.6.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

12.6.1.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Sieve Test, mass %	Repeatability, mass %
0 to 0.1	0.03

12.6.1.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Sieve Test, mass %	Reproducibility, mass %
0 to 0.1	0.08

13. COATING TEST

13.1 *Scope*:

13.1.1 This test method is applicable to those emulsified asphalts intended for use by mixing with aggregate. It is not applicable to RS types or diluted materials used for tack coats, priming or mulch treatments.

13.2 *Significance and Use*:

13.2.1 The intent of the coating test is to ensure that a given mixing-grade emulsified asphalt is adequately stable emulsified asphalt and otherwise possesses the ability to mix with a reference stone for the prescribed time and coat it uniformly and thoroughly.

13.3 *Apparatus and Material*:

13.3.1 *Sieves*—19.0-mm ($^{3}/_{4}$-in.) and 6.4-mm ($^{1}/_{4}$-in.) sieves conforming to M 92.

13.3.2 *Spatula*—A steel spatula or its equivalent, having a blade approximately 200 mm (8 in.) in length.

13.3.3 *Dish*—A round-bottom iron dish or a kitchen saucepan, of approximately 1-L (1-qt) capacity.

13.3.4 *Stone*—A supply of reference stone (hard limestone, trap rock, or other similar type) which has been washed with water and dried before using. All stone shall pass through a 19.0-mm ($^{1}/_{4}$-in.) screen and not more than 5 percent shall pass through the 6.4-mm ($^{1}/_{4}$-in.) screen.

Note 15—Each laboratory shall select its own reference stone supply, the source of which is not apt to change; this policy is to avoid rapid changes in the character of reference stone used in any one laboratory.

13.3.5 *Balance*—Conforming to the requirements of M 231, Class G 2.

13.4 *Procedure*:

13.4.1 Add 465 ± 0.1 g of stone into the dish. Add 35 ± 0.1 g of the emulsified asphalt to the stone in the dish, and mix vigorously with the spatula for 3 minutes.

13.4.2 Record whether or not there is appreciable separation of the asphalt base from the water in the emulsified asphalt, and whether or not the stone is uniformly and thoroughly coated with the emulsified asphalt.

14. MISCIBILITY WITH WATER

14.1 *Scope*:

14.1.1 This test may be applied to all MS and SS emulsified asphalts. It is not applicable to RS types.

14.2 *Significance and Use*:

14.2.1 It is sometimes desirable to dilute an emulsified asphalt in the field with water. This test is designed to ascertain if this operation may be completed safely without breaking the emulsified asphalt.

14.3 *Apparatus:*

14.3.1 *Breaker*—Glass beaker of 400-mL capacity.

14.4 *Procedure*:

14.4.1 Gradually add 150 mL of distilled water, with constant stirring, to 50 mL of the emulsified asphalt in a 400-mL glass beaker. The temperature should be between 21 and 25°C (70 and 77°F). Allow the mixture to stand for 2 hours; then examine it for any appreciable coagulation of the asphalt portion of the emulsified asphalt. Such coagulation indicates that the emulsified asphalt has broken.

14.5 *Report:*

14.5.1 Report whether or not the emulsified asphalt breaks as defined in Section 14.4.1.

15. FREEZING TEST

15.1 *Scope*:

15.1.1 Emulsified asphalt is normally damaged by freezing temperatures, but specially formulated materials are expected to pass this test.

15.2 *Significance and Use*:

15.2.1 Certain agencies, who desire to use, store, or transport emulsified asphalt under less-than-ideal weather conditions, may require that the product remain homogeneous (unbroken) after being subjected to temperatures of –17.8°C (0°F).

15.3 *Apparatus*:

15.3.1 *Container*—Metal container, 500-mL capacity, with a sealable lid.

15.3.2 *Freezer*—Capable of maintaining a temperature of –17.8 ± 0.5°C (0 ± 1°F).

15.4 *Procedure*:

15.4.1 Place approximately 400 g of the emulsified asphalt in a clean container, such as a 500-mL (1-Pt) press-top can.

15.4.2 Expose the emulsified asphalt in the closed container to an air temperature of –17.8 ± 0.5°C (0 ± 1°F) for a minimum of 12 hours.

15.4.3 At the expiration of the freezing period, permit the emulsified asphalt to thaw by exposure of the container to ambient temperature.

15.4.4 Repeat the freezing and thawing periods in Section 15.4.2 and 15.4.3 until the emulsified asphalt is subjected to three cycles of freezing and thawing.

15.4.5 After the third cycle, the emulsified asphalt may be homogeneous or may have separated into distinct layers which cannot be rendered homogeneous by stirring at ambient temperature.

15.5 *Report*:

15.5.1 Report the result of this test as either “Homogeneous” or “Broken” depending on the condition of the material as defined in Section 15.4.5.

16. COATING ABILITY AND WATER RESISTANCE

16.1 *Scope*:

16.1.1 This test method is intended to aid in the identification of emulsified asphalt suitable for mixing with coarse-graded calcareous aggregates.

Note 16—Aggregates other than limestone may be used provided calcium carbonate is omitted throughout the test method. Laboratory washing and air-drying of such aggregates shall also be omitted.

16.2 *Significance and Use*:

16.2.1 This test method covers the determination of the ability of an emulsified asphalt to (1) coat an aggregate thoroughly; (2) withstand a mixing action while remaining as a film on the aggregate; and (3) resist the washing action of water after completion of the mixing.

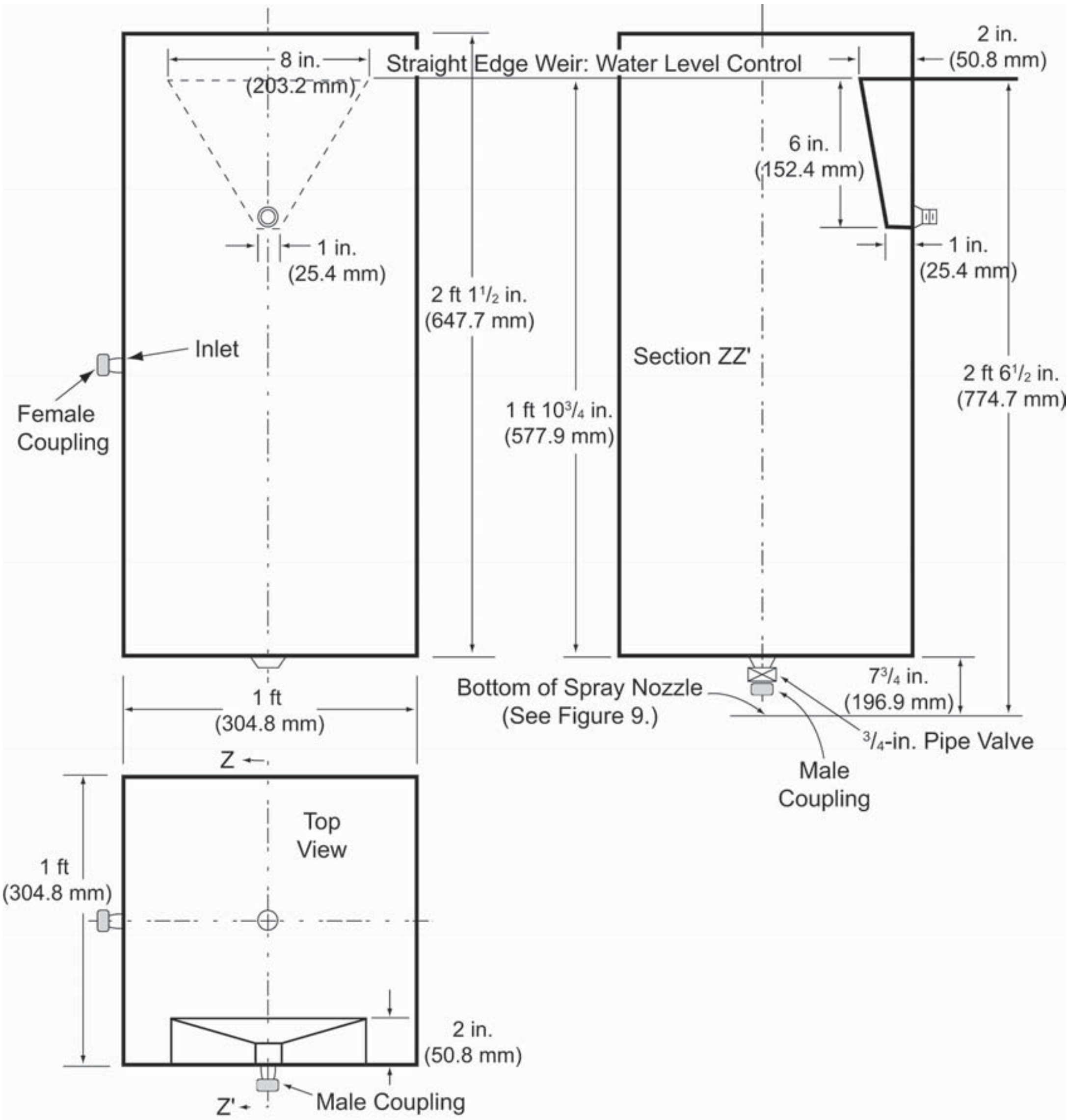
16.3 *Apparatus:*

16.3.1 *Mixing Pan*—An enameled kitchen saucepan with handle, of approximately 3-L (3-qt) capacity.

16.3.2 *Spatula*—A steel spatula or its equivalent, having a blade approximately 200 mm (8 in.) in length.

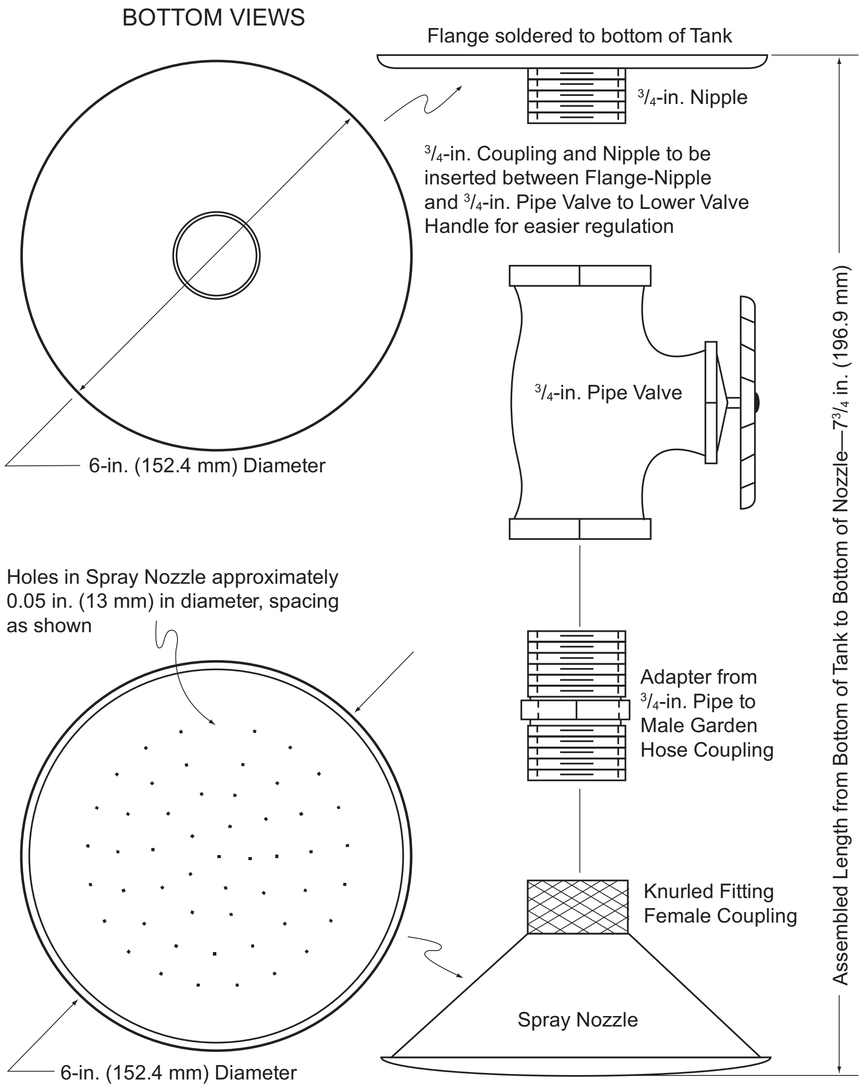
16.3.3 *Sieves*—19.0-mm ($^3/_4$-in.) and 4.75- mm (No. 4) sieves conforming to M 92.

16.3.4 *Constant-Head Water-Spraying Apparatus*—An apparatus for applying tap water in a spray under a constant head of 774.7 mm (2.54 ft) (Figures 8 and 9). The water shall issue from the apparatus in a low-velocity spray.



NOTE—Use galvanized steel sheeting for the tank. All joints and fitting attachments shall be soldered and shall be watertight. All couplings shall be standard brass garden hose fittings. The 19.0-mm ($^3/_4$-in.) pipe valve shall be placed as close as possible to the bottom of the tank, allowing space to shut off the valve. The tank shall be placed on a suitable stand, so that the distance from the bottom of the spray head to the top of the test sample is 919.4 ± 25.4 mm (3 ft ± 1 in.).

Figure 8—Constant-Head Flow Tank



NOTE 1—A Speakman, Model 235S, all brass, fixed shower head has been found acceptable.

NOTE 2—Existing 101.6-mm (4-in.) diameter shower heads may continue to be used.

Figure 9—Valve and Nozzle Assembly for Constant-Head Flow Tank

16.3.5 *Thermometer*—An ASTM Low Softening Point Thermometer 15C (or 15F), having a range from –2 to 80°C (or 30 to 180°F) and conforming to the requirements in ASTM E 1.

16.3.6 *Balance*—Conforming to the requirements of M 231, Class G 2.

16.3.7 *Pipet*—10-mL capacity.

16.4 *Materials*:

16.4.1 *Aggregate*—Reference aggregate shall be a laboratory-washed and air-dried limestone aggregate graded to pass the 19.0-mm ($^3/_4$-in.) sieve and be retained on the 4.75-mm (No. 4) sieve.[3] (Note 15)

16.4.2 *Calcium Carbonate*—Chemically pure, precipitated calcium carbonate ($CaCO_3$) shall be used as a dust to be mixed with the reference aggregate.

16.4.3 *Water*—Tap water with a hardness not over 250 ppm $CaCO_3$ for spraying over the sample.

16.4.4 *Absorbent Paper*.

16.5 *Procedure for Tests with Dry Aggregate*:

16.5.1 Conduct the test at 23.9 ± 5.5°C (75 ± 10°F).

16.5.2 Add 461 g of the air-dried, graded reference aggregate in the mixing pan.

16.5.3 Add 4.0 g of $CaCO_3$ dust in the mixing pan, and mix it with the 461 g of aggregate for approximately 1 minute with a spatula to obtain a uniform film of dust on the aggregate particles.

Note 17—The total mass of aggregate and dust shall equal 465 g. If no calcium carbonate is included, the mass of aggregate alone shall be 465 g.

16.5.4 Add 35 g of the emulsified asphalt into the aggregate in the pan and mix vigorously with the spatula for 5 minutes using a tossing action created by a back-and-forth motion in an elliptical path of the mixing blade. At the end of the mixing period, tilt the pan and permit any excess emulsified asphalt not on the aggregate to drain from the pan.

16.5.5 Remove approximately one half of the mixture from the pan and place it on absorbent paper to evaluate the coating.

16.5.6 Immediately spray the mixture remaining in the pan with tap water from the constant-head water-spraying apparatus to cover the mixture. The distance from the spray head to the sample shall be 305 ± 75 mm (12 ± 3 in.). Then carefully pour off the water. Continue spraying and pouring off the water until the overflow water runs clear. Carefully drain the water in the pan. Transfer the mixture from the mixing pan onto absorbent paper for evaluation of coating retention.

16.5.7 Evaluate the mixture immediately by visual estimation as to the total aggregate surface area that is coated with asphalt.

16.5.8 Repeat the evaluation by visual estimation of the coating of aggregate surface area with asphalt after the mixture has been air-dried in the laboratory at room temperature. A fan may be used for drying if desired.

16.6 *Procedure for Tests with Wet Aggregate*:

16.6.1 Proceed in accordance with Section 16.5.1 to 16.5.3.

16.6.2 Pipet 9.3 mL of water into the aggregate and $CaCO_3$ dust mixture in the mixing pan and mix thoroughly to obtain uniform wetting.

16.6.3 Continue in accordance with Section 16.5.4 to 16.5.8.

16.7 *Interpretation of Results*:

16.7.1 Evaluate and report the following information for tests with both dry and wet aggregate:

16.7.1.1 At the end of the mixing period, record the coating of the total aggregate surface area with emulsified asphalt as “good,” “fair,” or “poor, ” where a rating of “good” means fully coated with emulsified asphalt (exclusive of pinholes and sharp edges of the aggregate), a rating of “fair” applies to the condition of more area of coated than uncoated, and a rating of “poor” applies to the condition of more area uncoated than coated.

16.7.1.2 After spraying with water, record the coating of the total aggregate surface area with the asphalt as “good,” “fair,” or “poor,” according to the definitions for those terms in Section 16.7.1.1.

16.7.1.3 After air-drying in the laboratory, record the coating of the total aggregate surface area by the asphalt as good, fair, or poor.

Note 18—Comments about the results of the test may be included in the evaluation.

17. STORAGE STABILITY OF EMULSIFIED ASPHALT

17.1 *Scope*:

17.1.1 This test method relates to the ability of emulsified asphalt to remain as a uniform dispersion during storage. It is applicable to emulsified asphalt composed principally of a semisolid or liquid asphalt base, water, and an emulsifying agent.

17.2 *Summary of Test Method*:

17.2.1 This test method determines the difference in percent residue of samples taken from the top and bottom of material placed in undisturbed simulated storage for 24 hours. The result is expressed as the average of the two individual values obtained by determining the difference between the percent residue of the top and bottom samples for each storage cylinder.

17.3 *Significance and Use*:

17.3.1 This test method is useful for determining the storage stability of emulsified asphalt in a comparatively short amount of time. It is a measure of the permanence of the dispersion as related to time, but it is not to be construed to have significance as a measure of other stability aspects involved in use of emulsified asphalt.

17.4 *Apparatus*:

17.4.1 *Cylinders*—Two 500-mL glass cylinders, with pressed or molded glass bases and cork or glass stoppers, having an outside diameter of 50 ± 5 mm (2 ± 0.2 in.), and having 5-mL graduations. (Note 12)

17.4.2 *Glass Pipet*—A 60-mL siphon glass-tube pipet of optional form.

17.4.3 *Balance*—Conforming to the requirements of M 231, Class G 2.

17.4.4 *Beakers*—Low form, 1000-mL capacity, made of glass or metal, or a container of similar capacity.

17.4.5 *Oven*—Conforming to ASTM E 145, Type lB.

17.5 *Procedure*:

17.5.1 Heat the emulsified asphalt to room temperature, 21 to 27°C (70 to 80°F). Place a 500-mL representative sample in each of the two glass cylinders. Stopper the cylinders and allow them to stand undisturbed at laboratory air temperature, 21 to 27°C (70 to 80°F), for 24 hours. After standing for this period, remove approximately 55 mL from the top of the emulsified asphalt by means of the pipet or siphon without disturbing the balance (Note 12). Thoroughly mix each portion.

17.5.2 Pour 50 ± 0.1 g of each sample into separate l000-mL beakers; the mass of each beaker shall previously have been determined with a 6-mm ($^{1}/_{4}$-in.) diameter by 178-mm (7-in.) glass rod. Adjust the temperature of the oven to 163 ± 2.8°C (325 ± 5°F). Place the beakers containing the rods and sample in the oven for 2 hours. At the end of this period, remove each beaker and thoroughly stir the residue. Place the beakers in the oven for 1 hour (Note 6). Remove the beakers from the oven and allow them to cool to room temperature. Determine the mass of each beaker with the rods.

17.5.3 After removal of the top portion of the sample, siphon off approximately the next 390 mL from each of the cylinders. Thoroughly mix the emulsified asphalt remaining in the cylinders and pour 50 g into separate 1000-mL beakers. Determine the asphalt residue of these samples in accordance with Section 17.5.2.

17.6 *Calculation and Report*:

17.6.1 Calculate and report the storage stability in accordance with Section 10.5 and observe Note 13.

17.7 *Precision and Bias*:

17.7.1 *Repeatability*—The repeatability standard deviation is 0.2 percent. The average difference between two results, obtained by the same operator with the same equipment, but not concurrently, will be approximately 0.2 percent. Two such values should be considered suspect (95 percent confidence level) if they differ by more than 0.5 percent.

17.7.2 *Reproducibility*—The reproducibility standard deviation is 0.2 percent. The average difference between two results obtained by operators in different laboratories will be approximately 0.3 percent. Two such values should be considered suspect (95 percent confidence level) if they differ by more than 0.6 percent.

Note 19—If this test method is performed using only one cylinder instead of two for each determination as specified in the method, then the following precision criteria should be used:

	Repeatability, %
Standard deviation	0.2
Average difference	0.3
Suspect criterion	0.5

	Reproducibility, %
Standard deviation	0.2
Average difference	0.3
Suspect criterion	0.6

EXAMINATION OF RESIDUE

18. SCOPE

18.1 Tests for specific gravity, ash content, solubility in trichloroethylene, penetration, ductility, and the float test are suggested for examination of the emulsified asphalt residue obtained by distillation (Section 5) or evaporation.

19. SIGNIFICANCE AND USE

19.1 The suggested procedures are used to characterize and evaluate the properties of emulsified asphalt residues.

20. SPECIFIC GRAVITY

20.1 Determine the specific gravity on a representative portion of the residue in accordance with T 228 or ASTM D 3289.

21. ASH CONTENT

21.1 Determine the ash content on a representative portion of the residue in accordance with the rapid routine method of ash determination, as described in ASTM D 128.

22. SOLUBILITY IN TRICHLOROETHYLENE

22.1 Determine the solubility in trichloroethylene on a representative portion of the residue in accordance with T 44.

23. PENETRATION

23.1 Determine the penetration on a representative portion of the residue in accordance with T 49.

23.2 *Precision*—The following criteria should be used for judging the acceptability of results (95 percent probability):

23.2.1 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Penetration of Residue, range	Repeatability, points
80 to 200	15

23.2.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Penetration of Residue, range	Reproducibility, points
80 to 200	30

24. DUCTILITY

24.1 Determine the ductility on a representative portion of the residue in accordance with T 51.

25. FLOAT TEST

25.1 Perform the float test on a representative portion of the residue in accordance with T 50, except revise Section 7.2 of ASTM D 139 as follows:

25.1.1 Pour the residue into the collar at or near 260°C (500°F) preferably, directly from the distillation pot. If the residue has been allowed to cool below 260°C (500°F), reheat it to 260°C (500°F) with stirring and pour into the collar.

IDENTIFICATION TESTS

26. IDENTIFICATION TEST FOR CATIONIC RAPID-SETTING (CRS) EMULSIFIED ASPHALTS

26.1 *Scope*:

26.1.1 This test method covers a procedure for identifying CRS emulsified asphalt. The inability to coat a specific silica sand distinguishes CRS emulsified asphalt from MS and SS cationic grades.

26.2 *Significance and Use*:

26.2.1 This test method is based upon the rapid asphalt deposition properties of CRS emulsified asphalt as a function of sand surface area and surface charge. The test method differs from the usual coating test because the material passes the requirement when it fails to coat the specified silica sand.

26.2.2 Impurities in the silica sand often prevent the emulsified asphalt from passing the test. Washing the sand to remove impurities prior to the test is required. Impurities affecting test results are normally due to the presence of iron (Fe^+) and organic dewatering agents that can alter the sand surface charge.

26.3 *Apparatus*:

26.3.1 *Mixing Bowl*—Metal or porcelain saucepan, $2^1/_2$ to 3 L ($2^1/_2$ to 3 qt), equipped with a handle.

26.3.2 *Washing Container*—Beaker made from borosilicate glass, 1000-mL capacity.

26.3.3 *Stainless Steel Spatula or Glass Rod.*

26.3.4 *Oven*—Convection or forced-draft, capable of maintaining 120 to 150°C (248 to 302°F).

26.3.5 *Balance*—Conforming to the requirements of M 231, Class G 2.

26.3.6 *Drying Pan*—Stainless steel or glass, 150 mm (6 in.) by 225 mm (9 in.) or larger.

26.3.7 *Graduated Cylinder*—Made from borosilicate glass, 500-mL capacity.

26.3.8 *Thermometer*—ASTM No. 67C or 67F as specified in ASTM E 1.

26.3.9 *Eye Protection*—Suitable safety glasses or other appropriate eye protection.

26.3.10 *Hand Protection*—Sufficiently acid and alcohol resistant.

26.3.11 *Timer*—Graduated in 0.1 second and accurate within 0.1 percent when tested over a 15-minute interval.

26.4 *Material*:

26.4.1 *Hydrochloric Acid*—Reagent, 36.5 to 38.0 percent.

26.4.2 *Isopropyl Alcohol*—Reagent, 100 percent.

26.4.3 *Distilled Water*.

26.4.4 *Absorbent Paper*.

26.4.5 *Silica Sand*—F-95, whole grain, with a gradation similar to that in the table below.[4]

TYPICAL GRADATION

U.S. Sieve No.	30	40	50	70	100	140	200	270
Millimeters	0.850	0.425	0.300	0.212	0.150	0.106	0.075	0.053
% Passing	100	99	97	89	56	17	2	Trace

26.5 Emulsified Asphalt Sample.

26.5.1 Obtain a representative sample of the CRS emulsified asphalt for testing in accordance with T 40.

26.6 *Sand Preparation*:

26.6.1 Prepare 400 mL of 5-percent hydrochloric acid, by volume, in isopropyl alcohol by mixing 20 mL of hydrochloric acid into a blend of 80 mL of distilled water and 300 mL of isopropyl alcohol in a 500-mL graduated cylinder.

26.6.2 Add 500 g of the F-95 silica sand into a 1000-mL beaker. Add 400 mL of the “5-percent hydrochloric acid in isopropyl alcohol/water” mixture into the beaker containing the silica sand, and stir for 5 minutes with a stainless steel spatula or glass rod.

26.6.3 Decant the acid/alcohol/water mixture carefully without a loss of sand.

26.6.4 Wash the sand with at least 400 mL of hot distilled water, 50 to 70°C (122 to 158°F) and stir for approximately 1 minute. Decant the water without a loss of sand. Repeat water-washing the sand two more times.

26.6.5 Scrape the washed sand onto the drying pan (avoiding as much loss of sand as possible) and spread the sand over the surface of the drying pan. Place the pan with the sand in an oven and dry it to a constant mass at a temperature of 120 to 150°C (248 to 302°F).

26.6.6 Allow the sand to cool and transfer the dry sand to a suitable container. Mix the sand for approximately 30 seconds to obtain uniformity.

26.7 *Procedure*:

26.7.1 Perform the following operations at 25 ± 5°C (77 ± 9°F).

26.7.2 Add 465 g of the washed silica sand blend into a mixing bowl. Add 35 g of the emulsified asphalt to be tested and mix vigorously with a spatula for approximately 2 minutes using a combined stirring and kneading action. At the end of the mixing period, tilt the bowl, and allow any excess emulsified asphalt, which is not coating the sand, to drain from the bowl.

26.7.3 Place the mix on absorbent paper. Visually estimate the amount of uncoated and coated area in the mixture.

Note 20—Visual estimation is less accurate at moderate levels of coating than at the two extremes. If the results are inconclusive, the washing and mixing procedure should be repeated.

26.8 *Interpretation of Results*:

26.8.1 From the visual estimation of the amount of uncoated area and coated area in the mixture, record the coating of the total sand surface area by the emulsified asphalt. More uncoated area than coated area shall be considered as a passing rating for identification of CRS emulsified asphalt. (Note 20)

26.9 *Precision and Bias*:

26.10 This test method, which requires a subjective evaluation of test results and reports only two possible conditions, does not lend itself readily to a statistical round-robin exercise. Development of a procedure to quantitatively determine the comparative coating will be considered.

27. IDENTIFICATION TEST FOR CATIONIC SLOW-SETTING (CSS) EMULSIFIED ASPHALTS

27.1 *Scope*:

27.1.1 This test method is intended to identify a CSS grade of emulsified asphalts if the results of the particle charge test are inconclusive (Section 7.4.6).

27.2 *Summary of Test Method*:

27.2.1 A specified amount of washed and dried silica sand is hand-mixed with a specified amount of emulsified asphalt. The mixing time should extend until the aggregate is completely coated. The amount of CSS-grade emulsified asphalt in the mix should yield a total mix asphalt content of about 5.0 percent. The sample is spread out and allowed to air-cure for 24 hours. The retained coating, after boiling, is then determined.

27.3 *Significance and Use*:

27.3.1 The conditions of the test are designed to identify the ability of a CSS grade of emulsified asphalt from M 208 to properly mix, coat, and adhere to a specified silica sand.

27.3.2 This test method is intended to confirm the adhesive properties that exist between a cationic emulsified asphalt and silica sand and the ability of the sample to remain coated after being submerged in boiling water.

27.4 *Apparatus and Material*:

27.4.1 *Heat Source*—Hot plate or bunsen burner. The use of a bunsen burner will necessitate the placement of an interfacial material between the flame and beaker.

27.4.2 *Screen*—No. 20 mesh folded into a circular configuration with the edges folded downward; or a strip of 0.850-mm (No. 20) mesh screen, 25.4 mm by 355.6 mm (1 in. by 14 in.) in length, and a circular screen of the circumference of the 1000-mL beaker. Bend the strip into a circle and insert it in the bottom of the beaker. Place the circular screen on top of the strip.

27.4.3 *Beaker*—l000-mL capacity.

27.4.4 Paper Napkin.

27.4.5 *20–30 Standard Ottawa Silica Sand*—As described in ASTM C 778 and washed to remove impurities prior to testing.[4]

27.4.6 *Spatula*—A steel spatula or its equivalent, having a blade of 203.2 mm (8 in.) in length.

27.4.7 *Mixing Container*—400-mL capacity, glass or stainless steel beaker or bowl.

27.4.8 *Beaker Tongs.*

27.4.9 *Eye Protection*—Suitable safety glasses with a side shield or any other appropriate eye protection.

27.4.10 *Hand Protection*—Heat-resistant gloves.

27.4.11 *Balance*—Conforming to the requirements of M 231, Class G 2.

27.4.12 *Distilled Water.*

27.5 *Procedure*:

27.5.1 Weigh 150 g of dry silica sand into the mixing container.

27.5.2 Add 12 g of the emulsified asphalt and immediately begin to mix vigorously for 20 to 60 seconds or until silica sand is completely coated.

Note 21—Water may be added to facilitate mixing; 1.0 percent is generally sufficient.

27.5.3 The sample should be spread onto a paper napkin in such a manner as to facilitate curing. Allow the sample to air-cure for 24 hours. Remove the sample from the paper napkin and break it into several pieces; observe whether the sample is completely cured. If the sample is not completely cured, allow additional curing time.

27.5.4 Boil about 500 mL of distilled water in a 1000-mL beaker containing 0.850-mm (No. 20) mesh screen shelf. Place the coated silica sand in the boiling water on top of the screen.

27.5.5 Boil for 10 minutes and then decant the water.

27.5.6 Spread the sample on a level surface and observe the coating of the mix.

27.6 *Report*:

27.6.1 From the visual examination of the amount of coated and uncoated areas in the mixture, record the retained coating, after boiling, of the total sand surface area. If the coating is in excess of 50 percent, the emulsified asphalt should be considered as having a passing rating for classification of CSS emulsified asphalt.

27.7 *Precision and Bias*:

27.7.1 This test method, which requires a subjective evaluation of test results and reports only two possible conditions, does not lend itself readily to a statistical round-robin exercise. At present, there is no precision and bias statement for this test method.

COATING TESTS ON EMULSIFIED ASPHALTS

28. FIELD COATING TEST

28.1 *Scope*:

28.1.1 This is a quick field method to ascertain the compatibility of emulsified asphalt with the job aggregate.

28.2 *Significance and Use*:

28.2.1 This test method is used at the project site to determine (1) the ability of the emulsified asphalt to coat the job aggregate; (2) the ability of the emulsified asphalt to withstand mixing; and (3) the water resistance of the aggregate coated with emulsified asphalt.

28.3 *Summary of Test Method*:

28.3.1 A measured amount of the job aggregate is hand-mixed with a measured amount of the emulsified asphalt supplied to the job. The ability of the emulsified asphalt to remain as a coating during a 5-minute mixing cycle is observed. The resistance offered by the coating to washing off is determined by repeated filling of a container of coated aggregate with water and emptying.

28.4 *Apparatus*:

28.4.1 *Metal Containers*—$^{1}/_{2}$-L (1-Pt) capacity (friction-top pint cans).

28.4.2 *Metal Porcelain Saucepan*—2$^{1}/_{2}$- to 3-L (2$^{1}/_{2}$- to 3-qt), equipped with a handle.

28.4.3 *Dispensing Graduate*—50-mL capacity, preferably plastic.

28.4.4 *Serving Spoon*—Long-handled.

28.4.5 *Sieve*—A 19-mm ($^{3}/_{4}$-in.) sieve, made of wire cloth and conforming to M 92.

28.4.6 *Timer* —Graduated in 0.1 second and accurate within 0.1 percent when tossed over a 15-minute interval.

28.4.7 *Newspapers*.

28.5 *Procedure*:

28.5.1 Remove the rim from the $^{1}/_{2}$-L (1-Pt) can.

28.5.2 Fill the can level with the job aggregate, discarding any sizes above 19 mm ($^{3}/_{4}$ in.).

28.5.3 Measure out 50 mL of emulsified asphalt.

28.5.4 Transfer the aggregate and the emulsified asphalt into the saucepan.

28.5.5 Hand-mix vigorously for 5 minutes with the spoon.

28.5.6 Observe (1) whether the stone is fully coated with the emulsified asphalt and rate the coating as “good,” “fair,” or “poor,” using the ratings as defined in Section 16.7.1.1; and (2) the presence, if any, of free water, which denotes breakdown of the emulsified asphalt.

28.5.7 Refill the $^{1}/_{2}$-L (1-Pt) can with the coated stone.

28.5.8 Set the can of coated stone upright in the saucepan.

28.5.9 Fill the can with water and pour if off. Repeat this step five times.

28.5.10 Transfer the contents of the can onto newspapers. Repeat the observations made in Section 28.5.6 and record the ratings.

28.6 *Report*:

28.6.1 Report the observations made in Sections 28.5.6 and 28.5.10 as the results from this test.

28.7 *Precision and Bias*:

28.7.1 The usual methods of analysis for precision cannot be applied to this test method because it is not fully quantitative.

29. EMULSIFIED ASPHALT/JOB AGGREGATE COATING TEST

29.1 *Scope*:

29.1.1 This test method may be used to identify the ability of SS grades of emulsified asphalt to mix with and coat a dense and fine-graded job aggregate. It is a laboratory test method for screening emulsified asphalt candidates for mixing with and coating job aggregates and is not to be construed as a mix design test method.

29.2 *Significance and Use*:

29.2.1 The conditions of the test are designed to identify the ability of emulsified asphalt, SS grades (CSS from M 208 and SS from M 140), to mix with and coat dense-graded and fine-graded job aggregate.

29.3 *Summary of Test Method*:

29.3.1 A specified amount of dry job aggregate is hand-mixed with a specified amount of water in order to "pre-wet" the aggregate. The wetted aggregate is then hand-mixed with a specified amount of emulsified asphalt of known asphalt content, until the maximum coating of the job aggregate is obtained. (Mix time is usually 15 to 120 seconds) The ability of the emulsified asphalt to mix with the job aggregate is determined by using various amounts of water and emulsified asphalt until a maximum coating of the job aggregate is obtained. This coating is rated as "good," "fair," or "poor."

29.4 *Apparatus*:

29.4.1 *Containers*—A 1000-mL glass beaker, a 1.0-L (l-qt) friction-top metal can, or 1000-mL stainless steel beaker or bowl.

29.4.2 *Mixing Tool*—A steel spatula or its equivalent, having a blade approximately 203.2 mm (8 in.) in length.

29.4.3 *Balance*—Conforming to the requirements of M 231, Class G 2.

29.5 *Procedure*:

29.5.1 Add 300 g of dry job aggregate into the container. Add and record the amount of water necessary to "pre-wet" the aggregate (based on the dry mass of the aggregate). Immediately begin to mix vigorously for 1 minute or until all aggregate surfaces subjectively appear to be wetted (as a guide, use 2 to 8 percent water for dense-graded aggregate and 4 to 12 percent water for fine-graded aggregate). The natural moisture in a job aggregate may be used in the test if the moisture content is predetermined. Additional water may then be added, if necessary, to obtain the desired level of water to be used for "pre-wetting" the aggregate.

29.5.2 Add and record the amount of emulsified asphalt (of known asphalt residue content) necessary to coat the aggregate. Immediately begin to mix vigorously, scraping the sides and bottom of the container, for 15 to 120 seconds or until the maximum coating has been attained (as a guide, based on the dry mass of the aggregate, use 3 to 7 percent asphalt residue for dense-graded aggregate and

4 to 8 percent residue for fine-graded aggregate). For example: 8 percent emulsified asphalt in 60 percent solids would be equivalent to 4.8 percent asphalt residue in the mix.

29.5.3 If the mix appears to be too dry and insufficiently coated, repeat Section 29.5.1 or 29.5.2, using an increased amount of water or emulsified asphalt, or both. If the mix appears to be too wet from excessive water or emulsified asphalt, or both, repeat Section 29.5.1 or 29.5.2, using less water or emulsified asphalt, or both.

29.5.4 For each job aggregate mix, observe and record the amount of water used to "pre-wet" the aggregate and asphalt residue from the emulsified asphalt, and note the one mix that provides the best aggregate coating.

29.5.5 Rate the best coating as "good," "fair," or "poor," using the ratings as defined in Section 16.7.1.1.

29.6 *Report*:

29.6.1 Report the amount of water used to "pre-wet" the aggregate and residual asphalt needed for the best aggregate coating obtainable.

29.6.2 Report the maximum coating achieved as "good," "fair," or "poor" in accordance with Section 16.7.

29.7 *Precision and Bias*:

29.7.1 The usual methods of analysis for precision cannot be applied to this test method because it is not fully quantitative.

DENSITY OF EMULSIFIED ASPHALTS

30. TEST TO DETERMINE MASS PER LITER (GALLON)

30.1 *Scope*:

30.1.1 This test method is used to determine the mass per liter (gallon) of emulsified asphalt used in highway construction. This density is computed by determining the mass of emulsified asphalt contained in a standard measure of known volume.

Note 22—The calculation of Imperial Gallon Weight may be made by using proper conversion factors.

30.2 *Significance and Use*:

30.2.1 This test method provides a controlled laboratory test for the determination of quantitative volumes of emulsified asphalt for use in bills-of-lading, invoicing, and application rates.

30.3 *Apparatus*:

30.3.1 *Mass-per-Gallon Cup*—Stainless steel measure of known standard volume (83.2 mL).

30.3.2 *Balance*—Conforming to the requirements of M 231, Class G 2.

30.3.3 *Water Bath*—Capable of maintaining a constant temperature of 25 ± 0.5°C (77 ± 1°F).

30.3.4 *Timer*—Graduated in 0.1 second and accurate within 0.1 percent when tested over a 15-minute interval.

30.3.5 *Sieve*—A 0.850-mm (No. 20) sieve, made of wire cloth and conforming to M 92.

30.4 *Procedure*:

30.4.1 Stir the emulsified asphalt sample and place it in a constant-temperature water bath maintained at 25 ± 0.5°C (77 ± 1°F) for approximately 1 hour.

30.4.2 Place the measure and its cap on the balance, and zero the balance.

30.4.3 Remove the emulsified asphalt sample from the bath and stir it, using care to avoid trapping air in the sample. If necessary, strain it through an 850-mm (No. 20) sieve to remove any skin or film that might be present in the emulsified asphalt.

30.4.4 Bring the measure to approximately 25°C (77°F) and pour the emulsified asphalt into the measure, filling it completely.

30.4.5 Start placing the cap onto the measure, and remove, with a clean dry rag or paper, the excess emulsified asphalt oozing through the orifice in the cap.

30.4.6 When the cap is tightly placed on the measure, clean the measure carefully, and determine the mass on the tared balance to the nearest 0.01 g. Record this mass.

30.5 *Calculation*:

30.5.1 Calculate the mass per liter of emulsified asphalt as follows:

$$D_e = M_e \times 11.98 \tag{9}$$

where:

D_e = density of the emulsified asphalt, g/L; and

M_e = mass of the emulsified asphalt in the measure, g.

30.5.2 When desired, calculate the mass per gallon of emulsified asphalt as follows:

$$D_e = M_e/10 \tag{10}$$

where:

D_e = density of the emulsified asphalt, lb/gal; and

M_e = mass of the emulsified asphalt in the measure, g.

30.6 *Report*:

30.6.1 Report the density of emulsified asphalts in grams per liter (pounds per gallon) to the nearest 5 g (0.01 lb) at 25°C (77°F).

30.7 *Precision and Bias*:

30.7.1.1 The following criteria should be used for judging the acceptability of results (95 percent probability):

30.7.1.2 Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Density	Repeatability
Grams per liter at 25°C (77°F)	0.019
Pounds per gallon at 25°C (77°F)	0.019

30.7.2 The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Density	Reproducibility
Grams per liter at 25°C (77°F)	0.034
Pounds per gallon at 25°C (77°F)	0.034

Note 23—Mass per liter (gallon) at 25°C (77°F) may be translated to mass per liter (gallon) at 15.6°C (60°F) by using a multiplier of 1.00475.

31. KEYWORDS

31.1 Asphalt residue; cationic; coating; demulsibility; distillation; emulsified asphalt; evaporation; medium-setting; miscibility; particle charge; rapid-setting; settlement; slow-setting; storage stability; viscosity; water content.

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[1] Available from Koehler Instrument Company, Inc., 1595 Sycamore Avenue, Bohemia, NY 11716; and Humboldt Manufacturing Co., 3801 North 25th Avenue, Schiller Park, IL 60176.

[2] Available from Humboldt Manufacturing Co., Catalog No. H-1876, 3801 North 25th Avenue, Schiller Park, IL 60176.

[3] Limestone from Vulcan Materials Midwest Division, 6857 North US Highway 421, Monon, IN 47959, has been found suitable as a reference aggregate.

[4] Fine aggregate is available from U.S. Silica Co., 701 Boyce Memorial Drive, Ottawa, IL 61350

Standard Method of Test for

Saybolt Viscosity

AASHTO Designation: T 72-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Saybolt Viscosity

AASHTO Designation: T 72-10

1. SCOPE

1.1 This test method covers the empirical procedures for determining the Saybolt Universal or Saybolt Furol viscosities of petroleum products at specified temperatures between 21 and 99°C (70 and 210°F). A special procedure for waxy products is indicated.

Note 1—T 201 and ASTM D 445 are preferred for the determination of kinematic viscosity. These methods require smaller samples and less time, and provide greater accuracy. Kinematic viscosities may be converted to Saybolt viscosities by use of the tables in ASTM D 2161. It is recommended that viscosity indexes be calculated from kinematic rather than Saybolt viscosities.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 40, Sampling Bituminous Materials
- T 59, Emulsified Asphalts
- T 201, Kinematic Viscosity of Asphalts (Bitumens)

2.2 *ASTM Standards*:

- D 117, Standard Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Oils of Petroleum Origin
- D 445, Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
- D 2161, Standard Practice for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 11, Standard Specification for Wire Cloth and Sieves for Testing Purposes
- E 102, Standard Test Method for Saybolt Furol Viscosity of Bituminous Materials at High Temperatures

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *Furol*—an acronym of "Fuel and road oils".

3.1.2 *Saybolt Furol viscosity*—the corrected efflux time in seconds of 60 mL (2 oz) of sample flowing through a calibrated Furol orifice under specified conditions. The viscosity value is reported in "Saybolt Furol seconds," abbreviated "SFS," at a specified temperature.

3.1.3 *Saybolt Universal viscosity*—the corrected efflux time in seconds of 60 mL (2 oz) of sample flowing through a calibrated Universal orifice under specified conditions. The viscosity value is reported in "Saybolt Universal seconds," abbreviated "SUS," at a specified temperature.

4. SUMMARY OF TEST METHOD

4.1 The efflux time in seconds of 60 mL of sample, flowing through a calibrated orifice, is measured under carefully controlled conditions. This time is corrected by an orifice factor and reported as the viscosity of the sample at that temperature.

5. SIGNIFICANCE AND USE

5.1 This test method is useful in characterizing certain petroleum products, as one element in establishing uniformity of shipments and sources of supply.

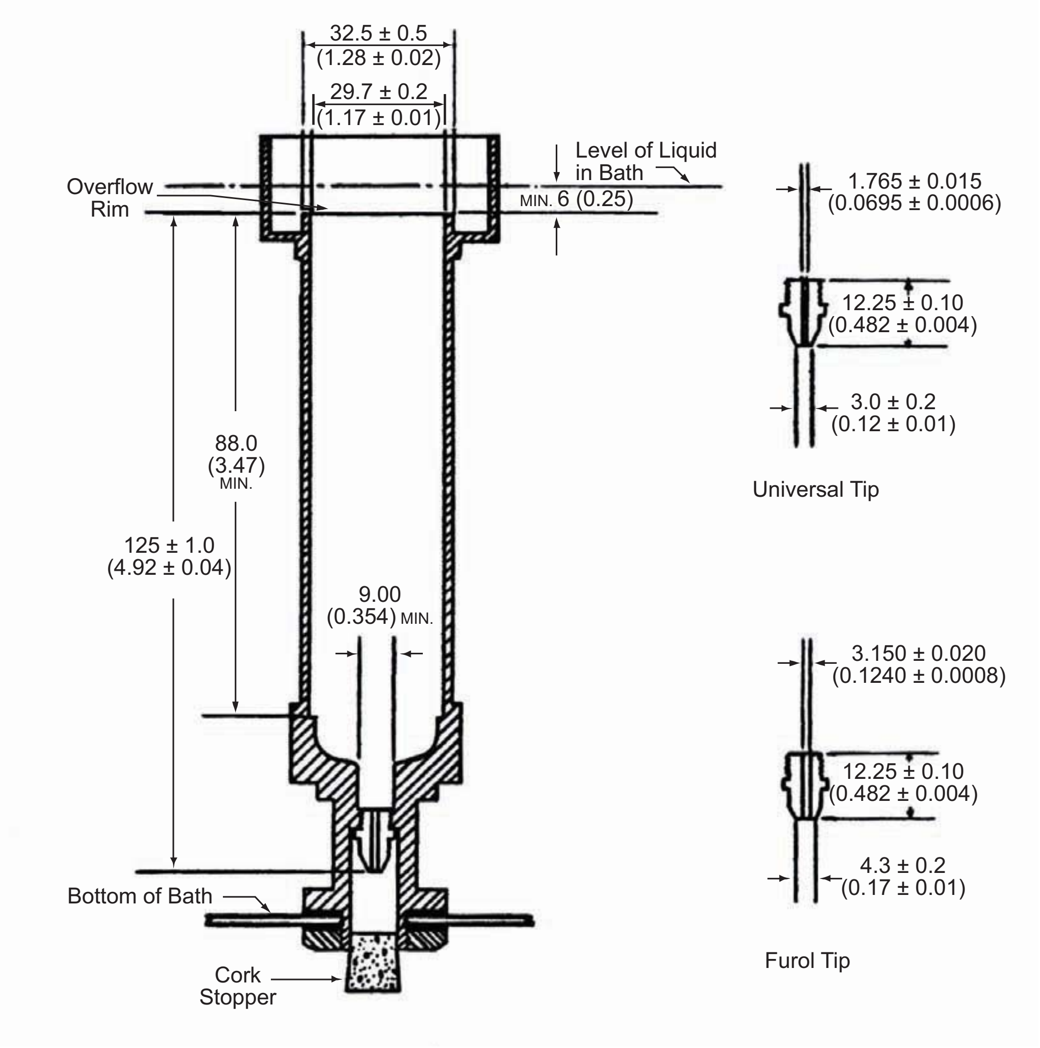
5.2 See ASTM D 117 for applicability to mineral oils used as electrical insulating oils.

5.3 The Saybolt Furol viscosity is approximately one tenth of the Saybolt Universal viscosity and is recommended for characterization of petroleum products such as fuel oils and other residual materials having Saybolt Universal viscosities greater than 1000 s.

5.4 Determination of the Saybolt Furol viscosity of asphalt materials at higher temperatures is covered by ASTM E 102.

6. APPARATUS

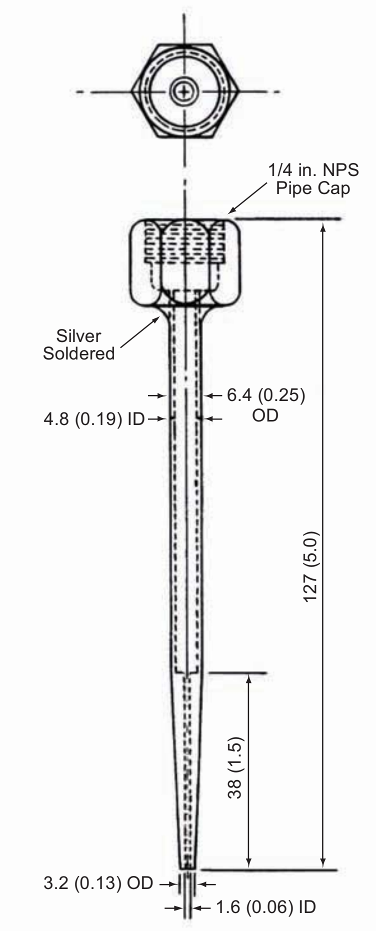
6.1 Saybolt Viscometer and Bath, as shown in Figure 1 and described in Annex A2.



Note—All dimensions are in millimeters (inches).

Figure 1—Saybolt Viscometer with Universal and Furol Orifice

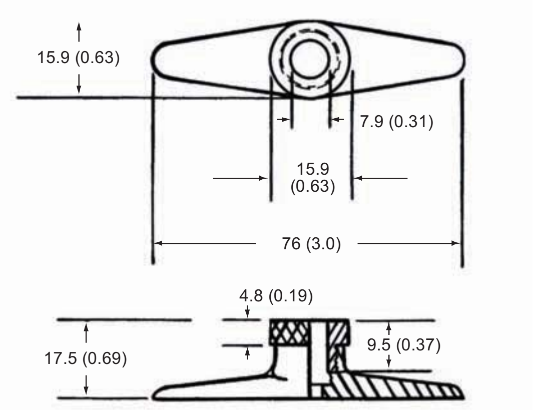
6.2 Withdrawal Tube, as shown in Figure 2, or other suitable device.



Note—All dimensions are in millimeters (inches).

Figure 2—Withdrawal Tube for Use with Saybolt Viscometer

6.3 *Thermometer Support*—One suitable design is shown in Figure 3.



Note—All dimensions are in millimeters (inches).

Figure 3—Thermometer Support

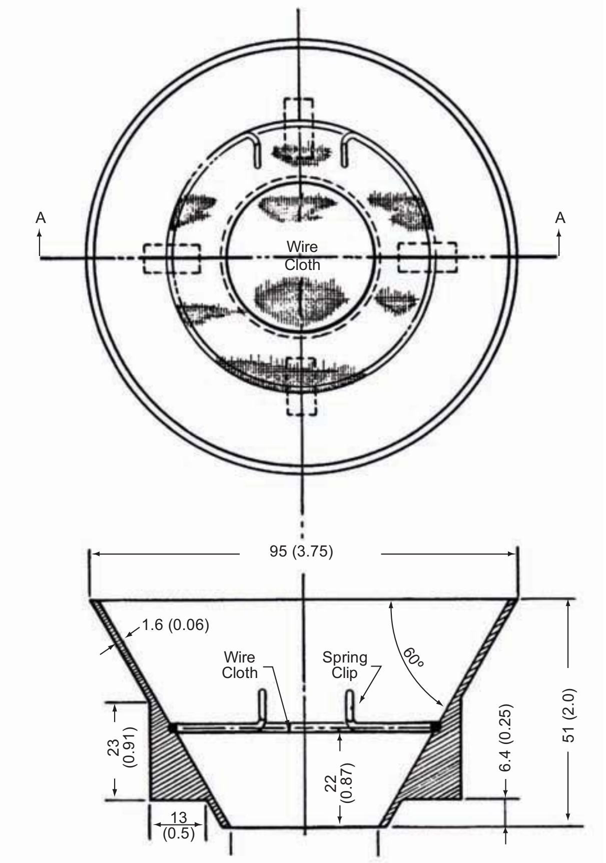
6.4 Saybolt Viscosity Thermometers, as listed in Table 1, for reading the temperature of the sample. Each thermometer shall conform to the requirements listed in ASTM E 1 for that ASTM Thermometer Number.

Table 1—ASTM Saybolt Viscosity Thermometers

Standard Test Temperature, °C (°F)	ASTM Thermometer Number	Thermometer	
		Range, °C (°F)	Subdivisions, °C (°F)
21.1 (70)	17C (17F)	19 to 27 (66 to 80)	0.1 (0.2)
25.0 (77)	17C (17F)	19 to 27 (66 to 80)	0.1 (0.2)
37.8 (100)	18C (18F)	34 to 42 (94 to 108)	0.1 (0.2)
50.0 (122)	19C (19F)	49 to 57 (120 to 134)	0.1 (0.2)
54.4 (130)	19C (19F)	49 to 57 (120 to 134)	0.1 (0.2)
60.0 (140)	20C (20F)	57 to 65 (134 to 148)	0.1 (0.2)
82.2 (180)	21C (21F)	79 to 87 (174 to 188)	0.1 (0.2)
98.9 (210)	22C (22F)	95 to 103 (204 to 218)	0.1 (0.2)

6.5 *Bath Thermometers*—Saybolt Viscosity thermometers, or any other temperature-indicating devices of equivalent accuracy.

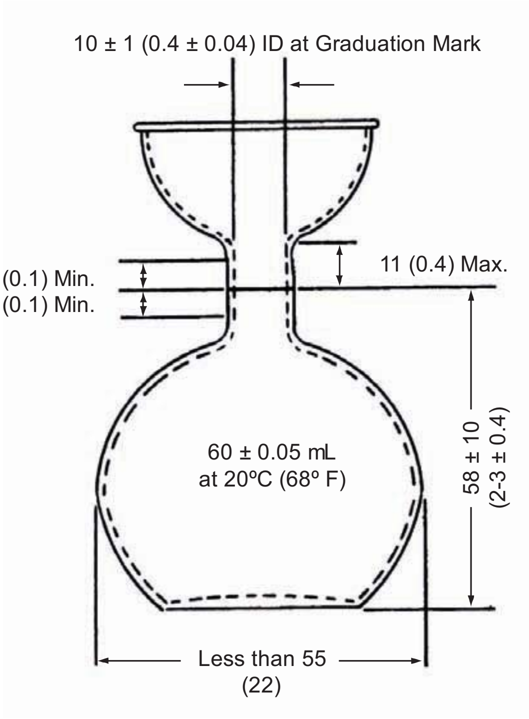
6.6 Filter Funnel, as shown in Figure 4, equipped with interchangeable 0.850-mm (No. 20), 0.150-mm (No. 100), and 0.075-mm (No. 200) wire-cloth inserts meeting the requirements of ASTM E 11 with respect to the wire cloth. Filter funnels of a suitable alternate design may be used.



Note—All dimensions are in millimeters (inches).

Figure 4—Filter Funnel for Use with Saybolt Viscometer

6.7 Receiving Flask, as shown in Figure 5.



Note—All dimensions are in millimeters (inches).

Figure 5—Receiving Flask

6.8 Timer, graduated in tenths of a second, and accurate to 0.1 percent when tested over a 60-min interval. Electric timers are acceptable if operated on a controlled-frequency circuit.

6.9 125-mL (4.2-oz.) Erlenmeyer flask

7. SAMPLING

7.1 Sample the material in accordance with T 40, as appropriate.

8. PREPARATION OF APPARATUS

8.1 Use a Universal orifice or tip for lubricants and distillates with efflux times greater than 32 s to give the desired accuracy. Liquids with efflux times greater than 1000 s are not conveniently tested with this orifice.

8.2 Use a Furol orifice or tip for residual materials with efflux times greater than 25 s to give the desired accuracy (see also Section 5.3).

8.3 Clean the viscometer thoroughly with an appropriate solvent of low toxicity; then remove all solvent from the viscometer and its gallery. Clean the receiving flask in the same manner.

Note 2—The plunger commonly supplied with the viscometer should never be used for cleaning as this might damage the overflow rim and walls of the viscometer.

8.4 Set up the viscometer and bath in an area where they will not be exposed to drafts or rapid changes in air temperature and dust or vapors that might contaminate a sample.

8.5 Place the receiving flask (Figure 5) beneath the viscometer so that the graduation mark on the flask is from 100 to 130 mm (4 to 5 in.) below the bottom of the viscometer tube and so that the stream of oil will just strike the neck of the flask.

8.6 Fill the bath to at least 6 mm ($^1/_4$ in.) above the overflow rim of the viscometer with an appropriate bath medium selected from Table 2.

8.7 Provide adequate stirring and thermal control for the bath so that the temperature of a test sample in the viscometer will not vary more than ±0.05°C (±0.09°F) after reaching the selected test temperature.

8.8 Do not make viscosity measurements at temperatures below the dew point of the room's atmosphere.

8.9 For calibration and referee tests, keep the room temperature between 20 and 30°C (68 and 86°F), and record the actual temperature. However, room temperatures up to 38°C (100°F) will not introduce errors in excess of 1 percent.

Table 2—Bath Media

Standard Test Temperature, °C (°F)	Bath Medium	Max Temp Differential,[a] °C (°F)	Bath Temperature Control Functional Precision, °C (°F)
21.1 (70)	water	± 0.05 (0.09)	± 0.05 (0.09)
25.0 (77)	water	± 0.05 (0.09)	± 0.05 (0.09)
37.8 (100)	water, or oil of 50 to 70 SUS viscosity at 37.8°C (100°F)	± 0.15 (0.27)	± 0.05 (0.09)
50.0 (122)	water, or oil of 120 to 150 SUS viscosity at 37.8°C (100°F)	± 0.20 (0.36)	± 0.05 (0.09)
54.4 (130)	water, or oil of 120 to 150 SUS viscosity at 37.8°C (100°F)	± 0.30 (0.54)	± 0.05 (0.09)
60.0 (140)	water, or oil of 120 to 150 SUS viscosity at 37.8°C (100°F)	± 0.50 (0.90)	± 0.05 (0.09)
82.2 (180)	water, or oil of 300 to 370 SUS viscosity at 37.8°C (100°F)	± 0.80 (1.40)	± 0.05 (0.09)
98.9 (210)	oil of 330 to 370 SUS viscosity at 37.8°C (100°F)	± 1.10 (2.0)	± 0.05 (0.09)

[a] Maximum permissible difference between bath and sample temperatures at the time of the test.

9. CALIBRATION AND STANDARDIZATION

9.1 Calibrate the Saybolt Universal viscometer at intervals of not more than three years by measuring the efflux time at 37.8°C (100°F) of an appropriate viscosity oil standard, following the procedure given in Section 10. See Annex A2 for viscosity oil standards available.

9.2 The efflux time of the viscosity oil standard shall equal the certified Saybolt viscosity value. If the efflux time differs from the certified value by more than 0.2 percent, calculate a correction factor, F, for the viscometer as follows:

$$F = V/t \quad (1)$$

where:

V = Certified Saybolt viscosity of the standard; and

t = Measured efflux time at 37.8°C (100°F), s.

Note 3—If the calibration is based on a viscosity oil standard having an efflux time between 200 and 600 s, the correction factor applies to all viscosity levels at all temperatures.

9.3 Calibrate the Saybolt Furol viscometer at 50°C (122°F) as discussed in Section 9.1, using a viscosity oil standard having a minimum efflux time of 90 s.

9.4 Viscometers or orifices requiring corrections greater than 1.0 percent shall not be used in referee testing.

10. PROCEDURE

10.1 Establish and control the bath temperature at the selected test temperature.

10.1.1 Standard test temperatures for measuring Saybolt Universal viscosities are 21.1, 37.8, 54.4, and 98.9°C (70, 100, 130, and 210°F).

10.1.2 Standard test temperatures for measuring Saybolt Furol viscosities are 25.0, 37.8, 50.0, and 98.9°C (77, 100, 122, and 210°F).

10.1.3 Other standard test temperatures in use include 60.0 and 82.2°C (140 and 180°F).

10.2 Insert a cork stopper into the air chamber at the bottom of the viscometer; a small chain or cord may be attached to the cork to facilitate rapid removal. The cork shall fit tightly enough to prevent the escape of air, as evidenced by the absence of oil on the cork when it is withdrawn as described in Section 10.9.

10.3 If the selected test temperature is above room temperature, the test may be expedited by preheating the sample in its original container to not more than 1.7°C (3.0°F) above the test temperature.

10.4 Stir the sample well; then strain it through a wire cloth of appropriate mesh directly into the viscometer until the level is above the overflow rim. The wire cloth shall be 0.150-mm (No. 100) mesh except as noted in T 59.

10.5 For liquid asphalt materials having highly volatile components, such as rapid-curing and medium-curing cutbacks, preheating the material in an open container shall not be permitted. The material shall be poured at room temperature into the viscometer, or if the material is too viscous to pour conveniently at room temperature, it shall be warmed sufficiently by placing the sample in the original container in a water bath at 50°C (122°F) for a few minutes prior to pouring. The step that requires filtering through a wire cloth shall be omitted for liquid asphalt materials containing highly volatile components. For tests on these materials above room temperature, greater temperature differentials than indicated in Table 2 will be permitted during the heating period, but the bath temperature must be adjusted within the prescribed limits prior to the final minute of stirring (during which the temperature of the sample remains constant).

10.6 The viscosities of steam-refined cylinder oils, black lubricating oils, residual fuel oils, and similar waxy products can be affected by their thermal histories. Use the following preheating procedure with such products to obtain uniform results at temperatures below 93°C (200°F):

10.6.1 Heat the sample in its original container to about 50°C (122°F), while stirring and shaking it to dissolve and blend waxy materials. Probe the bottom of the container with a stirring rod to ensure that all waxy materials are in solution, and then mix the solution well.

10.6.2 Pour about 100 mL into a 125-mL (4.2-oz) Erlenmeyer flask. Stopper the flask loosely with a cork or rubber stopper.

10.6.3 Immerse the flask in a bath of boiling water for 30 min.

10.6.4 Mix the solution well and remove the sample from the boiling water bath. Wipe the outside of the flask dry, and strain the sample through the 0.075-mm (No. 200) wire cloth in the filter funnel directly into the viscometer until the level is above the overflow rim. Complete the viscosity test within 1 h after reheating.

10.7 Stir the sample in the viscometer with the appropriate viscosity thermometer equipped with the thermometer support (Figure 3). Use a circular motion at 30 to 50 r/min in a horizontal plane. When the sample temperature remains constant within 0.05°C (0.09°F) of the test temperature during 1 min of continuous stirring, remove the thermometer.

Note 4—Never attempt to adjust the temperature by immersing hot or cold bodies in the sample. Such thermal treatment might affect the sample and the precision of the test.

10.8 Immediately place the tip of the withdrawal tube (Figure 2) in the gallery at one point, and apply suction to remove oil until its level in the gallery is below the overflow rim. Do not touch the overflow rim with the withdrawal tube in order to avoid reducing the effective liquid head of the sample.

10.9 Ensure that the receiving flask is in proper position. Then snap the cork from the viscometer, and start the timer at the same instant. A small chain or cord may be attached to the cork to facilitate rapid removal.

10.10 Stop the timer the instant the bottom of the oil meniscus reaches the graduation mark on the receiving flask. Record the efflux time in seconds to the nearest 0.1 s.

11. CALCULATION AND REPORT

11.1 Multiply the efflux time by the correction factor for the viscometer determined in Section 9.2.

11.2 Report the corrected efflux time as the Saybolt Universal or Saybolt Furol viscosity of the oil at the temperature at which the test was performed.

11.2.1 Report the viscosity values to the nearest whole second.

12. PRECISION AND BIAS

12.1 *Results should not differ from the mean by more than the following (see Note 5)*:

12.1.1 Repeatability (one operator and apparatus)—1 percent.

12.1.2 Reproducibility (different operators and apparatus)—2 percent.

Note 5—For petroleum products, the precision and bias are based on data from ASTM E 102.

13. KEYWORDS

13.1 Asphalt materials; kinematic; Saybolt; viscosity.

ANNEXES

(Mandatory Information)

A1. SAYBOLT VISCOMETER AND ACCESSORIES

A1.1. *Viscometer*—The viscometer, illustrated in Figure 1, shall be constructed entirely of corrosion-resistant metal, conforming to the dimensional requirements shown in Figure 1. The orifice tip, Universal or Furol, may be constructed as a replaceable unit in the viscometer. Provide a nut at the lower end of the viscometer for fastening it in the bath. Mount the viscometer vertically in the bath, and test the alignment with a spirit level on the plane of the gallery rim. Provide a cork or other suitable means to prevent the flow of material until the start of the test; a small chain or cord may be attached to the cork to facilitate rapid removal.

A1.2. *Bath*—The bath serves both as a support to hold the viscometer in a vertical position as well as the container for the bath medium. Equip the bath with effective insulation and with an efficient stirring device. Provide the bath with a coil for heating and cooling and with thermostatically controlled heaters capable of maintaining the bath within the functional precision given in Table 2. The coil should be located at least 75 mm (3 in.) from the viscometer. Provide a means for maintaining the bath medium at least 6 mm (0.25 in.) above the overflow rim. The bath media are given in Table 2.

A2. VISCOSITY STANDARDS

A2.1. *Saybolt Viscosity Standards*—Certified Saybolt viscosity oil standards conforming to ASTM requirements are established by Saybolt viscosity values by cooperative determinations of kinematic viscosity values. The kinematic values are converted to Saybolt Universal and Saybolt Furol viscosity values by means of conversion tables given in ASTM D 2161. The approximate Saybolt viscosities are shown in Table A2-1.

Table A2-1—Saybolt Viscosity Oil Standards [a]

Note—All values are nominal and will vary by lot.

Viscosity Oil Standard	At 37.8°C (100°F)		At 98.9°C (210°F)		At 50°C (122°F)	
	SUS	mm^2/s	SUS	mm^2/s	SUS	mm^2/s
S3	36	3.0	—	—	—	—
S6	46	6.0	—	—	—	—
S20	100	20	—	—	—	—
N26	130	27	—	—	—	—
N35	170	35	—	—	—	—
N44	220	48	—	—	—	—
S60	280	60	—	—	—	—
N75	380	82	—	—	—	—
N100	500	110	—	—	—	—
N140	720	160	—	—	—	—
S200	925	200	105	20	—	—
N250	1300	280	140	29	—	—
N350	1570	340	160	32	—	—
N415	2180	470	200	41	—	—
S600	—	—	240	50	120	310
S2000	—	—	360	72	—	—

Note: All values are nominal and will vary by lot.

[a] These viscosity oil standards are available in 0.5-L (16.9-oz) containers from the Cannon Instrument Co., 2139 High Tech Rd., State College, PA 16803.

A2.2. *Standards Conforming to ASTM Saybolt Viscosity Standards*—The viscosity standards may also be used for routine calibrations at other temperatures as shown in Table A2-1. Other reference liquids, suitable for routine calibrations, may be established by selecting stable oils covering the desired range and determining their viscosities in a viscometer calibrated with a standard conforming to ASTM requirements.

A2.3. *Routine Calibrations*—The viscosity standards may also be used for routine calibrations at other temperatures as shown in Table A2-1.

Standard Method of Test for

Distillation of Cutback Asphaltic (Bituminous) Products

AASHTO Designation: T 78-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Distillation of Cutback Asphaltic (Bituminous) Products

AASHTO Designation: T 78-10

1. SCOPE

1.1 This test method covers a distillation test for cut-back asphalt products.

1.2 The values given in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:
- M 231, Weighing Devices Used in the Testing of Materials
- T 49, Penetration of Bituminous Materials

2.2 *ASTM Standards*:
- D 86, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D 370-02$^{\epsilon 1}$, Standard Practice for Dehydration of Oil-Type Preservatives (Withdrawn in 2006)
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 133, Standard Specification for Distillation Equipment
- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques

2.3 *British Institute of Petroleum (IP) Standards*:
- IP 123, Determination of Distillation Characteristics at Atmospheric Pressure

2.4 *Other*:
- C.O.3—Standard Methods for Testing Tar and Its Products. Watkins, P. V., ed., published by Leeds, London, UK for Standardization of Tar Products Tests Committee

3. SUMMARY OF METHOD

3.1 Two hundred milliliters (6.8-oz) of the sample are distilled in a 500-mL (16.9-oz) flask, at a controlled rate, to a temperature in the liquid of 360°C (680°F), and the volumes of distillate obtained at specified temperatures are measured. The residue from the distillation, and also the distillate itself, may be tested as required.

4. SIGNIFICANCE AND USE

4.1 This procedure measures the amount of the more volatile constituents in cut-back asphalt products. The properties of the residue after distillation are not necessarily characteristic of the asphalt used in the original mixture, nor of the residue which may be left at any particular time after field application of the cut-back asphalt product. The presence of silicone in the cut-back asphalt product may affect the distillation residue by retarding the loss of volatile material after the residue has been poured into the residue container.

5. APPARATUS

5.1 *Distillation Flask*—500-mL (16.9-oz) side-arm type, having the dimensions shown in Figure 1.

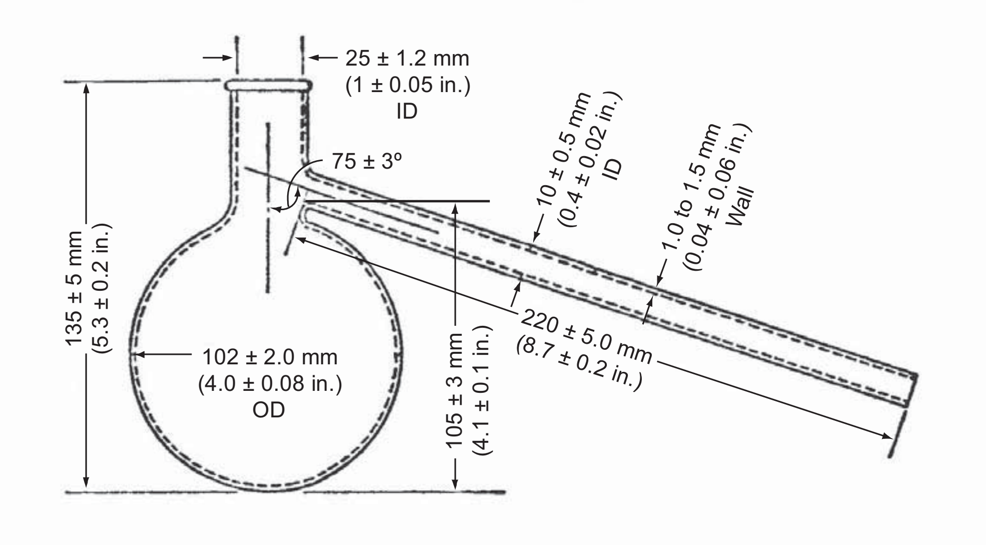


Figure 1—Distillation Flask

5.2 *Condenser*—Standard glass-jacketed, of nominal jacket length from 200 to 300 mm (7.9 to 11.8 in.) and overall tube length of 450 ± 10 mm (17.7 ± 0.4 in.) (see Figure 2).

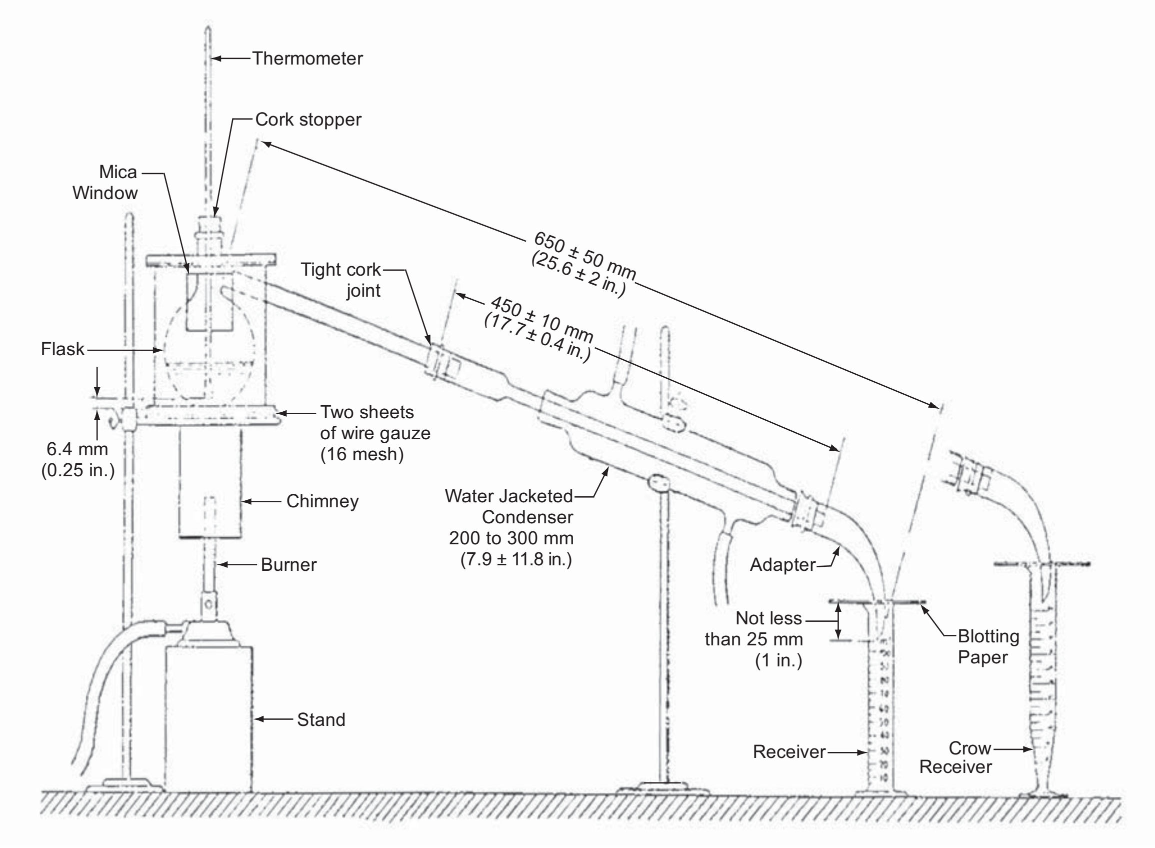
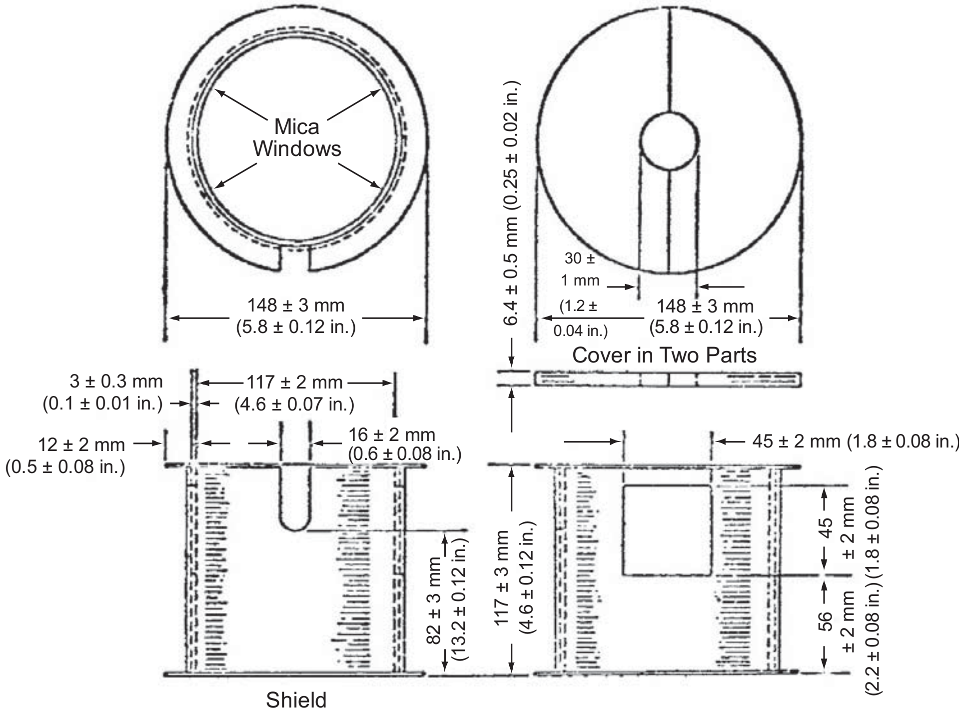


Figure 2—Distillation Apparatus

5.3 *Shield*—Steel, lined with 3-mm (0.1-in.) fireproof insulation and fitted with transparent mica windows, of the form and dimensions shown in Figure 3, used to protect the flask from air currents and to reduce radiation. The cover (top) shall be made in two parts of 6.4-mm (0.25-in.) fireproof insulation.



Flanged Open-End Cylinder made of 22-gauge galvanized iron with 3-mm (0.1-in.) fireproof lining riveted to metal

Two Mica Windows are provided at right angles to the end slot.

Figure 3—Shield

5.4 *Adapter*—Heavy-wall [1-mm (0.04-in.)] glass, with a reinforced top, having an angle of approximately 105 degrees. The inside diameter at the large end shall be approximately 18 mm (0.7 in.), and at the small end, not less than 5 mm (0.2 in.). The lower surface of the adapter shall be on a smooth descending curve from the larger end to the smaller. The inside line of the outlet end shall be vertical, and the outlet shall be cut or ground (not fire-polished) at an angle of 45 ± 5 degrees to the inside line. Figure 2 indicates the appropriate location of the adapter in the distillation apparatus.

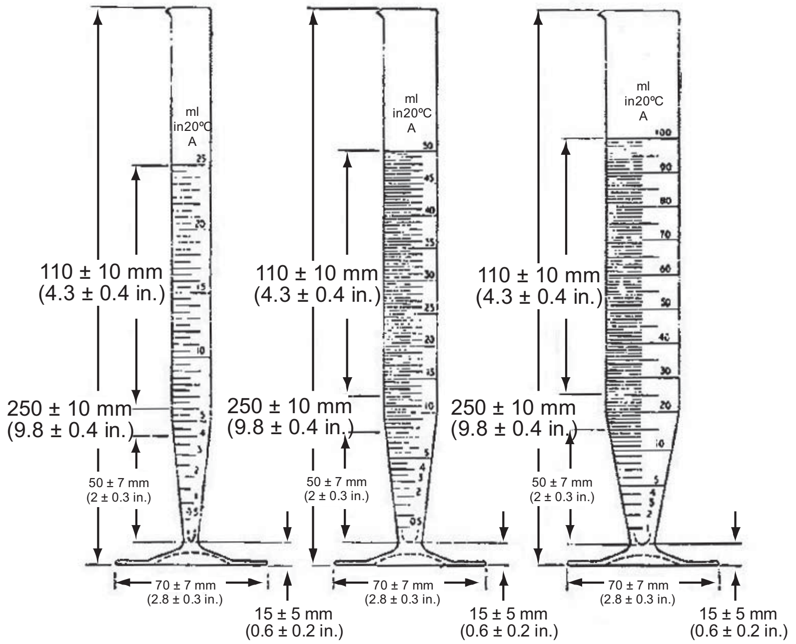
5.5 *Shield and Flask Support*—Two 15-cm^2 (2.3-in.^{2}) sheets of 1.18-mm (No. 16)-mesh Chromel wire gauze on a tripod or ring.

5.6 *Heat Source*:

5.6.1 Adjustable Tirrill-type gas burner or equivalent.

5.6.2 An electric heater equipped with a transformer capable of controlling from 0 to 750 W. The shield and support shall be a refractory with an opening of 79 mm (3.1 in.), with the upper surface beveled to 86 mm (3.4 in.) to accommodate the specified 500-mL (16.9-oz) flask. When the flask is placed on the refractory, there should be a distance of approximately 3 mm (0.1 in.) between the bottom of the flask and the heating elements.

5.7 *Receiver*—A standard 100-mL (3.4-oz) graduated cylinder conforming to the dimensions of ASTM E 133, or a 100-mL (3.4-oz) Crow receiver as shown in Figure 4.



Note—All dimensions are in millimeters (inches).

Figure 4—Crow Receivers of 25- (0.8-), 50- (1.7-), and 100-mL (3.4-oz) Capacity

Note 1—Receivers of smaller capacity having 0.1-mL (0.003-oz) divisions may be used when low volumes of total distillate are expected and the added accuracy required.

5.8 *Residue Container*—A seamless metal container with a slip-on cover of 75 ± 5 mm (3.0 ± 0.2 in.) in diameter and 55 ± 5 mm (2.2 ± 0.2 in.) in height.

5.8.1 **Caution**—Provide a cover suitable in size and material to extinguish a flame in the residue container if the residue flames after pouring.

5.9 *Thermometer*—ASTM high-distillation thermometers having a range from –6 to 400°C (20 to 760°F) and conforming to the requirements for Thermometer 8C (8F) as prescribed in ASTM E 1, or IP Thermometer 6C conforming to IP Specifications for Standard Thermometers, or an equivalent thermometric device that has been calibrated in accordance with ASTM E 220. ASTM 8C Thermometers shall be used for referee testing.

5.10 *Balance*—Conforming to the requirements of M 231, Class G 2.

5.11 Thermometers as specified in IP Standards.

5.12 Crow Receiver as specified in British Standards 658:1989.

6. SAMPLING

6.1 Stir the sample thoroughly, warming it if necessary, to ensure homogeneity before removal of a portion for analysis.

6.2 If sufficient water is present to cause foaming or bumping, dehydrate a sample of not less than 250 mL (8.5-oz) by heating it in a distillation flask sufficiently large to prevent foaming over into the side-arm. When foaming has ceased, stop the distillation. If any light oil has distilled over, separate and pour this material back into the flask when the contents have cooled just sufficiently to prevent the loss of volatile oil. Mix the contents of the flask thoroughly before removal of a portion for analysis. An alternative procedure is described in ASTM D 370.

7. PREPARATION OF APPARATUS

7.1 Calculate the mass of 200 mL (6.8-oz) of the sample from the specific gravity of the material at 15.6/15.6°C. Add this amount ± 0.5 g into the 500-mL (16.9-oz) flask.

7.2 Place the flask in the shield supported by two sheets of gauze on a tripod or ring. Connect the condenser tube to the tubulature of the flask with a tight cork joint. Clamp the condenser so that the axis of the bulb of the flask through the center of its neck is vertical. Adjust the adapter over the end of the condenser tube so that the distance from the neck of the flask to the outlet of the adapter is 650 ± 50 mm (25.6 ± 2.0 in.) (see Figure 3).

7.3 Insert the thermometer through a tightly fitting cork in the neck of the flask so that the bulb of the thermometer rests on the bottom of the flask. Raise the thermometer 6 mm (0.25 in.) from the bottom of the flask using the scale divisions on the thermometer to estimate the 6-mm (0.25-in.) distance above the top of the cork.

7.4 Protect the burner by a suitable shield or chimney. Place the receiver so that the adapter extends at least 25 mm (1 in.) but not below the 100-mL (3.4-oz) mark. Cover the graduate closely with a piece of blotting paper, or similar material, suitably weighted, which has been cut to fit the adapter snugly.

7.5 The flask, condenser tube, adapter, and receiver shall be clean and dry before starting the distillation. Place the seamless residue container on its cover in an area free from drafts.

7.6 Pass cold water through the condenser jacket. Use warm water, if necessary, to prevent formation of solid condensate in the condenser tube.

8. PROCEDURE

8.1 Correct, to the nearest 1°C (2°F), the temperatures to be observed in the distillation for barometric pressure in millimeters of mercury. If the prevailing barometric pressure in millimeters of mercury is known, correct the temperature to be observed with the factors shown in Table 1. Do not correct for the emergent stem of the thermometer if used. See the example corrections that follow.

Correction = (Observed pressure in mm Hg – 760) × Correction per mm Hg

Correction per mm Hg = $^{1}/_{10}$ the correction per 10 mm Hg given in Table 1

Example:

Barometric Pressure = 748 mm Hg

Nominal Observation Temperature = 260°C (500°F)

Celsius Correction = (748 – 760) × (0.632/10) = –0.758

Corrected Temperature = 260 – 0.758 = 259°C (rounded to nearest 1°C)

Fahrenheit Correction = (748 – 760) × (1.138/10) = –1.366

Corrected Temperature = 500 – 1.366 = 498°F (rounded to nearest 2°F)

Note 2—Table 1 covers a wide range of temperatures from 160 to 360°C (320 to 680°F) and is preferred for worldwide specifications other than ASTM or IP specifications.

Table 1—Factors for Calculating Temperature Corrections

Nominal Temperature, °C (°F)	Correction per 10 mm Hg Difference in Pressure,[a] °C (°F)
160 (320)	0.514 (0.925)
175 (347)	0.531 (0.957)
190 (374)	0.549 (0.989)
225 (437)	0.591 (1.063)
250 (482)	0.620 (1.116)
260 (500)	0.632 (1.138)
275 (527)	0.650 (1.170)
300 (572)	0.680 (1.223)
315.6 (600)	0.698 (1.257)
325 (617)	0.709 (1.277)
360 (680)	0.751 (1.351)

[a] To be subtracted when the barometric pressure is below 760 mm Hg; to be added when the barometric pressure is above 760 mm Hg.

8.2 Apply heat so that the first drop of distillate falls from the end of the flask side-arm in 5 to 15 min. Conduct the distillation so as to maintain the following drop rates (count the drop count to be made at the tip of the adapter):

- 50 to 70 drops per minute up to 260°C (500°F)
- 20 to 70 drops per minute between 260 and 316°C (500 and 600°F)
- Not over 10 min to complete distillation from 316 to 360°C (600 to 680°F)

Note 3—Some cut-back asphalt products yield either no distillate or very little distillate over portions of the temperature range up to 316°C (600°F). In this case, it becomes impractical to maintain the distillation rates above. For such cases the intent of the method shall be met if the rate of temperature rise exceeds 5°C (9°F)/min.

8.2.1 Record the volumes of distillate to the nearest 0.5 mL (0.02-oz) in the receiver at the corrected temperatures. If the volume of distillate recovered is critical, use receivers graduated in 0.1-mL (0.003-oz) divisions and immersed in a transparent bath maintained at 15.6 ± 3°C (60 ± 5°F).

8.3 When the temperature reaches the corrected temperature of 360°C (680°F), discontinue the heat, and remove the flask and thermometer. With the flask in a pouring position, remove the thermometer, and immediately pour the contents into the residue container. The total time from discontinuing the heat to starting the pour shall not exceed 30 s. When pouring, the side-arm should be substantially horizontal to prevent condensate in the side-arm from returning to the residue.

Note 4—The formation of skin on the surface of a residue during cooling entraps vapors which will condense and cause higher penetration results when they are stirred back into the sample. If skin begins to form during cooling, it should be gently pushed aside. This operation can be done with a spatula with a minimum of disturbance to the sample.

8.4 Allow the condenser and any distillates trapped in the condenser neck to drain into the receiver, and record the total volume of distillate collected as total distillate up to 360°C (680°F).

8.5 When the residue has cooled until the point that fuming just ceases, stir it thoroughly, and, when the material reaches 135 ± 5°C (275 ± 9°F), pour the residue into the appropriate receptacles for testing properties such as penetration, viscosity, or softening point. Proceed as required by the appropriate method from the point that follows the pouring stage.

8.6 If desired, the distillate, or the combined distillates from several tests, may be submitted to a further distillation, in accordance with IP 123 or ASTM D 86, or when the distillate is of coal-tar origin, Method C.O.3.

9. CALCULATION AND REPORT

9.1 *Asphalt Residue*—Calculate the percent residue to the nearest 0.1 as follows:

$$R = [(200 - TD/200] \times 100$$

where:

R = residue content, in volume percent, and

TD = total distillate recovered up to 360°C (680°F), mL.

9.1.1 Report the percent volume by difference as the residue from distillation up to 360°C (680°F).

9.2 *Total Distillate*—Calculate the percent total distillate to the nearest 0.1 as follows:

$$TD\% = TD/200 \times 100$$

9.2.1 Report the volume percent as the total distillate up to 360°C (680°F).

9.3 *Distillate Fractions*:

9.3.1 Determine the percentages by volume of the original sample by dividing the observed volume (in milliliters) of the fraction by 2. Report the volume percent to the nearest 0.1as follows:

- Up to 190°C (374°F)
- Up to 225°C (437°F)
- Up to 260°C (500°F)
- Up to 316°C (600°F)

9.3.2 Determine the percentages by volume of total distillate by dividing the observed volume (in milliliters) of the fraction by the milliliters recovered up to 360°C (680°F) and multiplying by 100. Report the distillate, volume percent of total distillate to 360°C (680°F), to the nearest 0.1 as follows:

- Up to 190°C (374°F)
- Up to 225°C (437°F)
- Up to 260°C (500°F)
- Up to 316°C (600°F)

9.4 Where penetration, viscosity, or other tests have been performed, report the results with reference to this test method as well as to any other method used.

9.4.1 *Example*—Penetration by T 49 of residue obtained from T 78.

10. PRECISION AND BIAS

10.1 *The following criteria shall be used for judging the acceptability of results (95 percent probability)*:

10.1.1 *Repeatability*—Duplicate values by the same operator shall not be considered suspect unless the determined percentages differ by more than 1.0 "volume percent" of the original sample.

10.1.2 *Reproducibility*—The values reported by each of two laboratories shall not be considered suspect unless the reported percentages differ by more than the following:

Distillation fractions, volume percent of the original sample:

Up to 175°C (347°F)	3.5
Above 175°C (347°F)	2.0
Residue, volume percentage by difference from the original sample	2.0

10.2 Criteria for judging variability of test results on the distillation residue have not been determined.

11. KEYWORDS

11.1 Cut-back asphalt; distillate; residue.

Standard Method of Test for

Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93.3°C (200°F)

AASHTO Designation: T 79-96 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Flash Point with Tag Open-Cup Apparatus for Use with Material Having a Flash Point Less Than 93.3°C (200°F)

AASHTO Designation: T 79-96 (2008)

1. SCOPE

1.1. This method covers the procedure for the determination of flash points by the tag open-cup apparatus of cutback asphalts having flash points of less than 93.3ºC (200ºF).

The sample is placed in the tester and heated at a slow and constant rate. A small test flame is passed at a uniform rate in a level plane across the cup at specified intervals. The flash point is the lowest temperature at which application of the test flame causes the vapor at the surface of the liquid to flash.

Note 1—Specifications commonly designate the Cleveland Open-Cup method (AASHTO T 48) for asphalt binders and cutback asphalts having flash points above 79.5ºC (175ºF).

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This test may involve hazardous materials, operations, and equipment. This test does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 48, Flash and Fire Points by Cleveland Open Cup

2.2. *ASTM Standard*:

- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. APPARATUS

3.1. *Tag Open-Cup Tester*—This apparatus consists of a glass test cup, copper water bath, thermometer holder, small gas burner, ignition taper, liquid leveling device, and draft shield. The apparatus is described in detail in Appendix X1.

3.2. *Thermometer*—A Pensky-Martens, low-range thermometer capable of measuring –5 to 110ºC (20 to 230ºF) and conforming to the requirements for an ASTM Thermometer No. 9C (9F) as prescribed in ASTM E 1 shall be used.

4. BATH MEDIA

4.1. Water for flash points up to 79.5ºC (175ºF).

4.2. Water-glycol solution (1:1) for flash points above 79.5ºC (175ºF).

5. ASSEMBLY AND PREPARATION OF APPARATUS

5.1. The tag open-cup tester shall be placed in a firm and level position on a solid, vibration-free table in a draft-free hood or flash room, or well toward the back of a draft shield such as that described in Section X1.1.7. The top of the tester shall be shielded from strong light so that the flash may be easily seen. A room temperature of 25 ± 5ºC (77 ± 9ºF) should be maintained throughout the test.

5.2. Adjust the horizontal and vertical positions of the ignition taper so that the jet passes on the circumference of a circle having a radius of 152 mm (6 in.) and in a level plane, 3.2 mm ($^1/_8$ in.) above the upper edge of the cup as measured from the center of the orifice. The jet should pass across the center of the cup. These adjustments should be made only when required, as usually the apparatus is used continuously for a series of tests.

Note 2—The leveling device is used as a gauge to adjust the height of the taper.

6. PROCEDURE

6.1. Place the glass test cup in the metal bath, and adjust the thermometer holder so that the thermometer is supported firmly in a vertical position halfway between the center and edge of the cup and on a line passing through the center of the cup and the pivot of the taper. Place the thermometer so that the bottom of the bulb is 6.4 mm ($^1/_4$ in.) above the inner bottom of the cup.

6.2. Fill the metal bath with water or water-glycol solution having a temperature at least 16.5ºC (30ºF) below the probable flash point of the material to be tested. Cool tap water is satisfactory in most instances when water is used, and may be introduced into the chamber between the bath and sample cups until a slight overflow is noted at the overflow spout. The bath should be filled to a level approximately 3.2 mm ($^1/_8$ in.) from the top of the bath when the test cup is in place.

6.3. Rest the metal leveling device on the rim of the cup, and fill the cup with material to be tested until the level of material just touches the pointers of the leveling device [this level should be approximately 3.2 mm ($^1/_8$ in.) below the rim of the cup].

Note 3—The test sample should be at least 10ºC (18ºF) below the anticipated flash point.

6.4. Light the ignition taper, and adjust the test flame to approximately the same size as the comparison bead or the reference hole in the leveling device, but in no case greater than 4 mm ($^5/_{32}$ in.).

6.5. Apply heat to the bath so that the temperature of the sample rises at the rate of 1.0 ± 0.3ºC (2.0 ± 0.5ºF) per minute.

6.6. At 10 to 15ºC (18 to 27ºF) below the anticipated flash point, adjust the sample level in the test cup (a syringe or medicine dropper provides a convenient means of removing material from the cup). At successive 1ºC (2ºF) intervals, pass the ignition taper across the sample in a continuous motion so that the time consumed for each pass is 1 second. The center of the test flame must move in a plane, 3.2 mm ($^1/_8$ in.) above the upper edge of the cup passing in one direction first, then in the opposite direction at the next successive temperature.

6.7. Record, as the flash point, the temperature read on the thermometer at the time the test flame application causes a distinct flash in the interior of the test cup.

7. REPORT

7.1. Report the lowest temperature, in degrees Celsius or Fahrenheit, at which the initial flash is noted as the Tag Open-Cup Flash Point.

APPENDIX

(Nonmandatory information)

X1. APPARATUS

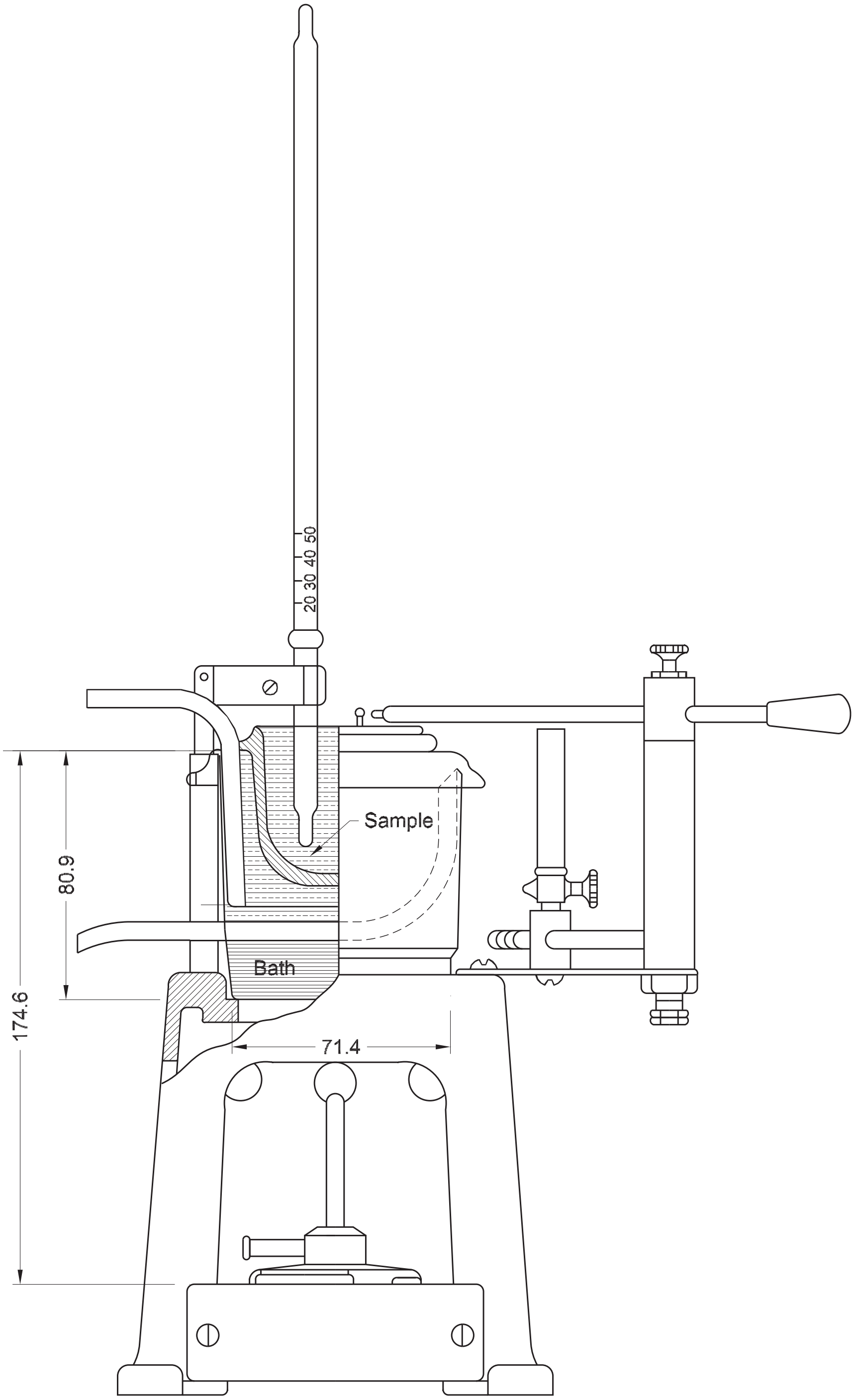
X1.1. The Tag Open-Cup Tester is shown in Figure X1.1. It consists of the following parts, which must conform to the dimensions shown, and have the additional characteristics as noted:

X1.1.1. *Copper Bath*—Equipped with a constant-level overflow so placed as to maintain the bath liquid level 3.2 mm ($^1/_8$ in.) below the ridge of the glass cup.

X1.1.2. *Thermometer Holder*—Supplied with the tester as shown in Figure X1.1. It shall support the thermometer firmly in a vertical position.

X1.1.3. *Glass Test Cup* (Figure X1.2)—Of molded clear glass, annealed, heat-resistant, and free from surface defects.

X1.1.4. *Filling Level Gauge* (Figure X1.3)—For proper adjustment of the liquid level in the cup. This device shall be made of suitable metal at least 3.2 mm ($^1/_8$ in.) thick, with two projections for adjusting the liquid level in the glass cup to 3.18 ± 0.25 mm (0.125 ± 0.01 in.) below the top edge or rim of the cup. Also, the holes in the leveling device may be used to adjust the size of the test flame and for gauging the height of the taper above the edge of the cup.

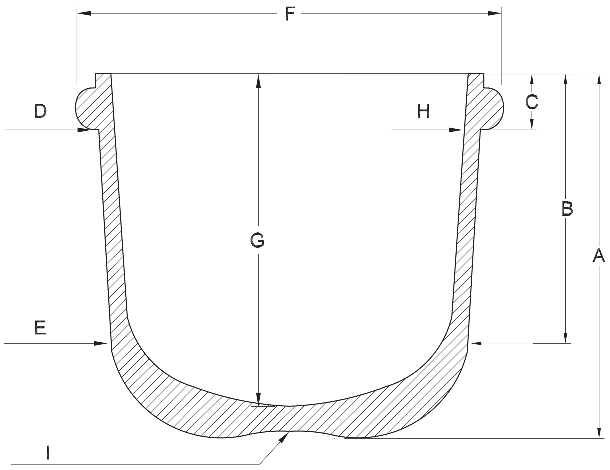


Dimensional Equivalents

Millimeters	Inches
71.4	2 $^{13}/_{16}$
80.9	3 $^{3}/_{16}$
174.6	6 $^{7}/_{8}$

Note: All dimensions are shown in millimeters unless otherwise noted.

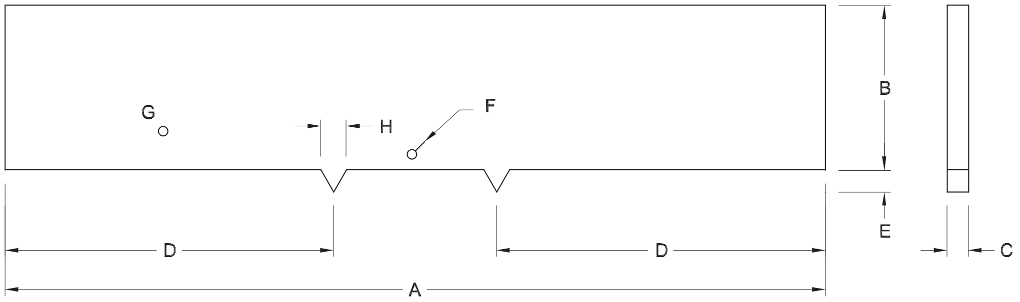
Figure X1.1—Tag Open-Cup Tester



	Millimeters	Inches
A	51.6 ± 1.6	2.03 ± 0.063
B	38.1 ± 1.6	1.50 ± 0.063
C	7.9 ± 0.8	0.31 ± 0.031
D Outside diameter	55.1 ± 1.9	2.17 ± 0.075
E Outside diameter	50.8 ± 1.6	2.00 ± 0.063
F Approximately	59.5	2.34
G	47.6 ± 1.6	1.88 ± 0.063
H	2.4 ± 0.4	0.09 ± 0.016
I Depression, diameter	15.9	0.63
depth	0.8	0.03

Note: Total mass shall not exceed 95 g.

Figure X1.2—Glass Test Cup



	Millimeters	Inches	
A	127	5	nominal
B	25.4	1	nominal
C	3.2	$^1/_8$	nominal
D	50.8	2	nominal
E	3.18 ± 0.25	0.125 ± 0.01	
F	0.8 mm in diameter, centered 3.2 mm from bottom and 63.5 mm from end	$^1/_{32}$ of an inch in diameter, centered $^1/_8$ in. from bottom and $2^1/_2$ in. from end	nominal
G	4 max in diameter, centered 3.2 mm from bottom and 25.4 mm from end	$^5/_{32}$ in. max in diameter, centered $^1/_8$ in. from bottom and 1 in. from end	nominal
H	3.2	$^1/_8$	nominal

Figure X1.3—Filling Level Gauge

X1.1.5. *"Micro" or Small Gas Burner*—Of suitable dimensions for heating the bath. A screw clamp may be used to help regulate the gas. A small electric heater controlled by a variable power transformer may be used.

X1.1.6. *Ignition Taper*—A small, straight, blowpipe-type gas burner. The tip of the taper should be approximately 1.6 mm ($^1/_{16}$ in.) in diameter. The ignition taper should be maintained in a fixed horizontal plane above the test cup by means of a swivel device so that the test flame passes on the circumference of a circle having a radius of at least 152 mm (6 in.). A comparison bead, 4.0 mm ($^5/_{32}$ in.) in diameter, may be mounted in a convenient spot. If mounted on the ignition taper, a portion of the tip of the taper, 1.6 mm ($^1/_{16}$ in.) in diameter, shall extend at least 3 mm ($^1/_8$ in.) beyond the bead.

X1.1.7. *Draft Shield*—A suitable shield may be made of two rectangular sheets of noncombustible material, 610 by 710 mm (24 by 28 in.), fastened together along the 710 mm (28 in.) side, preferably by hinges. A triangular sheet, 610 by 610 by 860 mm (24 by 24 by 34 in.), is fastened by hinges to one of the lateral sheets to form a top when the shield is open. The interior of the draft shield shall be painted a flat black.

Standard Method of Test for

Spot Test of Asphaltic Materials

AASHTO Designation: T 102-09

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Spot Test of Asphaltic Materials

AASHTO Designation: T 102-09

1. SCOPE

1.1. This method of test is applicable only to asphaltic products derived from petroleum and should not be applied to natural asphalts containing nonbituminous matter insoluble in xylene.

1.2. Materials, which by use of standard solvent are classed as positive, may be further tested to determine their degree of positiveness by means of their "xylene equivalent." The xylene equivalent shall be the lowest percentage by volume of xylene in a solvent composed of xylene and standard naphtha or xylene and normal heptane, as specified, which produces a "negative spot" for the material in question. These shall be known as the naphtha-xylene equivalent and heptane-xylene equivalent, respectively. The percentage of xylene in the solvents shall be stated in even 5.0 percent increments. When neither xylene equivalent is specified, the standard naphtha only shall be used as the solvent.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 81, Cutback Asphalt (Rapid-Curing Type)
- M 82, Cutback Asphalt (Medium-Curing Type)
- M 226, Viscosity-Graded Asphalt Cement
- M 231, Weighing Devices Used in the Testing of Materials
- T 40, Sampling Bituminous Materials
- T 78, Distillation of Cutback Asphaltic (Bituminous) Products

2.2. *ASTM Standards*:
- D 86, Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D 611, Standard Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. SIGNIFICANCE

3.1. The spot test is used to determine if an asphaltic material has been overheated during processing. A "positive" result indicates that an asphaltic material has been overheated. A "negative" result indicates that the materials have not been overheated.

3.2. The spot test has been used as an indicator of the compatibility of the components of an asphalt binder, with a negative spot indicating good compatibility and a positive spot indicating poor compatibility.

3.3. The spot test is an optional test for asphaltic materials as specified in M 81, M 82, and M 226.

4. APPARATUS

4.1. *Flask*—50-mL capacity, either Florence boiling flask or wide-mouth flat-bottom soxhlet extraction flask approximately 45 mm ($1^3/_4$ in.) in diameter by 60 mm ($2^3/_8$ in.) high.

4.2. *Stopper*—cork or rubber stopper for flask provided with a 200-mm (8-in.) length of 6.4 mm ($^1/_4$ in.) glass tubing.

4.3. *Filter Paper*—Whatman No. 50. (The 70-mm size is sufficient.)

4.4. *Glass Plate*—A smooth, clear glass plate shall first be cleaned with trichloroethylene, then washed with soap and water, wiped dry, cleaned with a suitable glass-cleaning preparation, and wiped dry and free from dust and lint. After this cleaning treatment, a drop of the asphalt mixture when applied to the glass should flow out evenly to form a smoothly bounded elliptical stain. If the stain is jagged and uneven in outline, the glass should again be cleaned with a suitable glass-cleaning liquid until a drop of the asphalt mixture flows out as described.

4.5. Pipette or burette with 0.1-mL graduations.

4.6. *Thermometer*—ASTM Precision Thermometer 64C (64F) conforming to requirements of ASTM E 1.

4.7. *Balance*—balance having sufficient capacity and conforming to M 231, Class G 1.

4.8. *Water bath*—maintained at temperature of 32.0º ± 0.5ºC (89.6º ± 1.0ºF).

5. MATERIALS

5.1. The standard naphtha shall be a straight run overhead distillate free from cracked products of any kind and shall conform to the requirements as indicated in Table 1.

Table 1—Naphtha

Gravity A.P.I.	49–50
Distillation:	
Initial boiling point	Above 149°C (300°F)
50 percent over	168–179°C (335–355°F)
End point	Below 210°C (410°F)
Aniline number	59 to 63°C (138 to 145°F)

5.1.1. The aniline number of the solvent shall be determined according to ASTM D 611.

Note 1—Naphtha conforming with these requirements may be obtained under the name of Skelly Solve "S" from Barton Solvents Inc., 201 S. Cedar, Valley Center, KS.

5.2. Xylene shall be chemically pure xylene showing a boiling range of 137 to 140ºC (278.6 to 284ºF) when distilled in accordance with ASTM D 86.

5.3. Normal heptane shall conform to the requirements as indicated in Table 2 (Note 2).

Table 2—Heptane

ASTM Motor Octane Number	0.0 ± 0.2
Density at 20°C, g/mL	0.68375 ± 0.00015
Refractive index, ND at 20°C	1.38775 ± 0.00015
Freezing point,[a] °C	–90.72 minimum
Distillation:[b]	
50 percent recovery, °C	98.43 ± 0.05
Increase from 20 to 80 percent recovery, °C	0.20 maximum

[a] Determined by means of Method of Test for Measurements of Freezing Points of High-Purity Compounds for Evaluation of Purity (ASTM D 1015).

[b] For equipment and methods used, see Research Paper RP 2079, *Journal of Research*, National Bureau of Standards, Vol. 44, pp. 309-310.

Note 2—Normal heptane meeting this specification may be obtained from the following sources:

- Enjay Col, Inc., 15 West 51st Street, New York, NY.
- Phillips Petroleum Co., Chemical Products Department, Bartlesville, OK.
- Westvaco Chlorine Products Corporation, 405 Lexington Avenue, New York, NY.
- Standard Oil Development Co., Linden, NJ.

6. SAMPLING

6.1. For asphalt cements, perform the test on the original material. For cutback asphalts, perform the test upon the residue from the distillation test T 78.

7. PROCEDURE

7.1. Place a 2.00 ± 0.02 g sample in the flask. If it does not flow readily at room temperature, carefully heat the flask until the sample can be spread in a thin film covering the bottom of the lower portion of the flask. Then allow the flask to cool to room temperature.

7.2. With the pipette or burette, place 10.2 mL of the specified solvent in the flask. Quickly insert the stopper with its 200-mm (8-in.) length of tubing into the neck of the flask, and swirl the flask with a rapid circular motion for 5 seconds. The flask shall then be immersed to its neck in a bath of gently boiling water for 55 seconds.

7.3. Remove the flask from the bath and swirl for 5 seconds. Each minute thereafter alternately immerse the flask for 55 seconds and remove and swirl for 5 seconds until complete dispersion has taken place.

7.4. After complete dispersion as judged by tilting the flask, lower the end of the glass tube shall below the level of the solution. Allow the flask to cool for 30 minutes at room temperature.

7.5. Warm the asphalt-solvent mixture for 15 minutes in a water bath maintained at 32.0 ± 0.5ºC (89.6 ± 1.0ºF). Thoroughly stir the asphalt-solvent mixture. By means of a clean stirring rod, place a drop of the warm mixture on the Whatman No. 50 filter paper. After 5 minutes, examine the spot by holding the paper at arm's length with the plane of the paper at approximately a right angle to the line of vision with a good light source (preferably diffused daylight) at the observer's back. If the drop forms a brown or yellowish-brown circular stain, with a darker solid or annular nucleus in the center, report the test as "positive."

7.6. If the drop forms a uniformly brown circular stain, set the asphalt-solvent mixture aside in its tightly stoppered flask at room temperature in a subdued light to be retested 24 hours after the first examination. Warm the mixture to 32.0 ± 0.5ºC (89.6 ± 1.0ºF) for 15 minutes as before. Vigorously stir until uniform. Place a drop of the asphalt-solvent mixture on filter paper. If the drop from the 24-hour-old mixture still forms a uniformly brown circular stain, report the test as "negative"; but if a darker solid or annular nucleus, as described in the Section 7.5, now forms in the center of the stain, report the test as "positive."

8. PROCEDURE IN DISPUTED CASES

8.1. In case of dispute, repeat the entire test. Make up any loss in mass of solvent during dispersion by adding additional solvent, and after dispersion is complete, keep the flask in subdued light at 25.0º± 1.7ºC (77º ± 3ºF) until the 24-hour tests are made. Warm the asphalt-solvent mixture for 15 minutes to 32.0 ± 0.5ºC (89.6 ± 1ºF), then place a drop of the mixture on a filter paper. If the appearance of the drop on the filter paper made with the 24-hour-old mixture is still in dispute, run the test on the glass plate as specified below.

8.2. Place a drop of the 24-hour-old mixture on the glass plate held at an angle of 45 degrees with the horizontal. If, as the drop flows out, a dull matted streak develops in the center of its path, report the test as "positive."

8.3. If a drop of the 24-hour-old mixture flows out to a uniform, clear, glossy brown film, without the central streak as described in the Section 8.2, report the test as "negative."

9. PROCEDURE FOR XYLENE EQUIVALENTS

9.1. The method used in testing for "xylene equivalents" is the same as specified in Section 7 except that the solvent shall be composed either of xylene and the standard naphtha or of xylene and normal heptane as specified.

9.2. To determine the xylene equivalent, disperse two or more samples of the asphalt to be examined in the prescribed mixed solvent. Vary the percentage of xylene by successive 5 percent (volume) increments until two asphalt solutions have been found, one of which shows a positive spot while the next (in which the solvent contains 5 percent more xylene) shows a negative spot. Report the xylene equivalent by the xylene percentage in the two solvents used in these two solutions; for example, as "10–15 percent naphtha-xylene equivalent" or "20–25 percent heptane-xylene equivalent."

9.3. When acceptance of material is based on a specified xylene equivalent, the exact lowest percentage of xylene that produces a "negative spot" need not be determined. The sample may be tested with solvent composed of the specified percentages of xylene and standard naphtha or xylene and normal heptane as required, and any material which shows negative for this solvent shall be reported as being less than the particular xylene equivalent which has been designated; for example, “less than 20 percent naphtha-xylene equivalent” or “less than 25 percent heptane-xylene equivalent.”

10. REPORT

10.1. This report shall include the following:

10.1.1. Identification of sample.

10.1.2. Solvent used in testing.

10.1.3. “Positive” or “Negative” result.

10.1.4. If performed, the xylene equivalent.

11. PRECISION AND BIAS

11.1. *Precision*—The research required to develop precision estimates has not been conducted.

11.2. *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

12. KEYWORDS

12.1. Asphalt, spot test, xylene equivalent

Standard Method of Test for

Moisture or Volatile Distillates in Hot Mix Asphalt (HMA)

AASHTO Designation: T 110-03 (2007)[1]
ASTM Designation: D 1461-85 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Moisture or Volatile Distillates in Hot Mix Asphalt (HMA)

AASHTO Designation: T 110-03 (2007)[1]
ASTM Designation: D 1461-85 (2006)

1. SCOPE

1.1. This method is intended for the determination, by direct measurement, of moisture or volatile fractions of the bitumen in hot mix asphalt (HMA).

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 168, Sampling Bituminous Paving Mixtures

3. SIGNIFICANCE AND USE

3.1. This method is used for determining either the amount of moisture or the amount of volatile petroleum distillates in HMA.

4. APPARATUS

4.1. *Metal Still*—A vertical cylindrical still, as illustrated in Figure 1, having a faced flange at the top to which the head is tightly attached by means of a clamp. The head shall be of metal and provided with a tubulation 25.4 mm (1 in.) in inside diameter.

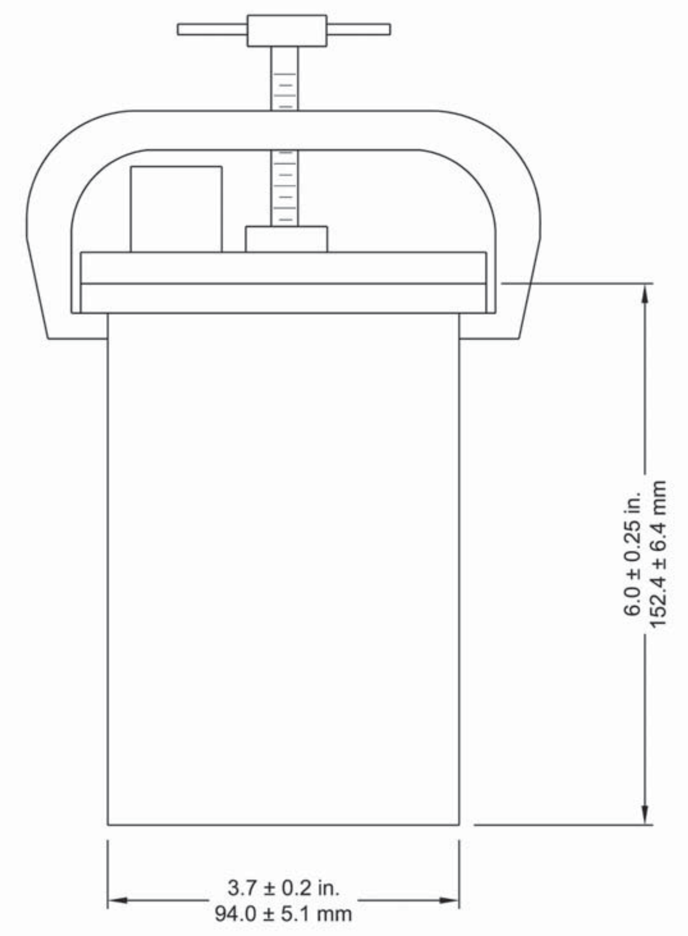


Figure 1—Metal Still

Note 1—Still diameters of up to 127 mm (5 in.) may be used if required to accommodate larger samples.

4.2. *Condenser*, of the water-cooled reflux glass-tube type, having a condenser jacket not less than 400 mm ($15^3/_4$ in.) long, with an inner tube 9.5 to 12.7 mm ($^3/_8$ to $^1/_2$ in.) in outside diameter. The end of the condenser inserted in the receiver shall be ground off at an angle of 30 degrees from the vertical axis of the condenser or otherwise configured to fit the receiver. For mixtures with very volatile solvents, it may be necessary to supplement this water-cooled condenser with a second water-cooled condenser of approximately the same dimensions.

4.3. *Receiver*, of well-annealed glass, of one of the following types depending upon the purpose of the test:

4.3.1. For determination of water in HMA, a glass receiver of 10- or 25-mL capacity shall be used. The receiver shall be graduated in 0.1-mL divisions with a ±0.05-mL maximum error below 1-mL and in 0.2-mL divisions with a ±0.1-mL maximum error above 1 mL as specified in Table 1 and Figures 2, 3, 4, and 5. Receivers with tapered or ball-bottom vapor tube ends require adaptors for connection to the metal still.

4.3.2. For determination of the volatile fractions of the HMA, the receiver shall conform to the dimensions shown in Figure 6.

Table 1—Description of Receivers

Style	Description			Figure	Size of Receiver, mL	Range, mL	Smallest Scale Division, mL	Maximum Scale Error, mL
	Top of Graduated Tube	Bottom of Graduated Tube	Bottom of Vapor Tube					
						0 to 1.0	0.1	0.05
A	§ joint	conical	§ joint	2	10	Over 1.0 to 10.0	0.2	0.1
B	§ joint	conical	§ joint	3				
C	§ joint	conical	plain	4		0 to 1.0	0.1	0.05
D	plain	conical	plain	5	25	Over 1.0 to 25	0.2	0.1
					5	0 to 5.0	0.1	0.05
E	§ joint	round	§ joint	6	10	0 to 10.0	0.1	0.1

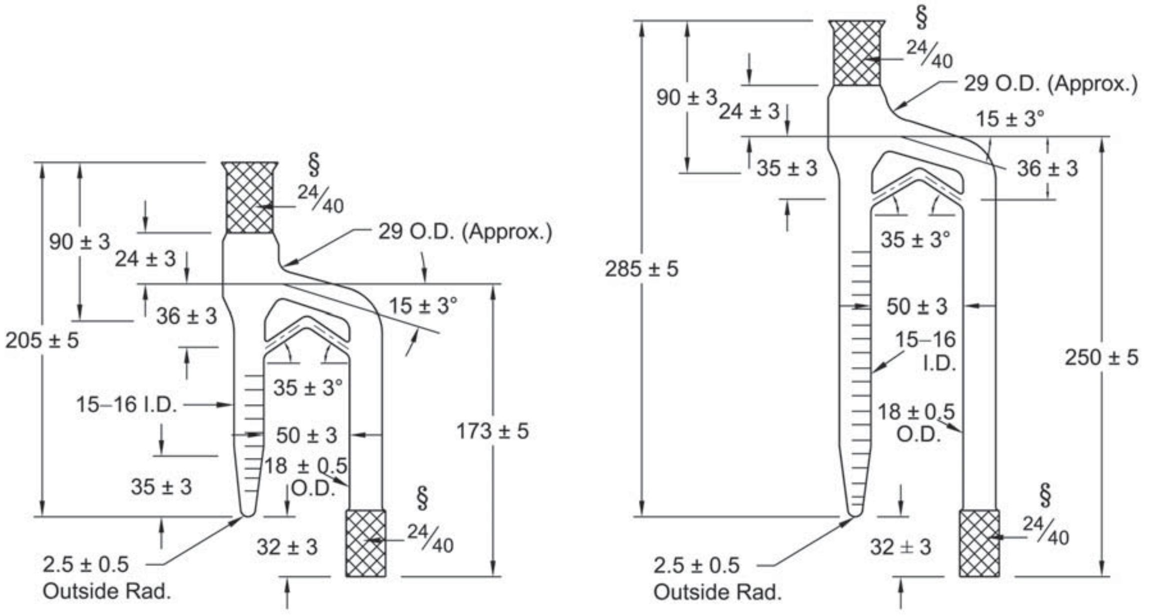
4.4. *Solvent*—For general use, an aromatic solvent is preferred since it has high solvency and dispersing power for most asphalt materials. Xylene, or a blend of 20 percent toluene and 80 percent xylene, is recommended. For asphalts and similar petroleum products, a petroleum distillate, five percent boiling between 90 and 100ºC (194 and 212ºF), and 90 percent distilling below 210ºC (410ºF), may be used. For coal tar, water-gas tar, and similar materials, an aromatic solvent must be used.

4.5. *Heating Device*—Any satisfactory source of heat capable of maintaining a rate of distillation of 85 to 95 drops per minute.

5. SAMPLING

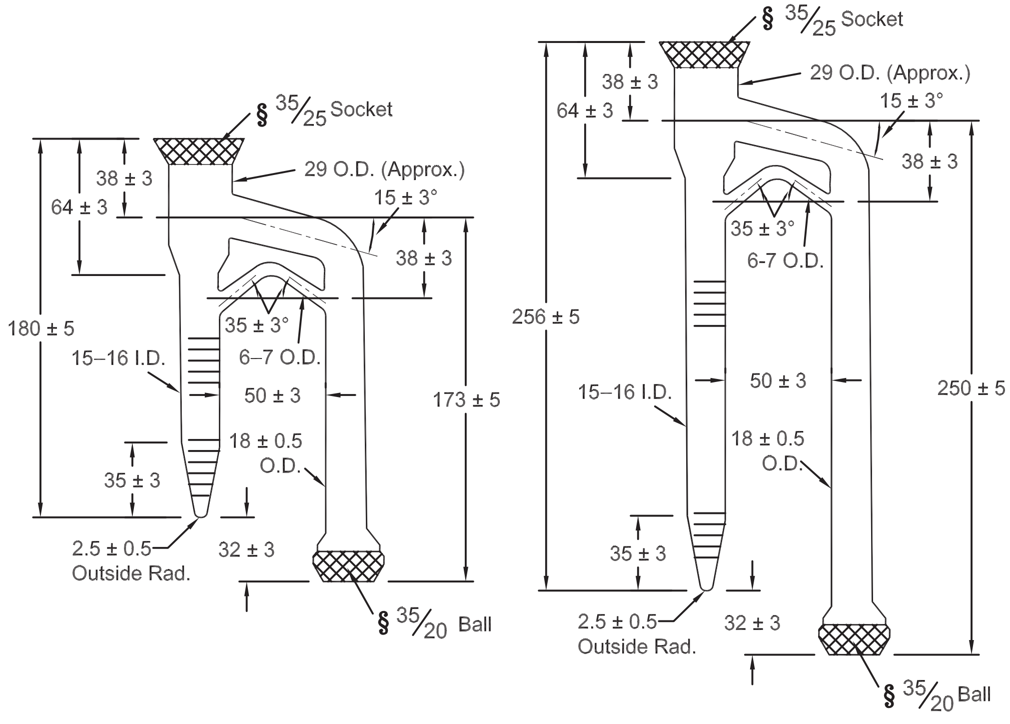
5.1. Sampling shall be performed in accordance with T 168.

5.2. The sample shall be representative of the material and of such size as practical to fill the container in which it is transported to the laboratory. For duplicate tests, a 2-L ($^1/_2$-gal) friction-top tin pail full of material would be satisfactory.



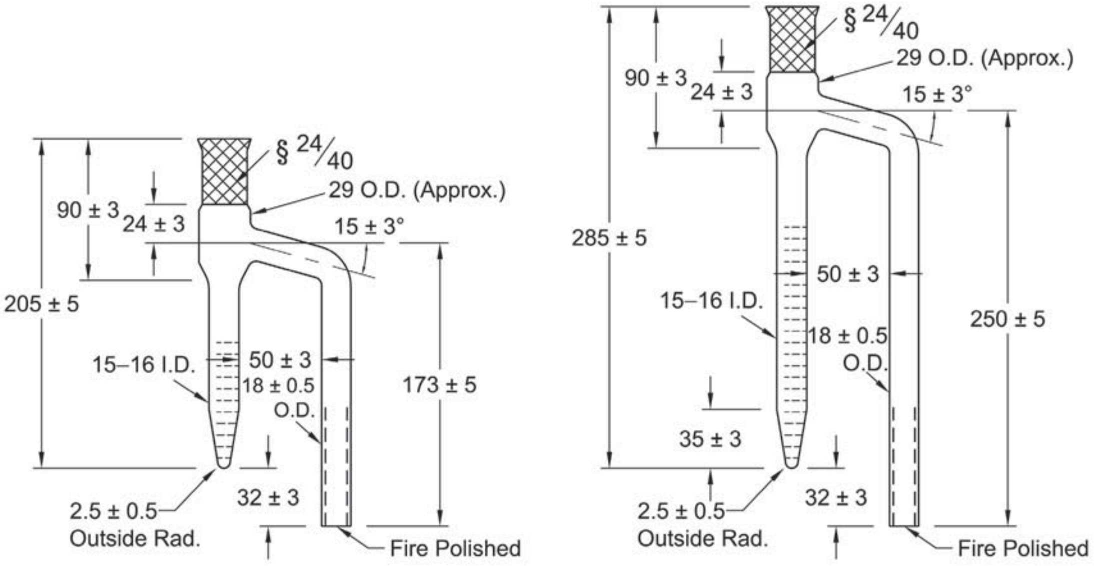
Note: All dimensions shown in millimeters unless otherwise noted.

Figure 2—Receivers (Style A)



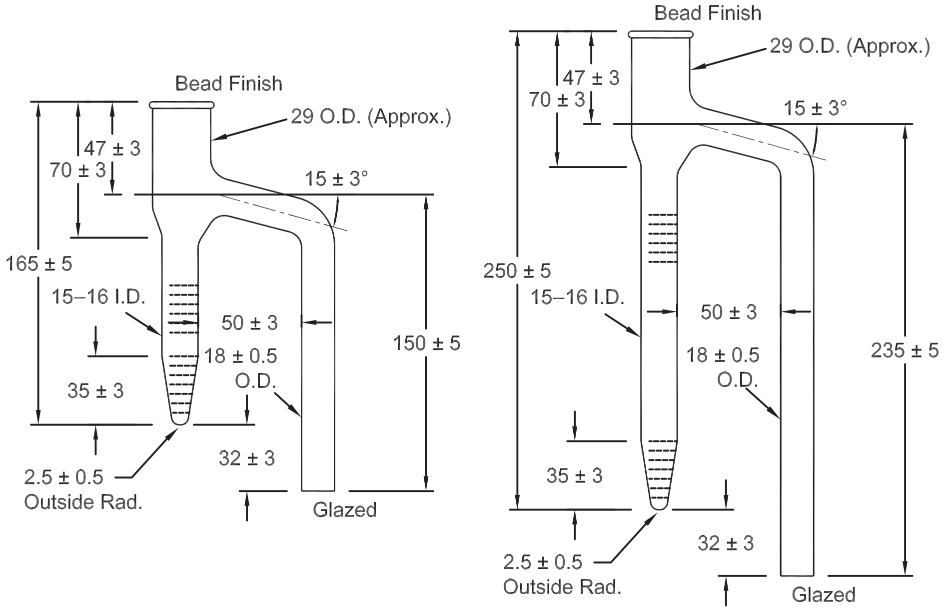
Note: All dimensions shown in millimeters unless otherwise noted.

Figure 3—Receivers (Style B)



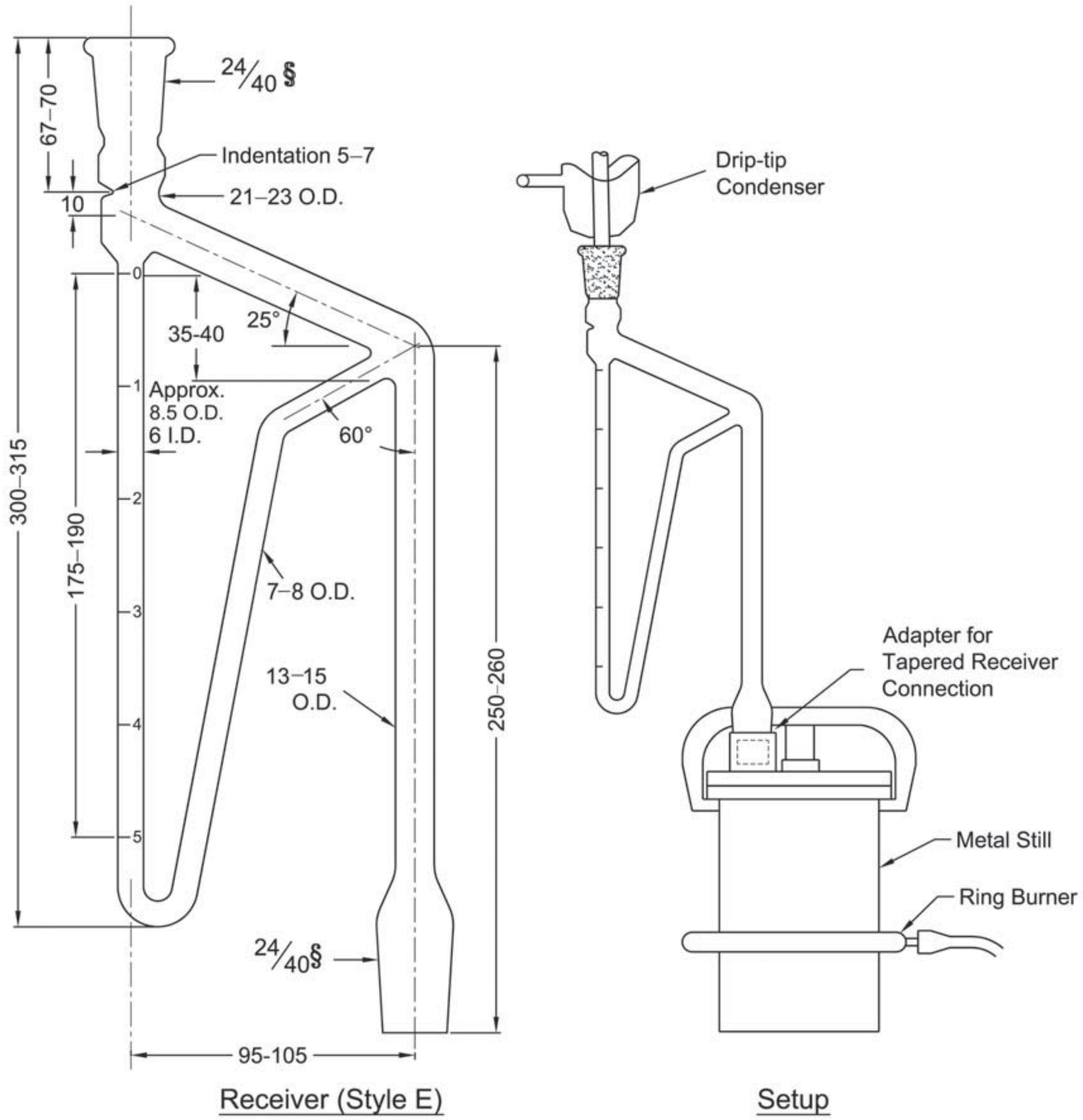
Note: All dimensions shown in millimeters unless otherwise noted.

Figure 4—Receivers (Style C)



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 5—Receivers (Style D)



Receiver (Style E)

Setup

Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 6—Apparatus for Determining Volatile Distillates

6. TEST SPECIMEN AND SAMPLE

6.1. Thoroughly mix the sample, and weigh out an amount estimated to yield a percentage of moisture or diluent within the capacity of the receiver calibration. Keep the remainder of the sample in its tightly covered container. The weighed sample should not be less than 500 g for normal mixtures. Thoroughly break up this sample to avoid large lumps, and place it in the still.

7. PROCEDURE FOR DETERMINATION OF MOISTURE

7.1. After the sample has been placed in the still, add 200 mL of the solvent, and quickly stir it into the sample.

7.2. Assemble the components of the apparatus as illustrated in Figure 7, choosing the receiver in accordance with the expected water content of the sample and making all connections vapor-and liquid-tight. Insert a gasket of heavy paper, moistened with water, between the still body and cover. The condenser tube and receiver must be chemically clean to assure free drainage of water into the bottom of the trap. Insert a loose cotton plug in the top of the condenser to prevent condensation of atmospheric moisture inside it. Circulate cold water through the jacket of the condenser.

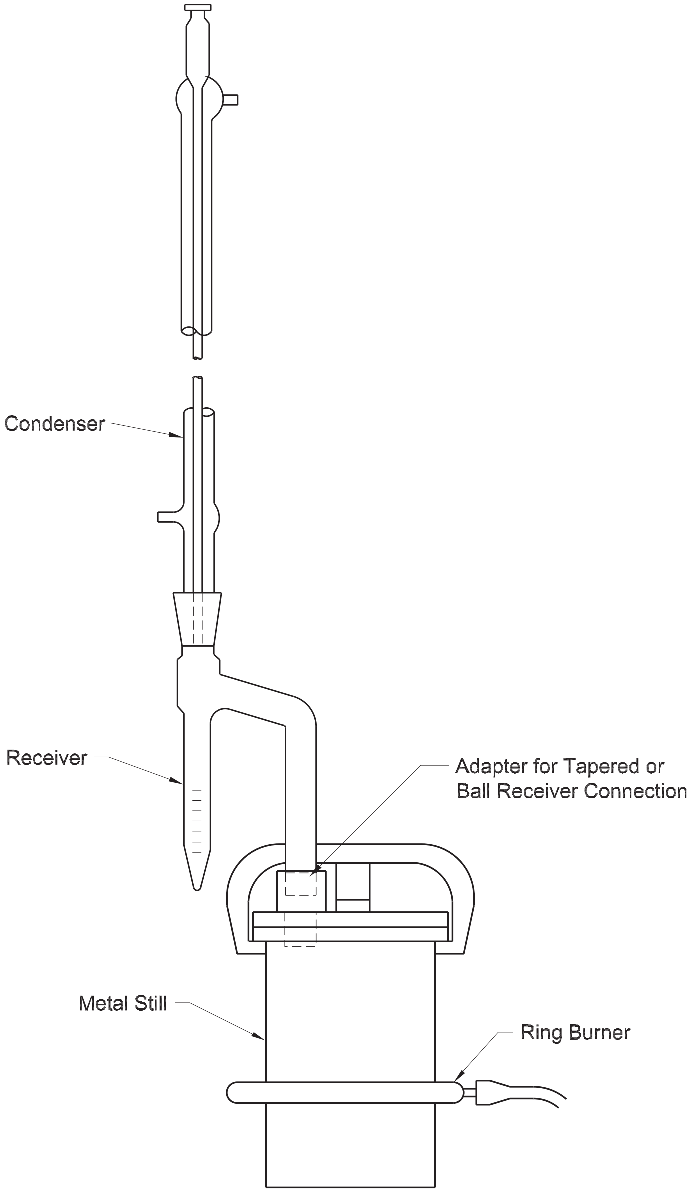


Figure 7—Typical Assembly for Determining Moisture Content

7.3. Apply heat at such a rate that refluxing will start within 5 to 10 minutes, after the heat has been applied, and the condensed solvent will drip into the receiver at a rate of 85 to 95 drops per minute. Continue the distillation until three successive readings of the receiver at 15-minute intervals show no increase in the amount of water being condensed, except that in no case shall distillation continue for more than 1.5 hours.

7.4. Allow the contents of the receiver to reach room temperature, and read the volume of water in the receiver to the nearest scale division. Record the volume of water, and calculate the percentage by mass of the sample taken as described in Section 9.1.

8. PROCEDURE FOR DETERMINATION OF VOLATILE DISTILLATES

8.1. After the sample has been placed in the still, add 350 mL of water and approximately 3 g of sodium carbonate (Na_2CO_3), and quickly stir it into the sample. Firmly attach the still cover, and assemble the receiver and condenser in the manner prescribed in Section 7.2, except that the gasket should be moistened with a solvent and the trap used shall be the dilution trap specified in Section 4.3.2.

8.2. Apply heat at such a rate that the water and solvent will begin to reflux in 5 to 10 minutes after the heat has been applied and will drip from the condenser at the rate of 85 to 95 drops per minute. In case the sample contains a large amount of very volatile solvent, it may be necessary to add a second water-cooled condenser above the first one or reduce the rate of distillation somewhat to prevent escape of the solvent.

8.3. Continue distillation until three successive readings of the upper and lower levels of the diluent at 15-minute intervals show no increase in the quantity being collected. Then remove the source of heat, and allow the apparatus to stand for 0.5 hour to permit the solvent to cool and separate.

8.4. Record the volume of diluent in the receiver to the nearest scale division, and calculate the percentage by mass of the sample taken as described in Section 9.2. Use the specific gravity of the diluent at 25ºC (77ºF).

Note 2—Assume the specific gravity of diluent based on knowledge of diluent type or values in the range of 0.85 to 0.90. This range only defines volatiles that are obtained at the maximum test temperature.

9. CALCULATION

9.1. Calculate the moisture content as follows:

$$\text{Moisture, \%} = \frac{A}{B} \times 100 \qquad (1)$$

where:

A = the volume of water in the receiver (mL), and

B = the mass of the sample (g).

9.2. Calculate the volatile distillate as follows:

$$\text{Volatile Distillates, \%} = C \times \frac{D}{E} \times 100 \qquad (2)$$

where:

C = the volume of diluent in the receiver (mL),

D = the specific gravity of the diluent at 25ºC (77°F), and

E = the mass of the sample (g).

10. REPORT

10.1. Report the moisture content as the mass percent of water content in accordance with Section 9.1.

10.2. Report the volatile distillates as the mass percent of diluent content in accordance with Section 9.2.

11. PRECISION

11.1. *Precision for Determination of Moisture*—The following criteria should be used for judging the acceptability of results (95 percent probability) when using the 10-mL or 25-mL receivers.

11.1.1. *Repeatability*—Duplicate determinations of water by the same operator should be considered suspect if they differ by more than the following amounts:

Water Collected	
0–1.0 mL	0.1 mL
1.1–25 mL	0.1 mL or 2% of the mean, whichever is greater

11.1.2. *Reproducibility*—The results submitted by each of two laboratories should be considered suspect if they differ by more than the following amounts:

Water Collected	
0–1.0 mL	0.2 mL
1.1–25 mL	0.2 mL or 10% of the mean, whichever is greater

11.2. *Precision for Determination of Volatile Distillates*—The precision of this method is obtained by statistical examination or interlaboratory test results as follows:

11.2.1. *Repeatability*—Duplicate determinations of volatile distillates by the same operator should be considered suspect if they differ by more than 0.6-volume percent.

11.2.2. *Reproducibility*—The results submitted by each of two laboratories should be considered suspect if they differ by more than 1.4-volume percent.

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[1] Similar but not identical to ASTM D 1461-85 (2006).

Standard Method of Test for

Mineral Matter or Ash in Asphalt Materials

AASHTO Designation: T 111-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Mineral Matter or Ash in Asphalt Materials

AASHTO Designation: T 111-10

1. SCOPE

1.1. This method of test is intended for the determination of mineral matter in solid, semisolid, or liquid asphalt.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 44, Solubility of Bituminous Materials
- T 55, Water in Petroleum Products and Bituminous Materials by Distillation
- T 170, Recovery of Asphalt from Solution by Abson Method

3. SIGNIFICANCE

3.1. This method of test is used to determine the amount of mineral material (ash content) in an asphalt sample by means of ignition. According to T 170, ash content testing is required for recovered asphalt residue.

3.2. Testing for solubility of asphalt (T 44) may be used for the determination of mineral matter provided all the insoluble material has been transferred to the Gooch crucible used in T 44.

4. APPARATUS

4.1. The apparatus required shall consist of the following:

4.1.1. *Crucible*—with cover and a capacity of 50 to 100 mL—either platinum, porcelain, or fused silica.

4.1.2. *Gas burner*.

4.1.3. *Analytical balance*—conforming to M 231, Class B.

4.1.4. *Desiccator*—with ground glass cover.

4.1.5. *Muffle furnace*—capable of igniting the residue to a dull red heat [500 to 600°C (930 to 1110°F)].

5. PREPARATION OF SAMPLE

5.1. If the sample contains more than 2.0 percent water, it shall be dehydrated by distillation in accordance with T 55, before testing. If the material is hard and brittle, it may be ground and dried at a temperature below the volatilization temperature of the asphalt.

6. PROCEDURE

6.1. Determine the mass of a sample of the material (2 to 5 g) to the nearest 0.001 g in a tared crucible. Heat the sample slowly to drive off the combustible material without spattering until the asphalt is ignited. Then continue heating only enough to maintain combustion. When all readily volatile material is burned, ignite all free carbon in a muffle furnace until all carbonaceous matter has disappeared.

6.2. Cool the residue in the desiccator, and determine the mass to the nearest 0.001 g. Repeat heating in the muffle furnace until a constant mass of the residue is obtained.

6.3. When carbonate materials are present, moisten the ash with a few drops of ammonium carbonate solution. Dry the sample in an oven at 100 ± 10ºC (212 ± 18ºF). After the sample is dry, place it in the muffle furnace, and heat to a dull red for a few minutes. Cool the residue in the desiccator, and determine the mass to the nearest 0.001 g.

7. CALCULATIONS

7.1. The mass of mineral matter (ash) divided by the mass of the original sample and multiplied by 100 gives the percentage of mineral matter (ash content).

8. REPORT

8.1. This report shall include the following:

8.1.1. Identification of sample.

8.1.2. The percentage of mineral matter (ash content) to the nearest 0.1 percent.

9. PRECISION AND BIAS

9.1. *Precision*—The research required to develop precision estimates has not been conducted.

9.2. *Bias*—The research required to establish the bias has not been conducted.

10. KEYWORDS

10.1. Ash, mineral matter, asphalt.

Standard Method of Test for

Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)

AASHTO Designation: T 164-10[1]
ASTM Designation: D 2172-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)

AASHTO Designation: T 164-10[1]
ASTM Designation: D 2172-05

1. SCOPE

1.1. These methods cover the quantitative determination of asphalt binder in hot mix asphalt (HMA) and HMA pavement samples. Aggregate obtained by these methods may be used for sieve analysis using T 30.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazards are given in Section 8.

Note 1—The results obtained by these methods may be affected by the age of the material tested, with older samples tending to yield slightly lower asphalt binder contents. Best quantitative results are obtained when the test is made on HMA mixtures and pavements shortly after their preparation. It is difficult to remove all the asphalt binder when some aggregates are used; some solvent may remain within the mineral matter affecting the measured asphalt binder content.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 30, Mechanical Analysis of Extracted Aggregate
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 110, Moisture or Volatile Distillates in Hot Mix Asphalt (HMA)
- T 168, Sampling Bituminous Paving Mixtures
- T 170, Recovery of Asphalt from Solution by Abson Method
- T 228, Specific Gravity of Semi-Solid Asphalt Materials
- T 329, Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 604, Standard Specification for Diatomaceous Silica Pigment (Withdrawn 2003)

- D 2111, Standard Test Methods for Specific Gravity and Density of Halogenated Organic Solvents and Their Admixtures
- D 4080, Standard Specification for Trichloroethylene, Technical and Vapor-Degreasing Grade
- D 6368, Standard Specification for Vapor-Degreasing Solvents Based on normal-Propyl Bromide and Technical Grade normal-Propyl Bromide

3. TERMINOLOGY

3.1. *nominal maximum size (of aggregate)*—One size larger than the first sieve that retains more than 10 percent aggregate.

3.2. *constant mass*—shall be defined as the mass at which further drying does not alter the mass by more than 0.05 percent when weighed at 2-h intervals.

4. SUMMARY OF TEST METHODS

4.1. The HMA is extracted with trichloroethylene, *normal*-propyl bromide, or methylene chloride, using the extraction equipment applicable to the particular method. Terpene extractant may be used in Method A or E. The asphalt binder content is calculated by differences from the mass of the extracted aggregate, moisture content, and mineral matter in the extract. The asphalt binder content is expressed as a mass percent of moisture-free mixtures.

5. SIGNIFICANCE AND USE

5.1. All of the methods can be used for quantitative determinations of asphalt binder in HMA mixtures and pavement samples for specification acceptance, service evaluation, quality control, and research. Each method prescribes the solvents and any other reagents that can be used in the method. T 170 requires that Method A or E (Note 2) and reagent grade trichloroethylene be used when asphalt binder is recovered from solution.

Note 2—The vacuum extractor, Section 22.1.1, can be modified by a vacuum trap attached to the top of the "end point" sight tube to collect the extract to allow its use for recoveries (Figure 4b).

6. APPARATUS

6.1. *Oven*—capable of maintaining the temperature at 110 ± 5ºC (230 ± 9ºF), for warming the sample.

6.2. *Oven*—capable of maintaining the temperature at 149 to 163ºC (300 to 325ºF), for drying the sample if the moisture content is not determined.

6.3. *Pan*—flat, of appropriate size.

6.4. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231.

6.5. *Cylinders*—graduated, 1000 or 2000-mL capacity.

7. REAGENTS

7.1. *Methylene Chloride*, technical grade. *Caution*—see Section 8.

7.2. *normal-propyl Bromide*, conforming to ASTM D 6368—see Section 8.

7.3. *Trichloroethylene*, reagent grade (Note 3) or conforming to ASTM D 4080—see Section 8.

7.4. *Terpene*—Extractant, shall be non-halogenated, non-toxic, and shall readily dissolve asphalt binder from HMA and place it into solution. This extractant shall be easily rinsed from the remaining aggregate without forming a gel, and the extractant rinsed from the aggregate shall pass readily through the diatomaceous earth and the filter.

Note 3—Reagent grade trichloroethylene may be required when asphalt binder is recovered from the solution. (See T 170, Note 1.)

Note 4—Only vented ovens should be used when terpene extractants are used.

8. PRECAUTIONS

8.1. The solvents listed in Section 7 should be used only under a hood or with an effective surface exhaust system in a well-ventilated area, since they are all toxic to some degree as described in R 16. Trichloroethylene, methylene chloride, and normal-propyl bromide in the presence of heat and moisture may form acids that are extremely corrosive to certain metals, particularly when subject to contact over lengthy periods of time. Proper precautions should be taken to not allow these solvents to remain in small quantities in the effluent tanks of aluminum vacuum extractors.

8.2. Trichloroethylene stored in a steel container and in continuous contact with moisture may decompose by dehydrohalogenation to form unsaturated hydrocarbon liquids and hydrogen chloride. Steel drums containing trichloroethylene should be stored in a cool, dry location, kept tightly sealed and opened as infrequently as possible. Trichloroethylene should be transferred from the drums to clean, dry, brown glass bottles for laboratory use. The hydrogen chloride in decomposed trichloroethylene may harden an asphalt during the extraction and Abson recovery test (T 170).

8.3. All local, State, and Federal regulations must be followed with when hauling, using, storing, and discarding extractants and rinse water. These requirements include fire ordinances as well as wastewater treatment regulations. The Materials Safety Data Sheet should be followed closely to avoid fires and explosions. Storage of extractant-soaked rags should be prohibited.

9. SAMPLING

9.1. Obtain samples in accordance with T 168.

9.2. *Preparation of Test Specimens*:

9.2.1. If the HMA is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan, and warm it in a 110 ± 5ºC (230 ± 9ºF) oven only until it can be handled or separated. Split or quarter the material until the mass of material required for the test is obtained.

9.2.2. The size of the test sample shall be governed by the nominal maximum aggregate size of the HMA and conform to the mass requirement shown in Table 1 (Note 5).

Table 1—Size of Sample

Nominal Maximum Aggregate Size		Minimum Mass of Sample, kg
Mm	in.	
4.75	No. 4	0.5
9.5	$^{3}/_{8}$ in.	1
12.5	$^{1}/_{2}$ in.	1.5
19.0	$^{3}/_{4}$ in.	2
25.0	1 in.	3
37.5	$1^{1}/_{2}$ in.	4

Note 5—When the mass of the test specimen exceeds the capacity of the equipment used (for a particular method), the test specimen may be divided into suitable increments, tested, and the results appropriately combined for calculation of asphalt binder content (Section 13).

9.2.3. Unless the HMA sample is free of moisture (Note 7), a test specimen is required for the determination of moisture (Section 10) in the HMA. Take this test specimen from the remaining sample in the HMA immediately after obtaining the extraction test specimen.

Note 6—If the extraction test is only being performed to recover asphalt binder from the HMA and the percent asphalt binder is not being determined, it is unnecessary to determine the moisture content of the HMA.

Table 2—Dimensional Equivalents

mm	in.	mm	in.	mm	in.
0.8	$^{1}/_{32}$	42.9	$1^{11}/_{16}$	155.6	$6^{1}/_{8}$
1.6	$^{1}/_{16}$	44.5	$1^{3}/_{4}$	157.2	$6^{3}/_{16}$
2.0	$^{5}/_{64}$	47.6	$1^{7}/_{8}$	158.8	$6^{1}/_{4}$
3.2	$^{1}/_{8}$	50.8	2	163.5	$6^{7}/_{16}$
4.0	$^{5}/_{32}$	55.6	$2^{3}/_{16}$	165.1	$6^{1}/_{2}$
4.8	$^{3}/_{16}$	56.4	$2^{7}/_{32}$	187.3	$7^{3}/_{8}$
5.6	$^{7}/_{32}$	57.2	$2^{1}/_{4}$	203.2	8
6.4	$^{1}/_{4}$	58.7	$2^{5}/_{16}$	247.7	$9^{3}/_{4}$
7.9	$^{5}/_{16}$	63.5	$2^{1}/_{2}$	254.0	10
9.5	$^{3}/_{8}$	66.7	$2^{5}/_{8}$	257.2	$10^{1}/_{8}$
12.7	$^{1}/_{2}$	71.4	$2^{13}/_{16}$	260.4	$10^{1}/_{4}$
15.9	$^{5}/_{8}$	76.2	3	279.4	11
19.1	$^{3}/_{4}$	88.9	$3^{1}/_{2}$	304.8	12
25.4	1	95.3	$3^{3}/_{4}$	320.7	$12^{5}/_{8}$
28.6	$1^{1}/_{8}$	101.6	4	330.2	13
30.2	$1^{3}/_{16}$	108.0	$4^{1}/_{4}$	342.9	$13^{1}/_{2}$
35.7	$1^{13}/_{32}$	127.0	5	355.6	14
38.1	$1^{1}/_{2}$	138.1	$5^{7}/_{16}$	368.3	$14^{1}/_{2}$
40.5	$1^{19}/_{32}$	149.2	$5^{7}/_{8}$	384.2	$15^{1}/_{8}$
41.3	$1^{5}/_{8}$	152.4	6	393.7	$15^{1}/_{2}$
47.6	$1^{7}/_{8}$	154.8	$6^{3}/_{32}$	406.4	16
0.9 mm	20 gauge	3.2 mm	#8 B&S	26 qt	24.6 L
1.2 mm	18 gauge	4.75 mm	No. 4 mesh		

10. MOISTURE CONTENT

10.1. When required, determine the moisture content of the mixture (Section 9.2.3) in accordance with the procedure described in T 110 or T 329.

Note 7—If recovery of asphalt binder from the solution obtained from the extraction test is not required, the entire test specimen may be dried in an oven at a temperature of 105 to 165ºC (221 to 329ºF) to constant mass prior to extraction, instead of determining the moisture content.

10.2. Calculate the mass of water (W_2, Section 13) in the extraction test portion by multiplying mass percent water (Section 10.1) by the mass of the extraction test portion (W_1, Section 13).

TEST METHOD A

11. APPARATUS

11.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Method A:

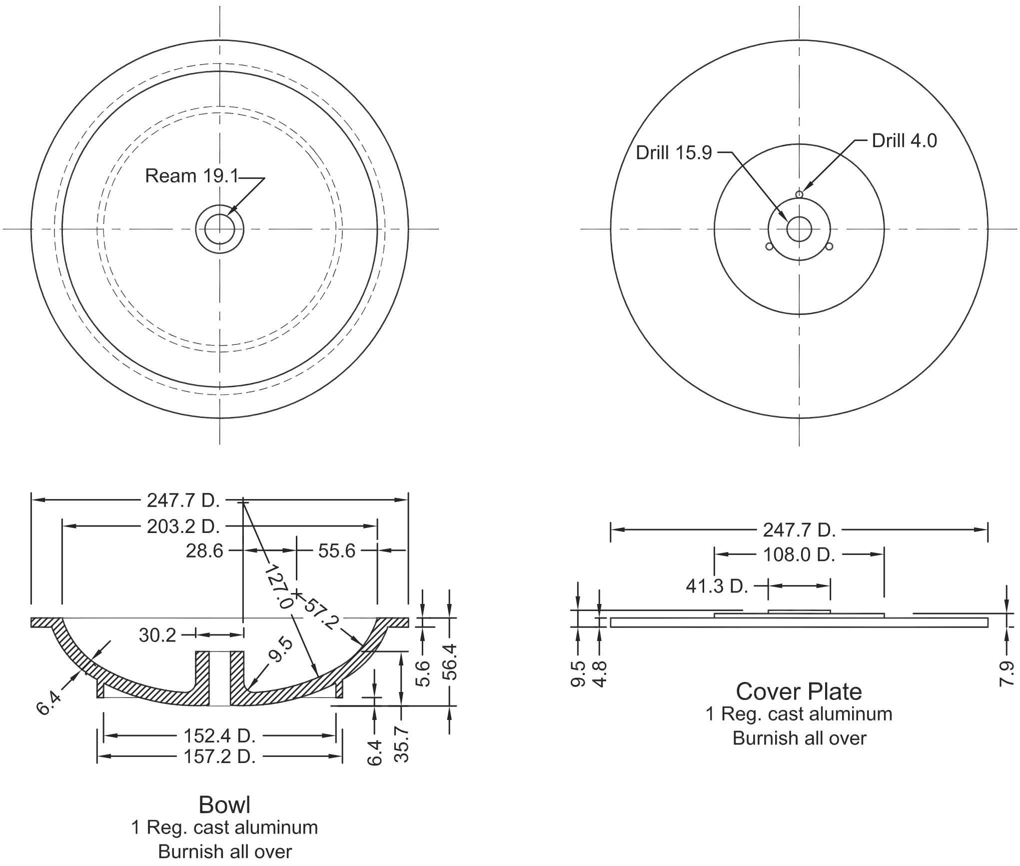
11.1.1. *Extraction Apparatus*, consisting of a bowl approximating that shown in Figure 1 and an apparatus in which the bowl may be revolved at controlled variable speeds up to 3600 r/min. The speed may be controlled manually or with a preset speed control. The apparatus should be provided with a container for catching the solvent discharged from the bowl and a drain for removing the solvent. The apparatus preferably shall be provided with explosion-proof features and installed in a hood or an effective surface exhaust system to provide ventilation.

Note 8—Similar apparatus of larger size may be used.

11.1.2. *Filter Rings*, felt or paper, to fit the rim of the bowl.

11.1.3. *Low-Ash Paper Filter Rings* may be used in place of the felt filter ring (Section 11.1.2). Such filter rings shall consist of low-ash filter paper stock, 1.27 ± 0.13 mm (0.05 ± 0.005 in.) thick. The nominal base weight of the paper shall be 150 ± 14 kg (330 ± 30 lb) for a ream [500 sheets, 635 by 965 mm (25 by 38 in.)]. The ash content of the paper should not exceed 0.2 percent (approximately 0.034 g per ring).

Note 9—Where terpene extractants are used, the gears and shaft should be lubricated frequently.



Note: See Table 2 for dimensional equivalents. All dimensions shown in millimeters unless otherwise noted.

Figure 1—Extraction Unit Bowl (Method A)

12. PROCEDURE

12.1. Determine the moisture content of the material in accordance with Section 10.

12.2. Place the test portion into a bowl.

12.3. Cover the test portion in the bowl with trichloroethylene, methylene chloride, *normal*-propyl bromide, or terpene extractant, and allow sufficient time for the solvent to disintegrate the test portion (not more than 1 h). Place the bowl containing the test portion and the solvent in the extraction apparatus. Dry the filter ring to a constant mass in an oven at 110 ± 5ºC (230 ± 9ºF), and fit it around the edge of the bowl. Clamp the cover on the bowl tightly, and place an appropriate container under the drain to collect the extract.

12.4. Start the centrifuge revolving slowly, and gradually increase the speed to a maximum of 3600 r/min until solvent ceases to flow from the drain. Allow the machine to stop; add 200 mL (or more as appropriate for the mass of the sample) of trichloroethylene, methylene chloride, *normal*-propyl bromide, or terpene extractant, and repeat the procedure. Use sufficient solvent additions (not less than three) until the extract is not darker than a light straw color. Collect the extract and the washings in an appropriate container for mineral matter determination.

12.5. Carefully transfer the filter ring and all of the aggregate in the centrifuge bowl into a tared metal pan. Dry in air under a hood until the fumes dissipate, and then to a constant mass in an oven at 110 ± 5ºC (230 ± 9ºF) (Notes 10 and 11). The mass of the extracted aggregate (W_3) is equal to the mass of the contents in the pan minus the initial dry mass of the filter ring. Brush off mineral matter adhering to the surface of the filter ring, and add it to the extracted aggregate for further testing.

Note 10—The filter and aggregate may be left inside the centrifuge bowl and dried to constant mass in an oven at 110 ± 5ºC (230 ± 9ºF) and the mass determined.

Note 11—The filter ring may be dried separately to constant mass in an oven at 110 ± 5ºC (230 ± 9ºF) provided that care is taken not to lose any of the fine material clinging to the filter. If this procedure is used, the aggregate may then be dried to constant mass either in an oven or on a hot plate at 110 ± 5ºC (230 ± 9ºF).

12.5.1. Use the following alternative procedure when low-ash filter rings are used. Place the aggregate and filter rings in a clean metal pan. Dry as specified above. Carefully fold the dried filter ring and stand it on the aggregate. Burn the filter ring. Determine the mass of the extracted aggregate in the pan (W_3).

Note 12—Since dry aggregate absorbs moisture when exposed to air containing moisture, determine the mass of the extracted aggregate immediately after cooling to a suitable temperature.

12.6. Determine the amount of mineral matter in the extract by one of the procedures specified in Annex A1.

13. CALCULATION OF ASPHALT BINDER CONTENT

$$\mathit{Asphalt\ Binder\ Content},\ \% = \frac{(W_1 - W_2) - (W_3 + W_4)}{W_1 - W_2} \times 100 \qquad (1)$$

where:

W_1 = mass of test portion;

W_2 = mass of water in test portion;

W_3 = mass of extracted mineral aggregate; and

W_4 = mass of mineral matter in the extract.

Note 13—When ashless filter rings are not used, add the increase in mass of the felt ring to W_4.

Note 14—When it is desired to express the asphalt binder content as a mass percent of the moisture-free aggregate, substitute the mass $W_3 + W_4$ for the mass $W_1 - W_2$ in the divisor of Equation 1.

TEST METHOD B

14. APPARATUS

14.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Test Method B:

14.1.1. *Extraction Apparatus*—similar to that shown in Figure 2.

Figure 2—Extraction Apparatus (Method B)

14.1.1.1. *Glass Jar*—cylindrical, plain, made of heat-resistant glass. The jar shall be free of cracks, scratches, or other evidence of flaws that might cause breakage during heating.

14.1.1.2. *Cylindrical Metal Frames*—one or two. The lower frame shall have legs of sufficient length to support the frame, including the apex of the metal cone and paper cone liner above the solvent level. When two frames are used, the upper frame shall have legs of sufficient length to support the metal cone and paper cone liner at or above the top rim of the lower frame. The legs of the upper frame shall fit securely in the top rim of the lower frame. A bail handle may be provided on the inside of the top rim of each frame for convenient handling. The metal used in fabricating the frames shall be essentially unreactive to the solvents used in the test.

14.1.1.3. *Condenser*—fabricated with a truncated hemispherical condensing surface and a truncated conical top. Other suitable geometric shapes may also be used provided they accomplish the condensing and flow functions intended. The material used in fabricating the condenser shall be essentially unreactive to water and to the solvent used and shall be provided with a suitable water inlet and outlet.

14.1.1.4. *Filter Paper*—medium-grade, fast-filtering. The diameter of the paper shall be such that when folded in accordance with the directions given below, it shall completely line the metal cones in the frames.

14.1.1.5. *Thermal Distributing Protective Pad*—approximately 3 mm (0.1 in.) thick for use as insulation between the glass jar and hot plates.

14.1.1.6. *Electric Hot Plate*—thermostatically controlled, of sufficient dimensions and heat capacity to permit refluxing of the solvent as described in Section 16.2.5.

15. PREPARATION OF TEST PORTION

15.1. Prepare a test portion for moisture determination and extraction in accordance with the procedure described in Section 9.

16. PROCEDURE

16.1. *Moisture*:

16.1.1. Determine the moisture content of the HMA (Section 9.2.3) in accordance with the method described in Section 10.

16.2. *Extraction*:

16.2.1. Dry one sheet of filter paper for each frame used to a constant mass in an oven at 110 ± 5ºC (230 ± 9ºF). Fold each paper on its diameter; fold the ends over, and spread it open to form a proper size to fit inside the metal cones.

16.2.2. Determine the mass of each frame with its filter paper liner to the nearest 0.5 g. Record the mass of each frame.

16.2.3. Place the test portion in the frame(s). If two frames are used, distribute the test portion approximately equally between the two. The top of the test portion must be below the upper edge of the paper liner. Determine the mass of each loaded frame separately to the nearest 0.5 g. Again, record the mass.

16.2.4. Use one of the solvents (Note 15) specified in Section 7.1, 7.2, or 7.3. Pour the solvent into the glass cylinder, and place the bottom frame into it. The solvent level should be below the apex of the one in the lower frame. If two frames are used, place the upper frame in the lower frame, fitting its legs into the holes in the upper rim of the lower frame.

Note 15—Sufficient denatured ethyl alcohol may be poured over the test portion(s) to wet the filter paper. A mixture of 20 percent denatured alcohol and 80 percent trichloroethylene has proven to be a better solvent for some aggregates.

16.2.5. If required, place the thermal insulating pad on the hot plate and then the cylinder on the pad. Cover the condenser. Circulate a gentle, steady stream of cool water through the condenser. Adjust the temperature of the hot plate so that the solvent will boil gently and a steady stream of condensed solvent flows into the cone. If necessary, adjust the temperature of the hot plate to maintain the solvent stream at a rate necessary to keep the test portions in the cone(s) completely covered with condensed solvent. Take care not to allow condensed solvent to overflow the filter cone(s). Continue the refluxing until the solvent flowing from the lower cone is a light straw color (when viewed against a white background). At this point, turn off the hot plate, and allow the apparatus to cool enough to handle; turn off the condenser, and remove it from the cylinder.

16.2.6. Remove the frame assembly from the cylinder. Allow it to dry in air (hood), and then dry it to a constant mass in an oven at 110 ± 5ºC (230 ± 9ºF) (Note 9).

16.2.7. Determine the mineral matter in the extraction solution by one of the procedures specified in Annex A1.

17. CALCULATION OF ASPHALT BINDER CONTENT

17.1. Calculate the percentage of asphalt binder in the test portion in accordance with the procedure described in Section 13.

TEST METHOD D

18. APPARATUS

18.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Test Method D:

18.1.1. *Extraction Apparatus*—As shown in Figure 3, consisting of an extraction kettle of metal or borosilicate glass, fitted with a perforated basket and a condenser top. The underside of the condenser shall be covered with numerous rounded knobs to distribute the condenser solvent uniformly over the surface of the sample. The suspension of the basket shall be arranged to support the basket 13 mm ($^1/_2$ in.) above the bottom of the kettle, for immersion of the test portion in the solvent, and at least 75 mm (3 in.) above the bottom of the kettle for refluxing (Note 8).

18.1.2. *Cloth Filter Sacks*—with an elastic hem for lining the basket.

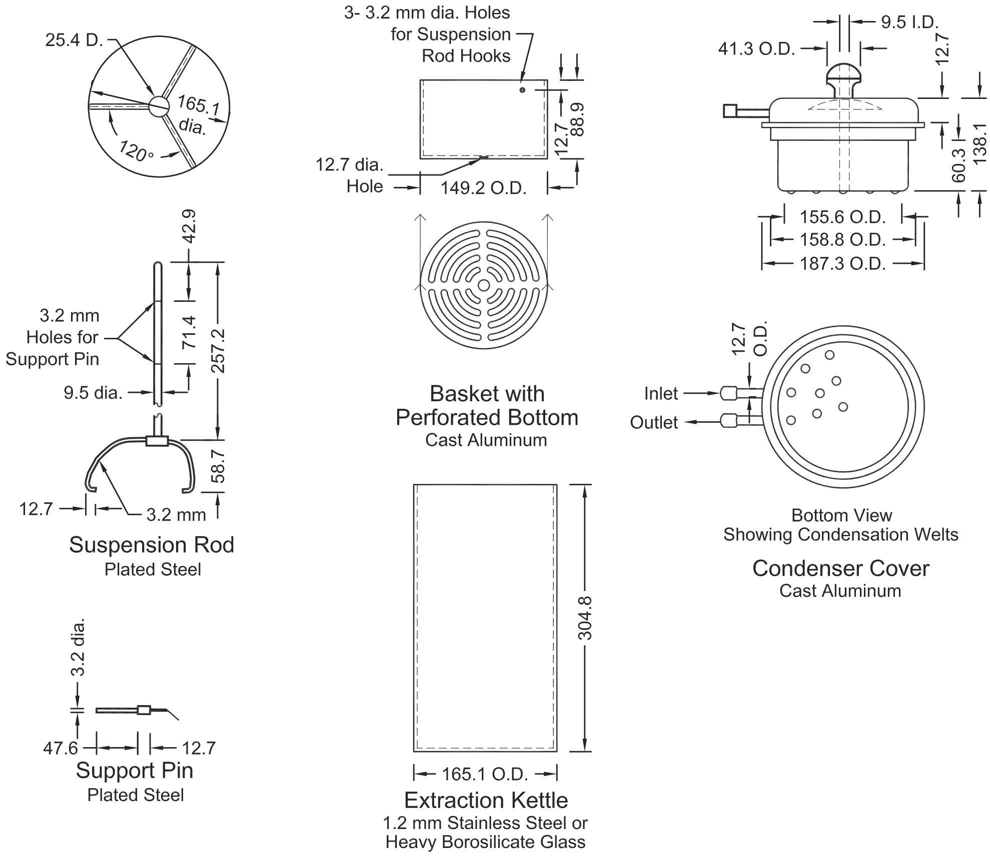


Figure 3—Extractor Unit (Method D)

19. PREPARATION OF TEST PORTIONS

19.1. Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 9.

20. PROCEDURE

20.1. *Moisture*:

20.1.1. Determine the moisture content of the HMA (Section 9.2.3) in accordance with the method described in Section 10.

20.2. *Extraction*:

20.2.1. Insert a filter sack in the extraction basket, and determine the mass with the tare pan to determine the total tare mass. Place the test portion in the filter sack, and determine the total mass. Calculate the mass of the test portion.

20.2.2. Attach the suspension rod to the loaded basket, and set the assembly into the extraction kettle. Pour approximately 600 mL of solvent (Section 7.1, 7.2, or 7.3) over the test portion. Set the condenser cover in place on the kettle. Provide a flow of cold water through the condenser lid. Raise the basket to immersion level, for example 13 mm ($^1/_2$ in.) above the bottom of kettle, by inserting the support pin through the upper hole of the suspension rod. Place the extractor on the hot plate, and adjust the heating rate so that solvent is maintained at a gentle boil, avoiding vigorous boiling which might wash fines over the sides of the basket.

20.2.3. Continue heating with the test portion in the immersion position for 15 to 30 min, and then raise the basket to refluxing level. Increase the heat, and maintain active boiling until solvent dripping from the basket appears to be a light straw color when viewed against a white background. If a stainless steel kettle is used, lift out the basket and the condenser cover assembly for examination of the solvent.

20.2.4. Remove the extractor from the hot plate, and allow it to cool for several minutes. Lift out the basket and condenser assembly. Cover the kettle; remove the filter sack, and distribute its contents into the tared pan in which the mass of the test portion was originally determined. Place the filter sack on top of the recovered aggregate. Dry on a steam bath and then in an oven at 110 ± 5ºC (230 ± 9ºF) to constant mass. Transfer the extract solution to a 1000-mL graduate. Wash the extractor clean with solvent, and add the washings to the extract solution.

20.2.5. Determine the mineral matter in the extract solution by one of the procedures specified in Annex A1.

21. CALCULATION OF ASPHALT BINDER CONTENT

21.1. Calculate the percentage of asphalt binder in the test portion in accordance with the procedure described in Section 13.

TEST METHOD E

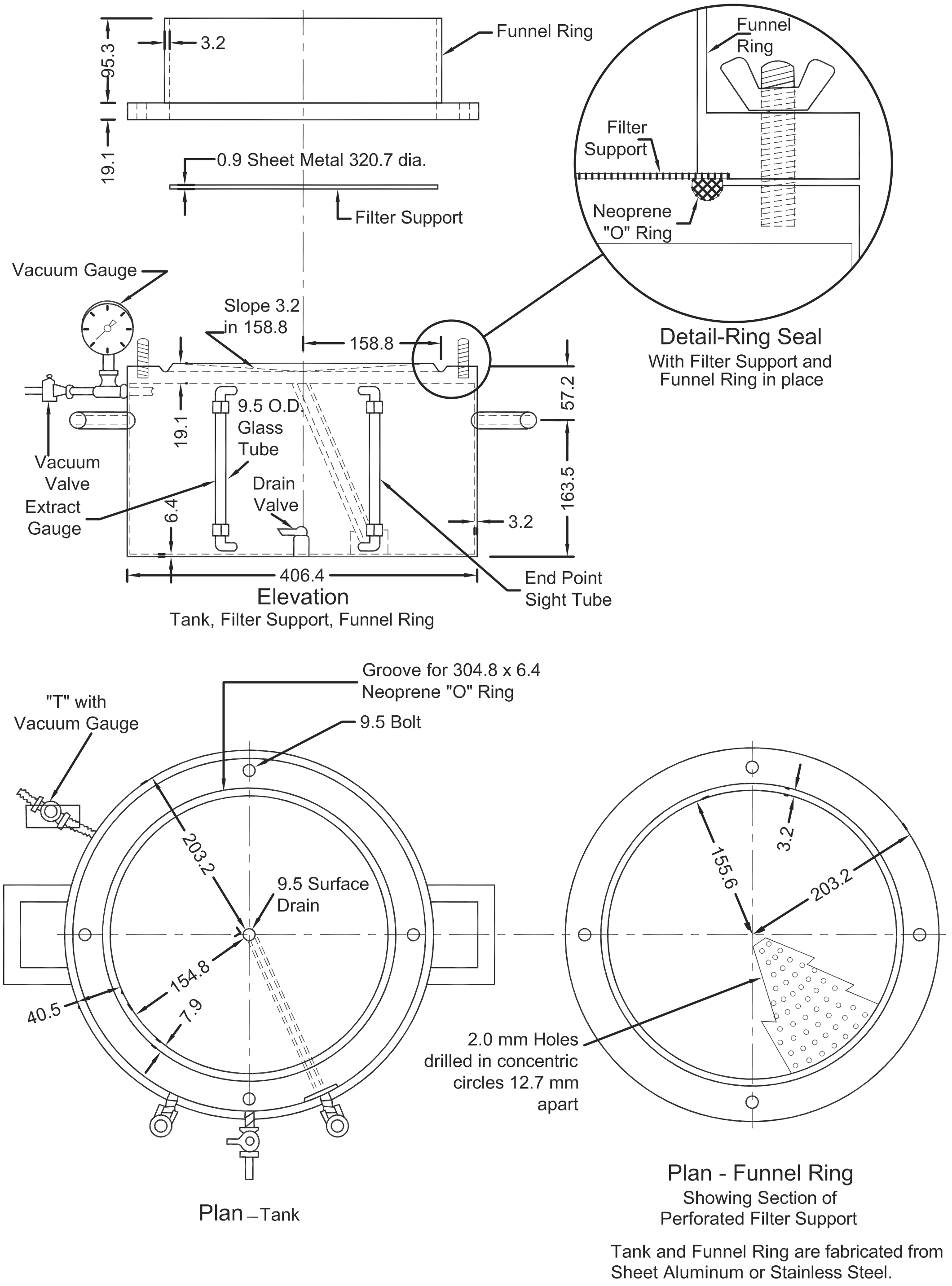
22. APPARATUS

22.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Test Method E:

22.1.1. *Vacuum Extractor*—complete with the vacuum pump, gasket, rubber tubing, filter paper, support plate, and funnel ring. The dimensional equivalents and apparatus shown in Table 3, and Figures 4a, 4b, and 4c and similar designs are suitable.

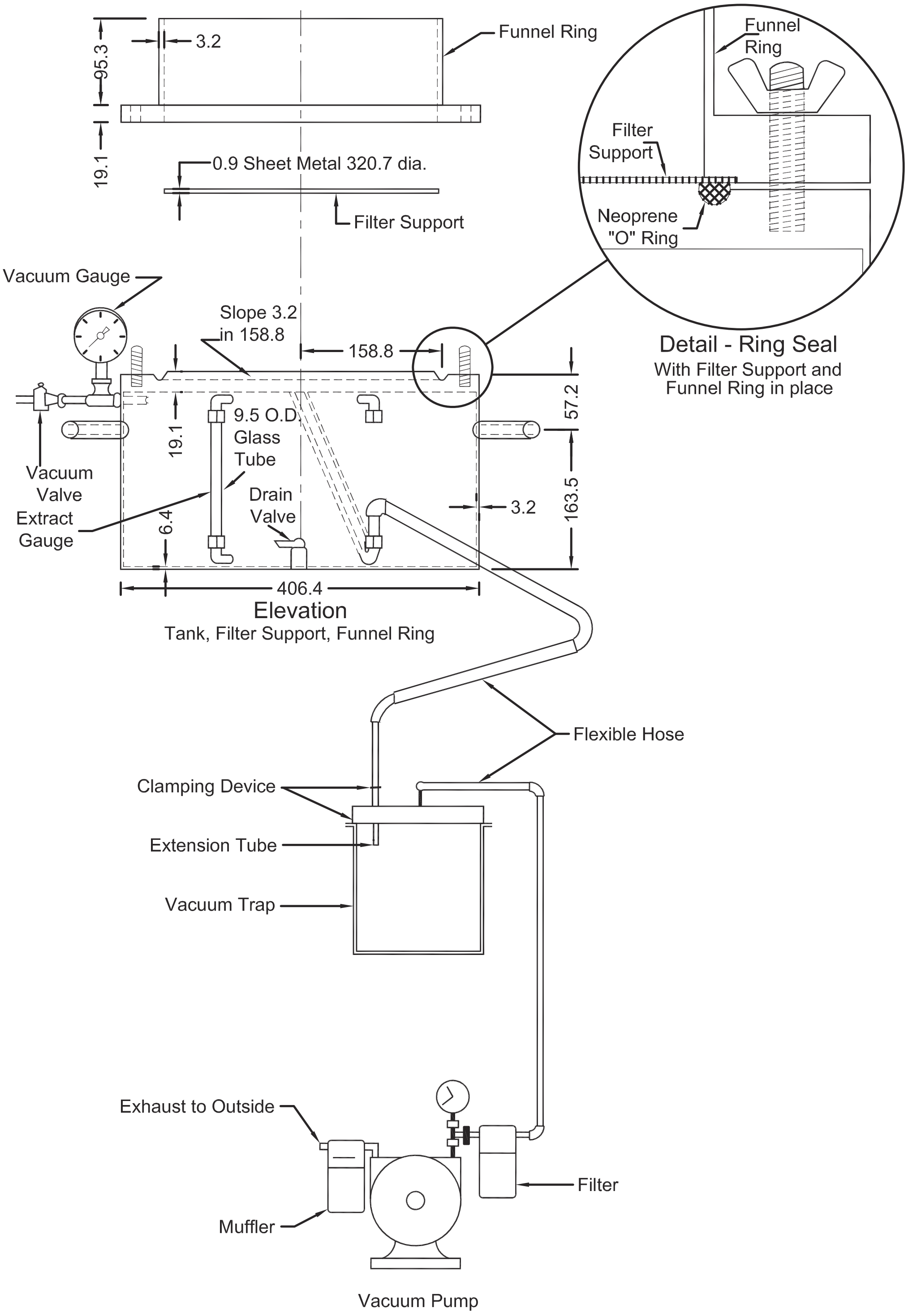
Table 3—Dimensional Equivalents

in.	mm	in.	Mm
16	406	$2^1/_4$	57
$12^5/_8$	321	$1^{19}/_{32}$	40
12	305	$^3/_4$	19
8	203	$^1/_2$	12.7
$6^7/_{16}$	164	$^3/_8$	9.5
$6^1/_4$	159	$^1/_4$	6.4
$6^1/_8$	156	$^3/_{64}$	1.19
$6^3/_{32}$	155	0.060	1.52
$3^3/_4$	95		



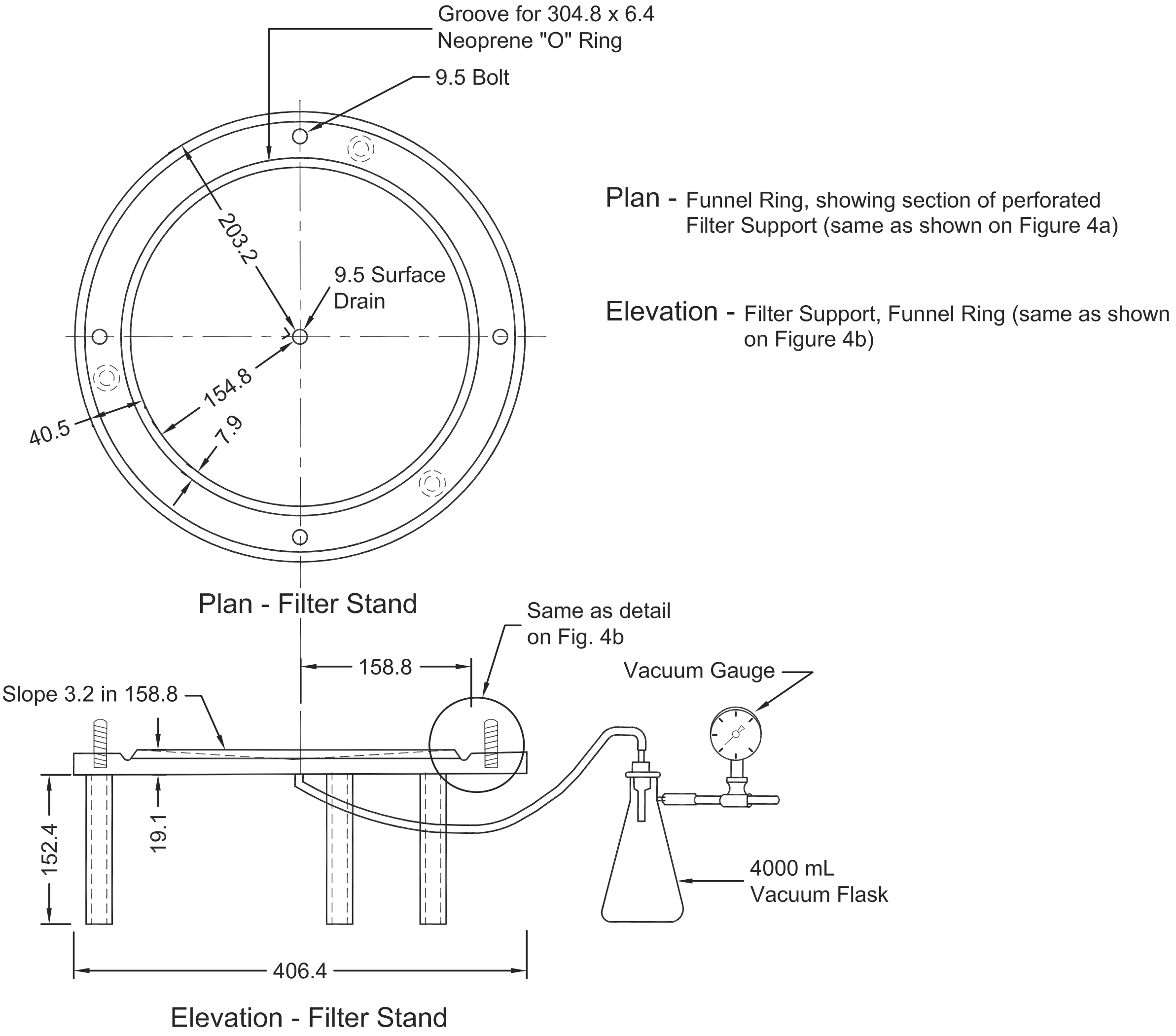
Note: See Table 3 for dimensional equivalents. All dimensions shown in millimeters unless otherwise noted.

Figure 4a—Vacuum Extractor



Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 4b—Vacuum Extractor



Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 4c—Vacuum Extractor

22.1.2. *Filter Paper*, medium-grade, fast-filtering, 330 mm (13 in.) in diameter.

22.1.3. *Sample Container*, 3.8-L (4-qt) capacity or greater.

22.1.4. *Erlenmeyer Flasks*, glass, two, having a capacity of 4000 mL each.

22.1.5. *Graduate*, glass, having a capacity of 500 mL.

22.1.6. *Wash Bottle*, plastic, having a capacity of 500 mL.

22.1.7. *Dial Thermometer*, having a range from 10 to 82ºC (50 to 180ºF).

22.1.8. *Mixing Spoon*.

22.1.9. *Spatula*.

22.1.10. *Stiff Bristled Brush*.

22.1.11. *Erlenmeyer Flask*, glass, having a capacity of 1000 mL.

22.1.12. *Watch Glass*, having a diameter of approximately 100-mm (4-in.) diameter.

22.1.13. *Metal Tongs*, 150 to 200 mm (6 to 8 in.) long.

22.1.14. 1.18-mm (No. 16) and 75-µm (No. 200) Sieves, 305 mm (12 in.) in Diameter (optional).

Note 16—Use apparatus and materials listed under Sections 22.1.11, 22.1.12, 22.1.13, 23.1, and 23.2 only with HMA that is hard to filter, as in Method E-II.

22.1.15. *Stainless Steel Beaker*.

23. REAGENTS AND MATERIALS

23.1. Diatomaceous Silica Filtering Aid conforming to Type B of ASTM D 604.[2]

23.2. *Ethyl Alcohol*, denatured (optional).

23.3. *Methylene Chloride* (Note 17).

Note 17—Any of the other solvents listed in Section 7 may be substituted for methylene chloride.

24. PREPARATION OF TEST PORTIONS

24.1. Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 9.

25. PROCEDURE

25.1. Determine the moisture content of the HMA (Section 9.2.3) in accordance with the method described in Section 10.

25.2. *Extraction*:

25.2.1. Place the extraction test portion into the tared stainless steel beaker, and determine the mass (Note 18).

25.2.2. If the test portion is above 54ºC (130ºF), allow it to cool to a temperature less than 54ºC (130ºF). When sufficiently cool, pour 200 mL of denatured alcohol, if needed, over the specimen (Note 18). Add approximately 700 mL of extractant, and stir until the asphalt binder is visually in solution (Note 19).

Note 18—Alcohol should not be needed with terpene extractants.

Note 19—If equipment is available, an ultrasonic cleaning tank may be used instead of the beaker (Section 25.2.1) in which to bring the asphalt binder into solution (Section 25.2.2).

25.2.3. Dry the filter paper (more than one filter paper may be used) to constant mass in an oven at 110 ± 5ºC (230 ± 9ºF), and place the filter paper on the extractor, taking care to center the filter paper and tighten the wing nuts "finger tight" (Note 20).

Note 20—Experience has shown that clogging of the filter may be reduced by decanting the extract solution through nested 1.18-mm (No. 16) and 75-µm (No. 200) sieves onto the filter. When sieves are used, the solution will be decanted onto the 1.18-mm (No. 16) sieve instead of the filter.

25.2.4. Start the vacuum pump and slowly decant extract solution from the sample container onto the filter. When all solution has been removed from the filter paper, the vacuum pump may be stopped or left running.

25.2.5. Cover the sample remaining in the container with extractant, up to 700 mL. Stir gently until the asphalt binder and aggregate fines appear to be in suspension (or start the ultrasonic cleaner if used). Repeat the step in Section 25.2.4.

25.2.6. Repeat Section 25.2.5 until the solution is a light straw color and the aggregate is visually clean. The flow of solvent may be slowed for color observation by partially opening the vacuum valve and reducing the vacuum. If terpene extractant is used, pour all of the extractant onto the filter, and allow the vacuum to continue until the fluid has passed through the filter. Repeat Sections 25.2.5 and 25.2.4, using water preferably above 43°C (110°F), as many times as necessary to remove the terpene residue from the aggregate and render the rinse water clear. Operate the vacuum pump for a few minutes after the last wash to aid in drying the test portion. Scrape the aggregate away from the side of the funnel ring toward the center of the filter to avoid loss when the ring is removed. Also wash the sides of the funnel ring to remove any fines. Stop the vacuum pump and remove the ring, brush the clinging aggregate into the tared drying pan. Carefully pick up the filter paper and aggregate by holding the paper on opposite sides and raising it straight up. Transfer the aggregate on the filter paper to the tared drying pan, and brush the clinging aggregate from the filter into the pan. Alternatively, the filter paper and aggregate may be contained separately in tared pans or the aggregate may be contained in a tared pan and the filter paper placed on top of it. In either case, use care to assure that all traces of aggregate in the test sample are transferred to the drying pan(s).

25.2.7. Dry the extracted aggregate and filter to a constant mass in an oven at 110 ± 5ºC (230 ± 9ºF) (Note 21).

Note 21—See the alternate procedure in Section 12.5.1 when low-ash filter paper is used.

25.2.8. Determine the mass of the filter and aggregate in the pan(s), and record it. Subtract the mass of the filter and pan to determine the mass of the extracted aggregate.

25.2.9. Determine the mineral matter in the extract solution by one of the procedures specified in Annex A1 (Note 22).

Note 22—Sections 25.2.9 and 25.2.15 may be omitted when this method is used only for control of asphalt binder content during HMA production (plant control).

TEST METHOD E-II

25.2.10. To extract a slow-filtering HMA mixture efficiently, prepare the test portion as described in Sections 25.2.1 and 25.2.2.

25.2.11. Dry the filter paper to constant mass in an oven at 110 ± 5ºC (230 ± 9ºF), and place the filter paper on the extractor, taking care to center the filter paper and tighten the wing nuts "finger tight" (Note 20).

25.2.12. Weigh between 50 and 200 g of oven-dried diatomaceous silica filtering aid into a 1000-mL Erlenmeyer flask; record the mass, and then add 500 mL of extractant. Swirl until the diatomaceous silica is completely in suspension.

25.2.13. Immediately pour the diatomaceous silica and extractant over the filter. Two pre-dried filters separated by an additional 50 to 100 g of diatomaceous earth may be used to retain the minus 75-µm (No. 200) material, if desired, to facilitate improved flow of the liquid. Start the vacuum pump, and let it run until the pad formed by the diatomaceous silica is surface dry and begins to crack slightly (Note 23).

Note 23—Some diatomaceous silica may be washed through the filter and included in the mineral matter determination of Section 25.2.15. Blank tests are recommended to determine the amount of diatomaceous silica, if any, lost through the filter. An appropriate correction will be required in the mineral matter mass.

25.2.14. Place the watch glass in the extractor, and slowly decant the extractant from the container over the watch glass (Note 24). Stop the vacuum pump when all the solution has been removed from the filter. Repeat as in Section 25.2.5, except decant the solution onto the watch glass. Complete the procedure as in Section 25.2.6. Also wash the watch glass with extractant to remove any fines onto the filter.

Note 24—When nested sieves are used, the watch glass may be omitted.

25.2.15. Determine the amount of mineral matter in the extract solution by one of the procedures specified in Annex A1 (Note 22).

26. CALCULATION OF ASPHALT BINDER CONTENT (APPLICABLE TO BOTH METHOD E-I AND METHOD E-II)

26.1. Calculate the percentage of asphalt binder in the test portion in accordance with the procedure described in Section 13.

27. PRECISION AND BIAS

27.1. The single-laboratory standard deviation has been found to be 0.18 percent. Therefore, results of two properly conducted tests by the same operator on the same batch should not differ by more than 0.52 percent. These values become 0.21 and 0.58, respectively, when extractant containing 85 percent terpene is used (Notes 25 and 26).

27.2. The multilaboratory standard deviation has been found to be 0.29 percent. Therefore, the results of two properly conducted tests from two different laboratories on samples from the same batch should not differ by more than 0.81 percent. These values become 0.29 and 0.83, respectively, when extractant containing 85 percent terpene is used (Notes 25 and 26).

Note 25—These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

Note 26—These precision statements are based on one pair of reference samples with 59 laboratories participating and three laboratory results deleted as outlying observations. The reference samples contained aggregate with 98 percent passing the 9.5-mm ($^3/_8$-in.) screen. All test methods were used in the interlaboratory test program.

ANNEX

(Mandatory Information)

A1. DETERMINING THE AMOUNT OF MINERAL MATTER IN THE EXTRACT

A1.1. *Ashing Method*:

A1.1.1. *Apparatus*:

A1.1.1.1. *Ignition Dish*—at least 125 mL in capacity.

A1.1.1.2. Ignition Furnace or Bunsen Burner.

A1.1.1.3. Steam bath or hot plate.

A1.1.1.4. Desiccator.

A1.1.1.5. *Analytical Balance*—conforming to the requirements of M 231, Class B.

A1.1.1.6. *Cylinder*—100 mL in capacity.

A1.1.2. *Reagents*:

A1.1.2.1. *Ammonium Carbonate Solution*—Saturated solution of reagent-grade ammonium carbonate [$(NH_4)_2CO_2$]

A1.1.3. *Procedure*:

A1.1.3.1. Determine either the volume or mass of the total extract (W_1). Condition the ignition dish in an ignition furnace or over a bunsen burner; cool it in a desiccator, and determine the mass of the ignition dish to the nearest 0.001 g. Agitate the extract thoroughly, and immediately measure 100 mL or 100 g into the ignition dish. Evaporate to dryness on a steam bath or hot plate. Ash the residue at a dull red heat [500 to 600ºC (932 to 1112ºF)] and cool it. Determine the mass of the ash, and add 5 mL of saturated ammonium carbonate solution per gram of ash. Digest at room temperature for 1 h. Dry in an oven at 110 ± 5ºC (230 ± 9ºF) to constant mass; cool in a desiccator, and determine the mass to the nearest 0.001 g (G).

A1.1.3.2. Calculate the mass of mineral matter in the total volume of extract (W_4) as follows:

$$W_4 = G\,(W_1/100) \tag{A1.1}$$

where:

G = ash remaining in the ignition dish to nearest 0.001 g; and

W_1 = total volume, mL (or total mass, g) of extract.

A1.2. *Centrifuge Method*:

A1.2.1. *Apparatus*:

A1.2.1.1. Any suitable high-speed (3000 r/min or higher) centrifuge of the continuous-flow type.[3]

A1.2.1.2. *Balance*—conforming to the requirements of M 231, Class G 1.

A1.2.1.3. Funnel or Steam Hood.

A1.2.2. *Procedure*:

A1.2.2.1. Determine the mass of a clean, empty centrifuge cup (or bowl) to the nearest 0.01 g, and place it in the centrifuge. Position a container at the appropriate spout to catch the effluent from the centrifuging operation. Transfer all of the extract (from Method A, B, D, or E as appropriate) to an appropriate (feed) container suitably equipped with a feed control (valve or clamp, etc.). To ensure quantitative transfer of the extract to the feed container, the receptacle containing the extract should be washed several times with small amounts of clean solvent and the washings added to the feed container. Start the centrifuge, and allow it to reach a constant operational speed (e.g., 9000 r/min for the SMM type and 20000 + r/min for the Sharples type). Open the feed line, and feed the extract into the centrifuge at a rate of 100 to 150 mL/min. After all the extract has passed through the centrifuge, wash the feed mechanism (with the centrifuge still running) with several increments of clean solvent, allowing each increment to run through the centrifuge until the effluent is essentially colorless.

A1.2.2.2. Allow the centrifuge to stop, and remove the cup (or bowl). Clean the outside with fresh solvent. Allow the residual solvent to evaporate in a funnel or steam hood, and then dry the container in an oven controlled at 110 ± 5ºC (230 ± 9ºF). Cool the container and redetermine the mass to the nearest 0.01 g immediately. The increase in mass is the mass of mineral matter, W_4 (Section 13), in the extract.

A1.3. *Volumetric Method*:

A1.3.1. *Apparatus*:

A1.3.1.1. Flask.

A1.3.1.2. *Water Bath*—capable of controlling temperature to ±0.1ºC (±0.2ºF).

A1.3.1.3. *Balance*—conforming to the requirements of M 231, Class G 2.

A1.3.2. *Procedure*:

A1.3.2.1. Place the extract in a previously tared and calibrated flask. Place the flask in a constant-temperature bath controlled to ±0.1ºC (±0.2ºF), and allow it to reach the temperature at which the flask was calibrated. When the desired temperature has been reached, fill the flask with solvent at the same temperature. Bring the level of the liquid in the flask up to the neck; insert the stopper, making sure the liquid overflows the capillary, and remove the flask from the bath. Wipe the flask dry; determine the mass to the nearest 0.1 g, and record this mass as the mass of flask plus extract, M_2.

Note A1—Instead of using a controlled temperature bath, the temperature of the extract may be measured and the necessary corrections to the volume of the flask and the density of the asphalt binder and solvent made.

A1.3.2.2. Calculate the volume of asphalt and fines in the extract as follows:

$$V_1 = V_2 - \frac{\left(M_1 - M_2\right)}{G_1} \qquad (A1.2)$$

where:

V_1 = volume of asphalt and fines in the extract, mL;

V_2 = volume of the flask, mL;

M_1 = mass of the contents of the flask, g;

M_2 = mass of the asphalt binder and fines in the extract (or mass of the total sample minus the mass of the extracted aggregate), g; and

G_1 = specific gravity of the solvent determined to the nearest 0.001 in accordance with ASTM D 2111.

A1.3.2.3. Calculate the mass of fines in the extract as follows:

$$M_3 = K\left(M_2 - G_3V_1\right) \qquad (A1.3)$$

where:

M_3 = mass of fines in the extract, g;

G_2 = specific gravity of fines as determined in accordance with T 84;

G_3 = specific gravity of asphalt binder as determined in accordance with T 228;

$K = \frac{G_2}{G_2 - G_3}$;

V_1 = as given in Section A1.3.2.2; and

M_2 = as given in Section A1.3.2.2.

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[1] This method is similar to ASTM D 2172-05.

[2] Celite 110, manufactured by Johns-Manville, has been found satisfactory for this purpose; however, all filtering aids should be presieved through a 75-µm (No. 200) sieve when the gradation test on the aggregate is to be performed.

[3] The Sharples Supercentrifuge and the SMM continuous-flow centrifuge have been found suitable for this method.

Standard Method of Test for

Effect of Water on Compressive Strength of Compacted Bituminous Mixtures

AASHTO Designation: T 165-02 (2006)
ASTM Designation: D 1075-96

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

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The AASHTO equivalent of this test method has been discontinued. Please refer to ASTM D 1075-96 for information formerly contained in this standard.

Standard Method of Test for

Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens

AASHTO Designation: T 166-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens

AASHTO Designation: T 166-10

1. SCOPE

1.1. This method of test covers the determination of bulk specific gravity of specimens of compacted hot mix asphalt (HMA).

1.2. This method should not be used with samples that contain open or interconnecting voids or absorb more than 2.0 percent of water by volume, as determined in Sections 7.2 or 10.2 herein.

1.3. The bulk specific gravity of the compacted HMA may be used in calculating the unit mass of the mixture.

1.4. The values stated in SI units are to be regarded as the standard.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 275, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens

2.2. *ASTM Standard:*

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *bulk specific gravity (of solids)*—the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. The form of the expression shall be:

Bulk specific gravity at x/y °C (1)

where:

x = temperature of the material; and
y = temperature of the water.

3.1.2. *constant mass*—shall be defined as the mass at which further drying does not alter the mass by more than 0.05 percent when weighed at 2-h intervals.

4. TEST SPECIMENS

4.1. Test specimens may be either laboratory-compacted HMA or sampled from HMA pavements.

4.2. *Size of Specimens*—It is recommended that: (1) the diameter of cylindrically compacted or cored specimens, or the length of the sides of sawed specimens, be at least equal to four times the maximum size of the aggregate; and (2) the thickness of specimens be at least one and one half times the maximum size of the aggregate.

4.3. Specimens shall be taken from pavements with a core drill, diamond or carborundum saw, or by other suitable means.

4.4. Care shall be taken to avoid distortion, bending, or cracking of specimens during and after the removal from the pavement or mold. Specimens shall be stored in a safe, cool place.

4.5. Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.

4.6. If desired, specimens may be separated from other pavement layers by sawing or other suitable means. Care should be exercised to ensure sawing does not damage the specimens.

METHOD A

5. APPARATUS

5.1. *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231. The weighing device shall be equipped with a suitable suspension apparatus and holder to permit weighing the specimen while suspended from the center of the scale pan of the weighing device.

5.2. *Suspension Apparatus*—The wire suspending the container shall be the smallest practical size to minimize any possible effects of a variable immersed length. The suspension apparatus shall be constructed to enable the container to be immersed to a depth sufficient to cover it and the test sample during weighing. Care should be exercised to ensure no trapped air bubbles exist under the specimen.

5.3. *Water Bath*—For immersing the specimen in water while suspended under the weighing device, equipped with an overflow outlet for maintaining a constant water level.

6. PROCEDURE

6.1. Dry the specimen to a constant mass at a temperature of 52 ± 3°C (125 ± 5°F). Samples saturated with water shall initially be dried overnight and then weighed at 2-h drying intervals. Recently compacted laboratory samples, which have not been exposed to moisture, do not require drying.

6.2. Cool the specimen to room temperature at 25 ± 5°C (77 ± 9°F), and record the dry mass as *A* (Note 1). Immerse each specimen in water bath at 25 ± 1°C (77 ± 1.8°F) for 4 ± 1 min, and record the immersed mass as *C*. Remove the specimen from the water, damp-dry the specimen by blotting with a damp towel as quickly as possible (not to exceed 5 s), and determine the surface-dry mass as *B*. Any water that seeps from the specimen during the weighing operation is considered part of the saturated specimen. Each specimen shall be immersed and weighed individually.

Note 1—If desired, the sequence of testing operations may be changed to expedite the test results. For example, first the immersed mass *C* can be taken, then the surface-dry mass *B*, and finally the dry mass *A*.

Note 2—Terry cloth has been found to work well for an absorbent cloth. Damp is considered to be when no water can be wrung from the towel.

7. CALCULATION

7.1. Calculate the bulk specific gravity of the specimen as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B - C} \qquad (2)$$

where:

A = mass of the specimen in air, g;
B = mass of the surface-dry specimen in air, g; and
C = mass of the specimen in water, g.

7.2. Calculate the percent of water absorbed by the specimen (on a volume basis) as follows:

$$\text{Percent of Water Absorbed by Volume} = \frac{B - A}{B - C} \times 100 \qquad (3)$$

7.3. If the percent of water absorbed by the specimen as calculated in Section 6.2 exceeds 2.0 percent, use T 275 to determine the bulk specific gravity.

METHOD B

8. APPARATUS

8.1. *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231.

8.2. *Water Bath*—For immersing the specimen in water.

8.3. *Thermometer*—ASTM 17C (17F), having a range of 19 to 27°C (66 to 80°F), graduated in 0.1°C (0.2°F) subdivisions.

8.4. *Volumeter*[1]—Calibrated to 1200 mL, or an appropriate capacity depending on the size of the test sample. The volumeter shall have a tapered lid with a capillary bore.

9. PROCEDURE

9.1. Dry the specimen to a constant mass at a temperature of 52 ± 3°C (125 ± 5°F). Samples saturated with water shall initially be dried overnight and then weighed at 2-h drying intervals. Recently compacted laboratory samples, which have not been exposed to moisture, do not require drying.

9.2. Cool the specimen to room temperature at 25 ± 5°C (77 ± 9°F), and record the dry mass as *A* (Note 1). Immerse the specimen in the water bath at 25 ± 1°C (77 ± 1.8°F), and let it saturate for at least 10 min. At the end of the 10-min period, fill a calibrated volumeter with distilled water at 25 ± 1°C (77 ± 1.8°F), and weigh the volumeter. Designate this mass as *D*. Remove the saturated specimen from the water bath and damp-dry the specimen by blotting with a damp towel (Note 2) as quickly as possible (not to exceed 5 s). Weigh the specimen, and record the surface-dry mass as *B*. Any water that seeps from the specimen during the weighing operation is considered part of the saturated specimen.

9.3. Place the specimen into the volumeter, and let it stand for at least 60 s. Bring the temperature of the water to 25 ± 1°C (77 ± 1.8°F), and cover the volumeter, making certain that some water escapes through the capillary bore of the tapered lid. Wipe the outside of the volumeter dry with a dry, absorbent cloth, and weigh the volumeter and its contents (Note 3). Record this weight as *E*.

Note 3—If desired, the sequence of testing operations can be changed to expedite the test results. For example, first the mass of the saturated, damp-dry specimen *B* can be taken. Then the volumeter containing the saturated specimen and water *E* can be weighed. The dry mass of the specimen *A* can be determined last.

Note 4—Method B is not acceptable for specimens that have more than 6 percent air voids.

10. CALCULATIONS

10.1. Calculate the bulk specific gravity of the specimen as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B + D - E} \qquad (4)$$

where:

A = mass of the dry specimen, g;
B = mass of the surface-dry specimen, g;
D = mass of the volumeter filled with water at 25 ± 1°C (77 ± 1.8°F), g; and
E = mass of the volumeter filled with the specimen and water at 25 ± 1°C (77 ± 1.8°F), g.

10.2. Calculate the percent of water absorbed by the specimen (on a volume basis) as follows:

$$\text{Percent of Water Absorbed by Volume} = \frac{B - A}{B + D - E} \times 100 \qquad (5)$$

10.3. If the percent of water absorbed by the specimen as calculated in Section 10.2 exceeds 2.0 percent, use T 275 to determine the bulk specific gravity.

METHOD C (RAPID TEST)

11. PROCEDURE

11.1. This procedure can be used for testing specimens which are not required to be saved and which contain a substantial amount of moisture. Specimens obtained by coring or sawing can be tested the same day by this method.

11.2. The testing procedure shall be the same as given in Sections 6 or 9 except for the sequence of operations. The dry mass *A* of the specimen is determined last as follows.

11.3. Place the specimen in a large, flat-bottom drying pan of known mass. Place the pan and specimen in an oven at 110 ± 5°C (230 ± 9°F). Leave the specimen in the oven until it can be easily separated to the point where the particles of the fine aggregate-asphalt portion are not larger than 6.3 mm ($^1/_4$ in.). Place the separated specimen in an oven at 110 ± 5°C (230 ± 9°F), and dry to a constant mass.

11.4. Cool the pan and specimen to room temperature at 25 ± 5°C (77 ± 9°F). Determine the mass of the pan and specimen; subtract the mass of the pan, and record as the dry mass *A*.

12. CALCULATIONS

12.1. Calculate the bulk specific gravity as given in Sections 7.1 or 10.1.

13. REPORT

13.1. The report shall include the following:

13.1.1. The method used (*A*, *B*, or *C*).

13.1.2. Bulk Specific Gravity reported to the nearest thousandth.

13.1.3. Absorption reported to the nearest hundredth.

14. PRECISION

Table 1—Precision Estimates for AASHTO T 166

Condition of Test	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]
Single-operator precision	0.002	0.006
Multilaboratory precision	0.006	0.017

[a] These values represent the 1s and 2ds limits described in ASTM C 670.

Note: Based on interlaboratory study described in NCHRP Research Report 9-26 Phase 2 involving 150-mm diameter specimens, 20 laboratories, three materials (9.5-mm, 12.5-mm, and 19.0-mm mixtures), and two replicates.

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[1] Suitable aluminum volumeters of different sizes are available from Pine Instrument Co., 101 Industrial Drive, Grove City, PA 16127; and Rainhart Co., 604 Williams St., Austin, TX 78765.

Standard Method of Test for

Compressive Strength of Hot Mix Asphalt

AASHTO Designation: T 167-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Compressive Strength of Hot Mix Asphalt

AASHTO Designation: T 167-10

1. SCOPE

1.1. This test method provides a method for measuring the compressive strength of compacted asphalt mixtures. It is for use with specimens weighed, batched, mixed, and fabricated in the laboratory, as well as for mixtures manufactured in a hot mix plant.

1.2. The values stated in SI units are to be regarded as the standard. The values given in parentheses are provided for information only.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 40, Sampling Bituminous Materials
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 201, Kinematic Viscosity of Asphalts (Bitumens)
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 248, Reducing Samples of Aggregate to Testing Size
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 341, Standard Practice for Viscosity-Temperature Charts for Liquid Petroleum Products
- D 2493, Standard Viscosity-Temperature Chart for Asphalts
- D 1075, Standard Test Method for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures
- E 4, Standard Practices for Force Verification of Testing Machines

2.3. *Federal Specification*:

- Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects

3. SIGNIFICANCE AND USE

3.1. The compressive strength of specimens prepared and tested by this test method along with density and voids properties are used for laboratory mix design of asphalt mixtures.

3.1.1. This test method also describes methods that can be used for molding, curing, and testing of specimens being evaluated by ASTM D 1075.

3.1.2. When used in conjunction with other mixture physical properties, the compressive strength may contribute to the overall mixture characterization and is one factor determining its suitability for use under given loading conditions and environment as a highway paving material.

3.2. Typical values of minimum compressive strengths for design of asphalt mixtures by this test method for different traffic densities are given in Table 402-1 of the “Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, 2003.” Some state departments of transportation and Federal agencies have specific requirements of their own based on their experience with this test method. The agencies should be consulted for their specific requirements if work is to meet their standards.

3.3. Reheated field mixtures are permissible in this test method, but the resulting compressive strengths will be higher than for newly prepared mixtures due to the change in the binder viscosity, an element of the compressive strength as measured under these loading conditions and temperature (Note 4).

4. APPARATUS

4.1. *Molds and Plungers*—Molds and plungers shall be as follows:

4.1.1. The molding cylinder shall have sufficient height to allow fabrication of a 101.6 by 101.6 mm (4 by 4 in.) specimen. It shall have an inside diameter of 101.60 to 101.73 mm (4.000 to 4.005 in.) and a nominal wall thickness of 6.4 mm ($^1/_4$ in.).

4.1.2. The mold plungers shall pass through the mold freely and shall have a diameter within 1.27 mm (0.050 in.) of the mold’s inside diameter. The plungers may be solid, hollow, or other structure as long as the ends are at least 12.7 mm ($^1/_2$ in.) thick and are at a right angle to the mold wall. The bottom plunger must be within 50 ± 4 mm (2 ± $^1/_8$ in.) high, but the top plunger may be any suitable height.

4.1.3. *Specimens Other Than 101.6 by 101.6 mm (4 by 4 in.)*—Molds and plungers for fabricating these size specimens may be used in accordance with Section 6.

4.2. *Supports*—Temporary supports shall be provided to raise the molding cylinder 25.4 mm (1 in.) during the molding operation. Steel bars 25.4 mm (1 in.) square are suitable.

4.3. *Testing Machine*—The testing machine must be of any type of sufficient capacity that will provide a range of accurately controllable rates of vertical deformation. Since the rate of vertical deformation for the compression test is specified as 0.05 mm/min·mm (0.05 in./min·in.) of specimen height, and it may be necessary to test specimens ranging in size from 50.8 by 50.8 mm

(2 by 2 in.) to perhaps 203.2 by 203.2 mm (8 by 8 in.) in order to maintain the specified minimum ratio of specimen diameter to particle size, the testing machine should have a range of controlled speeds covering at least 2.5 mm (0.1 in.)/min for 50.8-mm (2-in.) specimens to 10.2 mm (0.4 in.)/min for 203.2-mm (8-in.) specimens. The testing machine shall conform to the requirements of ASTM E 4. The testing machine shall be equipped with two steel bearing blocks with hardened faces, one of which is spherically seated and the other plain. The spherically seated block shall be mounted to bear on the upper surface of the test specimen and the plain block shall rest on the platen of the testing machine to form a seat for the specimen. The bearing faces of the plates shall have a diameter slightly greater than that of the largest specimens to be tested. The bearing faces, when new, shall not depart from a true plane by more than 0.0127 mm (0.0005 in.) at any point and shall be maintained within a permissible variation limit of 0.025 mm (0.001 in.). In the spherically seated block, the center of the sphere shall coincide with the center of the bearing face. The movable portion of this block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

4.4. *Oven*—The oven used in the preparation of materials or reheating of mixtures shall be controllable within ±3°C (±5°F) of any specified temperature above ambient up to 200°C (392°F).

4.5. *Hot Plate*—A small hot plate equipped with a rheostat shall be provided for supplying sufficient heat under the mixing bowl to maintain the aggregate and asphalt material at the desired temperature during mixing.

4.6. *Hot Water Bath or Oven*—A water bath or oven sufficiently large to hold three sets of 101.6-mm (4-in.) molds and plungers. If the water bath does not have an internal temperature control, a hot plate of sufficient capacity with a control to maintain the water bath at a temperature just under the boiling point will be required. The oven shall be capable of maintaining a temperature of 93.3 to 135°C (200 to 275°F).

4.7. *Air Bath*—The air bath shall be thermostatically controlled and shall maintain the air temperature for storing the specimens at 25 ± 0.5°C (77 ± 1.0°F) immediately prior to performing the compression test.

4.8. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

4.9. *Mixing Machine*—Mechanical mixing is preferable to hand mixing. Any type of mixer may be used, provided it can maintain the mixture at the required mixing temperature and will produce a well-coated, homogeneous mixture of the required size in 2 minutes or less, and further provided that it is of such design that fouling of the blades will be minimized and each individual batch can be retrieved in essentially its entirety, including asphalt and fines. Hand mixing is allowable, if necessary, but for hot mixtures the time required to obtain satisfactory coating is often excessive, and generally the test results are less uniform than when machine mixing is employed.

4.10. *Spatulas*—A flexible spatula for scraping the mixing bowl and a stiff spatula for spading the specimen in the mold.

5. PREPARATION OF TEST MIXTURES

5.1. Limit the size of the individual batches to the amount required for one test specimen.

5.2. Mix an initial batch for the purpose of "buttering" the mixing bowl and stirrers. Empty this batch after mixing and clean the sides of the bowl and stirrers of mixture residue by scraping with a small limber spatula. Do not wipe with cloth or wash clean with solvent, except when a change is to be made in the asphalt binder or at the end of a run.

5.3. Mold a trial specimen in order to determine the correct weight of materials to produce a specimen of the desired height. Use the initial or "buttering" batch for this purpose, if desired.

5.4. Aggregate ingredient samples shall be obtained in accordance with T 2 and reduced to the appropriate size by T 248. When preparing aggregates for batching, each reduced ingredient sample shall be separated into the desired size fractions in accordance with T 27. Agency practice will specify which sieves should be used to derive the desired fractions.

5.4.1. The Mixture Design, Job Mix Formula, or other control shall be used to combine the appropriate weight of each size from each ingredient aggregate to obtain the appropriate gradation and batch weight, and to determine the appropriate weight of asphalt binder to use for each specimen.

5.5. A representative sample of asphalt binder shall be obtained in accordance with T 40 from a representative stock of the material.

5.5.1. For unmodified asphalt binders, the temperature versus kinematic viscosity relationship for the asphalt binder involved dictates the temperature that should be used for preparing the hot mix asphalt test specimens. The mixing temperature is typically the temperature that yields 170 ± 20 centistokes of viscosity. The compacting temperature is typically the temperature that yields 280 ± 30 centistokes of viscosity. Mixing and compacting temperatures may be provided by the asphalt binder manufacturer (Note 1). Aggregate is heated no hotter than 28°C (50°F) above the mixing temperature to allow for dry mixing prior to adding the asphalt binder.

Note 1—Modified asphalt binders may not adhere to the equi-viscous ranges noted in Section 5.5.1. The user should refer to the asphalt binder manufacturer to establish appropriate mixing and compaction temperature ranges. In no case should the mixing temperature exceed 175°C (350°F).

5.5.2. The mixing and compacting temperatures are normally available from the asphalt binder supplier; however, it may be determined by testing the asphalt binder for kinematic viscosity (T 201) at two temperatures and plotting a graph showing the temperature and corresponding viscosity for each of the two points. Temperatures of 135°C (275°F) and 163°C (325°F) are convenient for asphalt binder grade PG 64-22; however, lower temperatures may be more appropriate for less viscous grades.

5.5.3. The graph paper may be a single or double cycle semi-log paper with the log axis (y) ranging from 100 to 1000 centistokes and the linear (x) axis established to cover the above two temperatures. Greater precision is derived by selecting ranges that utilize most of the page. General descriptions of the graph paper can be observed in ASTM D 2493 and ASTM D 341.

5.6. *Laboratory-Mixed Material*—Preheat the bowl and batch of aggregate in an oven meeting the requirements of Section 4.4 to a temperature that complies with the aggregate temperature in Section 5.5. This will result in an acceptable temperature after dry mixing. With the bowl of aggregate resting on a balance, quickly pour the prescribed weight of hot asphalt binder onto the hot aggregate and immediately mix the asphalt binder into the aggregate (Section 4.9). If mixing by hand, this can be done with a large spoon by rolling the material from perimeter toward the center to maximize aggregate and asphalt contact and minimize asphalt contact with the bowl. The mixing should be completed within 90 to 120 seconds, during which time the temperature should have dropped to about 3 to 5°C (5 to 9°F) above the compacting temperature. As soon as the material has been thoroughly mixed and has reached temperature within the specified range, charge the mold and compact the specimen.

Note 2—If the countertop is metal, an insulator such as paper may be used to reduce the rate of cooling.

5.6.1. When mixing is complete, the temperature of the mixture must be at least 3°C (5°F) above the compacting temperature; otherwise, discard the mixture and repeat mixing procedures according to Section 5.6, taking precautions to maintain temperature.

Note 3—Reheating may result in increased aging of the asphalt binder. Depending on the particular asphalt binder being tested, this can result in significantly higher-strength values.

Note 4—Laboratory samples prepared according to this test method may produce different test results, such as compressive strength values and percent air voids, when compared to results obtained from reheated plant-mixed field samples due to the effect of additional cure time and the absorption of asphalt binder by the aggregate in the field sample.

5.7. *Plant-Mixed Material*—Plant mixed hot mix asphalt shall be sampled in accordance with AASHTO T 168 and reduced to slightly more than the amount needed to fabricate the specimen. The size reduction shall be in accordance with AASHTO T 248, Method B. Adjust the weight of the reduced sample to the required weight by removing and discarding a small amount of the mixture. Care must be exercised to discard both fine and coarse particles to maintain the proper gradations.

5.7.1. Place the weighed sample into an appropriate container and heat in an oven to the mixing temperature provided in Section 5.5 for the asphalt represented in the mixture. Thoroughly mix the mixture until the temperature is 3 to 5ºC (5 to 9ºF) above the compacting temperature. This will result in the mixture being at the compacting temperature when compacting begins.

5.7.2. Compacting may commence immediately, or the material may be placed into an oven for a short time to allow more efficient handling of multiple plant-mixed samples; however, a sample should not remain in the oven for more than 1 hour.

6. TEST SPECIMENS

6.1. Generally, the test specimens shall be cylinders 101.6 mm (4.0 in.) in diameter and 101.6 ± 2.5 mm (4.0 ± 0.1 in.) in height. It is recognized that the size of test specimens has an influence on the results of the compressive strength test. Cylindrical specimens of dimensions other than 101.6 mm (4.0 in.) diameter are allowable, provided that:

6.1.1. The height shall be equal to the diameter within ±2.5 percent;

6.1.2. The diameter shall be not less than four times the nominal diameter of the largest aggregate particles;

6.1.3. The diameter shall be not less than 50.8 mm (2 in.); and

6.1.4. The unit rate of deformation shall be kept constant during the compression test (Section 8).

7. MOLDING AND CURING TEST SPECIMENS

7.1. Wipe the molds and plungers with a clean cloth that has a few drops of oil on it. Place approximately one half of the mixture (Laboratory-manufactured material according to Section 5.6, or reheated Plant-mixed material according to Section 5.7) in the molding cylinder which, together with the top and bottom plunger, has been preheated for at least 1 hour in the water bath maintained at a temperature just under the boiling point or preheated for at least 2 hours in an oven maintained at a temperature between 93.3 and 135°C (200 and 275°F). With the bottom plunger in place and the molding cylinder supported temporarily on the two steel support bars, spade the mixture vigorously 25 times with a heated spatula, with 15 of the blows being delivered around the perimeter of the mold to reduce honeycombing, and the remaining ten at random over the mixture.

7.2. Quickly transfer the remaining half of the mixture to the molding cylinder and repeat a similar spading action. Penetrate the mixture with the spatula as deeply as possible. A spatula having a slightly curved cross section has been used to advantage by some laboratories. The top of the mixture must be slightly rounded or cone-shaped to aid in firm seating of the upper plunger.

7.3. Compress the mixture between the top and bottom plungers under an initial load of about 1 MPa (150 psi) to set the mixture against the sides of the mold. Remove the support bars to permit full double–plunger action and apply the entire molding load of 20.7 MPa (3000 psi) for 2 minutes. When specimens are to be tested in accordance with ASTM 1075 for loss of strength resulting from the action of water, the standard molding load of 20.7 MPa (3000 psi) may be increased or decreased to achieve a target air void percentage or percent density.

Note 5—Based on the specified area of the plunger used with a 101.6-mm (4-in) molding cylinder, 1 MPa (150 psi) is approximately 8.2 kN (1850 lb) and 20.7 MPa (3000 psi) is approximately 168 kN (37 700 lb).

Note 6—Alternate methods of compaction may be utilized provided approximately 7 percent air voids are achieved.

7.4. Remove the specimen from the mold with an ejection device that provides a smooth, uniform rate of travel for the ejection head.

7.5. After removal from the mold, oven-cure specimens for 24 hours at 60°C (140°F). In case specimens are to be stored dry for more than 24 hours from completion of oven curing to compression testing, protect them from exposure to the air by sealing them in closely fitting, airtight containers.

8. PROCEDURE

8.1. Allow the test specimens to cool at room temperature for at least 2 hours after removal from the curing oven; then determine the bulk specific gravity of each specimen in accordance with T 166.

8.2. Bring the test specimens to the test temperature 25 ± 1°C (77 ± 1.8°F) by storing them in an air bath maintained at the test temperature for not less than 4 hours.

8.3. Test the specimens in axial compression without lateral support at a uniform rate of vertical deformation of 0.05 mm/min·mm (or 0.05 in./min·in.) of height. For specimens 101.6 mm (4 in.) in height, use a rate of 5.08 mm/min (0.2 in./min). Specimen failure is defined as the maximum load experienced by the specimen during the compression process.

8.4. The theoretical specific gravity and density shall be determined by T 209, or by any other method deemed appropriate by the agency involved. If T 209 is used, a sample of the mixture prepared but not molded, and compacted may be used.

8.5. Calculate the percent air voids in each specimen in accordance with T 269.

9. REPORT

9.1. *Report the following information*:

9.1.1. The bulk specific gravity, theoretical maximum specific gravity, density, and percent air voids of the specimens;

9.1.2. The compressive strength in kilopascals (lb/in.^{2}), determined by dividing the maximum vertical load obtained during deformation at the rate specified in Section 8 by the original cross-sectional area of the test specimen. Not fewer than three specimens shall be prepared for each asphalt increment, and the average of the three shall be reported as the compressive strength; and

9.1.3. The nominal height and diameter of the test specimens.

9.1.4. The compaction method utilized.

10. PRECISION AND BIAS

10.1. *Single-Operator Precision*—The single-operator standard deviation of a single test result (where the test result is, as defined in this test method, the average of a minimum of three separate compressive strengths) has been found to be 145 kPa (21 psi) (Note 7). Therefore, results of two properly conducted tests (each consisting of the average of a minimum of three individual compressive strengths) in the same laboratory on the same material by the same operator should not differ by more than 407 kPa (59 psi) (Note 7), and the range (difference between highest and lowest) of the individual measurements used in calculating the average should not exceed 841 kPa (122 psi) (Note 8).

Note 6—These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

Note 7—Calculated as described in ASTM C 670.

10.2. *Multilaboratory Precision*—The multilaboratory standard deviation of a single test result (where the test result is, as defined in this test method, the average of a minimum of three separate compressive strengths) has been found to be 372 kPa (54 psi) (Note 7.) Therefore, results of two properly conducted tests (each consisting of the average of a minimum of three individual compressive strengths) in different laboratories on the same material should not differ by more than 1055 kPa (153 psi).

Note 8—The precision statements given are applicable only to the static compaction method.

10.3. This test method has no bias because the compressive strength of asphalt mixtures is defined only in terms of the test method.

11. KEYWORDS

11.1. Asphalt paving mixtures; compression testing; compressive strength.

Standard Method of Test for

Sampling Bituminous Paving Mixtures

AASHTO Designation: T 168-03 (2007)
ASTM Designation: D 979-01 (2006)$^{\in 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling Bituminous Paving Mixtures

AASHTO Designation: T 168-03 (2007)

ASTM Designation: D 979-01 (2006)$^{\in 1}$

AASHTO T 168-03 (2007) is identical to ASTM D 979-01 (2006)$^{\in 1}$ except for the following provisions:

1. All references to the ASTM standards listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standard	
ASTM	AASHTO
C 702	T 248

2. Insert an additional section between Sections 4.1.1 and 4.1.2 containing the following:

   Care shall be taken in sampling to avoid segregation of coarse aggregate and asphalt mortar. Care shall be taken also to prevent contamination by dust or other foreign matter.

3. Insert new Sections 5.2.3.3, 5.2.3.4 and 5.2.3.5 after Section 5.2.3.2 as follows:

   5.2.3.3 If the mixture is in a windrow (cold mix), random samples of the windrow at intervals of not more than 150 m (500 ft) shall be secured and tested separately. Samples of the windrow shall be secured by flattening it at one point into a layer of approximately 0.3 m (1 ft) thick and coring this layer at three or more random points to obtain the required sample size as shown in Table 1.

   5.2.3.4 If the mix has been bladed into a relatively uniform layer, samples shall be secured at intervals of not more than 150 m (500 ft).

   5.2.3.5 Samples from a stockpile shall be obtained by combining equal quantities of the mixture taken from holes dug into points near the top, middle, and bottom of the stockpile. Reduction of the sample to the required size shall be as described in Section 5.3.2.

4. Insert an additional section between Sections 6.2.3 and 6.2.4 containing the following:

   Lot number.

Standard Method of Test for

Recovery of Asphalt Binder from Solution by Abson Method

AASHTO Designation: T 170-00 (2009)[1]
ASTM Designation: D 1856-95a (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Recovery of Asphalt Binder from Solution by Abson Method

AASHTO Designation: T 170-00 (2009)[1]
ASTM Designation: D 1856-95a (2003)

1. SCOPE

This method covers the recovery, by the Abson Method, of asphalt binder from a previously conducted extraction with reagent-grade trichloroethylene or reagent-grade methylene chloride (Note 1). The asphalt binder is recovered with properties substantially the same as those it possessed in the asphalt mixture and in quantity sufficient for further testing.

Note 1—Trichloroethylene conforming to ASTM D 4080 or technical grade methylene chloride may be used, but it is recommended that for each new supply of the solvent, a blank should be run on an asphalt binder of known properties. In case of dispute, reagent grade should be used.

Blank Determinations—Introduce about 70 g of asphalt binder into a 2000-mL flask (68-oz); add about 800 mL (27 oz) of solvent to dissolve the asphalt, allow the solution to stand for about 4 h; concentrate the solution by distillation to about 200 mL (6.8 oz) and then recover the asphalt binder. Total elapsed time from when the solvent is added to the time the recovery test is completed is about 7 h.

1.1 The values stated in SI units are to be regarded as the standard.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 111, Mineral Matter or Ash in Asphalt Materials
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)

2.2 *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 96, Standard Test Methods for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure) (Withdrawn 2000)
- D 4080, Standard Specification for Trichloroethylene, Technical and Vapor-Degreasing Grade
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. SUMMARY OF METHOD

3.1 The solution of solvent and asphalt binder from a prior extraction is distilled under prescribed conditions to a point where most of the solvent has been distilled, at which time carbon dioxide gas is introduced into the distillation process to remove all traces of the extraction solvent. The recovered asphalt binder (distillation residue) can then be subjected to further testing as required.

4. SIGNIFICANCE AND USE

4.1 The asphalt binder should be extracted from the asphalt mixture in accordance with Method A or E (Note 2) of T 164, as there is some experimental evidence that the recovered asphalt binder may have slightly lower penetration values when recovered from solutions obtained from hot extraction methods.

Note 2—Equipment in Method E of T 164 can be modified by a vacuum trap attached to the top of the "end point" site tube to collect the extract to allow its use for recoveries.

5. APPARATUS

5.1 *Centrifuge*—Batch unit capable of exerting a minimum centrifugal force of 770 times gravity or a continuous unit capable of exerting a minimum force of 3000 times gravity. The apparatus specified in ASTM D 96 may also be used.[2]

5.2 *Centrifuge Tubes*—A supply of 250- to 500-mL (8.5- to 16.9-oz) wide-mouth bottles, or centrifuge tubes as shown in Figure 1 or 2 of ASTM D 96.

5.3 *Distillation Assembly*—As shown in Figure 1 and consisting of the following items:

5.3.1 *Extraction Flasks*—A 250- to 500-mL (8.5- to 16.9-oz) wide-mouth, heat-resistant flask for distillation and a suitable flask for the receiver.

5.3.2 *Glass Tubing*—Heat-resistant glass tubing, having a 10-mm (0.4-in.) inside diameter and a goose-neck-shaped delivery tube (as shown in Figure 1) for connecting the flask to the condenser.

5.3.3 *Inlet Aeration Tube*—At least 180 mm (7 in.) in length having a 6-mm ($^1/_4$ in.) outside diameter with a 10-mm (0.4-in.) bulb containing six staggered holes approximately 1.5 mm (0.06 in.) in diameter.[3]

5.3.4 *Electric Heating Mantle*—With a variable transformer, oil bath, or fluidized sand bath, to fit a 250- to 500-mL (8.5- to 16.9-oz) flask.

5.3.5 *Water-Jacketed Condenser*—Allihn type, with a 200-mm (7.9-in.) minimum jacket length or equivalent.

5.3.6 *Thermometer*—An ASTM Low Distillation Thermometer 7ºC (7ºF), having a range of –2 to 300ºC (28 to 572ºF), and conforming to the requirements in ASTM E 1.

5.3.7 *Gas Flow Meter*—As shown in Figure 1, or any type capable of indicating a gas flow of up to 1000 mL/min.[4]

5.3.8 *Corks*—No. 20, drilled as shown in Figure 1.

5.3.9 *Flexible Elastometric Tubing*—resistant to chlorinated solvents, having a sufficient length and size to connect the aeration tube to a flowmeter, and equipped with a pinch clamp or stopcock to close the aeration tube prior to introducing carbon dioxide.

5.3.10 *Separatory Funnel* [5]—(alternative procedure, see Subsection 9.3.1), 125-mL (4.2 oz) capacity or larger.

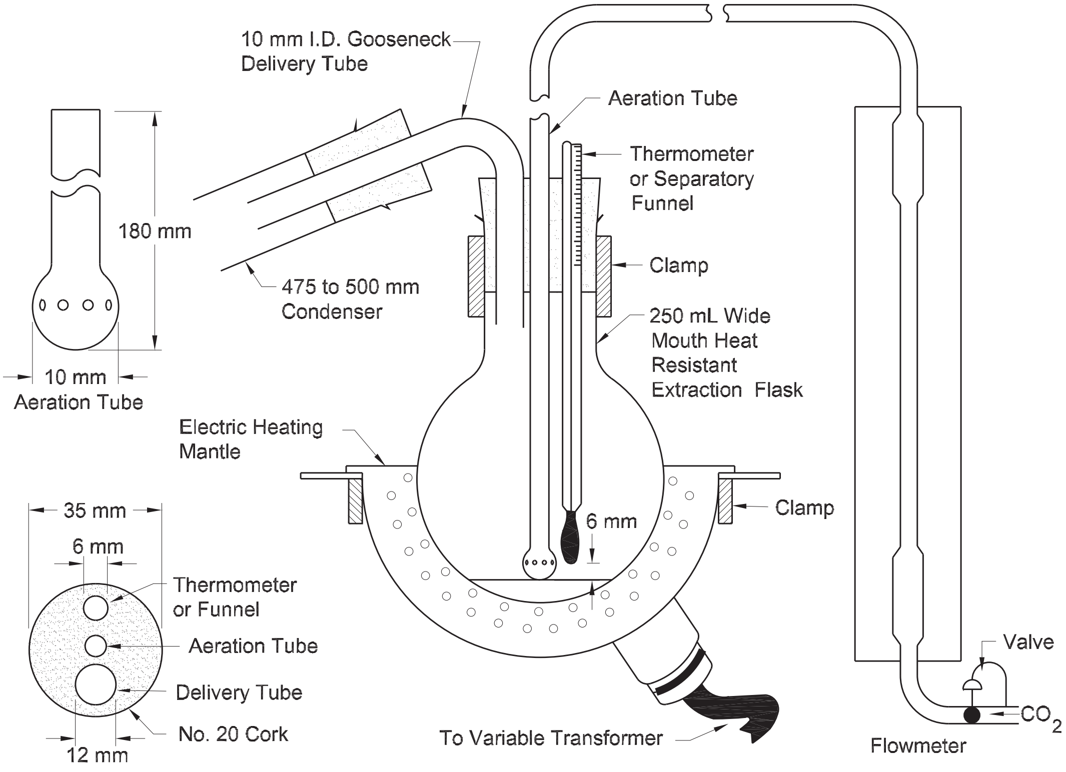

Figure 1—Distillation Assembly for Asphalt Recovery

6. REAGENTS AND MATERIALS

6.1 *Carbon Dioxide Gas*—A pressurized tank, with a pressure-reducing valve, or other convenient source.

6.2 The solvent for extracting the asphalt binder from the mixture should be reagent-grade trichloroethylene or reagent-grade methylene chloride. Other solvents may affect the asphalt binder and change its properties significantly from that as it exists in the mixture (Note 1.)

7. PRECAUTIONS

7.1 **Caution**—The solvents listed in Section 6.2 should be used only under a hood, or with an effective surface exhaust system in a well-ventilated area, since they are toxic to some degree as indicated in R 16.

8. SAMPLE

8.1 The sample shall consist of a solution, from previous extraction by Method A or E of T 164, of a sample of sufficient mass to result in approximately 75 to 100 g of recovered asphalt binder. More or less quantities of asphalt binder may be recovered; however, the properties of the recovered asphalt binder may not be in agreement with those recovered from a quantity of 75 to 100 g. In case of a dispute, 75 to 100 g should be recovered.

8.2 During the extraction process, it is important that all of the asphalt binder in the mixture be extracted, as there could be some selective solvency of the asphalt binder, and the harder, more viscous components of the asphalt binder might be left in the mixture if the extraction is not carried to completion.

8.3 Since heavy petroleum distillates such as mineral spirits or kerosene will affect the properties of the recovered asphalt binder, it is important to avoid the use of such solvents in cleaning the extraction and recovery apparatus and use only trichloroethylene or methylene chloride for cleaning. Residues of heavy petroleum solvents on the equipment may contaminate the recovered asphalt binder and affect its test properties. It is also necessary to use new filter rings, clean felt pads, or other uncontaminated filtering media in the extraction process to avoid contamination from a previous extraction.

8.4 Generally, the asphalt binder in mixtures will progressively harden when exposed to air, particularly if the mixtures are in a loose condition. Therefore, it is important to protect asphalt mixtures from exposure to air and preferably to store them in airtight containers at a temperature below 0ºC (32ºF) until they can be tested. When samples of asphalt mixture are warmed for preparing representative portions for extraction tests in accordance with Method A or E (Note 2) of T 164, they should be placed in an oven in covered containers and heated to a maximum temperature of 110ºC (230ºF) for the minimum time necessary to obtain workability, but no longer than 30 min. If the samples have been stored at a low temperature, they should be allowed to reach room temperature before placing them in the oven.

9. PROCEDURE

9.1 The entire procedure, from the start of the extraction to the final recovery, must be completed within 8 h.

9.2 Centrifuge the solution from the previous extraction for a minimum of 30 min at 770 times gravity in 250- to 500-mL (8.5- to 16.9-oz) wide-mouth bottles or centrifuge tubes in the batch apparatus specified. If a continuous centrifuge is used, the extract solution shall be charged at a rate not to exceed 150 mL/min (5.1 oz/min), while the unit is operating at a speed calculated to produce a centrifugal force of not less than 3000 times gravity.

9.3 Concentrate the solution to approximately 200 to 300 mL (6.8 to 10.1 oz) by any primary distillation operation using a flask large enough to hold all the solution from the extraction. Transfer the residue from the primary distillation flask, using several washes of solvent to rinse all of the residue into the 250- to 500-mL (8.5- to 16.9-oz) distillation flask. Assemble the apparatus as shown in Figure 1, and introduce carbon dioxide gas at a low rate (approximately 100 mL/min) to provide agitation and prevent foaming. Continue the distillation until the temperature reaches 157 to 160ºC (315 to 320ºF); at that point increase the carbon dioxide gas flow to approximately 900 mL/minute. Maintain this gas flow rate for 10 min while also maintaining the temperature of the residue in the flask at 160 to 166ºC (320 to 330ºF). The setting of the variable transformer for obtaining this temperature can be established by a few trial runs; generally a higher setting can be used for the main distillation. Reduce the setting when most of the solvent has been vaporized. In place of the electric heating mantle, an oil bath or a fluidized sand bath may be substituted in which the temperature during the introduction of the carbon dioxide gas is maintained 8 to 14ºC (15 to 25ºF) higher than the inside temperature. If, after 10 min, dripping of condensed solvent from the delivery tube is still occurring, maintain the gas flow and temperature until 5 min after the dripping ceases in order to flush solvent vapors from the flask. In no case shall the time of flow of carbon dioxide gas be less than 15 minutes. At the end of this period, discontinue the gas flow and heat.

9.3.1 *Alternative Procedure*—Assemble the apparatus as shown in Figure 1 with the separatory funnel in the thermometer hole in the cork. As an alternative, the separatory funnel may be inserted in a separate hole drilled in the cork stopper. Raise the aeration tube so that the bulb is above the surface of the solution. Fill the separatory funnel with the centrifuged solution, and open the stopcock to fill the flask approximately one half full of solution. Apply low heat to the flask, and start distillation. At this time, lower the aeration tube so that the bulb is in contact with the bottom of the flask, and introduce carbon dioxide gas at a low rate (approximately 100 mL/min) to provide agitation and prevent foaming. Adjust the funnel stopcock to introduce fresh solvent at a rate that will keep the flask approximately one half full during distillation, adding additional solution to the funnel until all of the solution has been introduced into the distillation flask. Wash the solution container and funnel with fresh solvent to transfer all asphalt binder into the distillation flask. If the separatory funnel has not been inserted into a separate hole drilled in the cork stopper, remove the separatory funnel, and insert the thermometer. When the temperature reaches 157 to 160ºC (315 to 320ºF), increase the carbon dioxide gas flow to approximately 900 mL/minute. Maintain this gas flow rate for 10 min while also maintaining the temperature of the residue in the flask at 160 to 166ºC (320 to 330ºF). If, after 10 min, dripping of condensed solvent from the delivery tube is still occurring, maintain the gas flow and temperature until 5 minutes after the dripping ceases in order to flush solvent vapors from the flask. In no case shall the time of flow of carbon dioxide gas be less than 15 min. At the end of this period, discontinue the gas flow and heat.

9.4 If the residue in the flask is highly viscous at 163ºC (325ºF), so that dispersion of the carbon dioxide in the residue is restricted and the recovered asphalt binder is expected to have a penetration at 25ºC (77ºF) of less than 30, maintain the carbon dioxide gas flow and temperature for 20 to 22 min, which includes the initial 15 min.

9.5 The recovered asphalt binder can be heated to reliquefy, and portions taken for testing. Testing may include dynamic shear, bending beam, direct tension, rotational viscosity, penetration, softening point, ductility, ash content, and kinematic and absolute viscosity determinations as required. Ash content determinations shall be conducted on all recovered asphalt binder in accordance with T 111 and reported with other test data on the recovered asphalt binder. Ash contents of recovered asphalt binder greater than 1 percent may affect the accuracy of the penetration, ductility, softening point, or viscosity tests.

Note 3—Determination of the mass of recovered asphalt binder serves as a check to assure that all of the solvent has been removed when this mass is compared with the mass of extracted asphalt binder as determined by T 164. The mass of the recovered asphalt binder should be corrected for the ash content determined.

10. PRECISION AND BIAS

10.1 *Precision*—Data from the AMRL proficiency sample database from 1974 to 1992 was analyzed to develop estimates of test precision. [6] The results of the analysis are summarized below. The grades of asphalt binders included in the analysis consisted of AC-5, AC-10, AC-15, AC-20, AC-30, AC-

40, AR-2000, and AR-4000. The precision estimates provided apply to unaged asphalt binder having physical test properties within the following ranges:

■ Penetration at 25°C (77°F)	29 to 181
■ Kinematic viscosity at 135°C (275°F), cSt	200 to 720
■ Viscosity at 60°C (140°F), P	520 to 5320

10.1.1 *Single-Operator Precision*—The figures given in Column 2 of the table below are the coefficients of variation that have been found to be appropriate for the tests and conditions described in Column 1 of the same table. When performed by the same operator on the same sample in the same laboratory using the same apparatus, the difference in the results of two properly conducted tests, expressed as a percent of their mean, shall not exceed the figures given in Column 3 of the following table.

Test Index	Coefficient of Variation (Percent of Mean) [7]	Acceptable Range of Two Results (Percent of Mean)[7]
Single-Operator Precision:		
Penetration at 25°C (77°F)	11	30
Kinematic viscosity at 135°C (275°F), cSt	9	26
Viscosity at 60°C (140°F), P	18	51

10.1.2 *Multilaboratory Precision*—The figures given in Column 2 of the table below are the coefficients of variation that have been found to be appropriate for the tests and conditions described in Column 1 of the same table. When performed by different operators in different laboratories, the difference in the results of two properly conducted tests on the same material, expressed as a percent of their mean, shall not exceed the figures given in Column 3 of the following table.

Test Index	Coefficient of Variation (Percent of Mean)[7]	Acceptable Range of Two Results (Percent of Mean)[7]
Multilaboratory Precision:		
Penetration at 25°C (77°F)	21	58
Kinematic viscosity at 135°C (275°F), cSt	16	46
Viscosity at 60°C (140°F), P	33	93

10.2 *Bias*—Since there are no data at this time to prepare a bias statement, no statement on bias is made.

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[1] Similar, but not technically identical to ASTM D 1856-95a (2003).
[2] An "International" No. 2 Centrifuge operating at 1900 r/min or an "SMM Continuous Centrifuge," exerting a force of 3000 times gravity at 9000 r/min, has been found satisfactory for this purpose.
[3] Inlet Aeration Tube, Part No. 226, available from Wm. A. Sales Ltd., 419 Harvester Court, Wheeling, IL 60090, or equivalent, has been found suitable.
[4] The Monostat Corp., "Flowmeter," No. 9144, has been found satisfactory for this purpose.
[5] Kimball Separatory Funnel, No. 29028, has been found satisfactory for this purpose.
[6] The data are included in a research report available from ASTM Headquarters. Request RR: D04-1008
[7] These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670.

Standard Method of Test for

Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)

AASHTO Designation: T 179-05 (2009)[1]
ASTM Designation: D 1754-97 (2002)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)

AASHTO Designation: T 179-05 (2009)[1]
ASTM Designation: D 1754-97 (2002)

1. SCOPE

1.1. This method covers the determination of the effect of heat and air on a film of semisolid asphaltic materials. The effects of this treatment are determined from measurements of selected asphalt properties before and after the test.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 49, Penetration of Bituminous Materials
- T 51, Ductility of Asphalt Materials
- T 201, Kinematic Viscosity of Asphalts (Bitumens)
- T 202, Viscosity of Asphalts by Vacuum Capillary Viscometer

2.2. *ASTM Standards*:

- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 145, Standard Specification for Gravity-Convection and Forced-Ventilation Ovens

3. SUMMARY OF METHOD

3.1. A film of asphaltic material is heated in an oven for 5 hours at 163ºC (325ºF). The effects of heat and air are determined from changes occurring in physical properties measured before and after the oven treatment. An optional procedure is provided for determining the change in sample mass.

3.2. Precision values for the method have been developed for viscosity, viscosity change, penetration change, and mass change; precision for other properties is undefined.

4. SIGNIFICANCE

4.1. This method indicates approximate change in properties of asphalt during conventional hot-mixing at about 150ºC (300ºF) as indicated by viscosity, penetration, or ductility measurements. It yields a residue that approximates the asphalt condition as incorporated in the pavement. If the mixing temperature differs appreciably from the 150ºC (300ºF) level, more or less effect on properties will occur.

5. APPARATUS

5.1. *Oven*—The oven shall be electrically heated and shall conform to the performance requirements of ASTM E 145, for Gravity-Convection and Forced-Ventilation Ovens Type IB (Gravity-Convection), for operating temperatures up to 180ºC (356ºF). During the tests for compliance to ASTM E 145 requirements, the oven shelf, properly centered as described in Section 5.1.2, shall be in place and rotating.

5.1.1. *Construction*—The oven shall be rectangular with minimum interior dimensions (exclusive of space occupied by the heating element) of 330 mm (13 in.) in each direction. (See Note 1.) The oven shall have, in front, a tightly fitted hinged door, which shall provide a clear opening substantially the same as the interior height and width of the oven. The door may contain a window with dimensions of at least 100 by 100 mm (4 by 4 in.) and with two sheets of glass separated by an air space, through which a vertical thermometer, located as specified in Section 5.2, may be read without opening the door; or the oven may be provided with an inner glass door, through which the thermometer may be observed on opening the outer door momentarily. The oven shall be adequately ventilated by convection currents of air and for this purpose shall be provided with openings for the entrance of air and for the exit of heated air and vapors. Openings may be of any size and arrangement provided the requirements of ASTM E 145, Type 1B are met.

5.1.2. *Rotating Shelf*—The oven shall be provided with a metal circular shelf having a minimum diameter of 250 mm (9.8 in.) (Note 1). The shelf construction shall be such that it provides a flat surface for support of the containers without blocking all air circulation through the shelf when the containers are in place. The shelf shall be suspended by a vertical shaft and centered with respect to the horizontal interior dimensions of the oven and shall be provided with a mechanical means of rotating it at the rate of 5.5 ± 1.0 r/min. The shelf shall be vertically located as close to the center of the oven as permitted by compliance with the requirements of Section 5.2 regarding thermometer placement. The shelf shall be constructed or marked in such a way that the sample containers can be placed in the same position during each test. There shall be a minimum of two and a maximum of six sample container positions. Each sample container position shall be symmetrical with respect to the shaft and to any holes in the shelf. The number of sample container positions shall be the maximum that will fit on the shelf without violating the above requirements and without excessive overhang.

Note 1—Minimum size ovens accommodate two containers. For routine or control operations, larger ovens, having proportionately larger shelves to accommodate a greater number of containers, may be advantageous and are suitable, provided the requirements of ASTM E 145, Type 1B are met. Under no circumstances should more than one shelf, properly centered, be used in an oven.

5.1.3. *Recovery Time*—When the oven obtains a temperature of 163ºC (325ºF) and two sample pans are introduced, the oven shall be capable of returning to 162ºC (323ºF) within 15 minutes.

5.2. *Thermometer*—An ASTM Loss on Heat Thermometer having a range of 155 to 170ºC and conforming to the requirements for Thermometer 13C, as prescribed in ASTM E 1. The thermometer shall be supported from the shaft of the circular shelf in a vertical position at a point equidistant from the center and outer edge of the shelf. The bottom of the thermometer bulb shall be approximately 6.4 mm ($^1/_4$ in.) above the top of the shelf.

5.3. *Container*—A cylindrical pan 140 mm ($5^1/_2$ in.) in inside diameter and 9.5 mm ($^3/_8$ in.) deep with a flat bottom. Fifty milliliters of the sample in this size container gives a film thickness of 3.2 mm ($^1/_8$ in.). Pans shall be made of stainless steel and should have a metal thickness of approximately 0.635 mm (0.025 in.).

Note 2—Pans have a tendency to become warped or bent with use. Although tests indicate that a small amount of warping does not significantly affect results, frequent inspection to eliminate badly warped or damaged pans is advisable. The indicated metal thicknesses are those found to provide adequate rigidity without excessive weight. Stainless steel pans manufactured from 0.6 mm (No. 24) stainless sheet-gauge steel comply with the recommended thickness. Pans made from 0.5 mm (No. 26) stainless sheet-gauge metal are also acceptable but have a greater tendency to warp during use. However, in no case shall the thickness of the metal be less than 0.381 mm (0.015 in.).

5.4. *Balances*—If the loss on heating is desired, a Class B balance conforming to the requirements of M 231 is required. If only the residue is desired, a Class G 2 balance conforming to M 231 may be used.

6. PREPARATION OF SAMPLES

6.1. Place sufficient material for the test in a suitable container and heat to a fluid condition. Extreme care should be taken so that there is no local overheating of the sample and that the highest temperature reached does not exceed 150°C (302°F). Stir the sample with a general purpose thermometer during the heating period, but avoid incorporating air bubbles in the sample. Weigh 50.0 ± 0.5 g into each of two or more tared sample pans meeting the requirements of Section 5.3 (Note 3).

Note 3—When tests on the residue other than penetration and ductility are desired, more than two containers may be needed to provide sufficient material for test.

6.2. At the same time, pour a portion of the sample into the containers specified for measurement of original asphalt properties. Complete these tests by appropriate AASHTO test methods.

6.3. If the quantitative value of the loss or gain in sample mass is desired, cool the samples for the oven test to room temperature and determine the mass of each sample separately to the nearest 0.001 g. If the change in mass is not required, allow the samples to cool to approximately room temperature before placing in the oven as directed in Section 7.3.

7. PROCEDURE

7.1. Level the oven so that the shelf rotates in a horizontal plane. Extreme care should be taken so that there is no local overheating of the sample and that the highest temperature reached does not exceed 150°C (302°F). Determine the temperature of the oven by means of the specified thermometer (Section 5.2).

7.2. Place an empty sample container in each of the predetermined sample container positions on the rotating shelf. Adjust the temperature control so the specified thermometer (Section 5.2) reads 163 ± 1°C (325 ± 2°F) when the oven is at equilibrium. Once the adjustment is complete, the empty sample containers may be removed at the discretion of the operator. However, the temperature control shall not be readjusted once any sample containers are removed.

Note 4—Removing sample containers will affect convection patterns in the oven and may cause the thermometer reading to change from the desired level. This phenomenon is normal and occurs because the thermometer is not in the same location as the temperature control sensor. Replacing the containers should cause the thermometer to return to the original level.

7.3. With the oven at 163ºC (325ºF), quickly place the containers with the sample on the circular shelf. Fill any vacant positions with empty sample containers, so that every sample container position is occupied. Close the oven door, and start rotating the shelf. Maintain the temperature at 163 ± 1ºC (325 ± 2ºF) for 5 hours after the sample has been introduced and the oven has again reached that temperature. The 5-hour period shall start when the temperature reaches 162ºC (323ºF) and in no case shall the total time that a sample is in the oven be more than 5.25 hours. At the conclusion of the heating period, remove the samples from the oven. If the change in mass is not being determined, proceed in accordance with Section 7.5. If the change in mass is being determined, cool to room temperature, determine the mass to the nearest 0.001 g, and calculate the change in mass on the basis of the asphalt in each container. When complete tests cannot be made in the same day, and if the loss or gain in the sample mass is being determined, determine the mass of the residues and store them overnight before reheating. If the change in mass is not being determined, transfer the residue to the 240-mL (8-oz) container as described in Section 7.4 before storing overnight.

Note 5—Materials having different mass-change characteristics should not generally be tested at the same time due to the possibility of cross-absorption.

Note 6—This test method does not prohibit placing an asphalt sample in the position under the thermometer. However, it is recommended that this position not be used for a sample, and that an empty pan remain in this position in order to minimize the risk associated with thermometer breakage.

7.4. After weighing the containers with the residues, place them on refractory board(s). Put the board(s) and the containers on the circular shelf of the oven maintained at 163ºC (325ºF). Close the oven and rotate the shelf for 15 ± 2 minutes, remove the samples and board(s), and immediately proceed as described in Section 7.5.

7.5. Pour the samples into a 240-mL (8-oz) ointment tin. Remove substantially all of the material from the 140-mm ($5^1/_2$-in.) pans by scraping with a suitable spatula or putty knife. Stir the combined residues thoroughly, placing the 240-mL (8-oz) container on a hot plate to maintain the material in a fluid condition if necessary. Pour the material into the proper containers or molds for the penetration, ductility, or other tests if required. Complete the tests on residue by appropriate AASHTO test methods within 72 hours of performing this test.

Note 7—The pans may be removed from the oven and scraped one at a time provided that each pan remains in the oven the required 15 ± 2 minutes.

8. REPORT

8.1. Report the values of the original asphalt properties measured in Section 6.2 and the residue property values as measured in Section 7.5. Viscosity change may also be expressed as the ratio of the residual asphalt viscosity to the original asphalt viscosity. Penetration change is evaluated as the penetration of the residue expressed as the percentage of the original penetration.

8.2. Report ductility or other test results in accordance with the appropriate AASHTO Methods of Test.

8.3. When determined, report the average change in mass of the material in all the containers used in the test as mass percent of the original material. A mass loss shall be reported as a negative number, while a mass gain shall be reported as a positive number.

Note 8—This test can result in either a mass loss or a mass gain. During the test, volatile components evaporate (causing a decrease in mass), while oxygen reacts with the sample (causing an increase in mass). The combined effect determines whether the sample has an overall mass gain or overall mass loss. Samples with a very low percentage of volatile components will usually exhibit a mass gain, while samples with a high percentage of volatile components will usually exhibit a mass loss.

9. PRECISION

9.1. Criteria for judging the acceptability of the viscosity at 60ºC (140ºF) and 135ºC (275ºF), viscosity ratio at 60ºC (140ºF), change in penetration at 25ºC (77ºF), and mass change test results obtained by this method are given in Table 1.

Table 1—Precision

Material and Type Index	Standard Deviation (1s)	Acceptable Range of Two Results (d2s)	Coefficient of Variation (Percent of Mean) (1s%)	Acceptable Range of Two Results (Percent of Mean) (d2s%)
Single-operator precision:				
Percentage of retained penetration	1.43	4.0	—	—
Change in mass percentage:				
Not more than 0.4% (max)	0.014	0.04	—	—
Greater than 0.4%	—	—	2.9	8.0
Viscosity at 60˚C (140˚F)	—	—	3.3	9.3
Viscosity at 135˚C (275˚F)	—	—	2.0	5.7
Viscosity Ratio at 60˚C (140˚F):[a]	—	—	5.6	16.0
Multilaboratory precision:[b]				
Percentage of retained penetration	2.90	8.0	—	—
Change in mass percentage:				
Not more than 0.4% (max)	0.055	0.16	—	—
Greater than 0.4%	—	—	14.0	40.0
Viscosity at 60˚C (140˚F)	—	—	11.6	33.0
Viscosity at 135˚C (275˚F)	—	—	6.4	18.0
Viscosity Ratio at 60˚C (140˚F):[a]	—	—	9.1	26.0

[a] Viscosity Ratio is the ratio of the viscosity at 60˚C (140˚F) after test to the viscosity at 60˚C (140˚F) before test.

[b] Multilaboratory precision is applicable to asphalt cements having viscosity ratios lower than 3.0. Precision for ratios greater than 3.0 have not been established.

9.1.1. The figures given in Column 2 are the standard deviations that have been found to be appropriate for the materials and conditions of test described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. The figures given in Column 4 are the coefficients of variation that have been found to be appropriate for the materials and conditions of test described in Column 1. The figures given in Column 5 are the limits that should not be exceeded by the difference between the results of two properly conducted tests expressed as a percent of their means.

9.2. Criteria for judging variability of other test results are not available at the present time.

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[1] Similar but not identical to ASTM D 1754-97 (2002).

Standard Method of Test for

Determining Degree of Particle Coating of Asphalt Mixtures

AASHTO Designation: T 195-67 (2007)
ASTM Designation: D 2489-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Degree of Particle Coating of Asphalt Mixtures

AASHTO Designation: T 195-67 (2007)
ASTM Designation: D 2489-02

1. SCOPE

1.1. This method covers the determination of the degree of particle coating in an asphalt mix on the basis of the percentage of coarse aggregate particles that are completely coated. Determination of the percentage of coated particles for varying mixing times may be used to establish the least mixing time required to produce satisfactory coating of the aggregate for a given set of conditions. This test method applies to mixtures containing aggregate of a nominal maximum aggregate size less than 38 mm ($1^1/_2$ in.).

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- T 168, Sampling Bituminous Paving Mixtures

3. APPARATUS

3.1. *Sieves*—9.5-mm ($^3/_8$-in.) and 4.75-mm (No. 4) sieves conforming to M 92.

3.2. *Stopwatch*—For checking the actual mixing time.

3.3. *Thermometer*—With a range from 10 to 204.4ºC (50 to 400ºF).

3.4. *Sample Shovel*.

3.5. *Sample Trays*.

4. SAMPLING

4.1. *Batch Plant*—Permit the plant to operate at an established mixing time per batch (timed by a stopwatch).

4.2. *Continuous Plant*—Establish a mixing time by use of the following formula:

$$\frac{\text{Pug Mill Contents, kg (lb)}}{\text{Pug Mill Output, kg/s (lb/s)}} \qquad (1)$$

4.3. Samples should be taken at the asphalt mixing plant, immediately after discharge from the pug mill, from three alternate truckloads of mixture. (See T 168.)

4.4. The amount of material required to perform the test is approximately 2.3 to 3.6 kg (5 to 8 lb).

5. PROCEDURE

5.1. Sieve each material immediately, while it is still hot, on a 9.5-mm ($^3/_8$-in.) sieve for materials with a maximum size larger than 9.5 mm ($^3/_8$ in.). For materials with a maximum size of 9.5 mm ($^3/_8$ in.) or less, use a 4.75-mm (No. 4) sieve. Take a sample large enough to yield between 200 and 500 coarse particles retained on the 9.5-mm ($^3/_8$-in.) or 4.75-mm (No. 4) sieve. Do not overload the sieves. If necessary, sieve the sample in two or three operations. Shaking should be reduced to a minimum to prevent recoating of uncoated particles.

5.2. Place the particles on a clean surface in a one-particle layer, and start counting immediately.

5.3. Very carefully examine each particle under direct sunlight, fluorescent light, or similar light conditions. If even a tiny speck of uncoated stone is noted, classify the particle as "partially uncoated." If completely coated, classify the particle as "completely coated."

6. CALCULATION

6.1. The required computation is as follows:

$$\text{Percent of Coated Particles} = \frac{\text{No. of Completely Coated Particles} \times 100}{\text{Total No. of Particles}} \qquad (2)$$

7. REPORT

7.1. *Report the following information*:

7.1.1. Type of plant—batch or continuous.

7.1.2. Type of mix.

7.1.3. Mixing time to the nearest 0.5 min.

7.1.4. Mixing temperature to the nearest 5°C (9°F).

7.1.5. Percent of coated particles to the nearest 0.1 percent.

8. PRECISION AND BIAS

8.1. *Precision*—No precision data is available at this time.

8.2. *Bias*—Since there are no accepted reference materials suitable for determining the bias of this test method, no statement of bias is presented.

9. KEYWORDS

9.1. Asphalt; asphalt mixing plant; coating; mixing time; pug mill.

Standard Method of Test for

pH of Aqueous Solutions with the Glass Electrode

AASHTO Designation: T 200-79 (2006)
ASTM Designation: E 70-97 (2002)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

pH of Aqueous Solutions with the Glass Electrode

AASHTO Designation: T 200-79 (2006)
ASTM Designation: E 70-97 (2002)

AASHTO T 200-79 (2006) is identical to ASTM E 70-97 (2002).

Standard Method of Test for

Kinematic Viscosity of Asphalts (Bitumens)

AASHTO Designation: T 201-10
ASTM Designation: D 2170-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Kinematic Viscosity of Asphalts (Bitumens)

AASHTO Designation: T 201-10
ASTM Designation: D 2170-07

AASHTO T 201-10 is identical to ASTM D 2170-07 except for the following provisions:

1. All references to ASTM D 92 shall be replaced with AASHTO T 48. Add reference to R 16, Regulatory Information for Chemicals Used in AASHTO Tests.
2. Delete the 1 in front of cm^2/s in the fourth sentence of Section 3.1.2.
3. Replace the last two sentences in Section 6.3 with the following:

   The efficiency of the stirring and the balance between heat losses and heat input must be such that the temperature of the bath medium does not vary by more than ±0.1ºC (±0.2ºF) over the length of the viscometer, or from viscometer to viscometer in the various bath positions.
4. Replace Section 8.2 with the following:

   8.2 Maintain the bath at the test temperature within ±0.1ºC (±0.2ºF). Apply the necessary corrections, if any, to all thermometer readings.
5. Add a last sentence to Section A2.3.3.1 as follows:

   When the sample travels through capillary R and fills bulb A approximately half full, arrest its flow by placing a stopper in tube L.
6. Add a last sentence to Section A2.3.3.3 as follows:

   This 15-minute period is part of and not in addition to the equilibration time of Section A2.3.4.
7. Revise the second sentence of Section A2.3.5 to read as follows:

   For the Zeitfuchs cross-arm viscometer, apply slight vacuum to tube M (or pressure to tube N) to cause…

Standard Method of Test for

Viscosity of Asphalts by Vacuum Capillary Viscometer

AASHTO Designation: T 202-10
ASTM Designation: D 2171-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Viscosity of Asphalts by Vacuum Capillary Viscometer

AASHTO Designation: T 202-10
ASTM Designation: D 2171-07

AASHTO T 202-10 is identical to ASTM D 2171-07 except for the following provisions:

1. The following reference is added:

   R 16, Regulatory Information for Chemicals Used in AASHTO Tests.
2. Replace the last sentence in Section 6.3 with the following:

   The efficiency of the stirring and the balance between heat loss and heat input must be such that the temperature of the bath medium does not vary by more than ±0.1ºC (±0.2ºF) over the length of the viscometer, or from viscometer to viscometer in the various bath positions.
3. Replace Section 8.1.1 with the following:

   8.1.1 Maintain the bath at the test temperature within ±0.1ºC (±0.2ºF). Apply the necessary corrections, if any, to all thermometer readings.
4. In Table X1.1, change the viscosity range for Viscometer Size Number 12 to "36 to 800 Pa•s (360 to 8000 P)."
5. In Table X3.1, change the approximate calibration factor for Viscometer Size Number 25, Bulb D from ".007" to "0.07", and change the title to "Standard Viscometer Sizes, Capillary Radii, Approximate Calibration Factors, *K*, and Viscosity Ranges for Modified Koppers Vacuum Capillary Viscometer."
6. Replace Section X4.3.1.7 with the following:

   X4.3.1.7 Calculate the calibration factor, *K*, for each bulb as follows:

   $$K = \eta / t \qquad (X4.1)$$

   where:

   K = viscometer bulb calibration factor at 40.0 kPa (300 mm Hg), Pa•s/s;
   η = viscosity of viscosity standard at calibration temperature, Pa•s; and
   t = flow time, s.

7. Replace Table X4.1 with the following table:

	Approximate Viscosity, Pa•s		
Viscosity Standard	At 25°C (77°F)	At 40°C (104°F)	At 60°C (140°F)
N30000[a]	80	—	4.7
N190000[a]	520	140	33
N270000[a]	5300	—	340
S30000[a]	80	21	—

[a] Available in 1-pint containers. Purchase orders should be addressed to Cannon Instrument Co., P.O. Box 16, State College, PA 16801 or see website, www.cannoninstrument.com. Shipment will be made as specified or by best means.

Standard Method of Test for

Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)

AASHTO Designation: T 209-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)

AASHTO Designation: T 209-10

1. SCOPE

1.1. This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted hot mix asphalt (HMA) at 25°C (77°F).

Note 1—The precision of the method is best when the procedure is performed on samples that contain aggregates that are completely coated. In order to assure complete coating, it is desirable to perform the method on samples that are close to the optimum asphalt binder content.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- PP 57, Establishing Requirements for and Performing Equipment Calibrations, Standardizations, and Checks
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 168, Sampling Bituminous Paving Mixtures

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 4311, Standard Practice for Determining Asphalt Volume Correction to a Base Temperature

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *density, as determined by this test method*—the mass of a cubic meter of the material at 25°C (77°F) in SI units, or the mass of a cubic foot of the material at 25°C (77°F) in inch–pound units.

3.1.2. *residual pressure, as employed by this test method*—the pressure in a vacuum vessel when vacuum is applied.

3.1.3. *specific gravity, as determined by this test method*—the ratio of a given mass of material at 25°C (77°F) to the mass of an equal volume of water at the same temperature.

4. SUMMARY OF TEST METHOD

4.1. A weighed sample of oven-dry HMA in the loose condition is placed in a tared vacuum container Sufficient water at a temperature of 25 ± 0.5°C (77 ± 0.9°F) is added to completely submerge the sample. Vacuum is applied for 15 ± 2 min to gradually reduce the residual pressure in the vacuum container to 3.7 ± 0.3 kPa (27.5 ± 2.5 mm Hg). At the end of the vacuum period, the vacuum is gradually released. The volume of the HMA sample is obtained either by immersing the vacuum container with the sample into a water bath and determining the mass (Section 13.1) or by filling the vacuum container level full of water and determining the mass in air (Section 13.2). At the time of weighing, the temperature is measured as well as the mass. From the mass and volume measurements, the specific gravity or density at 25°C (77°F) is calculated. If the temperature employed is different than 25°C (77°F), an appropriate correction is applied.

5. SIGNIFICANCE AND USE

5.1. The theoretical maximum specific gravities and densities of HMA are intrinsic properties whose values are influenced by the composition of the mixtures in terms of types and amounts of aggregates and asphalt materials.

5.1.1. These properties are used to calculate percent air voids in compacted HMA.

5.1.2. These properties provide target values for the compaction of HMA.

5.1.3. These properties are essential when calculating the amount of asphalt binder absorbed by the internal porosity of the individual aggregate particles in HMA.

6. APPARATUS

6.1. Follow the procedures for performing equipment calibrations, standardizations, and checks found in PP 57.

6.2. *Vacuum Container*:

6.2.1. The vacuum containers described must be capable of withstanding the full vacuum applied, and each must be equipped with the fittings and other accessories required by the test procedure being employed. The opening in the container leading to the vacuum pump shall be covered by a piece of 0.075-mm (No. 200) wire mesh to minimize the loss of fine material.

6.2.2. The capacity of the vacuum container should be between 2000 and 10,000 mL and depends on the minimum sample size requirements given in Section 7.2. Avoid using a small sample in a large container.

6.2.3. *Vacuum Bowl*—Either a metal or plastic bowl with a diameter of approximately 180 to 260 mm (7 to 10 in.) and a bowl height of at least 160 mm (6.3 in.) equipped with a transparent cover fitted with a rubber gasket and a connection for the vacuum line.

6.2.4. *Vacuum Flask for Mass Determination in Air Only (Section 13.2)*—A thick-walled volumetric glass flask and a rubber stopper with a connection for the vacuum line.

6.2.5. *Pycnometer for Mass Determination in Air Only*—A glass, metal, or plastic pycnometer.

6.3. *Balance*—A balance conforming to the requirements of AASHTO M 231, Class G 2. The balance shall be standardized at least every 12 months.

6.3.1. For the mass determination-in-water method (Section 13.1), the balance shall be equipped with a suitable apparatus and holder to permit determining the mass of the sample while suspended below the balance. The wire suspending the holder shall be the smallest practical size to minimize any possible effects of a variable immersed length.

6.4. *Vacuum Pump or Water Aspirator*—Capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm Hg).

6.4.1. When a vacuum pump is used, a suitable trap of one or more filter flasks, or equivalent, shall be installed between the vacuum vessel and vacuum source to reduce the amount of water vapor entering the vacuum pump.

6.5. *Vacuum Measurement Device*—Residual pressure manometer[1] or vacuum gauge to be connected directly to the vacuum vessel and capable of measuring residual pressure down to 4.0 kPa (30 mm Hg) or less (preferably to zero). The gauge shall be standardized at least annually and be accurate to 0.1 kPa (1 mm Hg.). It shall be connected at the end of the vacuum line using an appropriate tube and either a "T" connector on the top of the vessel or a separate opening (from the vacuum line) in the top of the vessel to attach the hose. To avoid damage, the manometer shall not be situated on top of the vessel.

Note 2—A residual pressure of 4.0 kPa (30 mm Hg) absolute pressure is approximately equivalent to a 97 kPa (730 mm Hg) reading on a vacuum gauge at sea level.

Note 3—Residual pressure in the vacuum container, measured in millimeters of mercury, is the difference in the height of mercury in the Torricellian vacuum leg of the manometer and the height of mercury in the other leg of the manometer that is attached to the vacuum container.

Note 4—An example of a correct arrangement of the testing equipment is shown in Figure 1. In the figure, the purpose of the train of small filter flasks is to trap water vapor from the vacuum container that otherwise would enter the oil in the vacuum pump and decrease the pump's ability to provide adequate vacuum. Insertion of a valve to isolate the line to each vacuum chamber can reduce wear on the bleeder valve atop each chamber and assist in tracing sealing leaks.

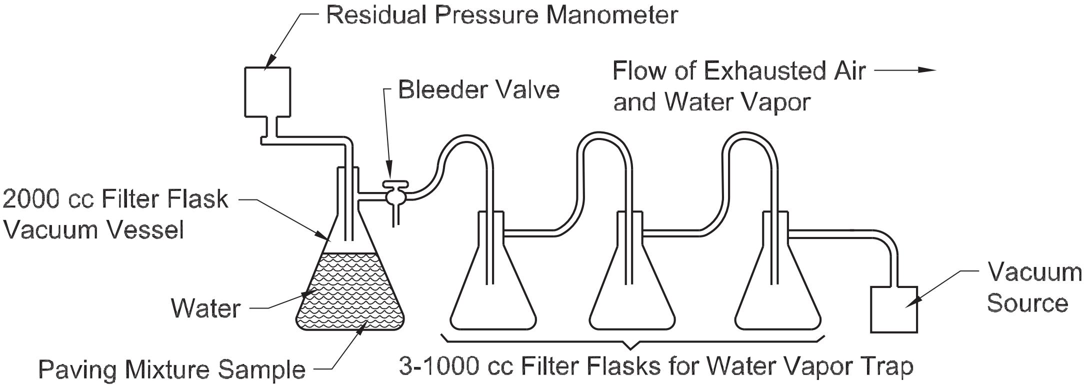

Figure 1—Example of Correct Arrangement of Testing Apparatus

6.6. *Bleeder Valve*—attached to the vacuum train to facilitate adjustment of the vacuum being applied to the vacuum container.

6.7. *Thermometric Device (Mass Determination in Air)*—A liquid-in-glass thermometer or other thermometric device, accurate to 0.5°C (1°F), of suitable range with subdivisions of 0.5°C (1°F). The thermometric device shall be standardized at the test temperature at least every 12 months.

6.8. *Water Bath*:

6.8.1. For vacuum bowls, a water bath capable of maintaining a constant temperature between 20 and 30°C (68 and 86°F) is required. (See Appendix X for a method for correcting the theoretical maximum specific gravity to 25°C (77°F) when measurements are made at temperatures other than 25°C (77°F).

6.8.2. *Thermometric Device (Mass Determination in Water)*—A liquid-in-glass thermometer or other thermometric device, accurate to 0.5°C (1°F) shall be used to measure the temperature of the water bath. The thermometric device shall be standardized at least every 12 months.

6.8.3. When using the mass determination-in-water technique (Section 13.1), the water bath must be suitable for immersion of the suspended container with its deaerated sample.

6.9. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 135 ± 5°C (275 ± 9°F) or 105 ± 5°C (221 ± 9°F).

6.9.1. *Thermometric Device*—A liquid-in-glass thermometer or other thermometric device accurate to 3°C (5°F) shall be used to measure the temperature of the oven. The thermometric device shall be standardized at least every 12 months.

6.10. *Protective Gloves*—used when handling glass equipment under vacuum.

7. SAMPLING

7.1. Obtain the sample in accordance with T 168.

7.2. The size of the sample shall conform to the following requirements. Samples larger than the capacity of the container may be tested a portion at a time.

Table 1—Minimum Sample Sizes

Nominal Maximum Aggregate Size, mm	Minimum Sample Size, g
37.5 or greater	4000
19 to 25	2500
12.5 or smaller	1500

8. STANDARDIZATION OF FLASKS, BOWLS, AND PYCNOMETERS

8.1. For the mass determination-in-water method (Section 13.1), standardize the vacuum bowls for temperature correction by determining the mass of each container when immersed in water over the range of water bath temperatures likely to be encountered in service (Figure 2).

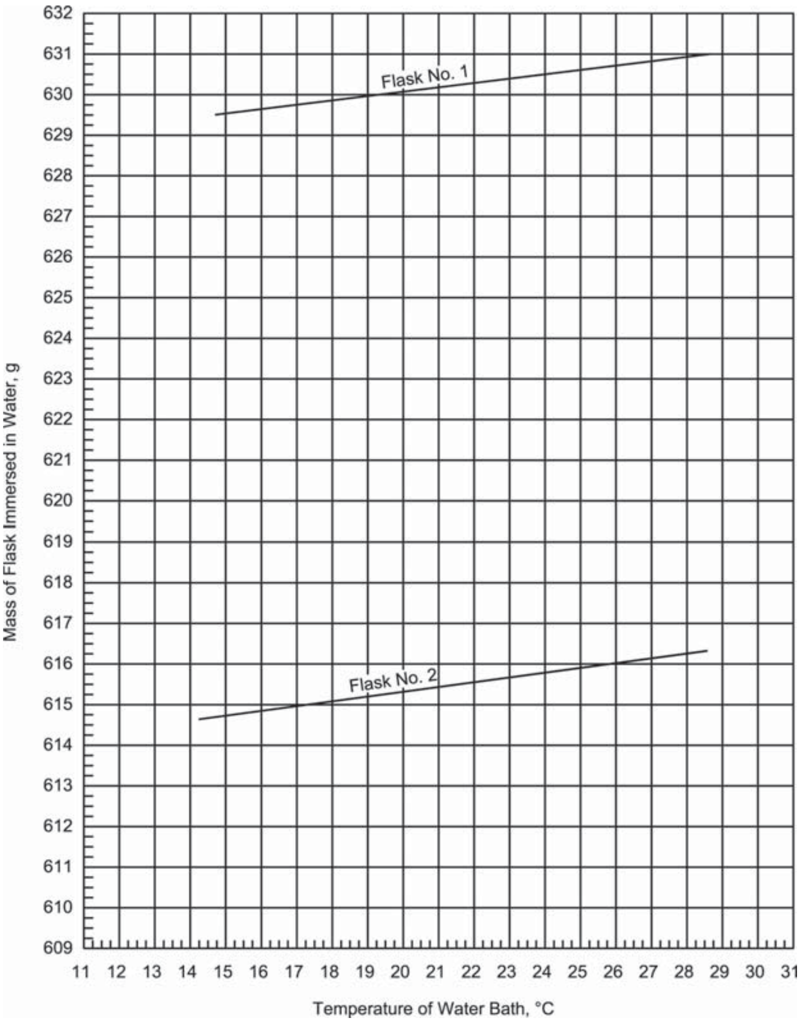

Figure 2—Example Standardization Curve for Volumetric Flask

8.2. For the mass determination-in-air method (Section 13.2), standardize the volumetric flasks or pycnometers for temperature correction by determining the mass of the container when filled with water over the range of water bath temperatures likely to be encountered in service (Figure 3). When standardized at 25 ± 0.5°C (77 ± 0.9°F) designate this mass as *D*. Accurate filling may be ensured by the use of a glass cover plate.

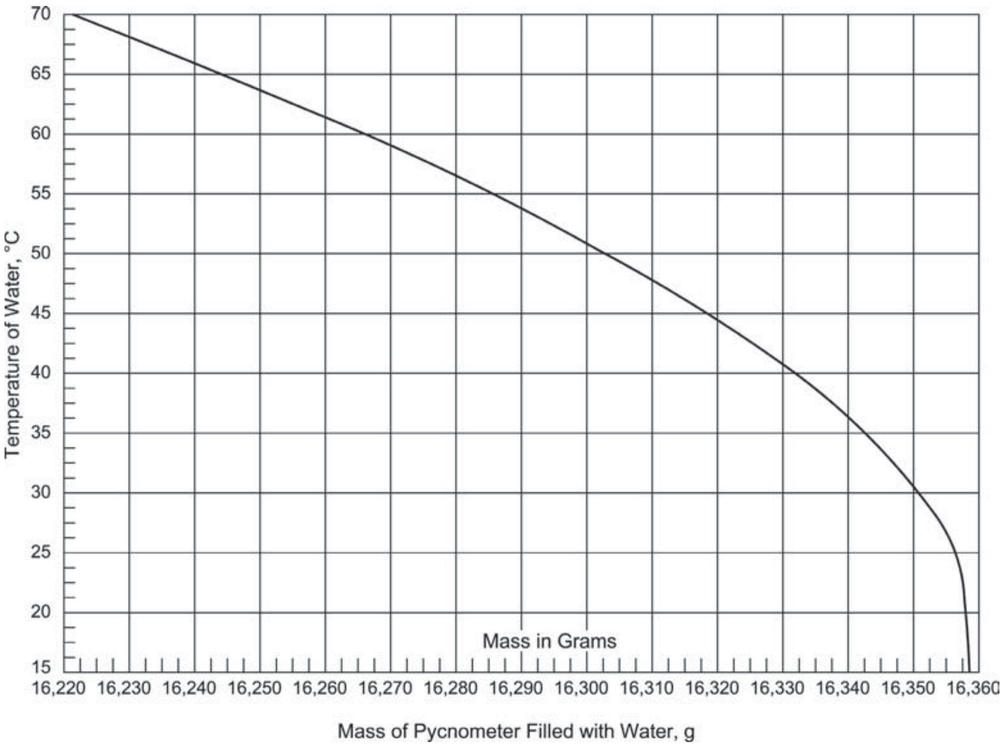

Figure 3—Example Standardization Curve for Pycnometer

8.3. Standardize the large-size plastic pycnometer by accurately determining the mass of water required to fill it over a range of temperature from about 20 to 65°C (70 to 150°F), and construct a standardization curve of mass versus temperature as shown in Figure 3. Care should be taken to follow exactly the same procedure in standardization as in conducting a test.

8.3.1. The following filling procedure may be used for the model with a latched lid and vented stopper. The domed lid is latched in place and the pycnometer nearly filled with water. Leave about 50 mm (2 in.) empty. The release of air bubbles may be facilitated by applying vacuum and by dropping first one side then the other of the pycnometer about 10 mm ($^1/_2$ in.) above a hard, flat surface. This vacuum application and bubble release procedure should take about 10 min so that the temperature equilibrium between the shell and the water approximates that attained when performing a test. The final amount of water is then gently poured in until the level is about halfway up the neck. Any air bubbles caught against the dome that cannot be released by jarring or by swirling the water may be "pricked" or pushed to the surface with a bent wire or other suitable device. Insert the vented stopper using only enough force to just seat the stopper and immediately wipe the excess water off the top.

8.3.2. For the models with a quick-disconnect vacuum line and unlatched lid, the filling procedure is as follows. With the inlet valve closed, apply a vacuum of about 30 kPa (225 mm Hg). Open the inlet valve slowly letting water in until the level reaches 25 mm (1 in.) below the top of the dome and close the valve. Continue applying vacuum and release the bubbles by jarring and rapping the vessel with a rubber mallet. Slowly open the inlet valve and allow more water in until the water overflows into the aspirator (vacuum) line and then close the valve. This vacuum application and bubble release procedure should take about 10 min so that the temperature equilibrium between the shell and the water approximates that attained when performing a test. Disconnect the vacuum line by pulling it out at the quick-disconnect joint below the gauge.

8.3.3. Wipe the outside of the pycnometer dry, determine the mass of the full pycnometer and measure the water temperature.

Note 5—The shape of the standardization curve is a function of two opposing factors that can be rationally defined. As the temperature is increased, the container itself expands (adding mass—"Pycnometer" line in Figure 4) and the density of the contained water decreases (resulting in loss of mass—"Water" line in Figure 4). These relationships are shown in Figure 4 for a typical large-size pycnometer. The "Water" curve may be constructed by multiplying the volume at 25°C (77°F) by the difference between the density of water at 25°C (77°F), which is 0.9970, and the density of water at the standardization temperature (see Equation 1).

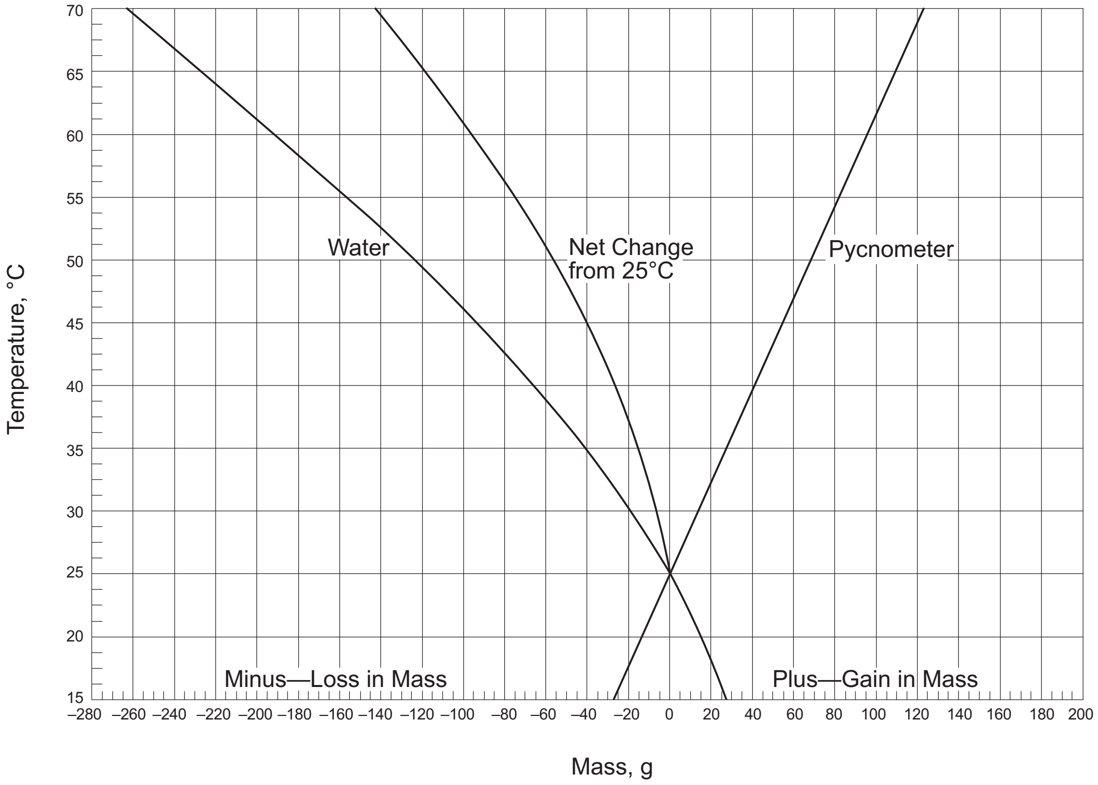

Figure 4—Effect of Change in Density of Water and Volume of Pycnometer with Change in Temperature

$$\text{Difference Due to Water Expansion} = V_{25}(0.9970 - dw)$$

$$\text{Since } V_{25} = W_{25} / 0.9970$$

$$V_{25}(0.9970 - dw) \text{ reduces to } W_{25}\left(1 - \frac{dw}{0.9970}\right) \qquad (1)$$

where:

V_{25} = volume of water to fill a container at 25°C (77°F), cm$^{3;}$

W_{25} = mass of water to fill a container at 25°C (77°F), g; and

dw = density of water at the standardization temperature, Mg/m^3.

The rate of change in capacity of the container due to thermal expansion of the pycnometer itself is essentially constant over the temperature range from 20 to 65°C (70 to 150°F). Thus, the "Pycnometer" line in Figure 4 can be drawn through the 0 at 25°C (77°F) point knowing only the slope of the straight line relationship. The slope can be established by averaging at least five standardization mass determinations at some elevated temperature, adding the loss due to water expansion and subtracting the mass at 25°C (77°F), W_{25}, to give the gain in capacity due to expansion of the container. The difference in mass divided by the difference in temperature is the slope of the "Pycnometer" line. For a polycarbonate pycnometer of about 13,500-mL capacity, the slope thus established was 2.75 g/°C (1.53 g/°F). This value is believed to be typical and reasonably constant.

The bending of the standardization curve (Figure 3) due to these offsetting thermal factors thus minimizes experimental error due to temperature effects in the normal working range, 25°C (77°F), for both the volumetric flask and the pycnometer containers. Defining the standardization curve makes it possible to correct for temperature, rather than "bringing the container and sample to temperature" thereby eliminating the cost of a water bath and making it feasible to improve accuracy by testing larger samples and to materially reduce the testing time.

8.4. While standardization of the flask or either pycnometer need to be performed only once, the standardization should be checked occasionally, particularly at 25°C (77°F). The equipment must be kept clean and free from any accumulation that would change the mass if the volume standardization is to remain constant. Care should be taken to use only neutral solvents, especially with plastic containers; glass vessels should not be subjected to high vacuum if they are scratched or damaged.

9. SAMPLE PREPARATION

9.1. Separate the particles of the HMA sample by hand, taking care to avoid fracturing the aggregate, so that the particles of the fine aggregate portion are not larger than 6.3 mm ($^1/_4$ in.). If an HMA sample is not sufficiently soft to be separated manually, place it in a pan, and warm it in an oven until it can be separated as described.

9.2. Samples prepared in a laboratory shall be conditioned and dried in an oven at 135 ± 5°C (275 ± 9°F) for a minimum of 2 h or as appropriate to match the mix design procedure being used. Longer drying time may be necessary for the sample to achieve a constant mass (mass repeats within 0.1 percent). HMA which has not been prepared in a laboratory with oven-dried aggregates shall be dried to a constant mass at a temperature of 105 ± 5°C (221 ± 9°F). This drying and conditioning operation shall be combined with any warming described in Section 9.1.

Note 6—The minimum 2 h time in the oven is specified as the short-term conditioning time for laboratory-prepared specimens. The short-term conditioning at the specified temperature is especially important when absorptive aggregates are used. This short-term conditioning will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced HMA should not be short-term conditioned since absorption takes place during production.

9.3. Cool the sample to room temperature, and place it in a tared and standardized flask, bowl or pycnometer. The sample is to be placed directly into a vacuum container. A container within a container is not to be used. Determine the mass and designate the net mass of the sample as *A*. Add sufficient water at a temperature of approximately 25°C (77°F) to cover the sample completely.

Note 7—The release of entrapped air may be facilitated by the addition of a suitable wetting agent such as Aerosol OT in concentration of 0.001 percent or 0.2 g in 20 L of water. This solution is then diluted by about 20:1 to make a wetting agent of which 5 to 10 mL may be added to the apparatus.

TEST METHOD A—MECHANICAL AGITATION

10. APPARATUS

10.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Method A:

10.1.1. *Mechanical Shaker*—Shaker for removing air from asphalt mix.

11. PROCEDURE

11.1. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mm Hg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents using the mechanical device during the vacuum period. Glass vessels should be shaken on a resilient surface such as a rubber or plastic mat, and not on a hard surface, so as to avoid excessive impact while under vacuum.

11.2. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mm Hg) per second and proceed with one of the mass determination methods in Section 13.

TEST METHOD B—MANUAL AGITATION

12. PROCEDURE

12.1. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mm Hg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents during the vacuum period by vigorously shaking at intervals of about 2 min. Glass vessels should be shaken on a resilient surface such as a rubber or plastic mat, and not on a hard surface, so as to avoid excessive impact while under vacuum.

12.2. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mm Hg) per second and proceed with one of the mass determination methods in Section 13.

13. MASS DETERMINATION

13.1. *Mass Determination in Water*—Suspend the container and contents in the water bath and determine the mass after a 10 ± 1 min immersion. Measure the water bath temperature, and if different from 25 ± 1°C (77 ± 2°F), correct the mass to 25°C (77°F) using the standardization temperature adjustment developed in Section 8.1. Designate the mass of the sample in water at 25°C (77°F) as C.

Note 8—Instead of using a chart like Figure 2 to establish the mass correction for the temperature of the vacuum vessel submerged by itself in the water bath, this correction can be easily established by rapidly and completely emptying the vacuum container immediately following the final mass determination, and then without delay, determining the mass of the vessel by itself when totally submerged in the water bath.

13.2. *Mass Determination in Air*—Fill the flask or any one of the pycnometers with water and adjust the contents to a temperature of 25 ± 1°C (77 ± 2°F). Determine the mass of the container and contents, completely filled, in accordance with Section 8.2 within 10 ± 1 min after completing Section 11.1 or 12.1. Designate this mass as E.

Note 9—See Appendix X1 for correcting the theoretical maximum specific gravity when measurements are made at temperatures other than 25°C (77°F).

14. CALCULATION

14.1. Calculate the theoretical maximum specific gravity of the sample at 25°C (77°F) as follows:

14.1.1. *Mass Determination in Water*:

$$\text{Theoretical Maximum Specific Gravity} = \frac{A}{A - C} \qquad (2)$$

where:

A = mass of the oven-dry sample in air, g; and

C = mass of the water displaced by the sample at 25°C (77°F), g.

14.1.2. *Mass Determination in Air*:

$$\text{Theoretical Maximum Specific Gravity} = \frac{A}{A + D - E} \qquad (3)$$

where:

A = mass of the oven-dry sample in air, g;

D = mass of the container filled with water at 25°C (77°F), g; and

E = mass of the container filled with the sample and water at 25°C (77°F), g.

14.1.3. *Large-Size Plastic Pycnometer Determinations*:

14.1.3.1. If the test temperature is between 22.2 and 26.7°C (72 and 80°F), Equation 3 may be used to calculate specific gravity within a minor amount of error due to thermal effects (0.001 points or less).

14.1.3.2. If the test temperature differs significantly from 25°C (77°F), correct for thermal effects as follows:

$$\text{Specific Gravity} = \frac{A}{(A+F)-(G+H)} \times \frac{dw}{0.9970} \qquad (4)$$

where:

A = mass of the oven-dry sample in air, g;

F = mass of the pycnometer filled with water at the test temperature (Figure 3), g;

G = mass of the pycnometer filled with water and the sample at the test temperature, g;

H = correction for thermal expansion of asphalt (Figure 5), g;

dw = density of water at the test temperature, Curve D in Figure 6, Mg/m^3; and

0.9970 = density of water at 25°C (77°F), Mg/m^3.

The ratio (*dw*/0.9970) is Curve R in Figure 6.

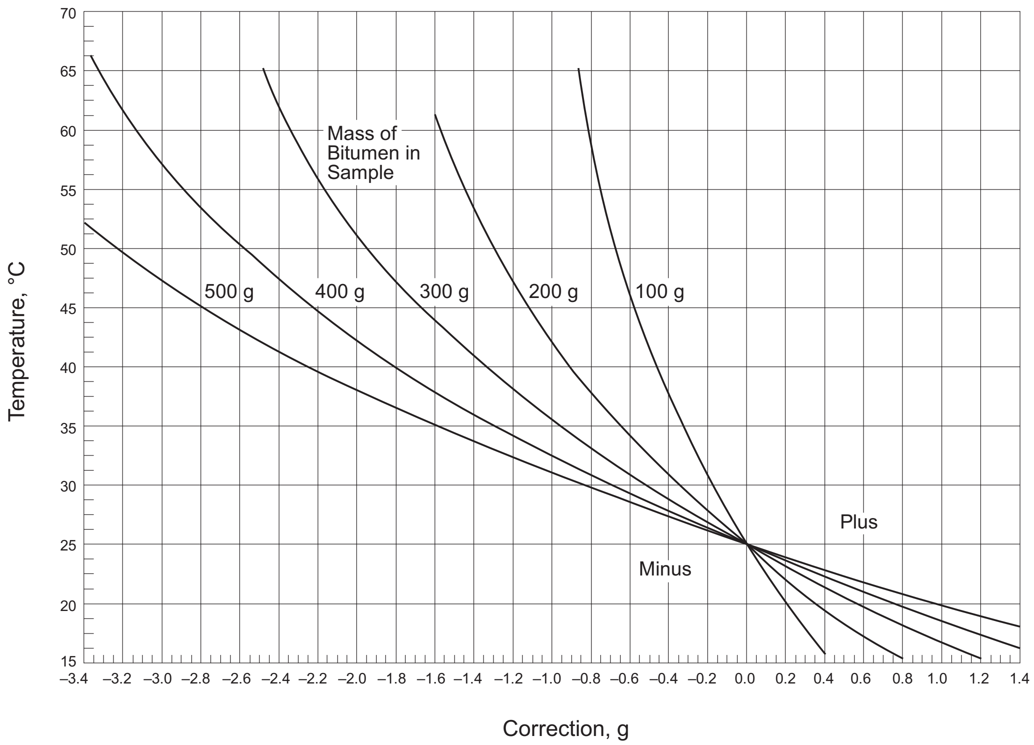

Figure 5—Correction Curves for Expansion of Asphalt, *H*, in Equation 4

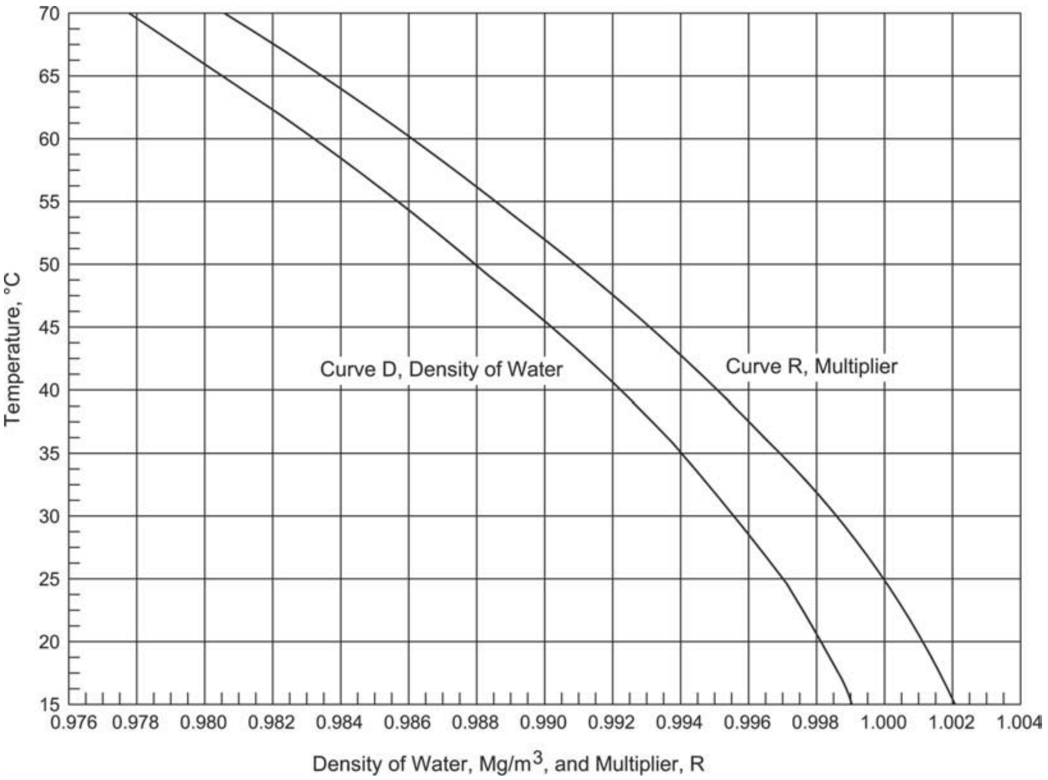

Figure 6—Curves D and R for Equation 4

Note 10—This general procedure for correcting for thermal effects should also be applicable to corresponding measurements made with other suitable containers.

Note 11—When samples are tested a portion at a time, differences between the maximum specific gravities for each portion should be within the precision statements listed in Section 17. If the values are within the precision statements, the specific gravities for each portion shall be averaged. If the values are outside the precision statements, the test shall be performed again.

14.2. *Theoretical maximum density at 25°C (77°F)*:

14.2.1. Calculate the corresponding theoretical maximum density at 25°C (77°F) as follows:

Theoretical maximum density at 25°C (77°F) = theoretical maximum specific gravity × 997.1 kg/m^3 in SI units, or

Theoretical maximum density at 25°C (77°F) = theoretical maximum specific gravity × 62.245 lb/ft^3 in inch–pound units.

where:

The density of water at 25°C (77°F) = 997.1 kg/m^3 in SI units or 62.245 lb/ft^3 in inch–pound units.

15. SUPPLEMENTAL PROCEDURE FOR MIXTURES CONTAINING POROUS AGGREGATE

Note 12—Experiments indicate that this supplemental procedure has an insignificant effect on the test results if the HMA contains individual aggregate with a water absorption below 1.5 percent.

15.1. If the pores of the aggregates are not thoroughly sealed by an asphalt film, they may become saturated with water during the application of vacuum. To determine if this condition has occurred, proceed as follows after completing Section 13.1 or 13.2. Drain the water from the sample. To prevent the loss of fine particles, decant the water through a towel held over the top of the container. Break several large pieces of aggregate and examine the broken surfaces for wetness.

15.2. If the aggregate has absorbed water, spread the sample before an electric fan to remove the surface moisture. Determine the mass at 15 min intervals, and when the loss in mass is less than 0.05 percent for this interval, the sample may be considered to be surface dry. This procedure requires about 2 h and shall be accompanied by intermittent stirring of the sample. Break conglomerations of HMA by hand. Take care to prevent loss of the HMA particles.

15.3. To calculate the specific gravity of the sample, substitute the final surface-dry mass determined in Section 15.2 for *A* in the denominator of Equation 2 or 3 as appropriate.

16. REPORT

16.1. *Report the following information*:

16.1.1. Specific gravity and density of the HMA to the nearest 0.001 for specific gravity or nearest 1 kg/m^3 (0.1 lb/ft^3) for density as follows: sp gr 25/25°C (77/77°F) or density at 25°C (77°F),

16.1.2. Type of HMA,

16.1.3. Size of the sample,

16.1.4. Number of samples,

16.1.5. Type of container, and

16.1.6. Type of procedure.

17. PRECISION

17.1. Criteria for judging the acceptability of specific gravity test results obtained by this test method are given in the following table:

Table 2—Precision Estimates

Test and Type Index	Standard Deviation (1s)	Acceptable Range of Two Results (d2s)
Test results obtained without use of Section 15		
Method A [a]		
Single-operator precision	0.0051	0.014
Multilaboratory precision	0.0084	0.024
Method B [b]		
Single-operator precision	0.0064	0.018
Multilaboratory precision	0.0103	0.029

[a] Basis of estimate: 1 replicate, 1 material, 344 laboratories.

[b] Basis of estimate: 1 replicate, 1 material, 134 laboratories.

17.2. The figures given in Column 2 are the standard deviations that have been found to be appropriate for the conditions of the test described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. Multi-laboratory precision has not been verified for 4500-mL or larger pycnometers.

17.3. The values in Column 3 are the acceptable range for two tests. When more than two results are being evaluated, the range given in Column 3 must be increased. Multiply the standard deviation(s) in Column 2 by the multiplier given in Table 1 of ASTM C 670 for the number of actual tests.

Example for three tests: 0.004 × 3.3 = 0.013.

Additional guidance and background is given in ASTM C 670.

APPENDIX

(Nonmandatory Information)

X1. THEORETICAL MAXIMUM SPECIFIC GRAVITY FOR LOOSE HMA

X1.1. *Scope*:

X1.1.1. This appendix has two objectives:

X1.1.1.1. To indicate a method for correcting the theoretical maximum specific gravity to 25°C (77°F) when measurements are made at temperatures other than 25°C (77°F).

X1.1.1.2. To indicate the range of temperature in °C above or below 25°C (77°F) within which no temperature correction is required, because the measured theoretical maximum specific gravity values are shown to be 0.0004 or less away from the value determined at 25°C (77°F).

X1.2. *Indicated Values*:

X1.2.1. The following example values are indicated for the theoretical maximum specific gravity of a loose HMA sample:

X1.2.1.1. Mass of the loose HMA sample = 1251.3 g.

X1.2.1.2. Volume of the loose HMA sample at 25°C (77°F) = 492.77 mL.

X1.2.1.3. Asphalt binder content = 5.0 percent of total mix.

X1.2.1.4. Specific gravity of the asphalt at 25°C (77°F) = 1.029.

X1.2.1.5. Combined bulk specific gravity of the aggregate = 2.714.

X1.2.1.6. Cubical coefficient of expansion of the asphalt binder at 20°C (68°F) = 6.2×10^{-4} mL/mL/°C (ASTM D 4311).

X1.2.1.7. Cubical coefficient of expansion of the aggregate at 20°C (68°F) = 2.2×10^{-5} mL/mL/°C.[2]

X1.3. *Basis of Calculation for One Gram of Loose HMA at 20°C (68°F)*:

X1.3.1. Mass of the asphalt binder = 0.05 g.

X1.3.2. Volume of the asphalt binder = 0.05/1.029 = 0.0486 mL.

X1.3.3. Mass of the aggregate = 0.95 g.

X1.3.4. Volume of the aggregate = 0.95/ 2.714 = 0.3500 mL.

X1.3.5. Volume of the asphalt binder plus aggregate in one gram of loose HMA at 20°C (68°F) = 0.0486 + 0.3500 = 0.3986 mL.

X1.4. *Basis of Calculation for Volume Change of One Gram of Loose HMA for1°C (2°F) from 20°C (68°F)*:

X1.4.1. Volume change for the asphalt binder = $6.2 \times 10^{-}4 \times 0.0486 = 0.3013 \times 10^{-4}$ mL = 3.0130×10^{-5} mL.

X1.4.2. Volume change for the aggregate = $2.2 \times 10^{-5} \times 0.3500 = 0.77 \times 10^{-5}$ mL.

X1.4.3. Volume change for of one gram of loose HMA for 1°C (2°F) change in temperature from 20°C (68°F) = $3.0130 \times 10^{-5} + 0.7700 \times 10^{-5} = 3.7830 \times 10^{-5}$ mL.

X1.5. *Volume Correction*:

X1.5.1. For a difference in water temperature of 1°C (2°F) above or below 20°C (68°F), a correction to the volume of water displaced by one gram of loose HMA can be made by the following equation:

$$\text{Correction} = \Delta T \times K_T \times V_T \text{ mL} \qquad (X1.1)$$

where:

ΔT = 1°C (2°F),

K_T = volume change of 1 g of loose HMA for a 1°C (2°F) change in temperature above or below 20°C (68°F) = 3.7830×10^{-5} mL, and

V_T = volume of water for a corresponding 1251.3-g mass of loose HMA at a test temperature of 20°C (68°F) = 492.77 mL.

Substituting these values into the equation gives the following:

Correction = $1 \times 3.7830 \times 10^{-5} \times 492.77 = 0.01864$ mL/g at 20°C (68°F).

X1.6. Table X1.1 illustrates an example of the influence of temperature corrections. For a measured volume and a given mass of HMA tested at specific temperatures, this table relates these influences to the specific gravity of the HMA.

Table X1.1—Influence of Temperature Corrections to a Measured Volume at 20°C of a Given Mass of Loose Paving Mixture, to Provide the Required Theoretical Maximum Specific Gravity at 25°C

Temperature, °C	Volume of HMA at 20°C (68°F), mL	Volume Correction for Temp Change	Corrected Volume of HMA at 20°C (68°F), mL	Mass of HMA, g	Specific Gravity of HMA
1	*2*	*3*	*4 = 2 + 3*	*5*	*6 = 5/4*
31	492.77	0.2046	492.975	1251.3	2.5383
30[a]	492.77	0.1860	492.956	1251.3	2.5384
29[a]	492.77	0.1674	492.937	1251.3	2.5385
28[a]	492.77	0.1488	492.919	1251.3	2.5386
27[a]	492.77	0.1302	492.900	1251.3	2.5386
26[a]	492.77	0.1116	492.882	1251.3	2.5387
25[a]	492.77	0.0930	492.863	1251.3	2.5388
24[a]	492.77	0.0744	492.844	1251.3	2.5389
23[a]	492.77	0.0558	492.826	1251.3	2.5390
22[a]	492.77	0.0372	492.807	1251.3	2.5391
21[a]	492.77	0.0186	492.789	1251.3	2.5392
20	492.77	0.0000	492.772	1251.3	2.5393
19	492.77	–0.0186	492.751	1251.3	2.5394

[a] Range less than 0.0005.

Notes: Strictly speaking, the above table shows that the specific gravity for this particular mix, as measured at 20°C (68°F), just fails to meet the corrected theoretical maximum specific gravity at 25°C (77°F), 2.5388 versus 2.5393, that is, by 0.0005, and that a temperature correction would be required.
If the measurement for volume had been made at 21°C (70°F), the table indicates that no temperature correction would have been necessary, because the measurement at 21°C (70°F) would have satisfied the theoretical maximum specific gravity at 25°C (77°F), 2.5388 versus 2.5392, a difference of less than 0.0005.

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[1] Sargent Welch, 39745 Gauge-Vacuum, Mercury Prefilled (or equivalent).

[2] Krebs and Walker, *Highway Materials*, McGraw-Hill, Inc., 1971, *p*. 274.

Standard Method of Test for

Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

AASHTO Designation: T 227-02 (2006)
ASTM Designation: D 1298-99 (2005)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

AASHTO Designation: T 227-02 (2006)
ASTM Designation: D 1298-99 (2005)

AASHTO T 227-02 (2006) is identical to ASTM D 1298-99 (2005) except for the following provision:

1. Insert a note after Section 5.2 containing the following:

   Note: This method may be used for the determination of the specific gravity of tars by use of an additional appropriate hydrometer.

Standard Method of Test for

Specific Gravity of Semi-Solid Asphalt Materials

AASHTO Designation: T 228-09
ASTM Designation: D 70-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Specific Gravity of Semi-Solid Asphalt Materials

AASHTO Designation: T 228-09
ASTM Designation: D 70-08

AASHTO T 228-09 is identical to ASTM D 70-08 except for the following provisions:

1. Replace all references to the ASTM standards listed in the following table with the corresponding AASHTO standards:

Referenced Standards

ASTM	AASHTO
D 140	T 40
D 3142	T 295

2. Add the following to Section 2:

   2.3 *AASHTO Standard*:

   M 231, Weighing Devices Used in the Testing of Materials

3. Add the following sentence to Note 2:

   The terms “relative density” and “specific gravity” are used interchangeably in this standard.

4. Replace Section 6.4 with the following:

   6.4 *Balance*—conforming to the requirements of M 231, Class B.

5. Replace Section 11.2 with the following:

   11.2 Fill the pycnometer with freshly boiled distilled or deionized water at test temperature and place the stopper in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the filled pycnometer in the beaker.

6. Replace the last sentence in Section 12.1 with the following:

   “Do not heat for more than 60 minutes over a flame or hot plate or for more than two hours in an oven, and avoid incorporating air bubbles in the sample.”

7. Replace Section 12.3 with the following:

   12.3 Fill the pycnometer with freshly boiled distilled or deionized water at the test temperature and place the stopper in the pycnometer. Do not allow any air bubbles to remain in the pycnometer. Place the filled pycnometer in the beaker.

8. Replace Section 15 with the following:

   15. **Precision and Bias**

   15.1 *Precision*—Criteria for judging the acceptability of the relative density results obtained by this method are given in Table 1.

   15.1.1 *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the values given in Table 1, Column 3.

15.1.2 *Multilaboratory Precision (Reproducibility)*—The figures in Column 4 of Table 1 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the values given in Table 1, Column 5.

Table 1—Precision Estimates

	Single-Operator		Multilaboratory	
Condition	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]
Asphalt:				
Specific Gravity (15.6°C)	0.0011	0.0032	0.0018	0.0051
Specific Gravity (25°C)	0.0008[b]	0.0021[b]	0.0013[b]	0.0035[b]
Soft Tar Pitch:				
Specific Gravity (15.6°C)	0.0013	0.0038	0.0029	0.0083
Specific Gravity (25°C)	0.00083	0.0023	0.0017	0.0048

[a] These values represent the 1s and d2s limits described in ASTM Practice C 670.

[b] The precision estimates denoted by the superscript “b” are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 104 to 121 laboratories for each of the eight pairs of samples. The analysis included four binder grades: PG 52-34, PG 64-16, PG 64-22, and PG 70-22. Average specific gravities in the analysis ranged from 1.0058 to 1.0428. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note: Values in Table 1 not marked with a superscript “b” are precision estimates retained from ASTM D 70-03, Section 14, Table 1. These values were not part of the scope of the AMRL research activities described with the superscript “b”.

15.2 *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

Standard Method of Test for

Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)

AASHTO Designation: T 240-09[1]
ASTM Designation: D 2872-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)

AASHTO Designation: T 240-09[1]
ASTM Designation: D 2872-04

1. SCOPE

1.1. This test is used to measure the effect of heat and air on a moving film of asphalt binder and to provide residue for additional testing. The effects of this treatment are determined from measurements of the properties of the asphalt binder before and after the test.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- M 320, Performance-Graded Asphalt Binder
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques
- E 644, Standard Test Methods for Testing Industrial Resistance Thermometers

3. SUMMARY OF TEST METHOD

3.1. A moving film of asphaltic material is heated in an oven for 85 minutes at 163°C (325°F). The effects of heat and air are determined from changes in physical test values as measured before and after the oven treatment. The residue from this test is also used for additional testing as required in M 320. An optional procedure is provided for determining the change in sample mass.

3.2. Precision values for this test method have been developed for viscosity at 60°C (140°F), ductility at 15.6°C (60°F), and mass change.

4. SIGNIFICANCE AND USE

4.1. This method indicates the approximate change in properties of asphalt binder during conventional batch plant mixing at about 150°C (302°F) as indicated by viscosity and other rheological measurements. The residue from this test is also used to determine the conformance of an asphalt binder to M 320. It yields a residue which approximates the condition of the asphalt binder immediately after the pavement is constructed. If the mixing temperature differs appreciably from 150°C (302°F), more or less effect on the properties will occur. This method can also be used to determine mass change, which is a measure of asphalt binder volatility and mass changes resulting from oxidation.

5. APPARATUS

5.1. *Oven*—A double-walled electrically heated convection type with inside dimensions as follows: a height of 381 mm (15 in.), a width of 483 mm (19 in.), and a depth (with door closed) of 445 ± 13 mm ($17^1/_2 \pm {}^1/_2$ in.). The door shall contain a symmetrically located window with dimensions of 305- to 330-mm (12- to 13-in.) wide by 203- to 229-mm (8- to 9-in.) high. The window shall contain two sheets of heat-resistant glass separated by an air space. The window should permit an unobstructed view of the interior of the oven. The heating element shall be located below the oven floor and shall be adequate to maintain the required temperature. The oven shall be vented at the top and bottom. The bottom vents shall be located symmetrically to supply incoming air around the heating elements. They shall have an open area of 15.0 ± 0.7 cm^2 (2.31 ± 0.11 $in.^2$). The top vents shall be symmetrically arranged in the upper part of the oven and have an open area of 9.3 ± 0.45 cm^2 (1.45 ± 0.07 $in.^2$).

5.1.1. The oven shall have an air plenum covering the side walls and ceiling, the air space being 38 mm ($1^1/_2$ in.) deep from the walls and ceiling. At a midpoint in the width of the oven and 152 mm (6 in.) from the face of the circular metal carriage to its axis, a squirrel cage-type fan 133.4 mm ($5^1/_4$ in.) outside diameter by 73 mm ($2^7/_8$ in.) wide shall be turned at 1725 r/min by an externally mounted motor. The squirrel cage fan shall be set so that the fan turns in an opposite direction to its vanes. The air flow characteristics of the fan-plenum system shall be suctioned from the floor of the oven through the wall plenums with the air exiting through the fan. Figures 1 and 2 show details of this fan-plenum system.

5.1.2. The oven shall be equipped with a proportional temperature controller capable of maintaining a temperature of 163 ± 1.0°C (325 ± 1.8°F). The sensing element of the controller may be placed at any location that enables the oven to maintain temperature control as specified in this standard. The temperature controller shall be capable of bringing the fully loaded oven back to the test temperature within a 10-minute period after insertion of the samples in a preheated oven.

5.1.3. A thermometer shall be hung from or affixed to a mounting in the ceiling which is 51 mm (2 in.) from the right side of the oven at a midpoint in the depth of the oven so that the bulb of the thermometer or the tip of the sensor of the alternative thermometric device is within 25 mm (1 in.) of an imaginary line level to the shaft of the circular metal carriage.

5.1.4. The oven shall be provided with a 305-mm (12-in.) diameter vertical circular carriage—see Figure 2 for details. This carriage shall be provided with suitable openings and clips for firmly holding eight glass containers—see Figure 3—in a horizontal position. The vertical carriage shall be mechanically driven through a 19-mm ($^3/_4$-in.) diameter shaft at a speed of 15 ± 0.2 r/min.

5.1.5. The oven shall be equipped with an air jet positioned to blow heated air into each container at its lowest point of travel. The air jet shall have an outlet orifice 1.02 mm (0.04 in.) in diameter (No. 60 drill) connected to a 7.6-m (25-ft) length of 7.9-mm ($^5/_{16}$-in.) O.D. refrigeration copper tubing. This tubing shall be coiled to lie flat on the bottom of the oven and lead to a source of fresh-dried, dust-free, regulated air. The tubing in the bottom of the oven shall be exposed to the plenum of the oven and shall not be covered by aluminum foil or other material.

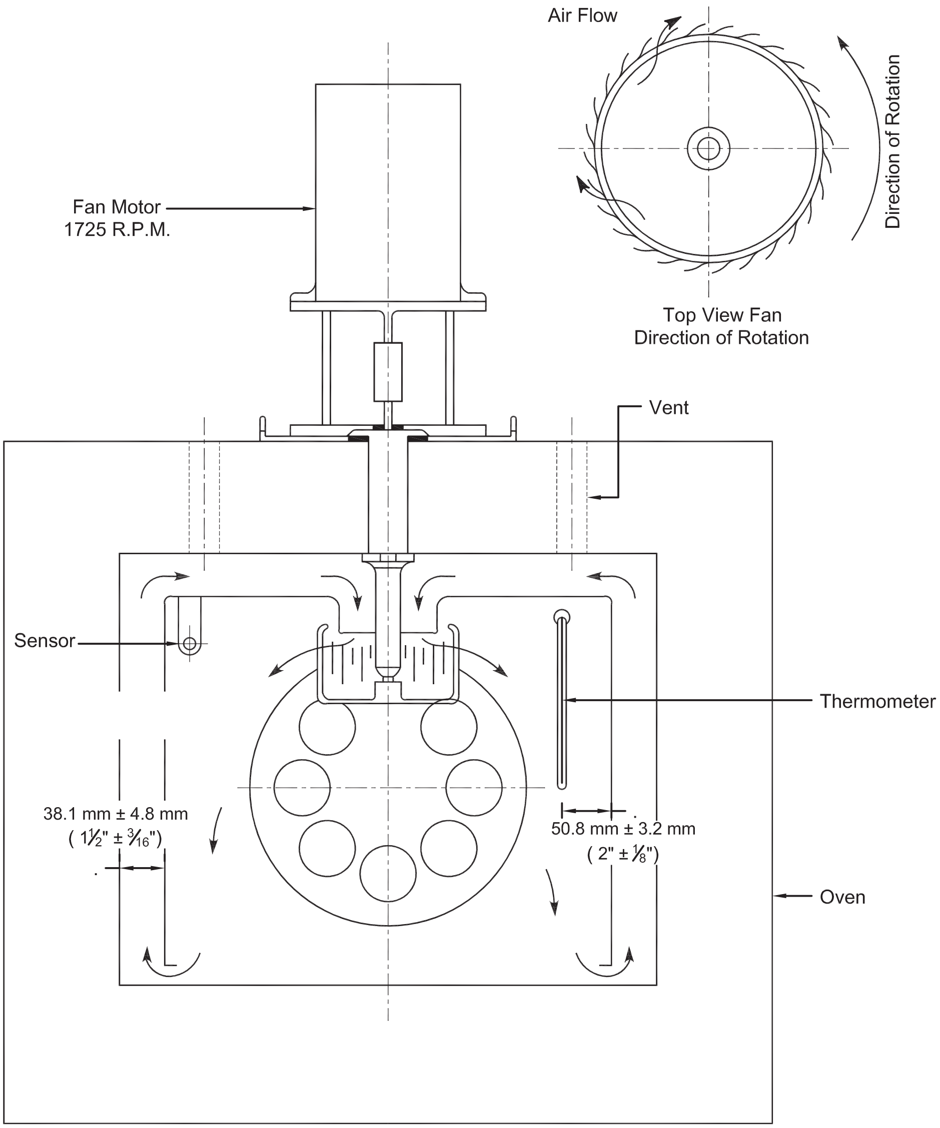

Figure 1—Schematic of Air Flow Front View

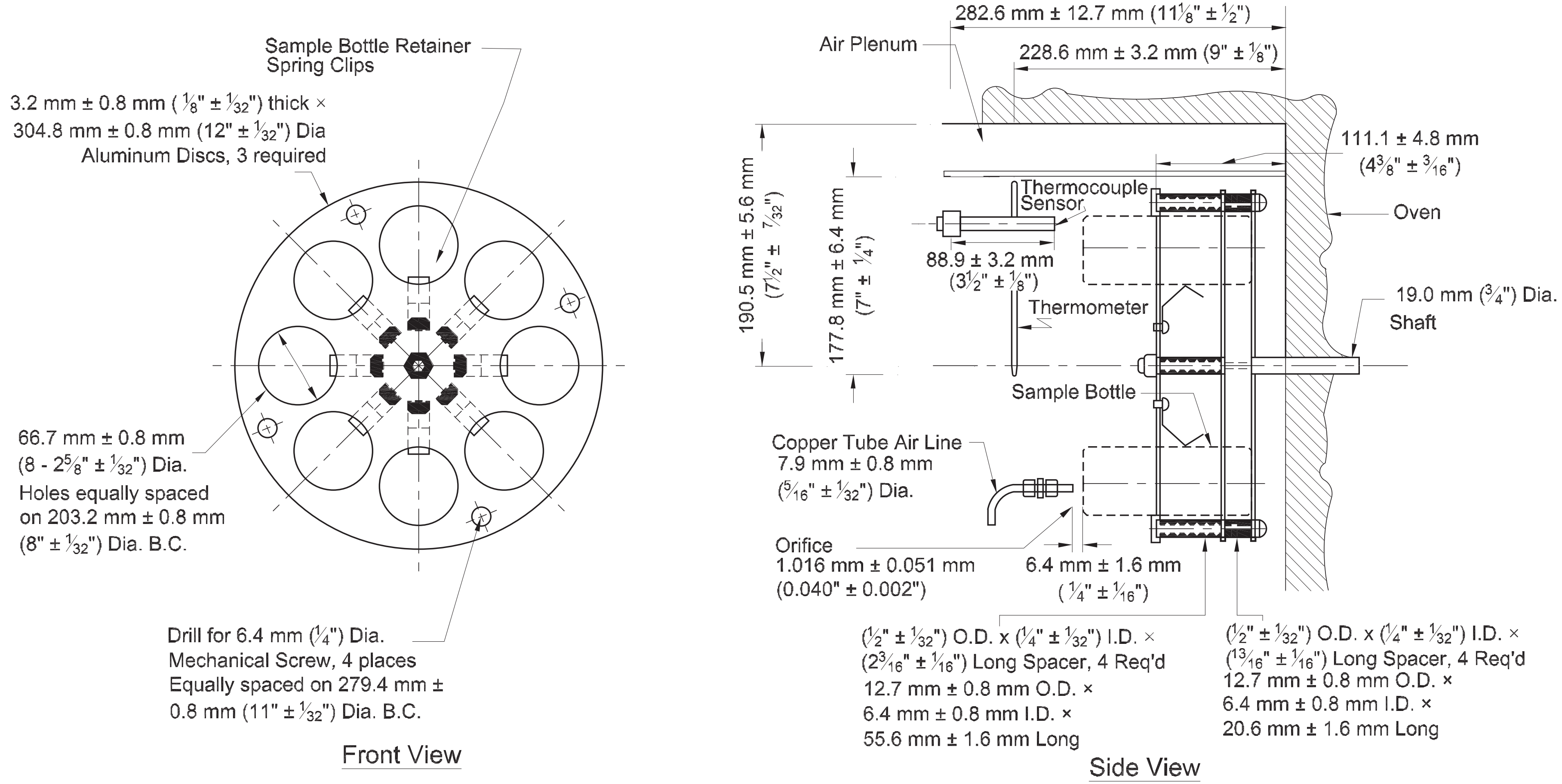

Figure 2—Circular Metal Carriage

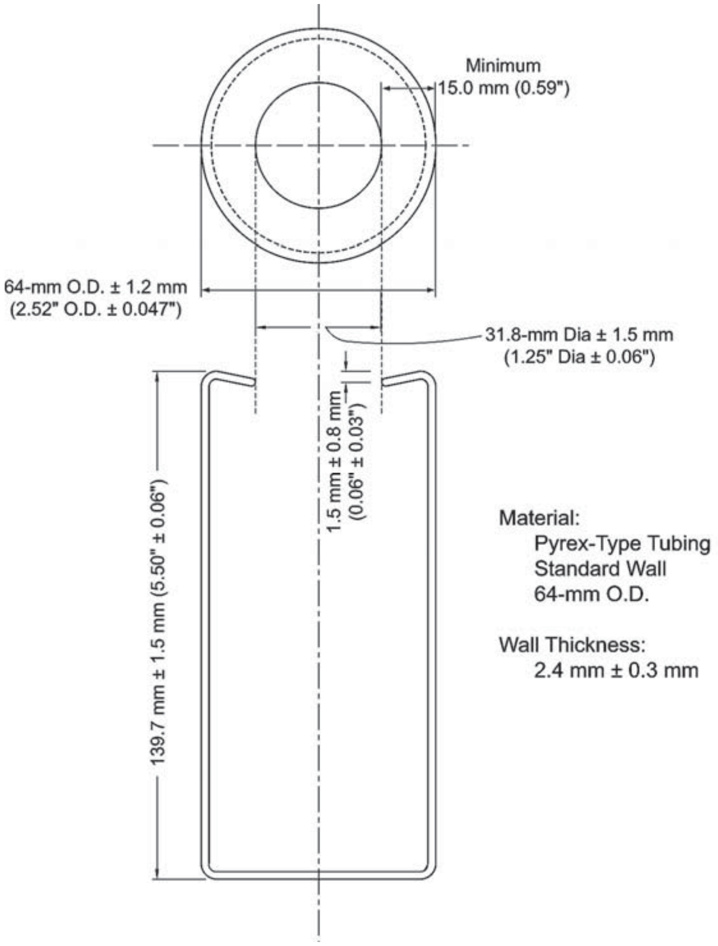

Figure 3—Sample Container

Note 1—Activated Silica Gel treated with an indicator is a satisfactory desiccant for the dried air.

5.2. *Flowmeter*—The flowmeter may be any suitable type capable of measuring the airflow at a rate of 4000 ± 100 mL/min. The flowmeter shall be located downstream of all regulating devices and upstream of the copper coil. The flowmeter shall be positioned so it is maintained at approximately room temperature. The flow meter shall be standardized at least every 12 months using a wet-test meter or other method. This standardization shall be based on airflow exiting the air jet and shall be conducted with the oven off and at room temperature.

5.3. *Thermometer*—An ASTM 13C (13F) thermometer as prescribed in (ASTM E 1 with an accuracy of 0.2°C (0.5°F). The thermometer shall be calibrated according to the requirements specified in R 18. This thermometer shall be used to make all temperature measurements required by this method. In order to reduce the risks associated with thermometer breakage, the thermometer may be fully or partially encapsulated in an optically transparent polymer sheath having a maximum thickness of 0.25 mm (0.01 in.). If a sheath is used, it shall be installed such that there is substantial mechanical contact with the thermometer. The thermometer shall be standardized after installation of the sheath.

5.3.1. The test thermometer may be replaced with an alternative thermometric device, provided the following requirements are met:

5.3.1.1. The thermometric device shall be mounted in the same position as the test thermometer it replaces.

5.3.1.2. The thermometric device shall (1) have a maximum scale error no greater than that of the test thermometer it replaces, and (2) be capable of indicating temperature within 0.1°C (0.2°F).

5.3.1.3. The thermometric device shall be standardized at the interval specified in R 18. Guidance for performing the standardization is given in ASTM E 220 or E 644.

5.4. *Container*—The container in which the asphalt binder is to be tested shall be of heat-resistant glass, with a smooth interior, conforming to the dimensions shown in Figure 3. Glass may be treated (e.g., frosted) on its exterior for handling purposes.

5.5. *Balance*—If the loss on heating is desired, a Class B balance conforming to the requirements of M 231 is required. If only the residue is desired, a Class G 2 balance conforming to M 231 may be used. The balance shall be standardized according to the requirements specified in R 18.

5.6. *Cooling Rack*—A wire or sheet metal rack, constructed of stainless steel or aluminum, which allows the sample containers to cool in a horizontal position. The rack shall be constructed in a way that allows air to flow freely around each container with at least 25-mm (1-in.) clearance between containers, and at least 25-mm (1-in.) clearance between the containers and any solid surface.

5.7. *Electronic Level (Optional)*—A precision level for measuring the levelness of the support provided by the circular openings in the metal carriage. The length shall be at least 125 mm (5 in.), and the width shall be 30 ± 3 mm (1.2 ± 0.1 in.). The bearing surface of the level shall be ground flat. Resolution, accuracy, and repeatability shall be ±0.1°. The level shall have a hold button freeze so that the level can be read after removing the level from the carriage.

Note 2—An SPI Tronic Digital Level PRO 360 or its equivalent has been found suitable for this purpose. The device may be purchased through local or mail order suppliers of machine tools.

6. PREPARATION OF OVEN

6.1. Position the air outlet orifice so that it is 6.4 mm ($^1/_4$ in.) from the opening of the glass container. The orifice shall also be so positioned that the jet blows horizontally into the center of the container opening when the rotating container is at its lowest position.

6.2. Position the thermometer specified in Section 5.3 so that the end of the bulb of the thermometer is within 25 mm (1 in.) of an imaginary line level to the center of the shaft holding the revolving carriage. If an alternative thermometric device is used, position it as specified in Section 5.3 so that the tip of the sensor is within 25 mm (1 in.) and level to the center of the shaft holding the revolving carriage.

6.3. Adjust the oven so that the horizontal axes of the glass containers, when in position in the carriage, are level to within ±1.0°. This shall be accomplished by checking the carriage, not by checking the level of the oven. A recommended procedure for ensuring that the containers are level to 1.0°is given in the Appendix. Alternative procedures may be used to ensure that the carriage is level to ±1.0. Check for wear in the bearing every 6 months and when the levelness of the carriage is checked.

Note 3—The bearing that supports the metal carriage is subject to wear, and excessive wear is known to allow the carriage to tilt. This affects the levelness of the containers and creates the potential for binder to creep from the bottles.

6.4. Start the fan. The fan shall remain on when the oven heater is on and the oven door is closed. The fan may be stopped when the oven door is opened. Stopping the fan may be accomplished manually, with an electronic door interlock, or through other means.

6.5. Preheat the oven for a minimum of 2 hours prior to testing, with the temperature controller adjusted to the setting that will be used during the test. This setting shall be selected such that when the oven is fully loaded and the air is on, the oven will equilibrate at 163.0 ± 1.0°C (325 ± 1.8°F), as indicated by the test thermometer.

Note 4—Because the presence of sample containers affects the temperature distribution in the oven, containers must be present in the oven when the controller setting is determined. The use of empty containers is acceptable for this purpose.

7. PROCEDURE

7.1. The sample as received shall be free of water. Heat the sample in its container with a loosely fitted cover in an oven not to exceed 163°C (325°F) for the minimum time necessary to ensure that the sample is completely fluid. Manually stir the sample but avoid incorporating air bubbles.

7.2. Pour 35 ± 0.5 g of the sample into each of the number of glass containers required to provide sufficient material for the tests that are to be performed on the residue.

7.3. Immediately after pouring the sample into a glass container, turn the container to a horizontal position. Rotate the container slowly for at least one full rotation, and attempt to precoat its cylindrical surface. It is not necessary to precoat the open end of the container, and care should be taken to prevent the sample from flowing out of the container during this step. Ensure that the asphalt binder does not coat the central part of the open end of the container. Place the container horizontally in a clean cooling rack that is maintained in a draft-free, room-temperature location away from ovens or other sources of heat.

Note 5—Complete precoating of the cylindrical surface may not be possible for highly modified binders.

Note 6—For maximum precision in determining mass change, the cooling rack should be in a location which is the same temperature and humidity as the balance used for measuring the mass of the containers.

Note 7—Static electricity may cause unstable mass measurements, due in part to the characteristics of the glass sample containers. This problem can be minimized by mounting a passive ion source inside the balance draft shield.

7.4. Allow the glass containers to cool in the cooling rack for at least 60 minutes but no more than 180 minutes before placing the containers in the oven.

7.5. When mass change is being determined, use two separate containers for this determination. After cooling, determine the mass of these containers using an analytical balance having a resolution of 0.001 g or better. Separately place each container vertically on the balance and record the mass to the full resolution of the balance.

7.6. With the oven at operating temperature and the airflow set at 4000 ± 300 mL/min, arrange the containers holding the asphalt binder in the carriage so that the carriage is balanced. Fill any unused spaces in the carriage with empty containers. Close the door, and rotate the carriage assembly at a rate of 15 ± 0.2 r/min. Maintain the glass containers in the oven with the air flowing and the carriage rotating for 85 minutes. The test temperature of 163 ± 1.0°C (325 ± 1.8°F) shall be reached within the first 10 minutes—otherwise discontinue the test.

7.7. At the conclusion of the testing period, remove any containers for mass change determination, and place them horizontally in the cooling rack. Then remove each remaining container, one at a time, and transfer its contents to a collection container having a capacity at least 30 percent greater than the total expected volume of residue. This transfer shall be accomplished by first pouring out any residue which will flow freely from the container, and then scraping out as much of the remaining residue as practical. While the residue is being removed from each container, the oven door shall remain closed, with the heater power on, the air on, and the remaining samples rotating in the carriage. The final container shall be removed from the oven within 5 minutes of removal of the initial container.

Note 8—Any scraping tool may be used, as long as an average of 90 percent or more of the residue is removed from the sample containers. It has been determined that circumferential scraping tends to be more effective than lengthwise scraping.

7.8. After removing the residue from each of the containers, gently stir the residue in the collection container to homogenize the residue without introducing air into it.

7.9. If the mass change is being determined, allow the designated containers to cool on the cooling rack for at least 60 minutes but not more than 180 minutes. After cooling, determine the mass of these containers using an analytical balance having a resolution of 0.001 g or better. Separately place each container vertically on the balance, and record the mass to the full resolution of the balance.

7.9.1. Make a note on the report if any sample appears to have flowed out of the container. If mass has flowed from the container, do not use the container for mass change determination. The results from one container may be used to determine mass change if mass has flowed from the container. If only one container is used to determine mass change, note it on the report. Use two containers for referee purposes.

Note 9—Some labs have reported problems with the asphalt binder flowing from the container during the test. If this occurs, check the levelness of the circular openings in the carriage and the dimensions of the container. Containers with a small annular ring appear to be particularly susceptible to this problem. Containers that do not comply with the dimensional requirements should be removed from service.

Note 10—To improve mass change precision, the containers used for determining mass change should only be handled with clean gloves or tongs. Transfer to the balance should be done with tongs to prevent contamination and temperature changes which could distort the mass measurement.

8. REPORT

8.1. Report the results from the RTFO test in terms of the physical changes in the asphalt binder brought about by this method. These values are obtained by performing appropriate tests on the asphalt binder before and after the RTFO test.

Note 11—Physical test results required for M 320 are reported as part of the test methods specified in M 320, not as part of this test method.

8.2. When determined, report the average mass change of the material in the two containers as a mass percent of the original material. Report this calculated result to the nearest 0.001 percent. A mass loss shall be reported as a negative number, while a mass gain shall be reported as a positive number.

Note 12—This test can result in either a mass loss or a mass gain. During the test, volatile components and reaction products (primarily water) evaporate (causing a decrease in mass) while oxygen reacts with the sample (causing an increase in mass). The combined effect determines whether the sample has an overall mass gain or an overall mass loss. Samples with a very low percentage of volatile components will usually exhibit a mass gain, while samples with a high percentage of volatile components will usually exhibit a mass loss.

8.3. Report asphalt binder loss from any of the mass change containers. Report if mass change is based on one container.

9. PRECISION AND BIAS

9.1. Criteria for judging the acceptability of the viscosity at 60°C (140°F) and the ductility at 15.6°C (60°F) test results on the residue after heating are given in Table 1. The values given in Column 2 are the standard deviations that have been found to be appropriate for the materials and conditions of test described in Column 1. The values given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. The values given in Column 4 are the coefficients of variation that have been found to be appropriate for the materials and conditions of test described in Column 1. The values given in Column 5 are the limits that should not be exceeded by the difference between the results of two properly conducted tests expressed as a percent of their mean.

Table 1—Precision of Test on Residue

Test Methods	Standard Deviation (1s)	Acceptable Range of Two Results (d2s)	Coefficient of Variation (Percent of Mean) (1s%)	Acceptable Range of Two Results (Percent of Mean) (d2s%)
Single-operator precision:				
Viscosity at 60°C (140°F)	—	—	2.3	6.5
Ductility at 15.6°C (60°F)[a]	3 cm	9 cm	—	—
Multilaboratory precision:				
Viscosity at 60°C (140°F)	—	—	4.2	11.9
Ductility at 15.6°C (60°F)	6 cm	16 cm	—	—

[a] This is based on the analysis of data resulting from tests by 16 laboratories on two asphalt binders ranging from 13 to 30 cm.

9.2. *Precision for Change in Mass*—Criteria for judging the acceptability of change in mass results obtained by this method are given in Tables 2 and 3. Table 2 should be consulted as the final qualifier for precision purposes. Table 3 has been added for the convenience of the user.

9.3. *Single-Operator Precision (Repeatability)*—The equation in Column 2 of Table 2 indicates that the standard deviation of the test results (1s) can be expressed as a function of the mass change (X) for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the value determined by multiplying the 1s estimate determined in Column 2 for the average value of the two results by a factor of 2.83. This is shown in Table 2, Column 3.

9.4. *Multilaboratory Precision (Reproducibility)*—The equation in Column 2 of Table 2 indicates that the standard deviation of the test results (1s) can be expressed as a function of the mass change (X) for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the value determined by multiplying the 1s estimate determined in Column 2 for the average value of the two results by a factor of 2.83. This is shown in Table 2, Column 3.

Table 2—Precision Estimates

Condition	Standard Deviation (1s)[a,b]	Acceptable Range of Two Test Results (d2s)[a,b,c]
Single Operator Precision:		
Mass Loss (%)	1s = 0.0061 + 0.0363(X)	d2s = (0.0061 + 0.0363(X_{avg})) × (2.83)
Multilaboratory Precision:		
Mass Loss (%)	1s = 0.00153 + 0.1365(X)	d2s = (0.00153 + 0.1365(X_{avg})) × (2.83)

[a] These values represent the 1s and d2s limits described in ASTM Practice C 670.

[b] X and X_{avg} should be entered into equations as positive numbers.

[c] The value X_{avg} represents the average value of two test results.

Note 13—The precision estimates given in Table 2 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 166 to 191 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). The samples used in the analysis had an average mass loss ranging from –0.05 to –0.51 percent. The equations for precision estimates are reliable only in situations when the change in mass is negative. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Table 3—Stratified Estimates of Precision

Condition	Standard Deviation (1s)[a]	Acceptable Range of Two Test Results (d2s)[a]
Single Operator Precision:		
Mass Loss (%)		
0.0 to 0.1%	0.0079	0.0224
0.1 to 0.2%	0.0115	0.0327
0.2 to 0.3%	0.0152	0.0429
0.3 to 0.4%	0.0188	0.0532
0.4 to 0.5%	0.0224	0.0635
Multilaboratory Precision:		
Mass Loss (%)		
0.0 to 0.1%	0.0084	0.0236
0.1 to 0.2%	0.0220	0.0623
0.2 to 0.3%	0.0357	0.1009
0.3 to 0.4%	0.0493	0.1395
0.4 to 0.5%	0.0630	0.1781

[a] The values represented in this table are the 1s and d2s limits described as stratified values. Table 2 of this standard should be consulted as the final qualifier for precision purposes.

9.5. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

APPENDIX

(Nonmandatory Information)

X1. RECOMMENDED PROCEDURE FOR DETERMINING THE LEVELNESS OF THE CARRIAGE'S OPENINGS

X1.1 Verify the accuracy and sensitivity of the electronic level as follows:

X1.1.1 *Accuracy*—Place a square glass plate on a rigid bench top and place the level in the center of the glass plate in a direction parallel to one of the sides. If necessary, shim the glass plate so that it does not rock when pressed at its corners. Observe the position of the bubble and shim one edge of the glass plate until the bubble is centered between the markings on the vial. Take a reading. Rotate the level end-for-end and again observe the position of the bubble and take a reading. The readings should not differ by more than 0.2°.

X1.1.2. *Sensitivity*—With the level in the center of the glass plate and parallel to one of the edges, shim one end of the level and observe the change in position of the bubble. The shim shall be of sufficient thickness to raise the level by 0.20° (0.5 mm in 140 mm [0.020 in. in 5.25 in.]). The addition of the shim shall cause a distinct and observable change in the position of the bubble. If the shift in the position of the bubble is not observable the level lacks adequate sensitivity and shall be replaced.

X1.2. Check the bearing that supports the carriage for wear. If there is any noticeable movement of the carriage when it is manually rotated in an upward motion, replace the bearing before proceeding.

X1.3. Rotate the carriage so that one of the openings is at 90° clockwise from the vertical direction (3 o'clock position). Insert the level into the opening, capture the reading, remove the level, and record the angle to the nearest 0.1°. Rotate the carriage by 180° in a clockwise direction and repeat the measurement.

X1.4. The readings for each position should be 0.0° ± 01.0°. Shim the underside of the oven until the requirements are met.

X1.5. Repeat the process for the other openings. All readings should be 0.0° ± 01.0°. If this requirement cannot be met consult the manufacturer.

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[1] Similar, but not technically identical to ASTM D 2872-04. The differences between standards are as follows:

- In Section 5.1.2, the required tolerance for the temperature of the oven is ± 1.0°C (± 1.8°F) in T 240 and ± 0.5°C (± 1.0°F) in the ASTM method.
- The position of the orifice is $^1/_4 \pm ^1/_{16}$ in. in Figure 2 of T 240 and is $^1/_4 \pm ^1/_8$ in. in Section 6.1 of the ASTM method.
- In Section 5.3.1, the T 240 requirements for the alternative thermometric device differ from the ASTM method.
- In Section 5.2, T 240 has requirements for the tolerance and standardization of the flowmeter.
- In Section 5.4, T 240 allows exterior frosting of the glass container.
- In Section 5.7, T 240 has optional electronic level.
- In Section 6.3, T 240 requirements for leveling and checking the bearing differ from the ASTM method.
- In Section 7.9.1, T 240 has detailed procedure in the event that mass flows out of the container.
- In Section 6.5, the RTFO is required to be preheated for at least 2 hours in T 240 and for at least 16 hours in the ASTM method.
- In Section 7.1, the maximum temperature of the oven for preparation of the sample is 163°C (325°F) in T 240 and 150°C (302°F) in the ASTM method.
- The Appendix is in T 240 but not in the ASTM method.

Standard Method of Test for

Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

AASHTO Designation: T 245-97 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

AASHTO Designation: T 245-97 (2008)

1. SCOPE

1.1. This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. This method is for use with mixtures containing asphalt cement, asphalt cutback or tar, and aggregate up to 25.4-mm (1-in.) maximum size.

2. APPARATUS

2.1. *Specimen Mold Assembly*—Mold cylinders 101.6 mm (4 in.) in diameter by 76.2 mm (3 in.) in height, base plates, and extension collars shall conform to the details shown in Figure 1. Three mold cylinders are recommended.

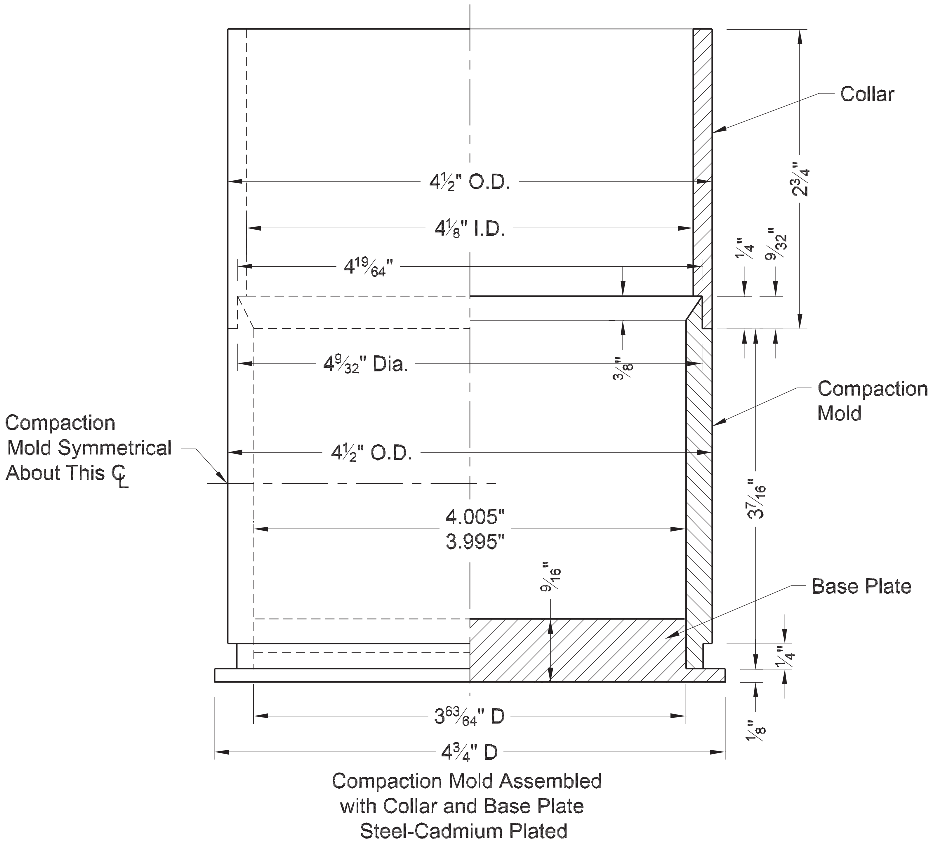


Figure 1—Compaction Mold

Table 1—Table of Equivalents for Figures 1 and 3

Metric Equiva-lents, mm	U.S. Customary Units, in.	Metric Equiva-lents, mm	U.S. Customary Units, in.	Metric Equiva-lents, mm	U.S. Customary Units, in.	Metric Equiva-lents, mm	U.S. Customary Units, in.
0.11	0.005	17.5	$^{11}/_{16}$	58.7	$2^{5}/_{16}$	104.8	$4^{1}/_{8}$
0.8	$^{1}/_{32}$	19.0	$^{3}/_{4}$	63.5	$2^{1}/_{2}$	108.7	$4^{9}/_{32}$
1.6	$^{1}/_{16}$	22.2	$^{7}/_{8}$	69.8	$2^{3}/_{4}$	109.1	$4^{19}/_{64}$
3.2	$^{1}/_{8}$	23.8	$^{15}/_{16}$	73.0	$2^{7}/_{8}$	114.3	$4^{1}/_{2}$
4.8	$^{3}/_{16}$	25.4	1	76.2	3	117.5	$4^{5}/_{8}$
6.4	$^{1}/_{4}$	28.6	$1^{1}/_{8}$	82.6	$3^{1}/_{4}$	120.6	$4^{3}/_{4}$
7.1	$^{9}/_{32}$	31.8	$1^{1}/_{4}$	87.3	$3^{7}/_{16}$	128.6	$5^{1}/_{16}$
9.5	$^{3}/_{8}$	34.9	$1^{3}/_{8}$	98.4	$3^{7}/_{8}$	130.2	$5^{1}/_{8}$
12.6	0.496	38.1	$1^{1}/_{2}$	101.2	$3^{63}/_{64}$	146.0	$5^{3}/_{4}$
12.67	0.499	41.3	$1^{5}/_{8}$	101.35	3.990	152.4	6
12.7	$^{1}/_{2}$	44.4	$1^{3}/_{4}$	101.47	3.995	158.8	$6^{1}/_{4}$
14.3	$^{9}/_{16}$	50.8	2	101.6	4	193.7	$7^{5}/_{8}$
15.9	$^{5}/_{8}$	57.2	$2^{1}/_{4}$	101.73	4.005	685.8	27

2.2. *Specimen Extractor*, steel, in the form of a disk with a diameter not less than 100 mm (3.95 in.) and 12.7 mm ($^{1}/_{2}$ in.) thick for extracting the compacted specimen from the specimen mold with the use of the mold collar. A suitable bar is required to transfer the load from the ring dynamometer adapter to the extension collar while extracting the specimen.

2.3. *Compaction Hammer*—The compaction hammer (Figure 2) shall have a flat, circular tamping face and a 4536 ± 9 g (10 ± 0.02 lb) sliding weight (including safety finger guard if so equipped) with a free fall of 457.2 ± 1.524 mm (18 ± 0.06 in.).

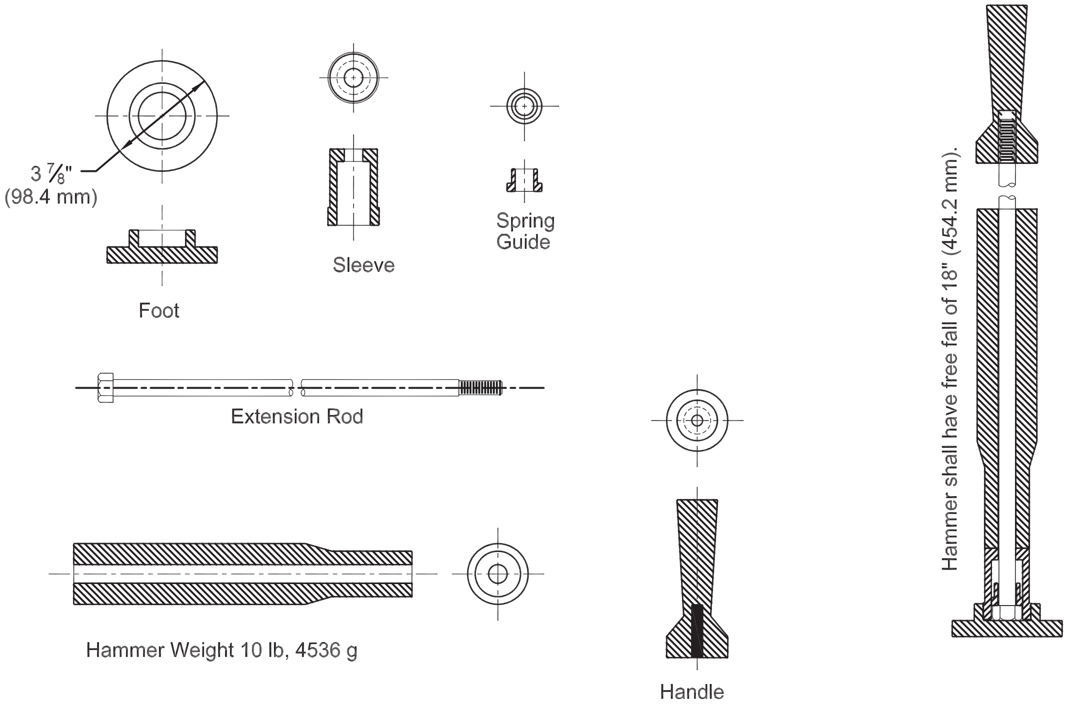


Figure 2—Compaction Hammer

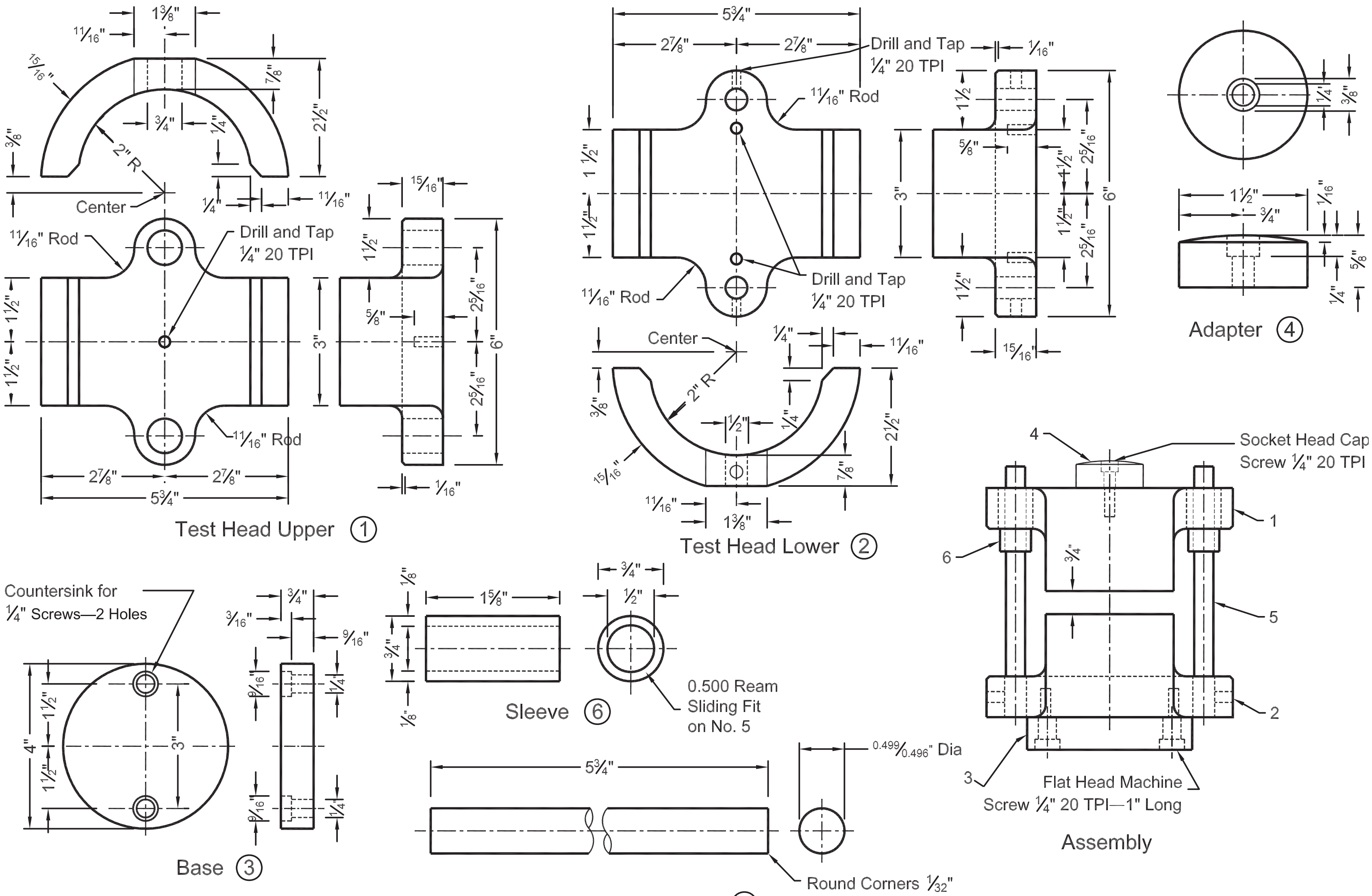
Note 1—The compaction hammer may be equipped with a finger safety guard as shown in Figure 2.

Note 2—Instead of a hand-operated hammer, and associated equipment described in Sections 2.3, 2.4, and 2.5, a mechanically operated hammer may be used provided it has been calibrated to give results comparable with the hand-operated hammer.

2.4. *Compaction Pedestal*—The compaction pedestal shall consist of a 203.2 by 203.2- by 457.2-mm (8- by 8- by 18-in.) wooden post capped with a 304.8- by 304.8- by 25.4-mm (12- by 12- by 1-in.) steel plate. The wooden post shall be oak, pine, or other wood having an average dry weight of 0.67 to 0.77 g/cm^3 (42 to 48 lb/ft^3). The wooden post shall be secured by four angle brackets to a solid concrete slab. The steel cap shall be firmly fastened to the post. The pedestal assembly shall be installed so that the post is plumb and the cap is level.

2.5. *Specimen Mold Holder*—mounted on the compaction pedestal so as to center the compaction mold over the center of the post. It shall hold the compaction mold, collar, and base plate securely in position during compaction of the specimen.

2.6. *Breaking Head*—(Figure 3) shall consist of upper and lower cylindrical segments or test heads having an inside radius of curvature of 50.8 mm (2 in.) accurately machined. The lower segment shall be mounted on a base having two perpendicular guide rods or posts extending upward. Guide sleeves in the upper segment shall be in such a position as to direct the two segments together without appreciable binding or loose motion on the guide rods.



(Table of Equivalents Same as for Figure 1)

Figure 3—Breaking Head

2.7. *Loading Jack*—The loading jack (Figure 4) shall consist of a screw jack mounted in a testing frame and shall produce a uniform vertical movement of 50.8 mm (2 in.)/min. An electric motor may be attached to the jacking mechanism.

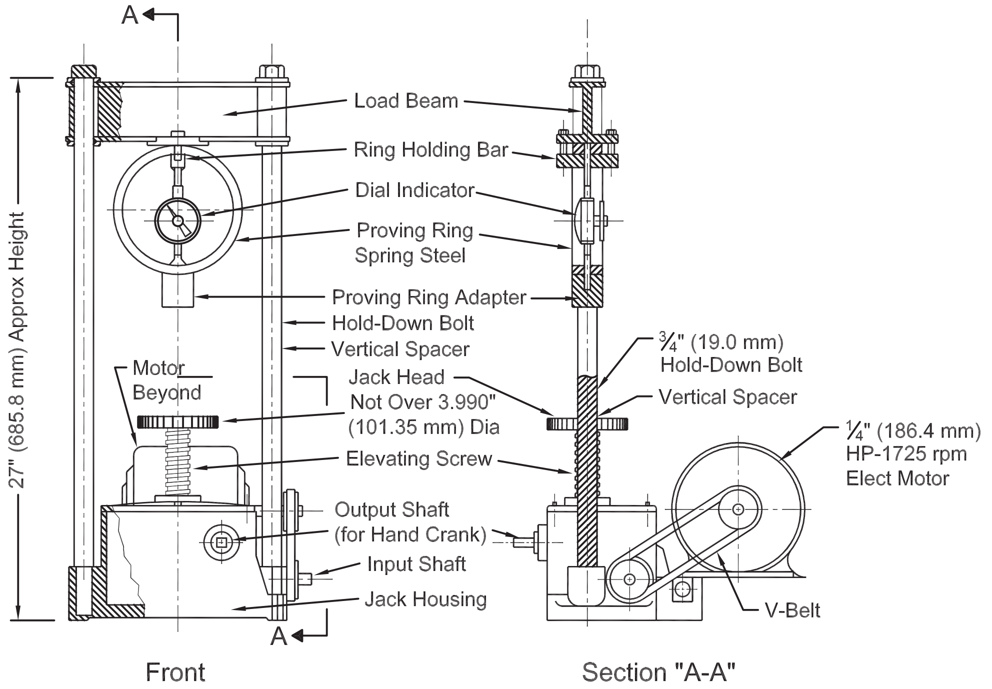


Figure 4—Compression Testing Machine

Note 3—Instead of the loading jack, a mechanical or hydraulic testing machine may be used provided the rate of movement can be maintained at 50.8 mm (2 in.)/min while the load is applied.

2.8. *Ring Dynamometer Assembly*—One-ring dynamometer (Figure 4) of 22.2 kN (5000 lbf) capacity and sensitivity of 44.5 N (10 lbf) up to 4.45 kN (1000 lbf) and 111.2N (25 lbf) between 4.45 and 22.2 kN (1000 and 5000 lbf) shall be equipped with a micrometer dial. The micrometer dial shall be graduated in 0.0025 mm (0.0001 in.). Upper and lower ring dynamometer attachments are required for fastening the ring dynamometer to the testing frame and transmitting the load to the breaking head.

Note 4—Instead of the ring dynamometer assembly, any suitable load-measuring device may be used provided the capacity and sensitivity meet the above requirements.

2.9. *Flowmeter*—The flowmeter shall consist of a guide sleeve and a gauge. The activating pin of the gauge shall slide inside the guide sleeve with a slight amount of frictional resistance. The guide sleeve shall slide freely over the guide rod of the breaking head. The flowmeter gauge shall be adjusted to zero when placed in position on the breaking head when each individual test specimen is inserted between the breaking head segments. Graduations of the flowmeter gauge shall be in 0.25-mm (0.01-in.) divisions.

Note 5—Instead of the flowmeter, a micrometer dial or stress-strain recorder graduated in 0.25 mm (0.01 in.) may be used to measure flow.

2.10. *Ovens or Hot Plates*—Ovens or hot plates shall be provided for heating aggregates, bituminous material, specimen molds, compaction hammers, and other equipment to the required mixing and molding temperatures. It is recommended that the heating units be thermostatically controlled so as to maintain the required temperature within 2.8ºC (5ºF). Suitable shields, baffle plates, or sand baths shall be used on the surfaces of the hot plates to minimize localized overheating.

2.11. *Heating Device*—A small hot plate with continuously variable heating rate, a sand bath, infrared lamp, or other suitable device shall be available for supplying sufficient heat under the mixing bowl to maintain the aggregate and bituminous material at the desired temperature during mixing. If a hot plate is used, a wire mesh or similar material shall be placed on the hot plate to prevent direct contact between the hot plate and mixing bowl.

2.12. *Mixing Apparatus*—Mechanical mixing is recommended. Any type of mechanical mixer may be used provided it can be maintained at the required mixing temperature and will produce a well-coated, homogeneous mixture of the required amount in the allowable time, and further provided that essentially all of the batch can be recovered. A metal pan or bowl of sufficient capacity and hand mixing may also be used.

2.13. *Water Bath*—The water bath shall be at least 152.4 mm (6 in.) deep and shall be thermostatically controlled so as to maintain the bath at 60 ± 1ºC (140 ± 2ºF) or 37.8 ± 1ºC (100 ± 2ºF). The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 50.8 mm (2 in.) above the bottom of the bath.

2.14. *Air Bath*—The air bath for asphalt cutback mixtures shall be thermostatically controlled and shall maintain the air temperature at 25 ± 1ºC (77º ± 2ºF).

2.15. *Miscellaneous Equipment*:

2.15.1. *Containers for Heating Aggregates*— flat-bottom metal pans or other suitable containers.

2.15.2. *Containers for Heating Bituminous Material*—either gill-type tins, beakers, pouring pots, or saucepans may be used.

2.15.3. *Mixing Tool*—either a steel trowel (garden type) or spatula, for spading, and hand mixing.

2.15.4. *Thermometers*—for determining temperatures of aggregates, bitumen, and bituminous mixtures. Armored-glass, dial type, or digital thermometers with metal stems are recommended. A range from 9.9 to 204ºC (50 to 400ºF), with sensitivity of 2.8ºC (5ºF) is required.

2.15.5. Thermometers for water and air baths sensitive to 0.2ºC (0.4ºF) with a range sufficient to determine the specified bath temperature.

2.15.6. *Balance*—2-kg capacity, sensitive to 0.1 g, for weighing molded specimens.

2.15.7. *Balance*—5-kg capacity, sensitive to 1.0 g, for batching mixtures.

2.15.8. *Gloves*—for handling hot equipment.

2.15.9. *Rubber Gloves*—for removing specimens from water bath.

2.15.10. *Marking Crayons*—for identifying specimens.

2.15.11. *Scoop*—flat bottom, for batching aggregates.

2.15.12. *Spoon*—large, for placing the mixture in the specimen molds.

3. TEST SPECIMENS

3.1. *Number of Specimens*—Prepare at least three specimens for each combination of aggregates and bitumen content.

3.2. *Preparation of Aggregates*—Dry aggregates to constant mass at 105 to 110ºC (221 to 230ºF) and separate the aggregates by dry-sieving into the desired size fractions.[1] The following size fractions are recommended:

- 25.0 to 19.0 mm (1 to $^3/_4$ in.)
- 19.0 to 9.5 mm ($^3/_4$ to $^3/_8$ in.)
- 9.5 mm to 4.75 mm ($^3/_8$ in. to No. 4)
- 4.75 mm to 2.36 mm (No. 4 to No. 8)
- Passing 2.36 mm (No. 8)

3.3. *Determination of Mixing and Compacting Temperatures*:

3.3.1. The temperatures to which the asphalt cement and asphalt cutback must be heated to produce a viscosity of 170 ± 20 cSt shall be the mixing temperature.

3.3.2. The temperature to which asphalt cement must be heated to produce a viscosity of 280 ± 30 cSt shall be the compacting temperature.

3.3.3. From a composition chart for the asphalt cutback used, determine from its viscosity at 60ºC (140ºF) the percentage of solvent by mass. Also determine from the chart the viscosity at 60ºC (140ºF) of the asphalt cutback after it has lost 50 percent of its solvent. The temperature determined from the viscosity temperature chart to which the asphalt cutback must be heated to produce a viscosity of 280 ± 30 cSt after a loss of 50 percent of the original solvent content shall be the compacting temperature.

3.3.4. The temperature to which tar must be heated to produce Engler specific viscosities of 25 ± 3 and 40 ± 5 shall be, respectively, the mixing and compacting temperature.

3.4. *Preparation of Mixtures*:

3.4.1. An initial batch shall be mixed for the purpose of "buttering" the mixture bowl and stirrers. This batch shall be emptied after mixing and the sides of the bowl and stirrers shall be cleaned of mixture residue by scraping with a small limber spatula but shall not be wiped with cloth or washed clean with solvent, except when a change is to be made in the binder or at the end of a run.

3.4.2. Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 63.5 ± 1.27 mm (2.5 ± 0.05 in.) in height (about 1200 g). Mix the aggregate in each pan and place the pans on a hot plate or in the oven and heat to a temperature not exceeding the mixing temperature established in Section 3.3 by more than approximately 28ºC (50ºF) for asphalt cement and tar mixes at 14ºC (25ºF) for cutback asphalt mixes. Heat, to the established mixing temperature, just sufficient bituminous material for the batch in a separate container. Charge the mixing bowl with the heated aggregate. Form a crater in the dry-blended aggregate and weigh the preheated required amount of bituminous material into the mixture. For mixes prepared with cutback asphalt, introduce the mixing blade in the mixing bowl and determine the total mass of the mix components plus bowl and blade before proceeding with mixing. Care must be exercised to prevent loss of the mix during mixing and subsequent handling. At this point, the temperature of the aggregate and bituminous material shall be within the limits of the mixing temperature established in Section 3.3. Mix the aggregate and bituminous material rapidly until thoroughly coated. To maintain proper mixing temperature, one of the methods described in Section 2.11 may be used.

3.4.3. Following mixing, cure asphalt cutback mixtures in a ventilated oven maintained at approximately 11.1ºC (20ºF) above the compaction temperature. Curing is to be continued in the mixing bowl until the precalculated weight of 50 percent solvent loss or more has been obtained. The mix may be stirred in a mixing bowl during curing to accelerate the solvent loss. However, care should be exercised to prevent loss of the mix. Weigh the mix during curing in successive intervals of 15 minutes initially and less than 10-minute intervals as the weight of the mix at 50 percent solvent loss is approached.

3.5. *Compaction of Specimens*:

3.5.1. Thoroughly clean the specimen mold assembly and the face of the compaction hammer and heat them either in boiling water, on the hot plate, or in an oven, to a temperature between 93.3 and 148.9ºC (200 and 300ºF). Place a piece of filter paper or paper toweling cut to size in the bottom of the mold before the mixture is introduced. Place the entire batch in the mold, spade the mixture vigorously with a heated spatula or trowel 15 times around the perimeter and 10 times over the interior. Remove the collar and smooth the surface of the mix with a trowel to a slightly rounded shape. Temperatures of the mixtures immediately prior to compaction shall be within the limits of the compacting temperature established in Section 3.3.

3.5.2. Replace the collar, then place a piece of filter paper or paper toweling cut to size on top of the mixture and place the mold assembly on the compaction pedestal in the mold holder, and unless otherwise specified, apply 50 or 75 blows with the compaction hammer with a free fall in 457.2 mm (18 in.). Hold the axis of the compaction hammer perpendicular to the base of the mold assembly during compaction. Remove the base plate and collar, and reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen. After compaction, remove the base plate and place the sample extractor on the end of the specimen. Place the assembly with the extension collar up in the testing machine, apply pressure to the collar by means of the load transfer bar, and force the specimen into the extension collar. Lift the collar from the specimen. Carefully transfer the specimen to a smooth, flat surface and allow it to stand overnight at room temperature. Weigh, measure, and test the specimen.

Note 6—In general, specimens shall be cooled as specified in Section 3.5.2. When more rapid cooling is desired, table fans may be used. Mixtures that lack sufficient cohesion to result in the required cylindrical shape on removal from the mold immediately after compaction may be cooled in the mold in air until sufficient cohesion has developed to result in the proper cylindrical shape.

4. PROCEDURE

4.1. Bring the specimens prepared with asphalt cement or tar to the specified temperature by immersing in the water bath 30 to 40 minutes or placing in the oven for two hours. Maintain the bath or oven temperature at 60 ± 1ºC (140 ± 1.8ºF) for the asphalt cement specimens and 37.8 ± 1ºC (100 ± 1.8ºF) for tar specimens. Bring the specimens prepared with asphalt cutback to the specified temperature by placing them in the air bath for a minimum of two hours. Maintain the air bath temperature at 25 ± 1ºC (77 ± 1.8ºF). Thoroughly clean the guide rods and the inside surfaces of the test heads prior to making the test, and lubricate the guide rods so that the upper test head slides freely over them. The testing-head temperature shall be maintained between 21.1 to 37.8ºC

(70 to 100ºF) using a water bath when required. Remove the specimen from the water bath, oven, or air bath, and place in the lower segment of the breaking head. Place the upper segment of the breaking head on the specimen, and place the complete assembly in position on the testing machine. Place the flowmeter, where used, in position over one of the guide rods and adjust the flowmeter to zero while holding the sleeve firmly against the upper segment of the breaking head. Hold the flowmeter sleeve firmly against the upper segment of the breaking head while the test load is being applied.

4.2. Apply the load to the specimen by means of the constant rate of movement of the loadjack or testing-machine head of 50.8 mm (2 in.) per minute until the maximum load is reached and the load decreases as indicated by the dial. Record the maximum load noted on the testing machine or converted from the maximum micrometer dial reading. Release the flowmeter sleeve or note the micrometer dial reading, where used, the instant the maximum load begins to decrease. Note and record the indicated flow value or equivalent units in twenty-five hundredths of a millimeter (hundredths of an inch) if a micrometer dial is used to measure the flow. The elapsed time for the test from removal of the test specimen from the water bath to the maximum load determination shall not exceed 30 seconds.

Note 7—For core specimens, correct the load when thickness is other than 63.5 mm ($2^1/_2$ in.) by using the proper multiplying factor from Table 2.

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5. REPORT

5.1. *The report shall include the following information*:

5.1.1. Type of sample tested (laboratory sample or pavement core specimen);

Note 8—For core specimens, the height of each test specimen in millimeters (or inches) shall be reported.

5.1.2. Average maximum load in pounds-force (or newtons) of at least three specimens, corrected when required;

5.1.3. Average flow value, in hundredths of an inch, twenty-five hundredths of a millimeter, of three specimens; and

5.1.4. Test temperature.

Table 2—Stability Correlation Ratios[a,b]

Volume of Specimen, cm^3	Approximate Thickness of Specimen, in.	mm	Correlation Ratio
200 to 213	1	25.4	5.56
214 to 225	$1^{1}/_{16}$	27.0	5.00
226 to 237	$1^{1}/_{8}$	28.6	4.55
238 to 250	$1^{3}/_{16}$	30.2	4.17
251 to 264	$1^{1}/_{4}$	31.8	3.85
265 to 276	$1^{5}/_{16}$	33.3	3.57
277 to 289	$1^{3}/_{8}$	34.9	3.33
290 to 301	$1^{7}/_{16}$	36.5	3.03
302 to 316	$1^{1}/_{2}$	38.1	2.78
317 to 328	$1^{9}/_{16}$	39.7	2.50
329 to 340	$1^{5}/_{8}$	41.3	2.27
341 to 353	$1^{11}/_{16}$	42.9	2.08
354 to 367	$1^{3}/_{4}$	44.4	1.92
368 to 379	$1^{13}/_{16}$	46.0	1.79
380 to 392	$1^{7}/_{8}$	47.6	1.67
393 to 405	$1^{15}/_{16}$	49.2	1.56
406 to 420	2	50.8	1.47
421 to 431	$2^{1}/_{16}$	52.4	1.39
432 to 443	$2^{1}/_{8}$	54.0	1.32
444 to 456	$2^{3}/_{16}$	55.6	1.25
457 to 470	$2^{1}/_{4}$	57.2	1.19
471 to 482	$2^{5}/_{16}$	58.7	1.14
483 to 495	$2^{3}/_{8}$	60.3	1.09
496 to 508	$2^{7}/_{16}$	61.9	1.04
509 to 522	$2^{1}/_{2}$	63.5	1.00
523 to 535	$2^{9}/_{16}$	65.1	0.96
536 to 546	$2^{5}/_{8}$	66.7	0.93
547 to 559	$2^{11}/_{16}$	68.3	0.89
560 to 573	$2^{3}/_{4}$	69.9	0.86
574 to 585	$2^{13}/_{16}$	71.4	0.83
586 to 598	$2^{7}/_{8}$	73.0	0.81
599 to 610	$2^{15}/_{16}$	74.6	0.78
611 to 625	3	76.2	0.76

[a] The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5 mm ($2^{1}/_{2}$-in.) specimen.

[b] Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

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[1] Detailed requirements for these sieves are given in M 92, Wire-Cloth Sieves for Testing Purposes.

Standard Method of Test for

Resistance to Deformation and Cohesion of Hot Mix Asphalt (HMA) by Means of Hveem Apparatus

AASHTO Designation: T 246-10[1]
ASTM Designation: D 1560-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance to Deformation and Cohesion of Hot Mix Asphalt (HMA) by Means of Hveem Apparatus

AASHTO Designation: T 246-10[1]
ASTM Designation: D 1560-09

1. SCOPE

1.1. These methods cover the determination of (1) the resistance to deformation of compacted HMA mixtures by measuring the lateral pressure developed from applying a vertical load by means of the Hveem stabilometer; and (2) the cohesion of compacted bituminous mixtures by measuring the forces required to break or bend the sample as a cantilever beam by means of the Hveem cohesiometer.[2]

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 247, Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

RESISTANCE TO DEFORMATION

3. APPARATUS

3.1. *Stabilometer*—The Hveem stabilometer (Figures 1 and 2) is a triaxial testing device consisting essentially of a rubber sleeve within a metal cylinder containing a liquid which registers the horizontal pressure developed by a compacted test specimen as a vertical load is applied.

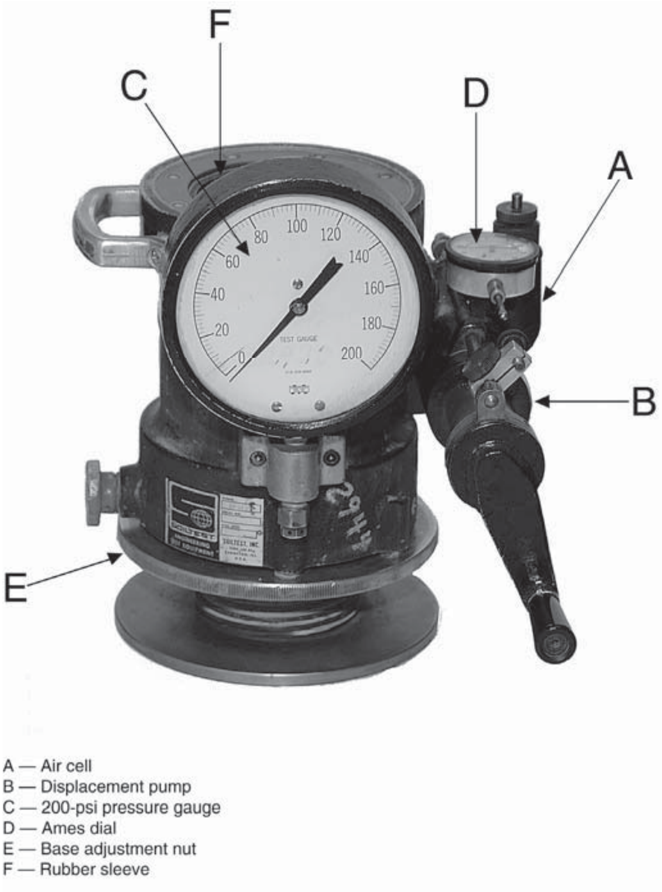
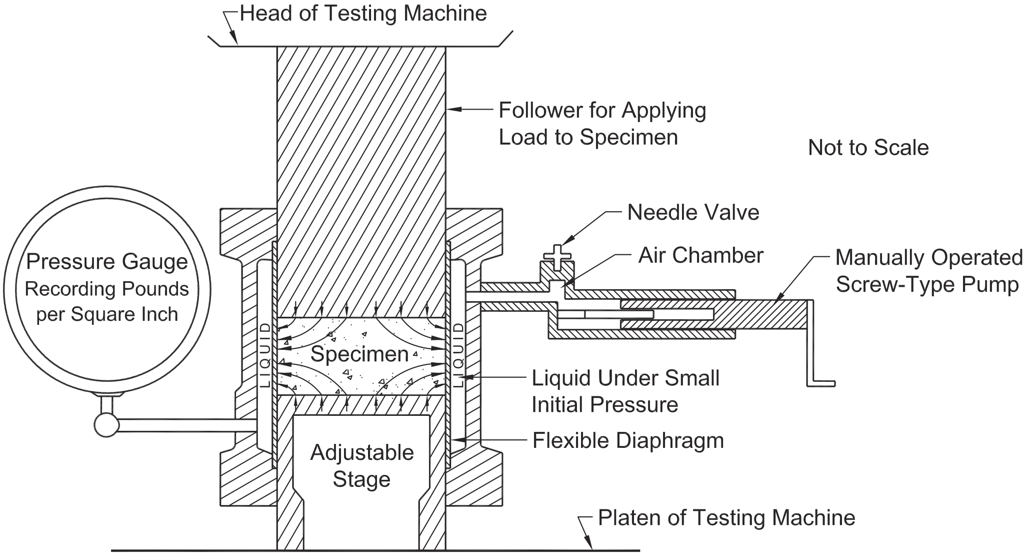


Figure 1—Hveem Stabilometer



Notes: 1. The specimen is given lateral support by the flexible sidewall, which transmits horizontal pressure to the liquid.
2. The magnitude of the pressure can be read on the gauge.

Figure 2—Diagrammatic Sketch of the Hveem Stabilometer (Not to Scale)

3.2. *Testing Machine*—A compression testing machine having a minimum capacity of 44.5 kN (10 000 lbf). Figure 3 shows the assembly of the stabilometer in a testing machine. The 222-kN (50 000-lbf) capacity compression testing machine specified in T 247 is normally used to perform the stabilometer test.

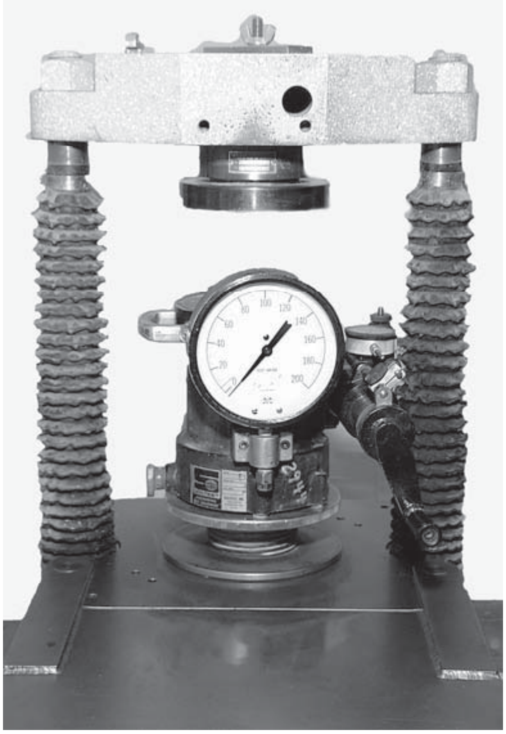


Figure 3—Hveem Stabilometer Mounted in the Testing Machine

3.3. *Test Specimen Push-Out Device*—A lever device, attached to the press, to push the specimen out of the mold. (See Figure 4.) Other acceptable apparatus may be used.

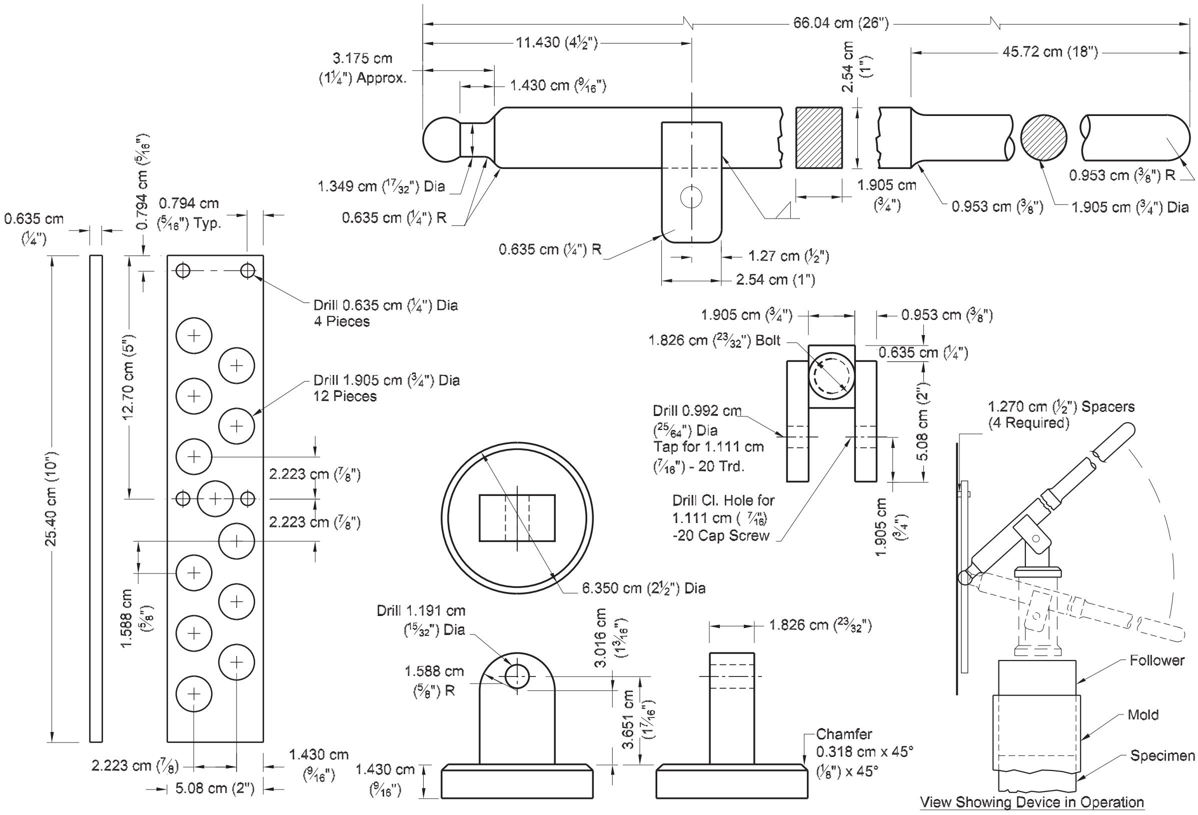


Figure 4—Detailed Drawings of the Test Specimen Push-Out Device

3.4. *Oven*—An oven capable of maintaining a temperature of 60 ± 3ºC (140 ± 5ºF).

3.5. *Calibration Cylinder*—A hollow metal cylinder, 101.6 ± 0.13 mm (4 ± 0.005 in.) in outside diameter by 140 ± 25 mm ($5^1/_2$ ± 1 in.) high (for calibration purposes).

3.6. *Rubber Bulb*—for introducing air into the stabilometer.

3.7. *Follower*—One solid wall metal follower, 101.2 mm (3.985 in.) in diameter by 140 mm ($5^1/_2$ in.) high (see Figures 5 and 6).

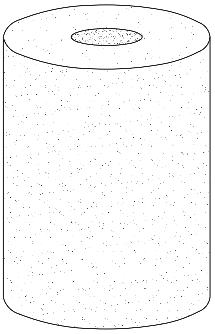


Figure 5—Specimen Follower

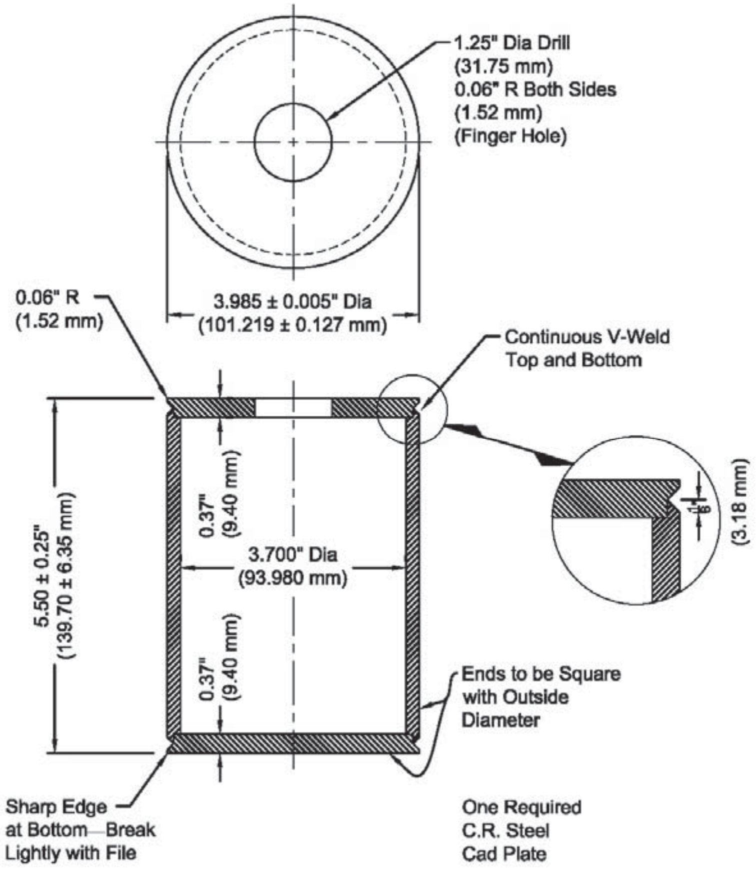


Figure 6—Detail Drawing of the Specimen Follower

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4. TEST SPECIMENS

4.1. *Size of Specimens*—Test specimens shall be 102 mm (4 in.) in diameter. The height of the test specimens should be 64 ± 3 mm (2.5 ± 0.1 in.). However, if this height cannot be obtained, the stabilometer value shall be corrected as indicated by Figure 9.

4.2. *Compaction of Specimens*—Test specimens shall be formed and compacted in accordance with T 247; or compacted into a 4-in. diameter mold using a Superpave gyratory compactor, gyratory shear compactor, or other types of compactors.

Note 1—Specimens compacted by different means may not have similar stabilometer or cohesiometer values.

5. ADJUSTMENT OF STABILOMETER

5.1. Adjust the stabilometer base so that the distance from the bottom of the upper tapered ring (Figure 1) to the top of the base is 89 mm (3.5 in.).

5.2. Adjust the amount of air in the air cell so that when the liquid pressure is increased from 34.5 to 689 kPa (5 to 100 psi) by turning the pump handle at the approximate rate of two turns per second, the turns indicator will indicate 2.00 ± 0.05 turns with the metal calibration cylinder in the stabilometer chamber.

5.3. With the stabilometer and stage base in position on the platen, adjust the testing machine so that the load will be applied at the rate of 1.3 mm (0.05 in.)/min.

6. PROCEDURE

6.1. Bring the specimen to a temperature of 60 ± 3ºC (140 ± 5ºF).

Note 2—Bring the specimen to room temperature in the case where it is desired to test with whatever moisture may be present in the mixture.

6.2. Transfer the compacted specimen from the mold to the stabilometer by means of the push-out device described in Section 2.3. Make sure that the specimen goes into the stabilometer straight, with the tamped end up, and that it is firmly seated level on the base. Place the 140-mm ($5^1/_2$-in.) follower on top of the specimen and turn the displacement pump until a horizontal pressure of exactly 34.5 kPa (5 psi) is recorded on the stabilometer gauge. If the testing machine has a spherically seated type of upper head, the locking shims used during the fabrication of the test specimen must be removed prior to performing the stabilometer test. Start the vertical movement of the press (speed of 1.3 mm (0.05 in.)/min) and record the stabilometer gauge readings when the vertical load is 2.23, 4.45, 8.90, 13.4, 17.8, 22.3, and 26.7 kN (500, 1000, 2000, 3000, 4000, 5000, and 6000 lbf). Stop the vertical movement of the press when the total load reaches 26.7 kN (6000 lbf). Immediately reduce the vertical load to 4.45 kN (1000 lbf) and then adjust the horizontal pressure to 34.5 kPa (5 psi). This will result in a further reduction of the vertical load in less than 4.45 kN (1000 lbf). This is normal and no compensation need be made. Measure the number of turns of the pump handle required to raise the horizontal pressure from 34.5 to 689 kPa (5 to 100 psi) with the specimen in place. Turn the pump handle at approximately two turns per second when applying this pressure. The number of turns measured is the displacement reading, *D*. In measuring the displacement, the vertical load will increase and at times exceed 4.45 kN (1000 lbf). As before, these changes in load are characteristic and no adjustment or compensation is required.

7. CALCULATIONS

7.1. Determine the stabilometer value of the specimen as follows:

$$S = \frac{22.2}{\left[P_h \bullet D / \left(P_v - P_h\right)\right] + 0.222} \quad (1)$$

where:

S = stabilometer value;

P_h = horizontal pressure, for corresponding P_v in kPa (or psi);

D = displacement on specimen; and

P_v = vertical pressure (typically 2800 kPa (400 psi)).

8. REPORT

8.1. The report shall include the following:

8.1.1. Stabilometer value,

8.1.2. Test temperature, and

8.1.3. Bitumen content.

COHESION

Note 3—Cohesion testing is optional and is not required to determine Hveem Stability.

9. APPARATUS

9.1. *Cohesiometer*—A Hveem cohesiometer, as shown in Figures 7 and 8.[3]

9.2. *Steel Shot*—2000 g of steel shot, size No. 10, all passing a 2-mm (No. 10) sieve and retained on a 1.4-mm (No. 14) sieve.

9.3. *Oven*—An oven capable of maintaining a temperature of 60 ± 1ºC (140 ± 2ºF).[3]

9.4. *Balance*—A balance having a capacity of 5 kg and sensitive to 1 g or less.

Note 3—Other materials may be used, provided a rate of loading is achieved which is equivalent to that obtained when using steel shot.

10. TEST SPECIMENS

10.1. *Preparation of Specimen*—The test specimen will normally be the compacted specimen used after completion of the stabilometer test. If the sample is taken from a compressed pavement slab by means other than coring, it should be cut to size with a suitable saw.

10.2. *Size of Specimens*—The cohesiometer is designed to test specimens up to 127 mm (5 in.) in width and from 25 mm (1 in.) to 76 mm (3 in.) high.

11. PROCEDURE

11.1. Place the specimen to be tested in the oven and allow to stand until the temperature is 60 ± 1ºC (140 ± 2ºF) throughout (this normally will require a minimum of 2 h).

11.2. Preheat the cohesiometer to 60 ± 1ºC (140 ± 2ºF). Clamp the test specimen firmly in the cohesiometer, being certain that it is well centered with the top plates parallel with the surface of the specimen. Tighten the clamp nuts until snug using the fingers only. Delay starting the test until the temperature within the cohesiometer cabinet returns to 60 ± 1ºC (140 ± 2ºF). Allow the shot to flow into the receiver at the end of the lever arm at a rate of flow of 1800 ± 20 g/min. Stop the flow of shot when the specimen breaks or when the lever arm deflects 13 mm ($^1/_2$ in.) from the horizontal, if that occurs before the specimen breaks. Determine and record the mass of shot to the nearest gram.

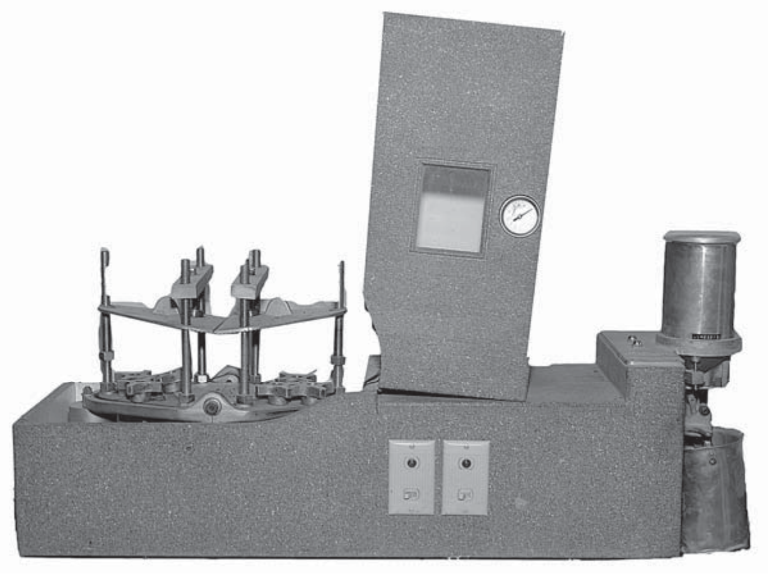

Figure 7—Hveem Cohesiometer

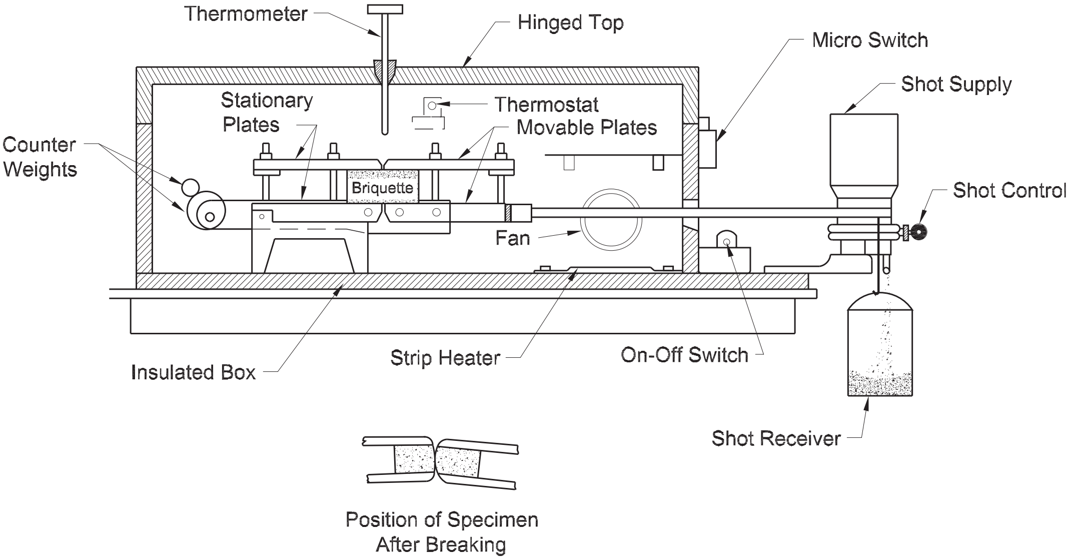

Figure 8—Detailed Drawing of the Hveem Cohesiometer

Chart for Correcting Stabilometer Values
to Specimen Height of 2.50" (64 mm)

Height Correction should be made using
the Table and Chart below.

Example: Overall Height of 2.74" (69 mm)
Select Correction Curve "B"
Stabilometer Value Uncorrected = 35
Stabilometer Value Corrected = 38

Overall Specimen Ht	Correction Curve
2.80" to 3.00" (71 mm to 76 mm)	A
2.60" to 2.79" (66 mm to 70 mm)	B
2.40" to 2.59" (61 mm to 65 mm)	C
2.20" to 2.39" (56 mm to 60 mm)	D
2.00" to 2.19" (51 mm to 55 mm)	E

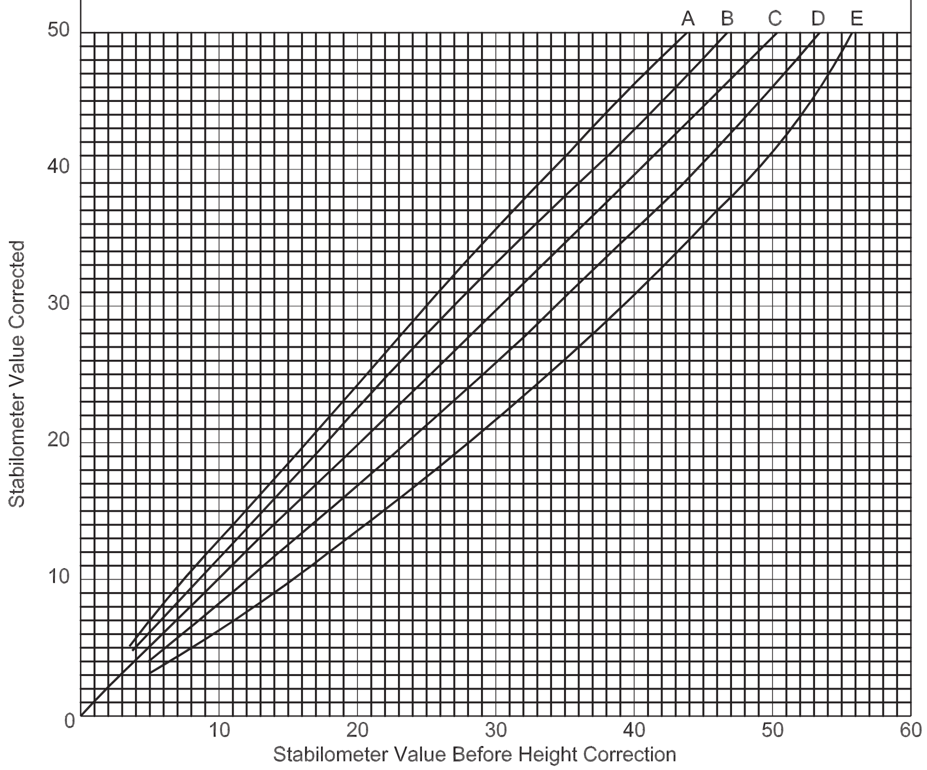

Figure 9—Chart for Correcting Stabilometer Values to Specimen Height of 2.5 in. (64 mm)

12. CALCULATIONS

12.1. Calculate the cohesiometer values as follows:

U.S. Customary Units:

$$C = L/W\left(0.20H + 0.044H^2\right) \qquad (2)$$

Metric Units:

$$C = L/W\left(0.0310H + 0.00269H^2\right) \tag{3}$$

where:

C = cohesiometer value, g/25 mm (1 in.) of width corrected to 76 mm (3 in.) height;
L = weight of shot, g;
W = diameter, or width of specimen, cm (or in.); and
H = height of specimen, cm (or in.).

13. REPORT

13.1. The report shall include the following:

13.1.1. Cohesiometer value,

13.1.2. Test temperature, and

13.1.3. Bitumen content.

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[1] Except for the allowable tolerances of the calibration cylinder in Section 2.5, this method is the same as ASTM D 1560-09.

[2] A more detailed description of the procedures for performing the tests is available on request from the California Division of Highways, Transportation Laboratory, 5900 Folsom Blvd., Sacramento, CA 95819. Also available is a procedure containing details regarding the operation and calibration of the stabilometer and the replacement of the stabilometer diaphragm.

[3] Detailed working drawings of the apparatus illustrated in Figure 8 are available at nominal cost from the American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959. Request Adjunct No. 12-415600-10.

Standard Method of Test for

Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor

AASHTO Designation: T 247-10
ASTM Designation: D 1561-92

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor

AASHTO Designation: T 247-10
ASTM Designation: D 1561-92

1. SCOPE

1.1. The method covers the compaction of test specimens of hot mix asphalt (HMA) by means of a mechanical compactor that imparts a kneading action to the test specimens by a series of individual impressions made with a ram.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 246, Resistance to Deformation and Cohesion of Hot Mix Asphalt (HMA) by Means of Hveem Apparatus
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

3. APPARATUS

3.1. *California Kneading Compactor*—Mechanical kneading compactor, as shown in Figure 1,[1] for consolidating test specimens.

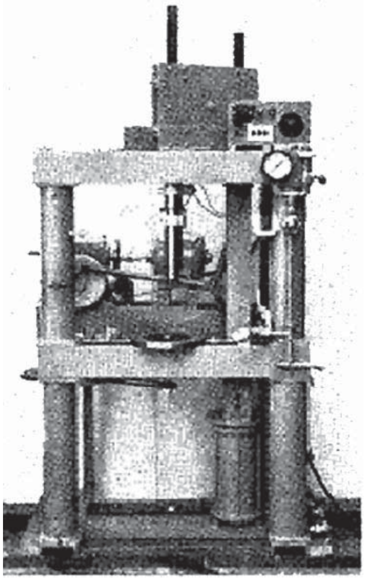


Figure 1—California Kneading Compactor

Note 1—Kneading compactors, which on standardization develop a trace curve similar to that of the California kneading compactor, shall be considered acceptable under this test method. Optionally, any kneading compactor capable of fabricating specimens that will provide stabilometer values equivalent to those obtained from the California kneading compactor shall be acceptable for use under this test method. The supplier has the responsibility of furnishing those substantiating data for his device.

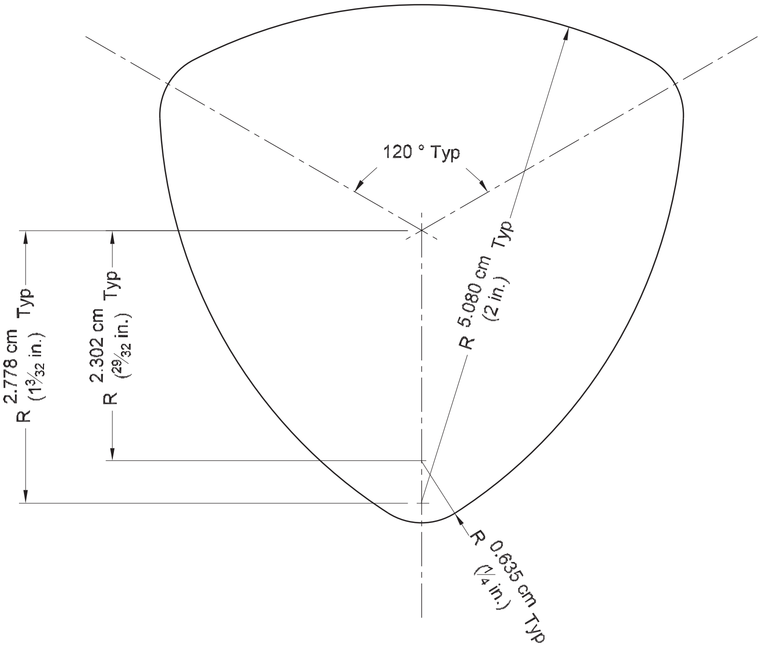
Note 2—Curves are considered within standardization when they show the same peak pressure and dwell time in load time trace obtained in the calibration procedure.

Note 3—This compactor shall be considered in standardization when the peak momentary load applied to a test specimen is held within 5 percent of the intended foot pressure (within the range from 2.4 to 3.4 MPa (350 to 500 psi)).

Note 4—The stabilometer values from replicate specimens fabricated by T 247 and tested in accordance with T 246 shall fall within a range of three units for all dense-graded HMA mixtures containing aggregates not larger than 12.5 mm ($^1/_2$ in.) and within a range of four units for coarser-graded HMA mixtures containing up to 25.0-mm (1-in.) maximum-sized aggregates.

3.2. *Compactor Foot*—A ram having a face shaped as shown in Figure 2, and having an area of approximately 20.059 cm^2 (3.1 in.^{2}).

3.3. *Mold Holder, Funnel, and Feeder Trough*, as shown in Figure 3.



Dimensional Limits, cm (in.)

	Min	Max
Distance Across Foot 3 Measurements 120° Apart	5.189 (2.042)	5.289 (2.082)

Figure 2—Face of Compactor Ram

Figure 3—Funnel, Feeder Trough, and Mold Assembly of the California Kneading Compactor

3.4. *Molds*—Molding cylinders for 101.60 ± 0.13 mm (4.000 ± 0.005 in.) in inside diameter by 127 mm (5 in.) in height. A minimum of three such compaction molds is recommended.

3.5. *Rod*—Round-nose steel rod, 9.5 mm ($^3/_8$ in.) in diameter by 406 mm (16 in.) long.

3.6. *Paper Disks*—Heavy paper disks, 102 mm (4 in.) in diameter.

3.7. *Shim*—Steel shim, 6.4 mm ($^1/_4$ in.) thick, 19 mm ($^3/_4$ in.) wide, and 64 mm ($2^1/_2$ in.) long.

3.8. *Metal Followers*—Two metal followers, 101.2 ± 0.11 mm (3.985 ± 0.005 in.) in diameter; one 140 mm (5.5 in.) high, the other 38.1 mm (1.5 in.) high.

3.9. *Testing Machine*—A compression testing machine having a minimum capacity of 222 kN (50 000 lbf).

3.10. *Ovens*—Electric ovens capable of maintaining temperatures of 60 ± 3ºC (140 ± 5ºF) and 110 ± 3ºC (230 ± 5ºF).

3.11. *Balance*—A balance having a capacity of 5 kg or more and sensitive to 1.0 g or less for determining the mass of the mixture.

3.12. *Measuring Device*—A device for measuring the height of the specimen to the nearest 0.3 mm (0.01 in.).

3.13. *Sample Mixing Apparatus*—Suitable equipment is required for mixing the aggregate and the asphalt binder. Hand mixing is permissible but mechanical mixing is recommended.[2]

3.14. *Sample Splitter*—Riffle-type.

3.15. *Miscellaneous Apparatus*—Thermometers, trowels, spatulas, scoops, gloves, and metal pans.

Note 5—**Caution:** rough interior of molds can cause a difference in test results.

4. TEST SPECIMENS

4.1. *Selection of Binder Content for Specimens*—Determine the theoretical or estimated optimum amount of bitumen for the aggregate (Note 6). On normal materials, conduct laboratory tests for a minimum of three binder contents, one above, one below, and one at the theoretical or estimated optimum content. The incremental change of binder content should be 0.5 percent. For extremely critical mixes, lower the incremental change of binder content to 0.3 percent, and increase the number of tests to a minimum of five. Conversely, for highly absorptive aggregates, increase the incremental change of binder content to 1.0 percent, and reduce the number of tests to three. Express the percentage of the binder as a percentage of the dry weight of the aggregate.

Note 6—The optimum amount of binder for the aggregate may be determined by the method commonly employed by the laboratory. A method that has been found suitable is the centrifuge kerosene equivalent method.

4.2. *Preparation of Aggregates*—Obtain a sieve analysis and specific gravity determination on the fine and coarse aggregate (aggregate shall be separated by means of a 4.75-mm (No. 4) sieve). Separate the aggregate into the various size fractions necessary for accurately recombining into test mixtures conforming to specified grading requirements.

4.3. *Preparation of Mixtures*—Combine the moisture-free aggregates into batches weighing 1200 g. (Every effort should be made to fabricate test specimens 64 ± 3 mm (2.5 ± 0.1 in.) in height.) The mixing temperature range is defined as the range of temperatures where the unaged binder has a viscosity of 0.17 ± 0.02 Pa·s when measured in accordance with T 316. Charge the mixing bowl with the heated aggregate from one pan and dry-mix thoroughly. Form a crater in the dry-blended aggregate, and weigh the required amount of binder into the mix. Immediately initiate mixing. Mix the aggregate and binder as quickly and thoroughly as possible to yield HMA having a uniform distribution of binder. As an option, mechanical mixing may be used.

Note 7—Modified binders may not adhere to the equiviscosity requirements noted, and the manufacturer's recommendations should be used to determine mixing and compaction temperatures.

5. PROCEDURE

5.1. *Temperatures*—After completing the mixture preparation, perform the required mixture conditioning in accordance with R 30.

5.2. *Molding Specimens*—The mixture and molds shall be brought to compaction temperature prior to molding operations. Place the compaction mold in position in the mold holder, and insert a paper disk, 102 mm (4 in.) in diameter, to cover the base plate of the mold holder. Place a steel shim under the edge of the mold temporarily in order for the base plate of the mold holder to act as a free-fitting plunger during the compaction operation. Weigh out the required amount of HMA mixture for one specimen at the specified temperature and place it in the insulated feeder trough, which shall have been preheated to the approximate compaction temperature for the HMA mixture. Spread the HMA mixture uniformly on the feeder trough to ensure uniformity when transferring it to the mold. By means of a paddle of suitable dimensions to fit the cross-section of the trough, push one half of the mixture into the mold. Preheat the round-nose rod. Rod the one-half portion of the HMA mixture 20 times in the center of mass and 20 times around the edge by means of the round-nose rod. Transfer the remainder of the sample to the mold and repeat the rodding procedure. Place the mold and assembly into position on the California kneading compactor. By means of the variable transformer controlling the heater, maintain the compactor foot sufficiently hot to prevent the HMA mixture from adhering to it. Apply approximately 20 tamping blows at a pressure of 1.7 MPa (250 psi). The number of tamping blows will vary, depending upon the type of the HMA mixture, the purpose being to form the HMA mixture into a semi-compacted condition so that it will not be unduly disturbed by the full pressure of 3.4 MPa (500 psi). After semi-compaction has been accomplished, remove the shim and release the mold-tightening screw sufficiently to permit free "up and down" movement of the mold. Increase the compactor foot pressure to 3.4 MPa (500 psi), and apply 150 tamping blows to complete compaction.

Note 8—When testing referee samples for the purpose of qualifying a compactor, use only material for the test specimens that will compact under the maximum foot pressure prescribed in Section 4.2 without visible movement, distortion, or penetration of the compactor foot.

Note 9—In some instances where sandy or unstable material is involved, it may not be possible to accomplish the compaction in the kneading compactor because of undue movement of the mixture under the compactor foot. In these instances, use a 178-kN (40,000 lbf) static load (for a 102-mm (4-in.) diameter specimen) applied by the double plunger method in which a free-fitting plunger is placed on both the bottom and top of the test specimen. Apply the load at the rate of 1.3 mm (0.05 in.)/min, and hold for 30 ± 5 s.

5.3. *Application of Static Load*—After compaction in the California kneading compactor, place the mold and the specimen in an oven at 60ºC (140ºF) for 1.5 h prior to applying the static "leveling off" load:

5.4. The "leveling off" load shall consist of the application of a static load of 6.9 MPa (1000 psi) in a compression testing machine. Apply the load by the double plunger method in which metal followers are employed as free-fitting plungers on the top and bottom of the specimen. After releasing the “leveling off” load, measure the height of the specimen to the nearest 0.25 mm (0.01 in.); record the measurement, and return the specimen in the mold to the 60ºC (140ºF) oven in order to retain temperature for testing. Complete testing of the specimens according to T 246 within 3 h of returning the specimens to the oven.

Note 10—A push-out device for removing the specimen is described in T 246. The temperature of the specimen and the method of transfer from the mold to the stabilometer are given in Section 5.2 of T 246.

6. REPORT

6.1. *The report shall include the following*:

6.1.1. Height of the specimen, and

6.1.2. Temperature of compaction in the California kneading compactor.

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[1] Blueprints of detailed drawings of the apparatus illustrated in Figure 1 are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Request Adjunct No. 12-415610-00.

[2] A mechanical mixing apparatus capable of mixing simultaneously from two to five batches has been developed by the California State Department of Public Works, Division of Highways. Working drawings are available at a nominal cost from the American Society for Testing and Materials, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959. Request Adjunct No. 12-415600-20.

Standard Method of Test for

Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

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AASHTO Designation: T 269-97 (2007)[1]
ASTM Designation: D 3203-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

AASHTO Designation: T 269-97 (2007)[1]
ASTM Designation: D 3203-05

1. SCOPE

1.1. This method covers determination of the percent air voids in compacted dense and open asphalt mixtures.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 275, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
- T 331, Bulk Specific Gravity and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method

2.2. *ASTM Standards*:

- D 3549, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 4460, Standard Practice for Calculating Precision Limits Where Values are Calculated from Other Test Methods
- E 1547, Standard Terminology Relating to Industrial and Specialty Chemicals

3. TERMINOLOGY

3.1. The terms *specific gravity* and *density* used in this test method are in accordance with ASTM E 1547.

3.2. *Definitions*:

3.2.1. *air voids*—the pockets of air between the asphalt-coated aggregate particles in a compacted asphalt mixture.

3.2.2. *dense asphalt mixture*—asphalt mixtures in which the air voids are less than 10 percent when compacted.

3.2.3. *open asphalt mixture*—asphalt mixtures in which the air voids are 10 percent or more when compacted.

3.2.3.1. For borderline cases, an asphalt mixture shall be designated an open asphalt mixture if the calculated percent air voids, based on either Section 6.1 or 6.2, is 10 percent or more.

4. SIGNIFICANCE AND USE

4.1. The percent air voids in an asphalt mixture is used as one of the criteria in the design methods and for evaluation of the compaction achieved on asphalt paving projects.

5. SAMPLING

5.1. Samples for testing shall consist of specimens from laboratory-molded mixtures or cores from field-compacted mixtures.

6. PROCEDURE

6.1. For dense asphalt mixtures, determine the bulk specific gravity of the compacted mixture either by T 166, T 275 or T 331. Determine the theoretical maximum specific gravity in accordance with T 209 on a comparable asphalt mixture to avoid the influence of differences in gradation, asphalt content, etc.

6.2. For open asphalt mixtures, determine the density of a regularly shaped specimen of compacted mixture from its dry mass (in grams) and its volume (in cubic centimeters). Obtain the height of the specimen by ASTM D 3549. Measure the diameter of the specimen at four locations, and average the measurements. Calculate the volume of the specimen based on the average height and diameter measurement. Convert the density to bulk specific gravity by dividing by 0.99707 g/cm^3 or 997 kg/m^3, the density of water at 25ºC (77ºF). Determine the theoretical maximum specific gravity in accordance with T 209 on a comparable asphalt mixture to avoid the influence of differences in gradation, asphalt content, etc.

For reference purposes, determine both the bulk specific gravity and the theoretical maximum specific gravity on portions of the same sample of compacted asphalt mixture.

7. CALCULATIONS

7.1. Calculate the percent air voids in a compacted asphalt mixture as follows:

$$\text{Percent Air Voids} = 100(1 - A/B) \qquad (1)$$

where:

A = the bulk specific gravity, and

B = the theoretical maximum specific gravity.

7.2. Report the percent air voids to one decimal place.

8. PRECISION AND BIAS

8.1. The precision of this test method depends on the precision of test methods for bulk specific gravity and theoretical maximum specific gravity. It is computed by a procedure described in ASTM D 4460. Since the computation for percent air voids in Section 7.1 involves the quotient of bulk specific gravity divided by the theoretical maximum specific gravity, the quotient formula is used:

$$\sigma_{x/y} = \sqrt{\frac{\overline{y}^2\ \sigma_x^2 + \overline{x}^2\ \sigma_y^2}{\overline{y}^4}} \qquad (2)$$

where:

$\sigma_{x/y}$ = the standard deviation for determining the precision limits of test results for a standard based on the quotient of two test results from two other standards,

$\overline{x}$ = the mean (average) value of the x standard (bulk specific gravity) test results,

$\overline{y}$ = the mean (average) value of the y standard (theoretical maximum specific gravity) test results,

σ_x = the standard deviation from the precision statement of the x standard, and

σ_y = the standard deviation from the precision statement of the y standard.

Note 1—The x standard (T 166, T 275, or T 331) is used to compute bulk specific gravity, and the y standard (T 209) is used to compute theoretical maximum specific gravity.

8.2. Criteria for judging the acceptability of percent air voids test results that are obtained by using T 275 and T 209 for nonporous aggregates are:

Test and Type Index	Standard Deviation	Acceptable Range of Two Results
Single-Operator Precision	0.32	0.91
Multilaboratory Precision	—	—

8.3. Criteria for judging the acceptability of percent air voids test results that are obtained by using T 166 and T 209 for nonporous aggregates are:

Test and Type Index	Standard Deviation	Acceptable Range of Two Results
Single-Operator Precision	0.51	1.44
Multilaboratory Precision	1.09	3.08

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE CALCULATION OF PRECISION

X1.1. *Assume the following precision data*:

Bulk Specific Gravity, x
When the average x = 2.423 and the standard deviation of x = 0.007.

Theoretical Maximum Specific Gravity, *y*
When the average $y = 2.523$ and the standard deviation of $y = 0.004$.

Then using Equation 2:

$$\sigma_{x/y} = \sqrt{\frac{(2.523)^2 (0.007)^2 + (2.423)^2 (0.004)^2}{(2.523)^4}} = 0.00316 \qquad (X1.1)$$

This value is in terms of air voids; therefore, the value should be multiplied by 100 to convert it into a percentage. Therefore:

$$\sigma_{x/y} = 0.0032(100) = 0.32\% \qquad (X1.2)$$

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[1] Similar, but not technically identical to ASTM D 3203-05.

Standard Method of Test for

Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens

AASHTO Designation: T 275-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens

AASHTO Designation: T 275-07

1. SCOPE

1.1. This method of test covers the determination of bulk specific gravity of specimens of compacted hot mix asphalt (HMA).

1.2. *Definition*:

1.2.1. *Bulk Specific Gravity (of solids)*—the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. The form of the expression shall be:

Bulk specific gravity at x, y°C

where:

x = temperature of the material, and

y = temperature of the water.

1.3. This method should be used with samples that contain open or interconnecting voids or absorb more than 2.0 percent of water by volume, as determined by T 166.

1.4. The bulk specific gravity of the compacted HMA may be used in calculating the unit mass of the mixture.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens

3. TEST SPECIMENS

3.1. Test specimens may be either laboratory-compacted HMA or sampled from HMA pavements. The mixtures may be surface or wearing course, binder or leveling course, or hot mix base.

3.2. *Size of Specimens*—It is recommended that: (1) the diameter of cylindrically compacted or cored specimens, or the length of the sides of sawed specimens, be at least equal to four times the maximum size of the aggregate; and (2) the thickness of specimens be at least one and one-half times the maximum size of the aggregate.

3.3. Specimens shall be taken from pavements with a core drill, diamond or carborundum saw, or by other suitable means.

3.4. Care shall be taken to avoid distortion, bending, or cracking of specimens during and after the removal from pavement or mold. Specimens shall be stored in a safe, cool place.

3.5. Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.

3.6. If desired, specimens may be separated from other pavement layers by sawing or other suitable means.

METHOD A

4. APPARATUS

4.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231. The balance shall be equipped with a suitable suspension apparatus and holder to permit weighing the specimen while suspended from the center of the scale pan of the balance.

4.2. *Suspension Apparatus*—The wire suspending the container shall be the smallest practical size to minimize any possible effects of a variable immersed length. The suspension apparatus shall be constructed to enable the container to be immersed to a depth sufficient to cover it and the test sample during weighing.

4.3. *Water Bath*—For immersing the specimen in water while suspended under the balance, equipped with an overflow outlet for maintaining a constant water level, and thermostatically controlled so as to maintain the bath at 25 ± 0.5ºC (77 ± 0.9ºF).

5. PROCEDURE

5.1. *Mass of Uncoated Specimens*—Weigh the specimen after it has been dried to a constant mass. Designate this mass as *A*. Constant mass shall be defined as the mass at which further drying at 52 ± 3ºC (125 ± 5ºF) does not alter the mass by 0.05 percent. The sample shall initially be dried overnight at 52 ± 3ºC (125 ± 5ºF) and then weighed at 2-h drying intervals.

5.2. *Mass of Coated Specimen in Air*—Coat the test specimen on all surfaces with melted paraffin sufficiently thick to seal all surface voids. Allow the coating to cool in air at room temperature at 25 ± 5ºC (77 ± 9ºF) for at least 30 min and then weigh the specimen. Designate this mass as *D*.

Note 1—If it is desired to utilize the specimen for further tests that require the removal of the paraffin coating, the specimen may be dusted with powdered talc prior to coating.

Note 2—Application of the paraffin may be accomplished by chilling the specimen in a refrigerating unit to a temperature of approximately 4.5ºC (40ºF) for at least 30 min and then dipping the specimen in warm paraffin (5.5ºC (10ºF) above the melting point). It may be necessary to brush the surface of the paraffin with added hot paraffin in order to fill any pinpoint holes.

5.3. *Mass of Coated Specimen in Water*—Weigh the coated specimen in a water bath at 25 ± 1ºC (77 ± 1.8ºF). Designate this mass as *E*.

5.4. *Specific Gravity of Paraffin*—Determine the specific gravity of the paraffin at 25 ± 1ºC (77 ± 1.8ºF), if unknown, and designate this value as *F*.

6. CALCULATION

6.1. Calculate the bulk specific gravity of the specimen as follows: round and report the value to the nearest three decimal places.

$$\text{Bulk Specific Gravity} = \frac{A}{D - E - \left(\frac{D - A}{F}\right)} \qquad (1)$$

where:

A = mass of the dry specimen in air, g;

D = mass of the dry specimen plus paraffin coating in air, g;

E = mass of the dry specimen plus paraffin coating in water, g; and

F = specific gravity of the paraffin at 25 ± 1ºC (77 ± 1.8ºF).

METHOD B

7. APPARATUS

7.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

7.2. *Water Bath*—Thermostatically controlled, so as to maintain the bath at 25 ± 0.5ºC (77 ± 0.9ºF).

7.3. *Thermometer*—ASTM 17C (17F), having a range of 19 to 27ºC (66 to 80ºF), graduated in 0.1ºC (0.2ºF) subdivisions.

7.4. *Volumeter*[1]—Calibrated to 1200 mL or appropriate capacity depending on the size of the test sample. The volumeter shall have a tapered lid with a capillary bore.

8. PROCEDURE

8.1. Dry the specimen to a constant mass (See Section 5.1). Cool the specimen to room temperature at 25 ± 5ºC (77 ± 9ºF), and record the dry mass. Designate this mass as *C*.

8.2. Coat the specimen on all surfaces with melted paraffin until sufficiently thick to seal all surface voids. Allow the coating to cool in air at 25 ± 0.5ºC (77 ± 0.9ºF) for at least 30 min, and then weigh the specimen (Notes 1 and 2). Designate this mass as *C*.

8.3. Fill a calibrated volumeter with distilled water at 25 ± 1ºC (77 ± 1.8ºF), and weigh the volumeter. Designate this mass as *D*.

8.4. Place the coated specimen into the volumeter and cover the volumeter, making certain that some water escapes through the capillary bore in the tapered lid. Wipe the outside of the volumeter dry with a dry absorbent cloth and weigh the volumeter and its contents. Designate this mass as *E*.

8.5. Determine the specific gravity of the paraffin at 25 ± 1ºC (77 ± 1.8ºF), if unknown, and designate this value as *F*.

9. CALCULATIONS

9.1. Calculate the bulk specific gravity of the specimen as follows: round and report the value to the nearest three decimal places.

$$\text{Bulk Specific Gravity} = \frac{A}{D - \left[E - C + \left(\frac{C - A}{F}\right)\right]} \qquad (2)$$

where:

A = mass of the dry specimen in air, g

C = mass of the dry specimen plus paraffin coating in air, g

D = mass of the volumeter filled with water at 25 ± 1ºC (77 ± 1.8ºF), g

E = mass of the volumeter filled with the paraffin-coated specimen and water at 25 ± 1ºC (77 ± 1.8ºF), g, and

F = specific gravity of the paraffin at 25 ± 1ºC (77 ± 1.8ºF).

10. PRECISION

10.1. Duplicate specific gravity results by the same operator should not be considered suspect unless they differ by more than 0.02.

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[1] Aluminum volumeters of different sizes are available from Pine Instrument Co., 101 Industrial Drive, Grove City, PA 16127; and Rainhart Co., 604 Williams St., Austin, TX 78765.

Standard Method of Test for

Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

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AASHTO Designation: T 283-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

AASHTO Designation: T 283-07

1. SCOPE

1.1. This method covers preparation of specimens and the measurement of the change of diametral tensile strength resulting from the effects of water saturation and accelerated water conditioning, with a freeze-thaw cycle, of compacted HMA. The results may be used to predict long-term stripping susceptibility of the HMA and evaluate liquid anti-stripping additives that are added to the asphalt binder or pulverulent solids, such as hydrated lime or portland cement, which are added to the mineral aggregate.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 167, Compressive Strength of Hot Mix Asphalt
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- T 247, Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2. *ASTM Standards*:

- D 979, Standard Practice for Sampling Bituminous Paving Mixtures
- D 2041, Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
- D 3387, Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)

- D 3549, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens

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3. SIGNIFICANCE AND USE

3.1. As noted in the scope, this method is intended to evaluate the effects of saturation and accelerated water conditioning, with a freeze-thaw cycle, of compacted HMA. This method can be used to test: (a) HMA in conjunction with mixture design testing (lab-mixed, lab-compacted); (b) HMA produced at mixing plants (field-mixed, lab-compacted); and (c) HMA cores obtained from completed pavements of any age (field-mixed, field-compacted).

3.2. Numerical indices of retained indirect-tensile properties are obtained by comparing the properties of laboratory specimens subjected to moisture and freeze-thaw conditioning with the similar properties of dry specimens.

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4. SUMMARY OF METHOD

4.1. Test specimens for each set of mix conditions, such as those prepared with untreated asphalt binder, asphalt binder treated with anti-stripping agent, or aggregate treated with lime, are prepared. Each set of specimens is divided into subsets. One subset is tested in dry condition for indirect-tensile strength. The other subset is subjected to vacuum saturation and a freeze cycle, followed by a warm-water soaking cycle, before being tested for indirect-tensile strength. Numerical indices of retained indirect-tensile strength properties are calculated from the test data obtained by the two subsets: dry and conditioned.

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5. APPARATUS

5.1. Equipment for preparing and compacting specimens from one of the following: T 245, T 247, T 312, or ASTM D 3387.

5.2. Equipment for determining the theoretical maximum specific gravity (G_{mm}) of the HMA from T 209 or ASTM D 2041.

5.3. Balance and water bath from T 166.

5.4. Water bath capable of maintaining a temperature of 60 ± 1ºC (140 ± 1.82ºF).

5.5. Freezer maintained at –18 ± 3ºC (0 ± 5ºF).

5.6. A supply of plastic film for wrapping specimens; heavy-duty, leakproof plastic bags to enclose the saturated specimens; and masking tape.

5.7. 10-mL graduated cylinder.

5.8. Pans having a surface area of 48 400 to 129 000 mm^2 (75 to 200 in.^2) in the bottom and a depth of approximately 25 mm (1 in.).

5.9. Forced-draft oven, thermostatically controlled, capable of maintaining any desired temperature setting from room temperature to 176ºC (350ºF) within ±3ºC (±5ºF).

5.10. Loading jack and ring dynamometer from T 245, or a mechanical or hydraulic testing machine from T 167, to provide a range of accurately controllable rates of vertical deformation, including 50 mm/min (2 in./min).

5.11. Steel loading strips with a concave surface having a radius of curvature equal to the nominal radius of the test specimen. For specimens 100 mm (4 in.) in diameter, the loading strips shall be 12.7 mm (0.5 in.) wide, and for specimens 150 mm (6 in.) in diameter, the loading strips shall be 19.05 mm (0.75 in.) wide. The length of the loading strips shall exceed the thickness of the specimens. The edges of the loading strips shall be rounded to the appropriate radius of curvature by grinding.

6. PREPARATION OF LABORATORY-MIXED, LABORATORY-COMPACTED SPECIMENS

6.1. Make at least six specimens for each test, half to be tested dry and the other half to be tested after partial saturation and moisture conditioning with a freeze-thaw cycle (Note 1).

Note 1—It is recommended that two additional specimens for the set be prepared. These specimens can then be used to establish compaction procedures as given in Section 6.5 or 7.4 and the vacuum saturation technique as given in Section 10.3.

6.2. Specimens 100 mm (4 in.) in diameter by 63.5 ± 2.5 mm (2.5 ± 0.1 in.) thick, or 150 mm (6 in.) in diameter by 95 ± 5 mm (3.75 ± 0.20 in.) thick are used. Specimens 150 mm (6 in.) in diameter by 95 ± 5 mm (3.75 ± 0.20 in.) thick should be used if aggregate larger than 25 mm (1 in.) is present in the mixture.

6.3. Prepare mixtures in batches large enough to make at least three specimens or, alternatively, prepare a batch large enough to just make one specimen at a time. If preparing a multi-specimen batch, split the batch into single-specimen quantities before placing in the oven.

6.4. After mixing, the mixture shall be placed in a pan having a surface area of 48 400 to 129 000 mm^2 (75 to 200 in.^2) in the bottom and a depth of approximately 25 mm (1 in.) and cooled at room temperature for 2 ± 0.5 h. Then, the mixture shall be placed in a 60 ± 3ºC (140 ± 5ºF) oven for 16 ± 1 h for curing. The pans should be placed on spacers to allow air circulation under the pan if the shelves are not perforated.

6.5. After curing, place the mixture in an oven for 2 h ± 10 min at the compaction temperature ±3ºC (5ºF) prior to compaction. Compact the specimens according to one of the following methods: T 245, T 247, T 312, or ASTM D 3387. The mixture shall be compacted to 7.0 ± 0.5 percent air voids. This level of voids can be obtained by adjusting the number of blows in T 245; adjusting foot pressure, number of tamps, leveling load, or some combination in T 247; or adjusting the number of revolutions in T 312 or ASTM D 3387. The exact procedure must be determined experimentally for each mixture before compacting the specimens for each set (Note 2).

Note 2—Due to the elevated void content and potential instability of the specimens, ensure each specimen is adequately cool and stable prior to removal from the mold.

6.6. After removal from the molds, the specimens shall be stored for 24 ± 3 h at room temperature.

7. PREPARATION OF FIELD-MIXED, LABORATORY-COMPACTED SPECIMENS

7.1. Make at least six specimens for each test, half to be tested dry and the other half to be tested after partial saturation and moisture conditioning with a freeze-thaw cycle (Note 1).

7.2. Specimens 100 mm (4 in.) in diameter by 63.5 ± 2.5 mm (2.5 ± 0.1 in.) thick, or 150 mm (6 in.) in diameter by 95 ± 5 mm (3.75 ± 0.20 in.) thick are used. Specimens 150 mm (6 in.) in diameter by 95 ± 5 mm (3.75 ± 0.20 in.) thick should be used if aggregate larger than 25 mm (1 in.) is present in the mixture.

7.3. Field-mixed asphalt mixtures shall be sampled in accordance with ASTM D 979.

7.4. No loose-mix curing as described in Section 6.4 shall be performed on the field-mixed samples. After sampling, divide the sample to obtain the desired size in accordance with R 49. Next, place the mixture in an oven until it reaches the compaction temperature ±3ºC (5ºF). Then, compact the specimen according to one of the following methods: T 245, T 247, T 312, or ASTM D 3387. The mixture shall be compacted to 7.0 ± 0.5 percent air voids. This level of voids can be obtained by adjusting the number of blows in T 245; adjusting foot pressure, number of tamps, leveling load, or some combination in T 247; or adjusting the number of revolutions in T 312 or ASTM D 3387. The exact procedure must be determined experimentally for each mixture before compacting the specimens for each set (Note 2).

7.5. After removal from the molds, the specimens shall be stored for 24 ± 3 h at room temperature.

8. PREPARATION OF FIELD-MIXED, FIELD-COMPACTED SPECIMENS (CORES)

8.1. Select locations on the completed pavement to be sampled, and obtain cores. When testing pavement layers with a thickness less than or equal to 63.5 mm (2.5 in.), use 100-mm (4-in.) diameter cores. Otherwise, use either 100-mm (4-in.) or 150-mm (6-in.) diameter cores. The number of cores shall be at least six for each set of mix conditions.

8.2. Separate the core layers as necessary by sawing them or by other suitable means, and store the layers to be tested at room temperature until they are dry.

8.3. No loose-mix curing (Section 6.4) or compacted-mix curing (Section 6.6) shall be performed on the field-mixed, field-compacted specimens (cores).

9. EVALUATION AND GROUPING OF SPECIMENS

9.1. After curing or heating mixture samples for the theoretical maximum specific gravity (G_{mm}) test as described in Sections 6.4 and 6.5, or Section 7.4 as appropriate, determine the G_{mm} of those samples by T 209 or ASTM D 2041.

9.2. Determine each specimen thickness (t) in accordance with ASTM D 3549.

9.3. Record each specimen diameter (D) as defined in Section 6.2, 7.2, or 8.1, as appropriate.

9.4. Determine each bulk specific gravity (G_{mb}) by Method A of T 166. Express the volume (E) of the specimens, or the saturated, surface-dry mass minus the mass in water, in cubic centimeters.

9.5. Calculate the percentage of air voids (P_a) in accordance with T 269.

9.6. Separate the specimens into two subsets, of at least three specimens each, so that the average air voids of the two subsets are approximately equal.

For those specimens to be subjected to vacuum saturation, a freeze cycle, and a warm-water soaking cycle, calculate the volume of air voids (V_a) in cubic centimeters using the following equation:

$$V_a = \frac{P_a E}{100} \tag{1}$$

where:

V_a = volume of air voids, cm^3;

P_a = air voids, percent; and

E = volume of the specimen, cm^3.

Note 3—A data sheet that is convenient for use with this test method is shown as Table 1.

10. PRECONDITIONING OF TEST SPECIMENS

10.1. One subset will be tested dry, and the other will be partially vacuum-saturated, subjected to freezing, and soaked in warm water before testing.

10.2. The dry subset will be stored at room temperature as described in Section 6.6 or Section 7.5, as appropriate. At the end of the curing period from Section 6.6 or 7.5, as appropriate, the specimens shall be wrapped with plastic or placed in a heavy-duty, leakproof plastic bag. The specimens shall then be placed in a 25 ± 0.5ºC (77 ± 1ºF) water bath for 2 h ± 10 min with a minimum 25 mm (1 in.) of water above their surface. Then, test the specimens as described in Section 11.

10.3. *The other subset shall be conditioned as follows*:

10.3.1. Place the specimen in the vacuum container supported a minimum of 25 mm (1 in.) above the container bottom by a perforated spacer. Fill the container with potable water at room temperature so that the specimens have at least 25 mm (1 in.) of water above their surface. Apply a vacuum of 13 to 67 kPa absolute pressure (10 to 26 in. Hg partial pressure) for a short time (approximately 5 to 10 minutes). Remove the vacuum and leave the specimen submerged in water for a short time (approximately 5 to 10 minutes).

10.3.2. Determine the mass of the saturated, surface-dry specimen after partial vacuum saturation (B') by Method A of T 166.

10.3.3. Calculate the volume of absorbed water (J') in cubic centimeters by use of the following equation:

$$J' = B' - A \tag{2}$$

where:

J' = volume of absorbed water, cm^3;

B' = mass of the saturated, surface-dry specimen after partial vacuum saturation, g; and

A = mass of the dry specimen in air, g (Section 9.4).

10.3.4. Determine the degree of saturation (S') by comparing the volume of absorbed water (J') with the volume of air voids (V_a) from Section 9.6 using the following equation:

$$S' = \frac{100J'}{V_a} \tag{3}$$

where:

S' = degree of saturation, percent.

10.3.5. If the degree of saturation is between 70 and 80 percent, proceed to Section 10.3.7.

10.3.6. If the degree of saturation is less than 70 percent, repeat the procedure beginning with Section 10.3.1 using more vacuum and/or time. If the degree of saturation is more than 80 percent, the specimen has been damaged and must be discarded. In this case, repeat the procedure on the next specimen beginning with Section 10.3.1 using less vacuum and/or time.

10.3.7. Cover each of the vacuum-saturated specimens tightly with a plastic film (Saran Wrap® brand or equivalent). Place each wrapped specimen in a plastic bag containing 10 ± 0. 5 mL of water and seal the bag. Place the plastic bags containing the specimens in a freezer at a temperature of –18 ± 3°C (0 ± 5°F) for a minimum of 16 hours. Remove the specimens from the freezer.

10.3.8. Place the specimens in a bath containing potable water at 60 ± 1°C (140 ± 2°F) for 24 ± 1 h. The specimens should have a minimum of 25 mm (1 in.) of water above their surface. As soon as possible after placement in the water bath, remove the plastic bag and film from each specimen.

10.3.9. After 24 ± 1 h in the 60 ± 1°C (140 ± 2°F) water bath, remove the specimens and place them in a water bath at 25 ± 0.5°C (77 ± 1°F) for 2 h ± 10 min. The specimens should have a minimum of 25 mm (1 in.) of water above their surface. It may be necessary to add ice to the water bath to prevent the water temperature from rising above 25°C (77°F). Not more than 15 minutes should be required for the water bath to reach 25 ± 0.5°C (77 ± 1°F). Remove the specimens from the water bath, and test them as described in Section 11.

11. TESTING

11.1. Determine the indirect-tensile strength of dry and conditioned specimens at 25 ± 0.5°C (77 ± 1°F).

11.2. Remove the specimen from 25 ± 0.5°C (77 ± 1°F) water bath, and determine the thickness (t') by ASTM D 3549. Place it between the steel loading strips and then place the specimen and loading strips between the two bearing plates in the testing machine. Care must be taken so that the load will be applied along the diameter of the specimen. Apply the load to the specimen, by means of the constant rate of movement of the testing machine head, at 50 mm/min (2 in./min).

11.3. Record the maximum compressive strength noted on the testing machine, and continue loading until a vertical crack appears. Remove the specimen from the machine, and pull it apart at the crack. Inspect the interior surface for evidence of cracked or broken aggregate; visually estimate the approximate degree of moisture damage on a scale from “0” to “5” (with “5” being the most stripped), and record the observations in Table 1.

Table 1—Moisture Damage Laboratory Data Sheet (Nonmandatory Information)

Project

Additive Dosage

Compaction Method Effort

Date Tested By

Sample identification									
Diameter, mm (in.)	D								
Thickness, mm (in.)	t								
Dry Mass in Air, g	A								
SSD Mass, g	B								
Mass in Water, g	C								
Volume ($B – C$), cm^3	E								
Bulk specific Gravity (A/E)	G_{mb}								
Maximum Specific Gravity	G_{mm}								
% Air Voids [$100(G_{mm} – G_{mb})/G_{mm}$]	P_a								
Volume of Air Voids ($P_aE/100$), cm^3	V_a								
Load, N (lbf)	P								
Saturated min @ kPa (psi) or mm Hg (in. Hg)									
Thickness, mm (in.)	t'								
SSD Mass, g	B'								
Volume of Absorbed Water ($B' – A$), cm^3	J'								
% Saturation ($100J'/V_a$)	S'								
Load, N (lbf)	P'								
Dry Strength [$2000P/\pi tD$ ($2P/\pi tD$)], kPa (psi)	S_1								
Wet Strength [$2000P'/\pi t'D$ ($2P/\pi t'D$)], kPa (psi)	S_2								
Visual Moisture Damage (0 to 5 rating)									
Cracked/Broken Aggregate?									
TSR (S_2/S_1)									

12. CALCULATIONS

12.1. Calculate the tensile strength as follows:

SI Units:

$$S_t = \frac{2000\,P}{\pi\,t\,D} \tag{4}$$

where:

S_t = tensile strength, kPa

P = maximum load, N

t = specimen thickness, mm

D = specimen diameter, mm

U.S. Customary units:

$$S_t = \frac{2\,P}{\pi\,t\,D} \tag{5}$$

where:

S_t = tensile strength, psi;

P = maximum load, lbf;

t = specimen thickness, in.; and

D = specimen diameter, in.

12.2. Express the numerical index of resistance of HMA to the detrimental effect of water as the ratio of the original strength that is retained after the moisture and freeze-thaw conditioning. Calculate the tensile strength ratio to two decimal places as follows:

$$\text{Tensile Strength Ratio (TSR)} = \frac{S_2}{S_1} \qquad (6)$$

where:

S_1 = average tensile strength of the dry subset, kPa (psi); and

S_2 = average tensile strength of the conditioned subset, kPa (psi).

13. REPORT

13.1. Report the following information:

13.1.1. Number of specimens in each subset;

13.1.2. Average air voids of each subset;

13.1.3. Tensile strength of each specimen in each subset;

13.1.4. Tensile strength ratio;

13.1.5. Results of visually estimated moisture damage observed when the specimen fractures; and

13.1.6. Results of observations of cracked or broken aggregate.

Standard Method of Test for

Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method

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AASHTO Designation: T 287-06

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Asphalt Binder Content of Asphalt Mixtures by the Nuclear Method

AASHTO Designation: T 287-06

1. SCOPE

1.1. This procedure covers the quantitative determination of the asphalt binder content of asphalt mixtures by testing a sample with a nuclear gauge that utilizes neutron-thermalization techniques.

1.2. The values expressed in SI units are to be regarded as the standard. The inch-pound equivalents of the SI units may be approximate.

1.3. Nuclear gauge operations and maintenance are not covered in detail. See the manufacturer's manual for details.

1.4. *This test method involves potentially hazardous materials, operations, and equipment. This method does not purport to address all of the safety concerns associated with its use. All operators will be trained in radiation safety prior to operating nuclear gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 40, Sampling Bituminous Materials
- T 110, Moisture or Volatile Distillates in Hot Mix Asphalt (HMA)
- T 168, Sampling Bituminous Paving Mixtures
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 329, Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

3. SUMMARY OF METHOD

3.1. This procedure can be used for rapid determination of the asphalt binder content of asphalt mixtures. It is suitable for quality control and acceptance testing for construction and for research and development applications. This procedure is useful in the determination of asphalt binder content only and does not provide for gradation analysis.

3.2. This procedure determines the asphalt binder content of a test sample by comparing the measured asphalt binder content with previously established calibration data. The asphalt binder content is expressed as a percentage of the mass of the asphalt mixture.

3.3. Accurate results are dependent upon proper calibration of the nuclear gauge to the material being tested as covered in Annex A. This procedure is sensitive to the type and gradation of the aggregate, liquid anti-stripping additive or hydrated lime, and the percentage and source of the asphalt binder.

3.4. This procedure measures the total amount of hydrogen in a sample including the hydrogen present in the form of water. Unless the test sample is totally free of water, the moisture content must be determined according to T 110 or T 329 and the percentage subtracted from the asphalt binder content measured by the nuclear gauge. Alternatively, prior to testing, the sample may be dried to a constant mass in an oven at 110 ± 5°C (230 ± 9°F), thereby nullifying the need for a moisture correction.

3.5. This procedure can be used with recycled asphalt pavement (RAP) incorporated into the asphalt mixture, provided that the RAP is of uniform gradation, asphalt binder content, and asphalt binder type. When RAP is used, the RAP should be mixed in the calibration samples in the same proportion that will be used on the construction project.

4. APPARATUS

4.1. *Nuclear asphalt binder content gauge system consisting of*:

4.1.1. *Neutron Source*—an encapsulated and sealed radioactive source;

4.1.2. Thermal neutron detectors;

4.1.3. Read-out instrument displaying, at a minimum, the percent of asphalt binder to the nearest 0.1 percent; and

4.1.4. Three or more stainless-steel sample pans conforming to the gauge requirements.

4.2. Mechanical mixer with a 10-kg (22-lb) capacity, capable of producing a completely mixed, well-coated, homogenous asphalt mixture.

4.3. Sample containers such as paint cans or unwaxed, nonabsorbent cardboard boxes that can be closed to prevent contamination of the sample and are capable of withstanding the heating of the asphalt mixture to the mixing temperature.

4.4. Sample-quartering apparatus conforming to the requirements of T 248, Method B.

4.5. General-purpose balance or scale conforming to M 231, 20-kg (44-lb) capacity, readable to 0.1 g.

4.6. *Drying Oven*—capable of handling the required number of samples and sample sizes, of either of the following types:

4.6.1. Forced-air convection oven capable of maintaining a temperature of 177 ± 3ºC (350 ± 5ºF).

4.6.2. Microwave oven, determined not to be detrimental to the aggregate, capable of maintaining a temperature of 177 ± 3°C (350 ± 5°F).

4.7. *Leveling Plate*—flat, rigid plate of metal [minimum thickness of 10 mm (0.4 in.)], Plexiglas [minimum thickness of 12.5 mm (0.5 in.)], or non-absorptive plywood [minimum thickness of 19 mm (0.75 in.)], slightly larger than the sample pans.

4.8. Thermometer with a temperature range of 10 to 260°C (50 to 500°F).

4.9. Assorted pans, spoons, spatulas, and mixing bowls.

4.10. *Radioactive materials information/calibration packet containing*:

4.10.1. Daily standard count log;

4.10.2. Factory/laboratory calibration data sheet;

4.10.3. Leak test certificate;

4.10.4. Shipper's declaration for dangerous goods;

4.10.5. Procedure memo for storing, transporting, and handling nuclear testing equipment; and

4.10.6. Other radioactive materials documentation conforming to local regulatory requirements.

5. PRECAUTIONS

5.1. *The nuclear asphalt binder content gauge may be sensitive to outside influences and therefore*:

5.1.1. Any other source of neutron radiation shall be kept at least 10 m (33 ft) from the apparatus during use;

5.1.2. The space within 1 m (3.3 ft) of the apparatus shall be kept free of hydrogenous material such as water, plastics, asphalt binder, or asphalt mixtures during use;

5.1.3. All personnel shall be kept at least 1 m (3.3 ft) away from the gauge during testing; and

5.1.4. The gauge shall not be located within 10 m (33 ft) of any water supply tanks, fuel tanks, or other liquid containers subject to fluctuating liquid levels.

5.2. Moving the apparatus to a different location, even within the same laboratory, may cause a change in the background radiation measurements. New background measurements, and possibly recalibration, will be necessary prior to use whenever background conditions have changed. See Sections 6 and 7 for instructions concerning calibration and background measurements.

6. CALIBRATION

6.1. Perform calibrations and cross-calibrations on asphalt mixtures tested in gauges, and transfer calibrations between gauges according to Annex A.

7. STANDARDIZATION

7.1. Obtain and record a background count in accordance with the manufacturer's procedure each day prior to taking test measurements or whenever the gauge has been moved or the conditions within 1 m (3.3 ft) of the gauge have changed. The measurement time for the background count should be the same as that used for the test measurements.

7.2. If the background count has not changed by more than 1 percent from the previous background count, then the apparatus shall be considered stable and acceptable for use. If the gauge has been moved or if the surrounding conditions have changed, additional background counts must be obtained until the 1-percent standard is satisfied.

8. PROCEDURE

8.1. Obtain a representative sample of asphalt mixture in accordance with T 168. If required, reduce the sample to the approximate test size by splitting or quartering according to T 248, Method B. It is recommended that testing be performed while the asphalt mixture is still hot, and not reheated, if possible. If the asphalt mixture cools and reheating is necessary, heat it to the mid-point of the compaction temperature range for the asphalt binder used in the asphalt mixture.

8.2. Determine the mass of a clean gauge-sample pan, and tare the pan on the scale.

8.3. Place the asphalt mixture into the pan until it is about half full. Lightly tamp the asphalt mixture in the pan with a preheated spoon or spatula.

8.4. Place additional asphalt mixture into the pan until the required mass, as determined in Annex A, is reached within ±5 g.

8.5. Place the leveling plate on top of the asphalt mixture immediately after filling the pan. Compact the sample into the pan until it is level with the top of the pan by pressing down on the plate. Sight across the top of the pan to ensure that the asphalt mixture does not protrude above the pan.

8.6. Record the mass of the asphalt mixture compacted into the pan. The mass shall be within ±5 g of the target mass.

Note 1—If the gauge does not have temperature-compensation capability, measure and record the temperature of the compacted specimen. This temperature must be within ±5°C (9°F) of the calibration-test-specimen temperature.

8.7. If the gauge has the ability to store multiple calibrations, activate the calibration for the particular asphalt mixture. Place the pan into the gauge, and perform a 4-minute count.

8.8. Determine the uncorrected asphalt binder content by direct read-out from the gauge, calibration graph, or formula supplied by the manufacturer. Record the uncorrected asphalt binder content from the 4-minute reading to the nearest 0.1 percent.

8.9. Using a representative portion of the original sample or a portion of the material removed from the gauge pan, determine the moisture in the asphalt mixture according to T 110 or T 329, and record it to the nearest 0.1 percent. Alternatively, prior to testing, the sample may be dried to a constant mass in an oven at 110 ± 5°C (230 ± 9°F), thereby nullifying the need for a moisture correction.

9. CALCULATION

9.1. When determined, subtract the moisture content from the uncorrected asphalt binder content. Record this value as the corrected asphalt binder content.

10. REPORT

10.1. *Report the following information*:

10.1.1. Make, model, and serial number of the nuclear asphalt binder content gauge;

10.1.2. Date and source of the calibration;

10.1.3. Date of the test;

10.1.4. Name and signature of the operator;

10.1.5. Background count for the day of the test;

10.1.6. Asphalt mixture identification;

10.1.7. Aggregate type and sources;

10.1.8. Asphalt binder grade and source;

10.1.9. When used, source and amount of liquid anti-stripping additive or hydrated lime;

10.1.10. Calibration sample mass and temperature;

10.1.11. Test-sample mass and temperature if the gauge does not have temperature-compensation capability;

10.1.12. Gauge reading; and

10.1.13. Corrected asphalt binder content value to the nearest 0.1 percent.

ANNEXES

(Mandatory Information)

A1. SCOPE

A1.1. This annex covers the preparation of samples for, and the calibration of, nuclear asphalt binder content gauges. Job-mix formula (JMF) calibration and cross-calibration of master and field gauges are included.

A2. SAMPLING

A2.1. Obtain samples of aggregate according to T 2. Approximately 50 kg (110 lb) will be required for the calibration specimens.

A2.2. Obtain samples of asphalt binder according to T 40. Approximately 4 L (1 gal) will be required.

Note A1—The more accurately the ingredient materials (including liquid anti-stripping additive or hydrated lime) are prepared to match the JMF, the closer the calibration points will be to the production asphalt mixture. Therefore, the more accurate the results will be.

A3. AGGREGATE PREPARATION

A3.1. When used, hydrate the appropriate amount of lime on the aggregate.

A3.2. Dry the aggregate to a constant mass using the apparatus and temperatures from T 255.

A3.3. Separate the aggregate blend by dry-sieving on the specified sieves, including the minus 75-µm (No. 200) material.

A3.4. Calculate the required cumulative mass for each specified sieve using the following formula:

$$X = \frac{T(100 - P)}{100} \tag{A3.1}$$

where:

X = the required, cumulative batch mass for each specified sieve (g);

T = the initial, total aggregate mass (g); and

P = the percent passing for each specified sieve according to the JMF.

A3.5. *Perform an aggregate dust correction as follows*:

A3.5.1. Prepare a washed-gradation sample from the masses calculated in Section A3.4.

A3.5.2. Perform a washed gradation according to T 27 and T 11.

A3.5.3. Calculate the corrected batch mass for each specified sieve for the calibration points using the following formula:

$$Z_n = \frac{X^2}{Y} \tag{A3.2}$$

where:

Z_n = the adjusted, cumulative batch mass for any sieve size, n (g);

X = the pre-wash, cumulative batch mass for each specified sieve (g); and

Y = the post-wash, cumulative batch mass for each specified sieve (g).

A3.6. Blend the aggregate together at the proper proportion to match the JMF using the masses calculated in Section A3.5.3.

A4. ASPHALT BINDER PREPARATION

A4.1. Heat a minimum of 2 L (0.5 gal) of asphalt binder to the mid-point of the mixing temperature range in a covered container(s). When used, add the appropriate amount of liquid anti-stripping additive to the asphalt binder. Use the asphalt binder as soon as it reaches the mid-point of the mixing temperature range. If this operation is not possible, maintain the asphalt binder at this temperature for no more than 4 hours. Do not cool and reheat the asphalt binder.

A4.2. *Method A*—Asphalt binder percent by mass of the asphalt mixture.

A4.2.1. Calculate the mass of asphalt binder for each calibration point as follows:

$$B = (E)(P_{bm}) \qquad (A4.1)$$

where:

B = the mass of the asphalt binder to the nearest 0.1 g;
E = the mass of the asphalt mixture (g); and
P_{bm} = the percent of asphalt binder by total mass of the asphalt mixture, expressed as a decimal.

Asphalt binder contents will be chosen at the optimum asphalt binder content and at increments of ±0.8 percent from the optimum asphalt binder content. The minimum four samples are at 0.8 below, optimum, 0.8 above, and 1.6 percent above the optimum.

A4.2.2. Calculate the mass of aggregate required for each calibration point as follows:

$$A = E - B \qquad (A4.2)$$

where:

A = the mass of the aggregate to the nearest 0.1 g.

A4.3. *Method B*—Asphalt binder percent by mass of the aggregate.

A4.3.1. Calculate the mass of aggregate for each calibration point as follows:

$$A = \frac{E}{1 + P_{ba}} \qquad (A4.3)$$

where:

P_{ba} = the percent of asphalt binder by mass of the aggregate, expressed as a decimal.

Asphalt binder contents will be chosen at the optimum asphalt binder content and at increments of ±0.8 percent from the optimum asphalt binder content. The minimum four samples are at 0.8 below, optimum, 0.8 above, and 1.6 percent above the optimum.

A4.3.2. Calculate the mass of asphalt binder required for each calibration point as follows:

$$B = (A)(P_{ba}) \qquad (A4.4)$$

A5. PREPARATION FOR SPECIMENS

A5.1. The aggregate and asphalt binder materials must be heated to the mid-point of the mixing temperature range for that asphalt binder. Once these materials have stabilized at that temperature, proceed with the following steps:

A5.2. Determine the mass of the heated mixing bowl to the nearest 0.1 g.

A5.3. Place a heated aggregate specimen, of the required mass to the nearest 0.1 g, in the mixing bowl.

A5.4. Form a crater in the aggregate large enough to hold the required mass of asphalt binder.

A5.5. Place the mixing bowl on the scale. Add the required, preheated asphalt binder mass, to the nearest 0.1 g, into the aggregate crater.

A5.6. Mechanically mix the aggregate and asphalt binder rapidly for a minimum of two minutes until they are thoroughly blended. Check the bottom and sides of the bowl for unmixed aggregate and asphalt binder. If necessary, remix the sample by hand until it is thoroughly mixed.

Note A2—Hand-mixing is not recommended. However, mixing may be performed by hand in a large bowl. In this case, the mixing time shall be a minimum of five minutes, but it may be longer to ensure thorough mixing.

A5.7. Remove the asphalt mixture from the bowl, and determine the mass of the empty bowl to ensure that all material has been removed. The mass of the bowl shall be within ±5 g of the mass determined in Section A5.2. If it is not, scrape the bowl with a spatula, and deposit the excess into the sample, until the mass of the bowl is within the tolerance.

A6. TARGET MASS DETERMINATION

A6.1. An initial, or “butter,” batch is prepared to determine the mass to be used for the calibration samples using an asphalt binder/aggregate blend approximating the real batches. Based on experience with aggregate specific gravity and gradation, the target mass will be from 6000 to 9000 g.

Note A3—To find an approximate starting mass, place the dry aggregate in a gauge-sample pan. Fill the pan half full; then drop it from a height of 25 mm (1 in.). Fill the pan just over full, and strike it off even with the top. Determine this mass, and add 10 percent to obtain an approximate starting mass.

A6.2. Mix the preheated aggregate and asphalt binder according to Section A5.

A6.3. Determine the mass of a clean gauge-sample pan, and tare the pan on the scale.

A6.4. Place the asphalt mixture into the pan until it is about half full. Lightly tamp the asphalt mixture in the pan with a preheated spoon or spatula.

A6.5. Place the remaining asphalt mixture into the pan so that the asphalt mixture is mounded about 13 mm (0.5 in.) above the top of the pan.

A6.6. Place the leveling plate on top of the asphalt mixture immediately after filling the pan. Compact the sample into the pan until it is level with the top of the pan by pressing down on the plate. Sight across the top of the pan to ensure that the asphalt mixture does not protrude above the pan.

A6.7. Determine and record the mass of the asphalt mixture compacted into the pan. This value is the target mass. The subsequent calibration and sample specimens must be within ±5 g of this mass.

A7. CALIBRATION (GENERAL)

A7.1. The type of aggregate, source and grade of asphalt binder, liquid anti-stripping additive or hydrated lime, and asphalt mixture gradation will influence the test results obtained using this procedure. Accordingly, a calibration curve must be developed for each combination of these factors.

A7.2. The calibration curve must cover the range of expected values found in field samples. The limits for the calibration curve must consider the allowable range of asphalt binder content plus the allowable aggregate moisture (which reads as asphalt binder in the gauge). At a minimum, use 0.8 below, optimum, 0.8 above, and 1.6 percent above the optimum asphalt binder content when making the calibration-curve pans.

A8. JMF CALIBRATION

A8.1. Prepare four aggregate samples using the target mass determined in Section A6.7. Place them in separate pans designed for, and capable of, transferring the dry aggregate into a mixing bowl with a minimum loss of aggregate. Place them in an oven set at the mid-point of the mixing temperature range for the asphalt binder to be used.

A8.2. Determine the mass of the aggregate and asphalt binder for each calibration sample according to Sections A3 and A4, respectively.

A8.3. Mix the preheated aggregate and asphalt binder according to Section A5.

A8.4. Determine the mass of a clean gauge-sample pan, and tare the pan on the scale.

A8.5. Place the asphalt mixture into the pan until it is about half full. Lightly tamp the asphalt mixture in the pan with a preheated spoon or spatula.

A8.6. Place the remaining asphalt mixture into the pan so that the asphalt mixture is mounded about 13 mm (0.5 in.) above the top of the pan.

A8.7. Place the leveling plate on top of the asphalt mixture immediately after filling the pan. Compact the sample into the pan until it is level with the top of the pan by pressing down on the plate. Sight across the top of the pan to ensure that the asphalt mixture does not protrude above the pan.

A8.8. Determine and record the mass of the asphalt mixture compacted into the pan. The mass shall be within ±5 g of the target mass determined in Section A6.7.

A8.9. Place the pan into the gauge, and proceed in accordance with the manufacturer's instructions for the operation of the equipment and the sequence of operations.

Note A4—Do not forget to perform a background count according to the manufacturer's instructions.

A8.10. Repeat Sections A8.2 through A8.9 for the other calibration samples.

A9. PRESENTATION OF CALIBRATION DATA

A9.1. *For gauges that generate the calibration internally to the gauge*:

A9.1.1. Print or otherwise record the formula coefficients, the coefficient of fit, and the calculated percent difference for each calibration point. If the coefficient of fit is less than 0.998 for a dense-graded asphalt mixture or 0.995 for an open-graded asphalt mixture, or any calibration point has a calculated percent difference greater than 0.09 percent, the calibration is not acceptable and must be performed again.

A9.1.2. Store the acceptable calibration in the gauge's memory, using the JMF and an easily recognizable calibration number, according to the manufacturer's instructions.

A9.2. *For gauges that do not generate the calibration internally to the gauge*:

A9.2.1. Prepare a calibration curve by plotting the gauge readings for the calibration samples versus asphalt binder content on linear graph paper, choosing convenient scale factors for the gauge readings and asphalt binder content.

A10. CROSS-CALIBRATION (WHEN APPLICABLE)

A10.1. The formula coefficients are entered into the field gauge in the transfer mode during the cross-calibration process. The new formula coefficients, when printed, will not resemble the values entered because they will change based on this relationship. For more detailed information on the formula coefficients, refer to the manufacturer's instructions. If required, a "straight" calibration may be performed and used instead of the transfer program. This option requires that the sample pans used for the calibration be tested in another gauge if the testing must be verified by the agency.

Note A5—Some agencies cross-calibrate gauges. This process creates a relationship between the field gauge and the gauge used in the JMF calibration, allowing the testing of production asphalt mixture without the need to perform calibrations in the field. When several gauges are cross-calibrated, the asphalt mixture calibrations may be transferred to each gauge.

A10.2. Prepare six calibration samples, using a locally available, agency-approved aggregate, with asphalt binder contents between 3 and 8 percent at 1-percent increments. Mix the samples so that each pan of asphalt mixture equals the target mass ±5 g as determined for the aggregate. Test each sample in the master gauge using 16-minute counts in the normal calibration mode. After all samples are tested, the gauge will automatically calculate a coefficient of fit. The coefficient of fit must be at least 0.999. Seal each pan to prevent a change in hydrogen content, and repeat the procedure. Sealed pans must meet the same criteria as above.

Note A6—To seal the pan, cut a piece of tin the size of the top of the sample pan. Seal the edges of the pan and tin lid with an epoxy. This process will seal any moisture out.

A10.3. Test each of the six sealed calibration samples in the field gauge while it is in the cross-calibration mode. For each calibration sample, input the data obtained from the master gauge into the field gauge. The master and field gauges are now cross-calibrated.

Note A7—Annually, or whenever a field gauge differs from the master gauge, a new cross-calibration must be performed using the sealed pans originally produced for the gauge standardization. These six pans must be checked monthly in the master gauge to verify that the counts have not changed substantially.

Standard Method of Test for

Specific Gravity or API Gravity of Liquid Asphalts by Hydrometer Method

AASHTO Designation: T 295-08
ASTM Designation: D 3142-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Specific Gravity or API Gravity of Liquid Asphalts by Hydrometer Method

AASHTO Designation: T 295-08
ASTM Designation: D 3142-05

1. SCOPE

1.1. This test method covers the determination of the density of cutback asphalts using a glass hydrometer. It is applicable to cutback asphalts which are liquid at room temperature (Note 1). It provides more explicit testing procedures than those in AASHTO T 227.

Note 1—For materials that are solid or semi-solid at room temperature, use AASHTO T 228 or ASTM D 3289.

1.2. The values in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 7.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 40, Sampling Bituminous Materials
- T 227, Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
- T 228, Specific Gravity of Semi-Solid Asphalt Materials

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 1250, Standard Guide for Use of the Petroleum Measurement Tables
- D 3289, Standard Test Method for Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method)
- D 4311, Standard Practice for Determining Asphalt Volume Correction to a Base Temperature
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 100, Standard Specification for ASTM Hydrometers

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *API gravity*—a function of specific gravity (SG) 15.6/15.6ºC, represented by the following equation: ºAPI = (141.5/SG 15.6/15.6ºC) – 131.5

3.1.2. *density*—the mass per unit volume of a material.

3.1.3. *observed values*—values observed at temperatures other than the standard reference temperature. Values observed at other temperatures are only hydrometer readings and not density, relative density (specific gravity), or API gravity.

3.1.4. *relative density*—the ratio of the mass of a given volume of a material to the mass of the same volume of water at the same temperature.

3.1.5. *specific gravity*—relative density.

4. SUMMARY OF TEST METHOD

4.1. The sample is brought to the testing temperature and transferred to a cylinder at approximately the same temperature. The cylinder and its contents are placed in a constant-temperature bath to avoid excessive temperature variation during the test. The appropriate hydrometer is lowered into the sample and allowed to settle. After temperature equilibrium is achieved, the hydrometer is read, and the temperature of the sample is noted. The hydrometer reading is converted to the density at 15ºC (60°F) using standard tables.

5. SIGNIFICANCE AND USE

5.1. Values of density are used for converting volumes to units of mass, and for correcting measured volumes from the temperature of measurement to a standard temperature using ASTM D 4311.

6. APPARATUS

6.1. *Hydrometers*—glass, graduated in units of specific gravity and accurate to 0.001, API gravity and accurate to 0.1° API, or density and accurate to 0.5 kg/m^3 (0.03 lb/ft^3), conforming to Table 1.

Table 1—Recommended Hydrometers

Hydrometer Designation	Measurement	Range	Total Length, mm	Body Diameter, mm
1H to 4H	API Gravity	–1 to 41ºAPI	325 to 335	23 to 27
21H to 28H	API Gravity	0 to 41ºAPI	158 to 168	12 to 15
85H to 90H	Relative Density (SG) 15.6/15.6ºC (60°F)	0.8 to 1.1	325 to 335	23 to 27
105H to 108H	Relative Density (SG) 15.6/15.6ºC (60°F)	0.8 to 1.0	250 to 270	20 to 24
315H to 320H	Density at 15ºC (60°F)	800 to 1100 kg/m^3 (50–69 lb/ft^3)	325 to 335	21 to 27

6.2. Other hydrometers conforming to the performance and accuracy requirements of ASTM E 100 may be used.

6.3. *Thermometric Device*—accurate to 0.1ºC (0.2°F). An ASTM 12C thermometer as defined in ASTM E 1 is suitable. Any other thermometric device of equal accuracy may be used.

6.4. *Hydrometer Cylinder*—clear glass, plastic (Note 2), or metal. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least 20 mm ($^3/_4$ in.) greater than the outside diameter of the hydrometer used in it. The height of the cylinder shall be such that the hydrometer floats in the sample with at least 25 mm (1 in.) clearance between the bottom of the hydrometer and the bottom of the cylinder.

Note 2—Hydrometer cylinders constructed of plastic materials shall be resistant to discoloration by oil samples and must not become opaque by prolonged exposure to sunlight or oil samples.

6.5. *Constant-Temperature Bath*—capable of maintaining the testing temperature within ±0.5ºC (1.0°F) and of such dimensions that the level of the liquid is approximately the same as that of the sample in the hydrometer cylinder.

6.5.1. *Thermometric Device*—a thermometer or electronic temperature-measuring device accurate to 0.25°C (0.5°F) shall be used to measure the temperature of the constant-temperature bath

6.6. *Oven*—for preheating the sample, and capable of maintaining the selected testing temperature within ±3ºC (5°F).

6.6.1. *Thermometric Device*—a thermometer or electronic temperature measuring device accurate to 1°C (2°F) shall be used to measure the temperature of the oven.

7. HAZARDS

7.1. Materials tested using this procedure may contain volatile and flammable hydrocarbons. Heat the sample in a covered container to minimize the loss of volatile components. Perform the test in a well-ventilated area, and avoid breathing any vapors that may be generated. Keep sources of ignition away from materials being tested.

8. SAMPLING

8.1. Take samples in accordance with AASHTO T 40. The sample shall be free of foreign substances.

8.2. Thoroughly mix the sample before removing a representative portion for testing.

9. TEMPERATURE OF TEST

9.1. Because of differences in viscosity between various grades of liquid asphalts, the temperature of the test must be adjusted so that it will provide sufficient fluidity to conduct the test over a reasonable period of time. The recommended testing temperatures for the various grades shown in Table 2 are based on a viscosity of approximately 200 to 500 cSt.

Table 2—Recommended Testing Temperatures for Various Grades of Liquid Asphalts

Grade	Testing Temperature, ºC (°F)
MC-30	Room
SC-70, MC-70, RC-70	40 (104)
SC-250, MC-250, RC-250	60 (140)
SC-800, MC-800, RC-800	80 (176)
SC-3000, MC-3000, RC-3000	100 (212)

9.2. When the hydrometer value is used to select multipliers for correcting volumes to standard temperatures, the hydrometer reading should be made preferably at a temperature within ±3ºC (5°F) of the temperature at which the bulk volume of the oil was measured (Note 3). However, in cases when appreciable amounts of light fractions may be lost during determination at the bulk asphalt temperature, the temperatures given in Table 2 should not be exceeded.

Note 3—Volume and density correction tables are based on an average coefficient of expansion for a number of typical materials. Since the same coefficients were used in computing both sets of tables, corrections made over the same temperature interval minimize errors arising from possible differences between the coefficients of the material under test and the standard coefficients. This effect becomes more important as temperatures diverge significantly from 15ºC (60°F).

10. PROCEDURE

10.1. Select the test temperature in accordance with Section 9. Heat the sample in an oven to ±3ºC (5°F) of the test temperature. The container shall be covered with a loose-fitting cover to prevent solvent evaporation. Bring the hydrometer cylinder and thermometer to approximately the same temperature as the sample to be tested.

10.2. Transfer the sample to a clean hydrometer cylinder (Note 4) without splashing to avoid the formation of air bubbles and reduce to a minimum the evaporation of the lower boiling constituents of the more volatile samples. Remove any air bubbles formed, after they have collected on the surface of the sample, by touching them with a piece of clean filter paper before inserting the hydrometer.

Note 4—When metal cylinders are used, accurate reading of the hydrometer can only be ensured if the level of the sample is within 5 mm (0.2 in.) of the top of the cylinder.

10.3. Place the cylinder containing the sample in the constant-temperature bath previously heated to the test temperature ±0.5ºC (1.0°F). Allow sufficient time for the sample to reach the bath temperature, and verify its temperature with the thermometer, ensuring that the mercury thread is fully immersed. If a thermohydrometer is used, it may be lowered into the sample at this point instead of the thermometer. As soon as a steady thermometer reading is obtained, record the temperature of the sample to the nearest 0.2ºC (0.5°F).

10.4. Lower the hydrometer gently into the sample. Avoid wetting the stem above the level to which it will be immersed in the liquid. Allow sufficient time for the hydrometer to become completely stationary and for all air bubbles to come to the surface. This step is particularly necessary in the case of more viscous samples.

10.5. When the hydrometer has come to rest, floating freely away from the walls of the cylinder, read the hydrometer to the nearest scale division. Take the reading by observing, with the eye slightly above the plane of the surface of the liquid, the point on the hydrometer scale to which the sample rises. This reading, at the top of the meniscus, requires correction, since hydrometers are standardized to be read at the principal surface of the liquid. The corrections for the particular hydrometer in use may be determined by observing the maximum height above the principal surface of the liquid to which oil rises on the hydrometer scale when the hydrometer in question is immersed in a transparent oil having a surface tension similar to that of the sample under test. For routine work, determine the height of the meniscus by sighting across the principal surface of the liquid and estimating the rise of the meniscus on the hydrometer scale.

10.6. Immediately after observing the hydrometer scale value, cautiously stir the sample with the thermometer, keeping the mercury thread fully immersed. Record the temperature of the sample to the nearest 0.2ºC (0.5°F) (Note 5). Should this temperature differ from the previous reading by more than 0.5ºC (1.0°F), repeat the hydrometer and thermometer observations until the temperature becomes stable within 0.5ºC (1.0°F).

Note 5—After use at a temperature higher than 37.8ºC (100ºF), allow all hydrometers of the "lead shot-in-wax" type to drain and cool in a vertical position.

11. CALCULATION

11.1. Apply any relevant corrections to the observed thermometer reading (for the scale and bulb) and to the hydrometer reading (for the scale). Make the appropriate correction to the observed hydrometer reading. Record the corrected hydrometer reading to the nearest 0.1ºAPI, 0.001 relative density (specific gravity), or 1 kg/m^3 (0.1 lb/ft^3). After application of any relevant corrections, record the mean temperature values observed immediately before and after the final hydrometer reading to the nearest 0.5ºC (1.0°F).

11.2. To convert the observed hydrometer reading to density at 15ºC (60°F), use the following tables from ASTM D 1250, Guide for Use of the Petroleum Measurement Tables:

11.2.1. When an API gravity hydrometer has been used, use Table 5A to convert the hydrometer reading to the API gravity. Then use Table 3 to obtain the density at 15ºC (60°F).

11.2.2. When a relative density (specific gravity) hydrometer has been used, use Table 23A to convert the hydrometer reading to the relative density 15.6/15.6ºC (60°F). Then use Table 21 to obtain the density at 15ºC (60°F).

11.2.3. When a density-scaled hydrometer has been used, use Table 53A to obtain the density at 15ºC (60°F).

12. REPORT

12.1. Report the density at 15ºC (60°F) to the nearest 1 kg/m^3 (0.1 lb/ft^3).

13. PRECISION AND BIAS

13.1. *Single-Operator Precision*—The single-operator standard deviation for the relative density of cutback asphalts has been found to be 0.00195. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 5.5 kg/m^3 (0.3 lb/ft^3).

13.2. *Multilaboratory Precision*—The multilaboratory standard deviation for the relative density of cutback asphalts has been found to be 0.00276. Therefore, results of two properly conducted tests by two laboratories on samples of the same material should not differ by more than 7.8 kg/m^3 (0.5 lb/ft^3).

Note 6—These numbers represent the 1s and d2s limits as described in ASTM C 670.

13.3. *Bias*—The bias of this test method has not been determined.

14. KEYWORDS

14.1. API Gravity; cutback asphalt; density; hydrometer; liquid asphalt; relative density; specific gravity.

Standard Method of Test for

Force Ductility Test of Asphalt Materials

AASHTO Designation: T 300-00 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Force Ductility Test of Asphalt Materials

AASHTO Designation: T 300-00 (2008)

1. SCOPE

1.1. The force ductility of an asphalt material is determined by measuring the tensile stress induced on a specimen when two ends of a briquet specimen of the material are pulled apart at 5 cm/min (2 in./min) and at a specified temperature. Unless otherwise specified, the test shall be performed at a temperature of 4.0 ± 0.5°C (39.2 ± 1.0°F) and a speed of 5 cm/min (2 in./min) ± 5.0 percent. The test is designed primarily for polymer-modified emulsions.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This test may involve hazardous materials, operations, and equipment. This test does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 316, Polymer-Modified Cationic Emulsified Asphalt

2.2. *ASTM Standards*:

- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques
- E 644, Standard Test Methods for Testing Industrial Resistance Thermometers

3. SIGNIFICANCE AND USE

3.1. The force ductility test is an indicator of the presence of polymer in an asphalt material.

3.2. When testing CRS-2P, a polymer-modified cationic emulsified asphalt specified in AASHTO M 316, perform the test at a temperature of 4°C (39°F) and a speed of 5 cm/min (2 in./min). The test is performed on the residue from evaporation.

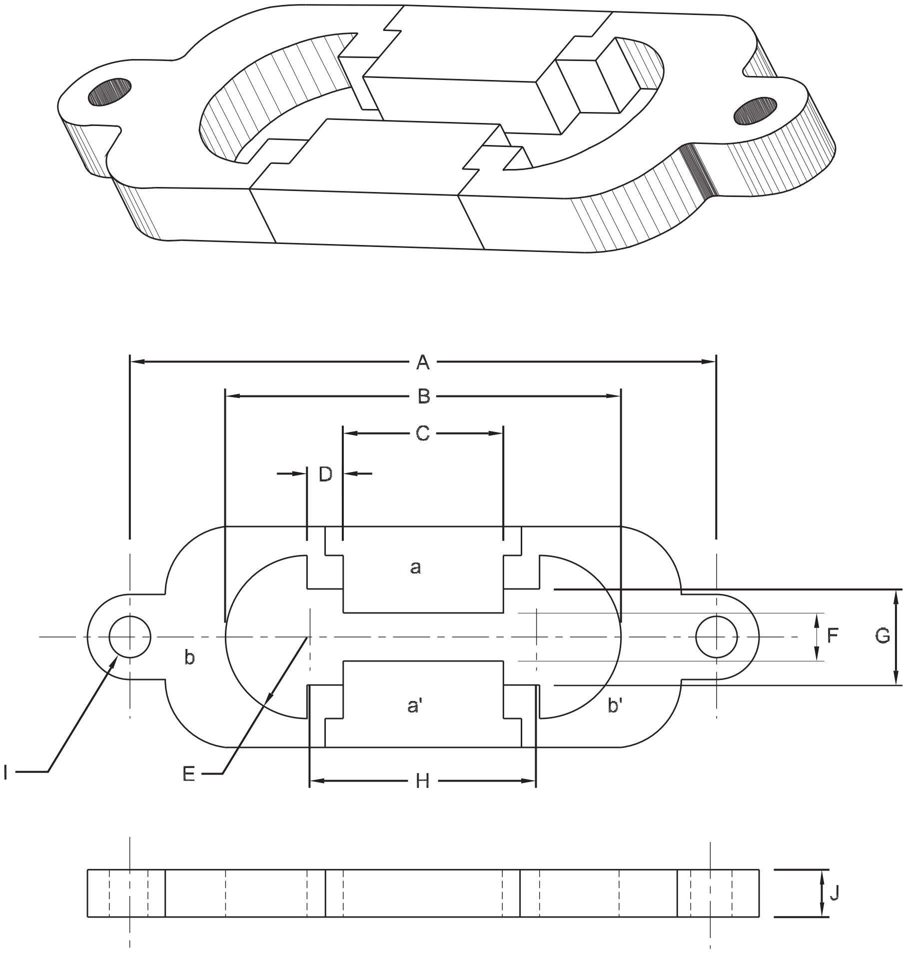
4. APPARATUS

4.1. *Molds*—The mold shall be similar in design to that shown in Figure 1 and made of brass. The dimensions of the assembled mold shall be as shown in Figure 1 with the permissible variations indicated.

4.2. *Base Plate*—The base plate shall be made of nonabsorbent material, of sufficient thickness to prevent deformation, and of a sufficient size to hold from one to three molds. The plate shall be uniformly flat to insure that the bottom surfaces of each mold will touch it throughout.

4.3. *Water Bath*—The water bath shall be maintained at the specified test temperature, varying not more than ±0.5ºC (±1.0ºF) from this temperature. The volume of water shall not be less than 10 L (10.5 qt). The depth of water shall not be less than 50 mm (2 in.) and such that the mold can be immersed to a depth of not less than 25 mm (1 in.). The water in the bath shall be free from oil and slime or other organic growth.

4.4. *Thermometers*—For tests at 4.0°C (39.2°F), use an ASTM Thermometer No. 63C (63F) as specified in ASTM E 1 to measure the temperature of the water bath and the temperature of the water in the testing machine. For tests at other temperatures, use ASTM thermometers of an appropriate range and accuracy equal to that of the No. 63. Since the accuracy of the test results is dependent upon closely controlled conditions of temperature, the thermometers should be standardized in accordance with ASTM E 77. An equivalent thermometric device that has been standardized in accordance with ASTM E 220 or E 644 may be used.



A - Distance between centers, 111.5 to 113.5 mm
B - Total length of briquet, 74.5 to 75.5 mm
C - Distance between clips, 29.7 to 30.3 mm
D - Shoulder, 6.8 to 7.2 mm
E - Radius, 15.75 to 16.25 mm
F - Width at minimum cross section, 9.9 to 10.1 mm
G - Width at mouth of clip, 19.8 to 20.2 mm
H - Distance between centers of radii, 42.9 to 43.1 mm
I - Hole diameter, 6.5 to 6.7 mm
J - Thickness, 9.9 to 10.1 mm

Figure 1—Mold Assembly

4.5. *Testing Machine*—For pulling the briquet of asphalt material apart, any apparatus may be used which is so constructed that the specimen will be continuously immersed in water, as specified in Section 4.3, while the two clips are pulled apart at a uniform speed, as specified, without undue vibration.

4.6. *Heater*—An oven or hot plate, heated by electricity or gas, may be used to melt the asphalt material.

4.7. *Container*—Any suitable container may be used to hold the asphalt material while it is being melted.

4.8. *Trimmer*—Any convenient implement, such as a putty knife or spatula, may be used provided that the cutting edge is straight and at least 38 mm ($1^1/_2$ in.) wide.

4.9. *Calibrated Force Adapter*—A stainless steel platform that incorporates an LVDT sensor for measuring tensile force [accurate to 0.04 N (0.01 lb)]. The unit is designed to utilize the existing pins on a ductility machine.

4.10. *Digital Indicator*—A power supply and digital display in Newtons (pounds) that serves the LVDT sensor on the force adapter. Includes a standard 0–5 VDC analog output for interfacing with a chart recorder, computer, or other readout.

4.11. *Chart Recorder (Optional)*—Records output of the digital indicator through the 0–5 VDC analog output.

5. PROCEDURE

5.1. *Preparation of Apparatus*—Assemble the mold on the base plate. To prevent the material from sticking, coat the surface of the plate and the interior surfaces of Sides a and a' (as indicated in Figure 1) with a suitable release agent.

Note 1—Mixtures of glycerin and dextrin or talc (3 g glycerin to about 5 g dextrin or talc has been used satisfactorily), Dow-Corning Silicone Stop-Cock Grease, or castor oil and Versamid 900 [100:1 mixture by mass heated to 204 to 232°C (400 to 450°F) and stirred until it is homogeneous] have proven suitable. Other release agents may be used provided the results obtained are comparable to those obtained when using one of the above.

5.2. *Molding Test Specimens*—Heat the sample with care to prevent local overheating until it has become sufficiently fluid to pour. After thorough stirring, pour the asphalt material into the mold, taking care not to entrain any air bubbles. Pour the material in a thin stream back-and-forth from end to end until the mold is more than “level full.” In filling the mold, take care not to disarrange the parts of the mold and distort the briquet. Let the mold and contents cool to room temperature for a period of 30 to 40 minutes, and then place the base plate and filled mold in the water bath maintained at the specified test temperature for 30 minutes. Remove the base plate and filled mold from the water bath, and with a hot trimmer, cut off the excess asphalt material so that the mold is just “level full.” Take care during the trimming operation that the specimen is not pulled away from the base plate or from the side pieces of the mold.

5.3. *Keeping Specimen at Standard Temperature*—Place the base plate and filled mold in the water bath or testing machine, and keep them at the specified temperature for a period of 85 to 95 minutes. Remove the briquet from the plate, detach the side pieces, and immediately test the briquet.

5.4. *Testing*—At the start of the test, the water in the tank of the testing machine shall cover the specimen both above and below by not less than 25 mm (1 in.). Attach the clips to the pins or hooks of the force adapter and the testing machine, and pull the clips apart at the specified rate of speed until the specified minimum ductility is met, the briquet ruptures, or the limit of travel of the machine is reached. If necessary, adjust the specific gravity of the liquid in the testing machine so that the asphalt material neither comes to the surface nor touches the bottom of the bath at any time during the test by adding a solute which does not interfere with the test (Note 2). Measure and record the distance through which the clips have been pulled.

Note 2—Solutes such as sodium chloride, methyl alcohol, or ethylene glycol have been used successfully.

6. REPORT

6.1. A normal test is one in which the material between the two clips is pulled out to a point where minimum ductility is met, rupture occurs at the point where the thread has practically no cross-sectional area, or until the capacity of the machine is reached. If the material comes in contact with the surface of the water or the bottom of the bath, the test shall not be considered normal.

6.2. A normal test will produce data which, when plotted, will result in a graph showing two peaks (f_1, f_2). Locate the two peaks on the graph of the data. The second peak will be less than the initial peak. If a readily definable second peak is not apparent, use the force at the minimum ductility (if specified), at the point of rupture, or at 30 cm (11.8 in.) as the second peak (f_2). The force ratio is defined as the force at the second peak (f_2) divided by the force at the initial peak (f_1).

6.3. Report the force ratio to the nearest 0.1.

7. PRECISION AND BIAS

7.1. *Precision*—The research required to develop precision estimates has not been conducted.

7.2. *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

8. KEYWORDS

8.1. Force ductility; ductility; force ratio; asphalt.

Standard Method of Test for

Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer

AASHTO Designation: T 301-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer

AASHTO Designation: T 301-08

1. SCOPE

1.1. This method is used to determine the elastic recovery of asphalt material through the use of a ductilometer and briquet specimens. The specimens are pulled apart at a rate of 5 cm/min (2 in./min) and held after a specified elongation. The specimens are then severed at the center and allowed to recover undisturbed for 1 hour.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This test may involve hazardous materials, operations, and equipment. This test does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standard*:

- E 77, Standard Test Method for Inspection and Verification of Thermometers

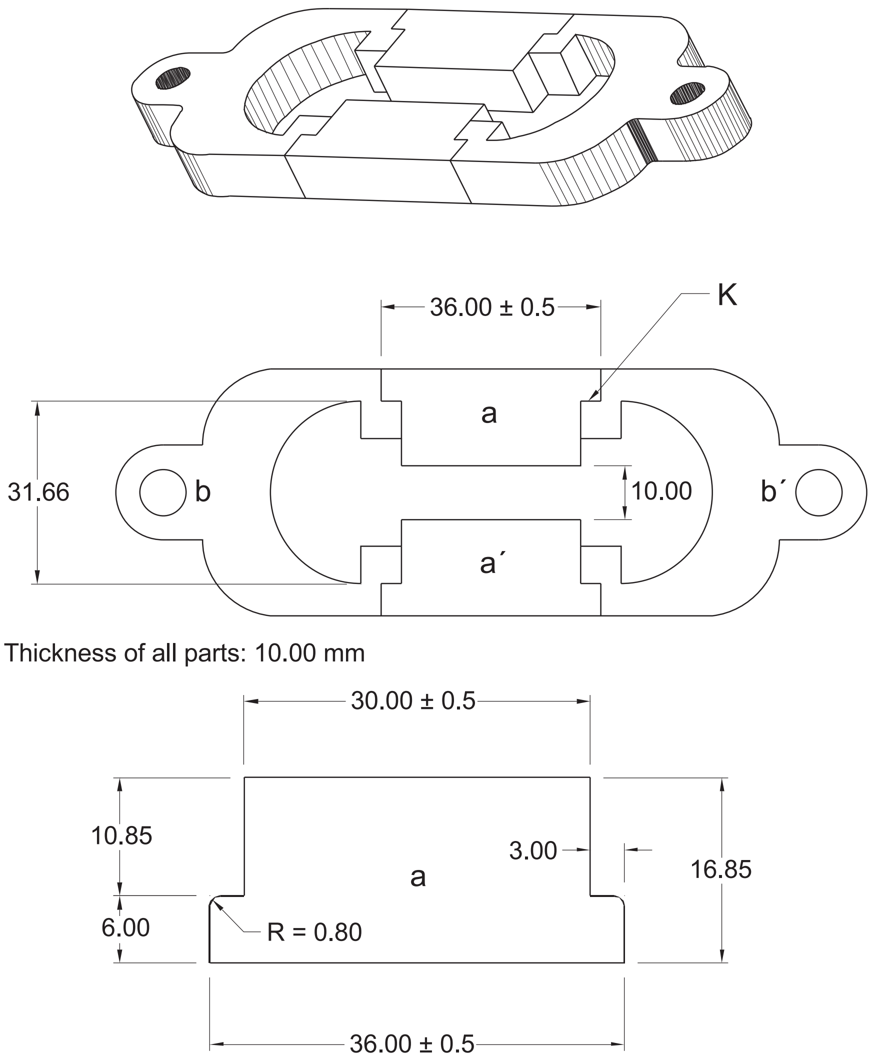
3. APPARATUS

3.1. *Molds*—The mold shall be similar in design to that shown in Figure 1. The mold shall be made of brass. The dimensions of the assembled mold shall be as shown with the permissible variations indicated.

3.2. *Base Plate*—The base plate shall be made of nonabsorbent material of sufficient thickness to prevent deformation and of a sufficient size to hold from one to three molds. The plate shall be uniformly flat to insure that the bottom surfaces of each mold will touch it throughout.

3.3. *Water Bath*—The water bath shall be maintained at the specified test temperature, varying not more than ±0.5ºC (±1.0ºF) from this temperature. The volume of water shall not be less than 10 L (2.6 gal). The depth of water shall not be less than 50 mm (2 in.) and such that the mold can be immersed to a depth of 25 mm (1 in.). The water in the bath shall be free from oil and slime or other organic growth.

3.4. *Thermometers*—For tests at 25ºC (77ºF), use ASTM Saybolt Viscosity Thermometer No. 17C (17F) to measure the temperature of the water bath and the temperature of the water in the testing machine. For tests at other temperatures, use ASTM thermometers of an appropriate range and accuracy equal to that of the No. 17. Since the accuracy of the test results is dependent upon closely controlled conditions of temperature, the thermometers should be calibrated in accordance with ASTM E 77.



Notes:
1. All dimensions in mm
2. Radius for clearance only
3. Thickness: 10.00 mm
4. Tolerances: ±0.1 mm unless otherwise specified
5. Material: 360 brass
6. Finish: None

Figure 1—Mold for Elastic Recovery Test Specimen

3.5. *Testing Machine*—For pulling the briquet of asphalt material apart, any apparatus may be used which is constructed so that the specimen will be continuously immersed in water as specified in Section 4.5 while the two clips are pulled apart at a uniform speed, without undue vibration.

3.6. *Heater*—An oven or hot plate, heated by electricity or gas, may be used to melt the asphalt material.

3.7. *Container*—Any suitable container may be used to hold the asphalt material while it is being melted.

3.8. *Trimmer*—Any convenient implement, such as a putty knife or spatula, may be used provided that the cutting edge is straight and at least 38 mm ($1^1/_2$ in.) wide.

3.9. *Scissors*.

4. PROCEDURE

4.1. *Preparation of Apparatus*—Assemble the mold on the base plate. To prevent the asphalt material from sticking, coat the surface of the plate and the interior surfaces of the sides with a suitable release agent (Note 1).

Note 1—Mixtures of glycerin and dextrine or talc (3 g of glycerin to about 5 g of dextrine or talc has been used satisfactorily), Dow-Corning Silicone Stop-Cock Grease, or castor oil-Versamid 900 (100:1 mixture by weight heated to 204 to 232ºC (400 to 450ºF) and stirred until it is homogeneous) has proven suitable. Other release agents may be used provided the results obtained are comparable to those obtained when using one of the above.

4.2. If the residue of a polymer-modified emulsion is being tested, the asphalt material obtained for the test should be the residue from oven evaporation of the emulsion sample at 162.8 ± 2.5ºC (325 ± 5ºF), not from distillation.

4.3. *Molding Test Specimens*—Heat the sample with care to prevent local overheating until it has become sufficiently fluid to pour. After thorough stirring, pour the asphalt material into the mold, taking care not to entrain any air bubbles. Pour the material in a thin stream back and forth from end to end until the mold is more than level full. In filling the mold, take care not to disarrange the parts of the mold and distort the briquet. Let the mold and contents cool to room temperature for 30 to 40 minutes. Then place the base plate and filled mold in the water bath maintained at the specified test temperature for 30 to 35 minutes. Remove the base plate and filled mold from the water bath and, with a hot trimmer, cut off the excess asphalt material so that the mold is just level full. Take care during the trimming operation that the specimen is not pulled away from the base plate or from the side pieces of the mold.

4.4. *Keeping Specimen at Standard Temperature*—Place the base plate and filled mold in the water bath or testing machine, and keep them at the specified temperature for 85 to 95 minutes. The test will be conducted at the specified temperature. Remove the briquet from the plate, detach the side pieces, and immediately test the briquet.

4.5. *Testing*—At the start of the test, the water in the tank of the testing machine shall cover the specimen both above and below. Also, the specimen shall be immersed to a depth of at least 25 mm (1 in.). Attach the clips to the pins of the testing machine, and pull the clips apart at 5 cm/min (2 in./min) ±5.0 percent until the briquet has been elongated to 20 cm (8 in.). After 20 cm (8 in.) has been reached, stop the ductilometer, and hold the specimen in its elongated position for 5 minutes. After 5 minutes, sever the specimen at its center with a pair of scissors, and allow the specimen to remain in the ductilometer, undisturbed, for 1 hour. At the end of 1 hour, release the ductilometer from the drive mechanism, and retract the half sample until the ends of the severed sample just touch. Read the ductilometer pointer, and record the value.

5. REPORT

5.1. Report the percent elongation recovery to the nearest whole number. The percent elongation recovery is given by the following equation:

$$\% \text{ Elongation Recovery} = \frac{20 - X}{20} \times 100 \qquad (1)$$

where:

X = final reading from the testing machine in centimeters after bringing the two severed ends of the specimen back together.

6. PRECISION AND BIAS

6.1. Information is not available to develop a precision and bias statement.

Standard Method of Test for

Polymer Content of Polymer-Modified Emulsified Asphalt Residue and Asphalt Binders

AASHTO Designation: T 302-05 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Polymer Content of Polymer-Modified Emulsified Asphalt Residue and Asphalt Binders

AASHTO Designation: T 302-05 (2009)

1. SCOPE

1.1. This test method is used to determine the percent concentration of a Styrene-Butadiene-Rubber (SBR), Styrene-Butadiene (SB), or Styrene-Butadiene-Styrene (SBS) polymer in a polymer-modified asphalt binder or emulsified asphalt residue. By using the infrared spectrum and the principles of Beer's Law, the polymer content of the asphalt material can be determined.

1.2. This test method implies that the equipment used for the analysis is operated by experienced personnel according to the manufacturer's directions for optimum performance. A thorough understanding of infrared spectral analysis is recommended.

1.3. *This standard involves hazardous materials, operations, or equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 59, Emulsified Asphalts

2.2. *Other Document*:

- Infrared Spectrophotometer Operator's Manual

3. APPARATUS

3.1. *Balance*—conforming to the requirements of M 231, Class G 1.

3.2. *Containers*—for blending the asphalt material with polymer–metal 1-Pt (0.47-L) cans with lids are suitable.

3.3. Variable-speed shearing mixer.

3.4. Heating coil with variable rheostat.

3.5. Thermometer for determining temperatures between 4 and 305ºC (40 and 580ºF).

3.6. High-temperature vacuum oven (if necessary for removal of residual moisture).

3.7. *Infrared Spectrophotometer or Fourier Transform Infrared Spectrometer*—capable of recording spectrum in the 1800 to 600 cm^{-1} region.

3.8. *Infrared Windows*—polished sodium chloride or potassium chloride windows, or other suitable medium for casting of infrared specimens. If testing by use of the attenuated total reflectance (ATR) method, an ATR accessory and the appropriate crystal are necessary.

3.9. *Testing by Solvent-Diluted Method*:

3.9.1. Glass vial with leak-resistant top.

3.9.2. Eyedroppers.

3.9.3. Infrared heat lamp.

3.9.4. Solvent.

Note 1—Trichloroethane, technical grade, or Tetrahydrofuran (THF) have been shown to be suitable solvents that do not interfere with the infrared spectrum. Other appropriate solvents may be used.

3.10. *Testing by ATR Method*:

3.10.1. Release paper (wax paper or other suitable medium).

3.10.2. *Spatula*—appropriate for spreading hot asphalt binder or emulsified asphalt residue.

3.10.3. *Solvent*—appropriate for removal of the test material from the infrared window.

4. PREPARATION OF CONTROL SAMPLES

4.1. Prepare a series of standards to cover the range from 0 to 5 percent weight-to-weight (w/w) polymer (rubber solids) according to Equation 1.

Note 2—The standards are prepared on a w/w percentage. This percentage is based on the solids weight of the polymer and the weight of the base asphalt binder or the emulsified asphalt residue. If the polymer is in an emulsified form or the standards are being made with an asphalt emulsion, an accurate determination of the rubber solids or percent asphalt residue must be made in order to prepare accurate standards.

4.1.1. This equation makes the assumption that there is no polymer contained in the base asphalt binder or emulsified asphalt (A) and that all solids in the polymer modifier are polymer (D):

$$E = \frac{(B)(A)(C)}{(100 - B)(D)} \qquad (1)$$

where:

E = mass of polymer modifier (g);

B = percent polymer in the standard (e.g., 1, 2, 3, etc.);

A = mass of the base asphalt binder or emulsified asphalt (g);

C = percent asphalt residue (determined by T 59 for emulsified asphalt, otherwise 100); and

D = percent rubber solids in polymer modifier (determined for emulsified polymers, otherwise 100).

4.2. For each standard, add the calculated amount of asphalt binder or emulsified asphalt needed into a container suitable for mixing. Allow sufficient material to be able to thoroughly blend each standard.

4.3. Heat the asphalt binder until it is fluid at a temperature not to exceed 163ºC (325ºF). An emulsion should be heated to 82 ± 1ºC (180 ± 2ºF).

4.4. While maintaining heat and with the mixer in operation, slowly add the calculated amount of polymer modifier for each standard to the container of base asphalt binder or emulsified asphalt. Allow the materials to mix thoroughly.

Note 3—The addition of solid polymers may require extensive heating and shearing. A gradual addition of the material may be necessary. Addition of emulsified polymers in heated asphalt binders should be performed slowly to prevent "boil-over."

5. PREPARATION OF POLYMER SAMPLES AND TESTING BY SOLVENT-DILUTED METHOD

5.1. Heat the asphalt binder until it is fluid, at a temperature not to exceed 163ºC (325ºF). An emulsion should be heated to 82 ± 1ºC (180 ± 2ºF) while stirring it to achieve a homogeneous state.

5.2. After the sample is thoroughly mixed, place approximately 1 g of the sample in a glass vial.

5.3. If there is any residual moisture in the sample, place the vial in a vacuum oven set at approximately 20 mm Hg and 104 ± 2ºC (220 ± 4ºF) until constant mass is achieved.

5.4. After drying, remove the vials from the oven, and cool them to room temperature.

5.5. Dilute the contents of each glass vial with approximately 10 mL (0.3 oz) of the solvent.

5.6. Shake the vial until the sample is completely dissolved in the solvent.

5.7. Place drops of each solvent-diluted material on a prepared infrared window using an eyedropper. Insure that an even layer is placed on the window.

Note 4—Five to nine drops of an asphalt material diluted 1 g to 10 mL (0.3 oz) on a 38 mm by 19 mm (1.5 in. by 0.75 in.) window has been shown to produce an adequate film thickness. Use of the ratio of the specified peak for the polymer to the peak for the asphalt negates any deviations due to film thickness.

5.8. Allow the solvent to evaporate at room temperature, or place the window under a heat lamp for approximately 10 min to drive off any residual solvent. Complete evaporation of any residual solvent will prevent the analysis of misleading spectra.

6. PROCEDURE—TESTING BY ATR METHOD

6.1. Heat the asphalt binder, or, heat the asphalt residue from evaporation (T 59) when testing emulsified asphalt, until it is fluid at a temperature not to exceed 163°C (325°F) while stirring it to achieve a homogenous state.

6.2. Pour the heated material, spreading it with a spatula, on a piece of release paper cut slightly larger than the face of an ATR crystal. Use enough material to result in a layer that will cover the face of the crystal. A thin film will make cleanup of the crystal easier. An asphalt thickness on the paper of about 1 mm (0.04 in.) is sufficient.

6.3. Prepare an ATR crystal following the manufacturer's guidelines.

6.4. Allow the material to cool for several minutes prior to affixing the asphalt surface in direct contact with the top of the face of the prepared ATR crystal. Apply finger pressure to the top of the asphalt material to push out any air bubbles. The material must make complete contact with the crystal without any bubbles. Examination of the underside of the crystal may expose any bubbles or points of non-contact.

Note 5—Follow the manufacturer's guidelines for treatment of the crystal. Placement of hot material or too much pressure on the face of the crystal may cause it to crack.

7. DATA COLLECTION AND ANALYSIS

7.1. *Analysis of the Standards*:

7.1.1. Using either the solvent-diluted or ATR method, acquire spectra on the prepared windows or crystal for each standard. Collection of a background spectrum is recommended prior to sample analysis.

7.1.2. Integrate the proper peak.

Note 6—The infrared spectrometer may be equipped with software that will quantify a specific peak or multiple peaks by using peak height or peak area. It may be necessary to correct the spectral baselines for offset or tilt.

7.1.2.1. For the solvent-diluted method, determine the absorbance at 965 cm^{-1} for the polymer modifier (SBR, SB, or SBS) and at 1375 cm^{-1} for the base asphalt binder or emulsified asphalt residue on each standard. Divide the value of the peak at 965 cm^{-1} (A_1) by the peak at 1375 cm^{-1} (A_2) to obtain the absorbance ratio of the relative peak values (A_1/A_2) of each standard. See the example in Figure 1.

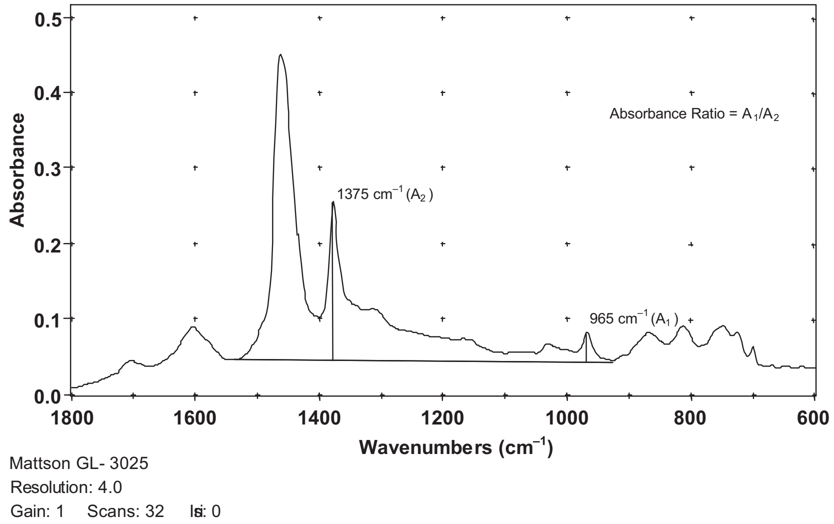


Figure 1—Infrared Scan of a Polymer-Modified Asphalt Material

7.1.2.2. For the ATR method, evaluate the peak area at 965 cm^{-1} for the polymer modifier (SBR, SB, or SBS). In the ATR method, the spectrum obtained is independent of the sample thickness, so it will not be necessary to integrate the peak at 1375 cm^{-1}.

7.1.3. Plot the absorbance ratio of the relative peak values (A_1/A_2) determined in the solvent-diluted method versus the corresponding polymer content or plot the peak area determined in the ATR method versus the corresponding polymer content, of each standard. Perform a first-order curve fit on the data to generate a standard curve. See the example for the solvent-diluted method in Table 1 and Figure 2.

Table 1—Typical Data for Standard Curve Development for Solvent-Diluted Method

Standard, % Polymer	Absorbance Ratio (A_1/A_2)
0	0.02
1	0.065
2	0.11
3	0.155
4	0.20
5	0.245

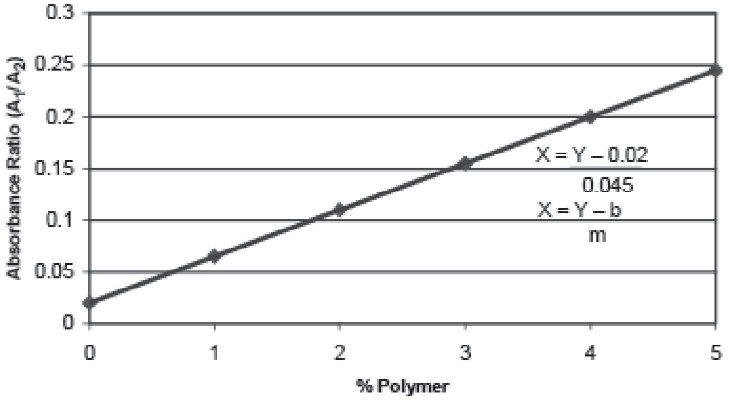


Figure 2—Polymer Content vs. Absorbance Ratio (A_1/A_2)—Solvent-Diluted Method

7.2. *Analysis of Sample*:

7.2.1. Analyze each sample using the applicable sections for the selected method (i.e., solvent-diluted or ATR) in Sections 7.1.1 through 7.1.2.2, and obtain the relative absorbance ratio (A_1/A_2) or peak area of the sample as appropriate.

7.2.2. Using the standard curve information, calculate the polymer content of the sample.

8. REPORT

8.1. The values determined for the polymer content shall be reported to the nearest 0.1 percent.

9. PRECISION AND BIAS

9.1. Information is currently not available to develop a precision and bias statement.

Standard Method of Test for

Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures

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AASHTO Designation: T 305-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures

AASHTO Designation: T 305-09

1. SCOPE

1.1. This test method covers the determination of the amount of draindown material in an uncompacted asphalt mixture sample when the sample is held at elevated temperatures comparable to those encountered during the production, storage, transport, and placement of the mixture. The test is particularly applicable to mixtures such as porous asphalt (open-graded friction course) and Stone Matrix Asphalt (SMA).

1.2. The values stated in the gram-millimeter units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

3. DEFINITIONS

3.1. *Draindown material*—for the purpose of this test method, draindown material is considered to be that portion of material that separates itself from the sample as a whole and is deposited outside the wire basket during the test. The draindown material may be composed of either asphalt binder or a combination of asphalt binder and fine aggregate.

3.2. *Draindown*—the process by which draindown material separates itself from the sample as a whole.

4. SUMMARY OF METHOD

4.1. A sample of the asphalt mixture to be tested is prepared in the laboratory or obtained from field production. The sample is placed in a wire basket, which is positioned on a plate or other suitable container of known mass. The sample, basket, and plate or container are placed in a forced-draft oven for 1 hour at a pre-selected temperature. At the end of 1 hour, the basket containing the sample is removed from the oven, along with the plate or container and the mass of the plate or container is determined. The amount of draindown material is then calculated.

5. SIGNIFICANCE AND USE

5.1. This test method can be used to determine whether the amount of draindown material measured for a given asphalt mixture is within acceptable levels. The test provides an evaluation of the draindown potential of an asphalt mixture during mixture design or during field production. This test is primarily used for mixtures with high coarse aggregate content such as porous asphalt (open-graded friction course) and SMA.

6. APPARATUS

6.1. *Forced-draft oven*—capable of maintaining the temperature in a range from 120 to175ºC (250 to 350ºF). The oven should maintain the set temperature to within ±2ºC (±3.6ºF).

6.2. *Plates*—or other suitable containers of appropriate size. The plates or containers used should be of appropriate durability to withstand the oven temperatures. Cake pans or pie tins are examples of suitable types of containers.

6.3. *Standard Basket*—meeting the dimensions shown in Figure 1. The basket shall be constructed using standard 6.3-mm (0.25-in.) sieve cloth as specified in M 92.

6.4. *Balance*—accurate to 0.1 g.

6.5. *Other apparatus*—spatulas, trowels, bowls, and mixer as needed.

7. SAMPLE PREPARATION

7.1. *Laboratory-Prepared Samples*:

7.1.1. *Number of Samples*—For each mixture tested, the draindown characteristics should be determined at two different temperatures. The two temperatures should be the anticipated plant production temperature as well as 15ºC (27ºF) above that temperature (Note 1). For each temperature, duplicate samples should be tested. Thus for one asphalt mixture, a minimum of four samples will be tested.

Note 1—When using the test as part of the mixture design procedure, the test should be performed at two temperatures in order to determine the potential effect that plant temperature variation may have on the mixture during production. When the test is used in the field during production, it should be necessary to perform the test at the plant production temperature only.

7.1.2. Dry the aggregate to a constant mass and sieve it into the appropriate size fractions as indicated in T 245.

7.1.3. Determine the anticipated plant production temperature or select a mixing temperature in accordance with T 245.

7.1.4. Place into separate pans for each test sample the amount of each size fraction required to produce completed mixture samples having a mass of 1200 ± 200 g. The aggregate fractions shall be combined such that the resulting aggregate blend has the same gradation as the job mix formula. Place the aggregate samples in an oven and heat them to a temperature not to exceed the mixing temperature established in Section 7.1.3 by more than approximately 28ºC (50ºF).

7.1.5. Heat the asphalt binder to the temperature established in Section 7.1.3.

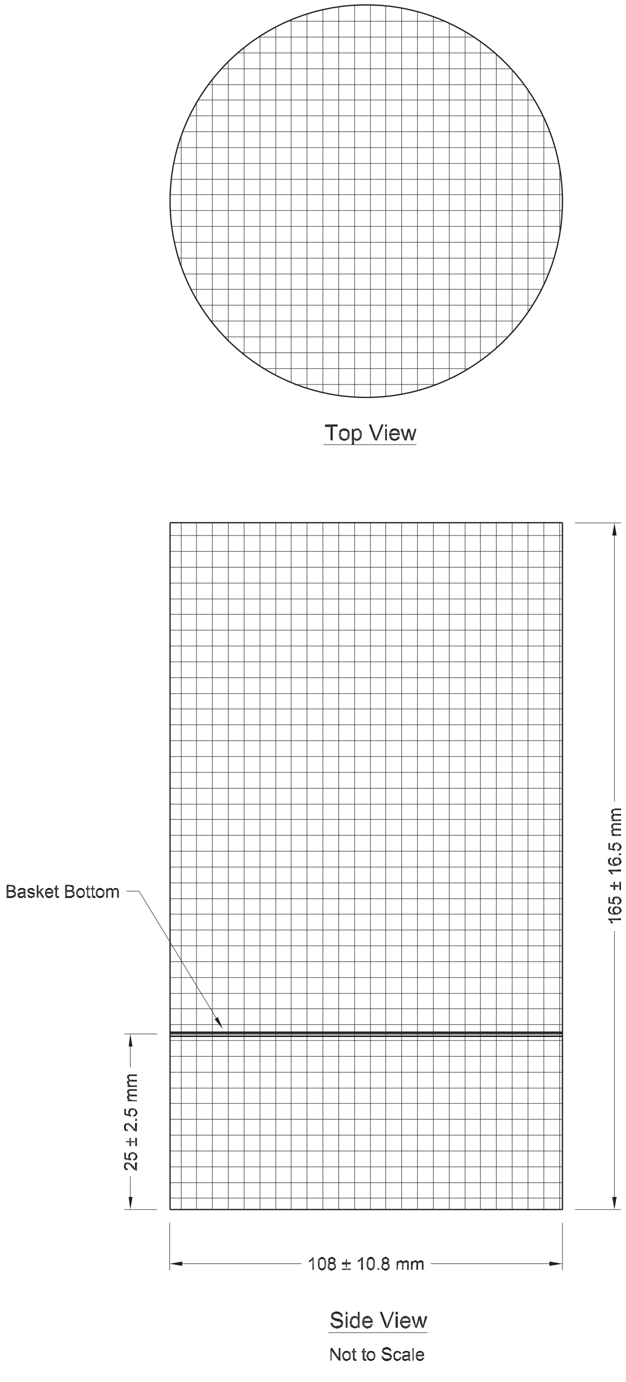

Figure 1—Wire Basket Assembly

7.1.6. Place the heated aggregate in the mixing bowl. Add any stabilizers (Note 2) and thoroughly mix the dry components. Form a crater in the aggregate blend and add the required amount of asphalt binder. The amount of asphalt binder shall be such that the final sample has the same asphalt content as the job mix formula. At this point, the temperature of the aggregate and asphalt binder shall be within the limits of the mixing temperature established in Section 7.1.3. Using a spatula (if mixing by hand) or a mixer, mix the aggregate (and stabilizer if any) and asphalt binder quickly until the aggregate is thoroughly coated.

Note 2—Some types of stabilizers such as fibers or some polymers must be added directly to the aggregate prior to mixing with the asphalt binder. Other types of stabilizers must be added directly to the asphalt binder prior to blending with the aggregate.

7.2. *Plant-Produced Samples*:

7.2.1. *Number of Samples*—For plant-produced samples, duplicate samples should be tested at the plant production temperature.

7.2.2. Samples may be obtained during plant production by sampling the mixture at any appropriate location such as the trucks prior to the mixture leaving the plant. Samples obtained during actual production should be reduced to the proper test sample size by R 47.

Note 3—Caution should be exercised when sampling from surge or storage bins because draindown may already have taken place.

8. PROCEDURE

8.1. Transfer the hot laboratory-produced or plant-produced uncompacted mixture sample to a tared wire basket as described in Section 6.3. Place the entire sample in the wire basket. Do not consolidate or otherwise disturb the sample after transferring it to the basket. Determine the mass of the sample to the nearest 0.1 g. Care should be exercised to ensure that the sample does not cool more than 25ºC (77°F) below the test temperature. (See Section 8.2.)

8.2. Determine and record the mass of a plate or other suitable container to the nearest 0.1 g. Place the basket on the plate or container and place the assembly into the oven at the temperature as determined in Section 7.1.1 or 7.2.1 for 60 ± 5 minutes. If the sample has cooled more than 25ºC (77°F) below the test temperature, the test should be conducted for 70 ± 5 min.

8.3. After the sample has been in the oven for the time specified in Section 8.2, remove the basket and plate or container from the oven. Determine and record the mass of the plate or container plus draindown material to the nearest 0.1 g.

9. CALCULATIONS

9.1. Calculate the percent of mixture that drained by subtracting the initial plate or container mass from the final plate or container mass and dividing this value by the initial total sample mass. Multiply the result by 100 to obtain a percentage.

$$\frac{M_f - M_i}{M_t} \times 100\% = \text{percent of mixture that drained or percent draindown}$$

where:

M_f = final plate or container mass,

M_i = initial plate or container mass, and

M_t = initial total sample mass.

10. REPORT

10.1. Report the average percent draindown (average percent of mixture that drained) at each of the test temperatures.

Standard Method of Test for

Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

AASHTO Designation: T 308-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

AASHTO Designation: T 308-10

1. SCOPE

1.1 This test method covers the determination of asphalt binder content of hot mix asphalt (HMA) by ignition at temperatures that reach the flashpoint of the binder in a furnace. The means of specimen heating may be the convection method or the direct infrared (IR) irradiation method. The aggregate remaining after burning can be used for sieve analysis using T 30.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 2, Sampling of Aggregates
- T 30, Mechanical Analysis of Extracted
- T 40, Sampling Bituminous Materials
- T 168, Sampling Bituminous Paving Mixtures
- T 248, Reducing Samples of Aggregate to Testing Size
- T 329, Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

2.2 *Other Document*:

- Manufacturer's Instruction Manual

3. SUMMARY OF TEST METHOD

3.1 The asphalt binder in the HMA is ignited using the furnace equipment applicable to the particular method. This procedure covers two methods. Method A requires an ignition furnace with an internal balance. Method B requires an ignition furnace with an external balance.

3.2 The asphalt binder content is calculated as the difference between the initial mass of the HMA and the mass of the residual aggregate, with adjustments for an asphalt binder correction factor and the moisture content. The asphalt binder content is expressed as a mass percent of the moisture-free mixture. This method may be affected by the type of aggregate in the mixture. Accordingly, to optimize accuracy, correction factors for asphalt binder and aggregate will be established by testing a set of correction factor specimens for each type of HMA. Correction factors must be determined before any acceptance testing is performed.

4. SIGNIFICANCE AND USE

4.1 This method can be used for quantitative determinations of asphalt binder content and gradation in HMA and pavement specimens for quality control, specification acceptance, and mixture evaluation studies. This method does not require the use of solvents. Aggregate obtained by this test method may be used for gradation analysis according to T 30.

5. APPARATUS

5.1 *Ignition Furnace*—A forced-air ignition furnace that heats the specimens by either the convection or direct IR irradiation method. The convection-type furnace must be capable of maintaining the temperature at 578°C (1072°F). The furnace chamber dimensions shall be adequate to accommodate a specimen size of 3500 g. The furnace door shall be equipped so that the door cannot be opened during the ignition test. A method for reducing furnace emissions shall be provided. The furnace shall be vented into a hood or to the outside and, when set up properly, shall have no noticeable odors escaping into the laboratory. The furnace shall have a fan with the capability to pull air through the furnace to expedite the test and reduce the escape of smoke into the laboratory.

5.1.1 For Method A, the furnace shall also have an internal balance thermally isolated from the furnace chamber and accurate to 0.1 g. The balance shall be capable of weighing a 3500-g specimen in addition to the specimen baskets. A data collection system will be included so that the mass can be automatically determined and displayed during the test. The furnace shall have a built-in computer program to calculate the change in mass of the specimen baskets and provide for the input of a correction factor for aggregate loss. The furnace shall provide a printed ticket with the initial specimen mass, specimen mass loss, temperature compensation, correction factor, corrected asphalt binder content (percent), test time, and test temperature. The furnace shall provide an audible alarm and indicator light when the specimen mass loss does not exceed 0.01 percent of the total specimen mass for 3 consecutive minutes. The furnace shall also allow the operator to change the ending mass loss percentage to 0.02 percent.

5.2 *Specimen Basket Assembly*—consisting of specimen basket(s), catch pan, and an assembly guard to secure the specimen basket(s) to the catch pan.

5.2.1 *Specimen Basket(s)*—of appropriate size that allows the specimens to be thinly spread and allows air to flow through and around the specimen particles. Sets with two or more baskets shall be nested. The specimen shall be completely enclosed with screen mesh, perforated stainless steel plate, or other suitable material.

Note 1—Screen mesh or other suitable material with maximum and minimum openings of 2.36 mm (No. 8) and 0.600 mm (No. 30), respectively, has been found to perform well.

5.2.2 *Catch Pan*—of sufficient size to hold the specimen basket(s) so that aggregate particles and melting asphalt binder falling through the screen are caught.

5.3 *Oven*—Capable of maintaining 110 ± 5°C (230 ± 9°F).

5.4 *Balance*—of sufficient capacity and conforming to the requirements of M 231, Class G 2.

5.5 *Safety Equipment*—safety glasses or face shield, dust mask, high temperature gloves, long-sleeved jacket, a heat-resistant surface capable of withstanding 650°C (1202°F), and a protective cage capable of surrounding the specimen baskets during the cooling period.

5.6 *Miscellaneous Equipment*—a pan larger than the specimen basket(s) for transferring the specimen after ignition, spatulas, bowls, and wire brushes.

6. SAMPLING

6.1 Obtain samples of freshly produced HMA in accordance with T 168.

6.2 The specimen shall be the end result of reducing a larger sample in accordance with R 47.

6.3 If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan in an oven at 110 ± 5°C (230 ± 9°F) until it is workable. Do not leave the specimen in the oven for an extended period of time. Excessive heating may cause detrimental effects such as asphalt drain-down or oxidation.

6.4 The size of the test specimen shall be governed by the nominal-maximum aggregate size of the HMA and shall conform to the mass requirement shown in Table 1. When the mass of the specimen exceeds the capacity of the equipment used, the specimen may be divided into suitable increments, tested, and the results appropriately combined for calculation of the asphalt binder content (using a weighted average). Specimen sizes shall not be more than 500 g greater than the minimum recommended specimen mass.

Note 2—Large specimens of fine mixes tend to result in incomplete ignition of asphalt binder.

Table 1—Mass Requirements

Nominal-Maximum Aggregate Size,[a] mm	Sieve Size	Min Mass of Specimen, g
4.75	No. 4	1200
9.5	$^3/_8$ in.	1200
12.5	$^1/_2$ in.	1500
19.0	$^3/_4$ in.	2000
25.0	1 in.	3000
37.5	$1^1/_2$ in.	4000

[a] Nominal-maximum aggregate size—one size larger than the first sieve to retain more than 10 percent.

TEST METHOD A—INTERNAL BALANCE

7. TEST PROCEDURES

7.1 *Test Initiation*:

7.1.1 For the convection-type furnace, preheat the ignition furnace to 538°C (1000°F) or to the temperature determined by the correction factor process in the Annex. Manually record the furnace temperature (set point) prior to the initiation of the test if the furnace does not record automatically.

7.1.2 For the direct IR irradiation-type furnace, use the same burn profile as used during the correction factor determination.

7.2 Oven dry the HMA specimen to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F), or determine the moisture content of a companion specimen according to T 329.

7.3 Enter into the ignition furnace, or manually record, the asphalt binder correction factor for the specific mix to be tested, as determined in the Annex.

7.4 Determine and record the mass of the specimen basket assembly to the nearest 0.1 g.

7.5 Prepare the specimen as described in Section 6. Place the specimen basket(s) in the catch pan. Evenly distribute the specimen in the basket(s), taking care to keep the material away from the edges of the basket. Use a spatula or trowel to level the specimen.

7.6 Determine and record the total mass of the specimen and specimen basket assembly at room temperature to the nearest 0.1 g. Calculate and record the initial mass of the specimen M_i (total mass minus the mass of the specimen basket assembly).

7.7 Input the initial mass of the specimen, M_i, in whole grams into the ignition furnace controller. Verify that the correct mass has been entered.

7.8 Open the chamber door, and place the specimen basket assembly in the furnace, carefully positioning the specimen basket assembly so it is not in contact with the furnace walls. Close the chamber door, and verify that the specimen mass (including the basket assembly) displayed on the furnace scale equals the total mass recorded in Section 7.6 within ±5 g. Differences greater than 5 g or failure of the furnace scale to stabilize may indicate that the specimen basket assembly is contacting the furnace wall.

Note 3—Due to the extreme heat of the furnace, the operator should wear safety equipment—high temperature gloves, face shield, fire-retardant shop coat—when opening the door to load or unload the specimen.

7.9 Initiate the test by pressing the start/stop button. This operation will lock the specimen chamber and start the combustion blower.

Note 4—The furnace temperature will drop below the set point when the door is opened but will recover with the door closed and when ignition occurs. Specimen ignition typically increases the temperature well above the set point, depending on the specimen size and asphalt binder content.

7.10 Allow the test to continue until the stable light and audible stable indicator indicate the test is complete (the change in mass does not exceed 0.01 percent for 3 consecutive minutes). Press the start/stop button. This operation will unlock the specimen chamber and cause the printer to print out the test results.

Note 5—An ending mass loss percentage of 0.02 may be substituted when aggregate exhibits an excessive amount of loss during ignition testing. The precision and bias statement was developed using 0.01 percent. Both precision and accuracy may be adversely affected by using 0.02 percent.

7.11 Open the chamber door; remove the specimen basket assembly, and place it on a cooling plate or block. Place the protective cage over the specimen basket assembly, and allow it to cool to room temperature (approximately 30 min).

7.12 Determine and record the total mass of the specimen and specimen basket assembly after ignition to the nearest 0.1 g. Calculate and record the final mass of the specimen, M_f (total mass minus the mass of the specimen basket assembly).

7.13 Use the corrected asphalt binder content (percent) from the printed ticket. If this value is not corrected, subtract the asphalt binder correction factor. If a moisture content has been determined per T 329, subtract the percent moisture from the asphalt binder content on the printed ticket, and report the resultant value as the corrected asphalt binder content (P_b).

Note 6—Asphalt binder content can also be calculated using Equation 1 from Method B (Section 8.16).

TEST METHOD B—EXTERNAL BALANCE

8. TEST PROCEDURES

8.1 Preheat the ignition furnace to 538°C (1000°F) or the temperature determined by the correction factor process in the Annex.

8.2 Oven dry the HMA specimen to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F), or determine the moisture content of a companion specimen according to T 329.

8.3 Record the asphalt binder correction factor for the specific mix to be tested, as determined by the correction factor process in the Annex.

8.4 Determine and record the mass of the specimen basket assembly to the nearest 0.1 g.

8.5 Prepare the specimen as described in Section 5. Place the specimen baskets in the catch pan. Evenly distribute the specimen in the basket(s), taking care to keep the material away from the edges of the basket. Use a spatula or trowel to level the specimen.

8.6 Determine and record the total mass of the specimen basket assembly at room temperature to the nearest 0.1 g. Calculate and record the initial mass of the specimen, M_i (total mass minus the mass of the specimen basket assembly).

8.7 Open the chamber door and place the specimen basket assembly in the furnace. Burn the HMA specimen in the furnace for at least 45 min.

Note 7—The appropriate time for the initial burn of an HMA specimen is dependent on the specimen size. For large specimens, the time could be significantly longer than 45 min. See the manufacturer's manual for guidelines.

8.8 Open the chamber door; remove the specimen and specimen basket assembly and place it on a cooling plate or block. Place the protective cage over the specimen basket assembly, and allow it to cool to room temperature (approximately 30 min).

8.9 Determine and record the total mass of the specimen and specimen basket assembly after cooling to the nearest 0.1 g.

8.10 Place the specimen and specimen basket assembly back into the furnace.

8.11 Burn the specimen for at least 15 min after the furnace reaches the set point temperature.

8.12 Open the chamber door, remove the specimen and specimen basket assembly, and place it on a cooling plate or block. Place the protective cage over the specimen basket assembly, and allow it to cool to approximately room temperature (approximately 30 min).

8.13 Weigh and record the total mass of the specimen and specimen basket assembly after cooling to the nearest 0.1 g.

8.14 Repeat Sections 8.10 through 8.13 until the change in measured mass of the specimen after ignition does not exceed 0.01 percent of the initial specimen mass, M_i.

Note 8—An ending mass loss percentage of 0.02 may be substituted when aggregate exhibits an excessive amount of loss during ignition testing. The precision and bias statement was developed using 0.01 percent. Both precision and accuracy may be adversely affected by using 0.02 percent. After the time required to obtain the specified mass loss has been established for each mixture, repeated mass determinations may not be necessary.

8.15 Calculate and record the final mass of the specimen, M (total mass minus the mass of the specimen basket assembly).

8.16 Calculate the asphalt binder content of the specimen as follows:

$$P_b, \% = \left[\frac{\left(M_i - M_f\right)}{M_i} \times 100 \right] - C_F - MC \qquad (1)$$

where:

P_b = the measured (corrected) asphalt binder content, percent;

M_i = the total mass of the HMA specimen prior to ignition, g;

M_f = the total mass of aggregate remaining after the ignition, g;

C_F = the correction factor, percent by mass of HMA specimen; and

MC = the moisture content of companion HMA specimen, percent, as determined by T 329. (If the specimen was oven dried prior to initiating the procedure, $MC = 0$.)

9. GRADATION

9.1 Allow the contents of the specimen baskets to cool to room temperature prior to performing the gradation analysis. Empty the contents of the baskets into a flat pan, being careful to capture all material. Use a small wire sieve brush to ensure that any residual fines are removed from the baskets and catch pan.

9.2 Perform the gradation analysis according to T 30.

10. REPORT

10.1 *The report shall include the following*:

10.1.1 Test method (A or B);

10.1.2 Corrected asphalt binder content;

10.1.3 Correction factor;

10.1.4 Temperature compensation factor (if applicable);

10.1.5 Total percent loss;

10.1.6 Specimen mass;

10.1.7 Moisture content (if determined, per T 329); and

10.1.8 Test temperature.

Note 9—If Method A is performed, attach the original printed ticket to the report.

11. PRECISION AND BIAS

11.1 *Precision*—Criteria for judging the acceptability of ignition burn results for asphalt content obtained by Method A or Method B are given in Table 2.

11.1.1 *Single-Operator Precision*—The figures in Column 2 of Table 2 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the values given in Table 2, Column 3.

11.1.2 *Multilaboratory Precision*—The figures in Column 2 of Table 2 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the values given in Table 2, Column 3.

Table 2—Precision Estimates

Condition	Standard Deviation, (1s)[a]	Acceptable Range of Two Test Results, (d2s)[a]
Single-Operator Precision		
Asphalt content (%)	0.069	0.196
Multilaboratory Precision		
Asphalt content (%)	0.117	0.330

[a] These values represent the 1s and d2s limits described in ASTM C 670

Note 10—The precision estimates given in Table 2 are based on the analysis of test results from three pairs of AMRL proficiency samples. The data analyzed consisted of results from 353 to 461 laboratories for each of the three pairs of samples. The analysis included two binder grades: PG 52-34 and PG 64-22. Average results for asphalt content ranged from 4.049 to 5.098 percent. The details of this analysis are in NCHRP Final Report, NCHRP Project No. 9-26, Phase 3.

Note 11—The precision estimates are based on four aggregate types, four replicates, and 12 laboratories participating with no laboratory results deleted as outlying observations. All four aggregates were tested in surface mixes and had relatively low absorption values.

11.2 *Bias*—Any biases inherent to the ignition oven process used for Test Methods A and B, when testing for asphalt content and aggregate gradation, are accounted for by the determination and application of appropriate correction factors.

ANNEX

(Mandatory Information)

CORRECTION FACTORS

A1. ASPHALT BINDER AND AGGREGATE

A1.1. Asphalt binder content results may be affected by the type of aggregate in the mixture and the ignition furnace. Therefore, asphalt binder and aggregate correction factors must be established by testing a set of correction specimens for each job mix formula (JMF) mix design. Correction factor(s) must be determined before any acceptance testing is completed and repeated each time a change in the mix ingredients or design occurs. Any changes greater than 5 percent in stockpiled aggregate proportions should require a new correction factor. Historical data or scientific studies may be used to determine the correction factor(s) in lieu of using this testing procedure if the testing agency provides reference to the studies/data.

A1.1.1. *Asphalt binder correction factor*—Certain aggregate types may result in unusually high correction factors (greater than 1.0 percent). Such mixes should be corrected and tested at a lower temperature, as described below. Each ignition furnace will have its own unique asphalt binder correction factor determined in the location where testing will be performed.

A1.1.2. *Aggregate correction factor*—Due to potential aggregate breakdown during the ignition process, an aggregate correction factor will be determined for each ignition furnace in the location where testing will be performed when the following conditions occur: aggregates that have a proven history of excessive breakdown or aggregates from an unknown source.

A2. CORRECTION FACTOR PROCEDURE

A2.1. Obtain samples of aggregate in accordance with T 2.

A2.2. Obtain samples of asphalt binder in accordance with T 40.

Note A1—Include other additives that may be required by the JMF.

A2.3. Prepare an initial, or "butter mix" at the design asphalt binder content. Mix and discard the butter mix prior to preparing any of the correction specimens to ensure an accurate asphalt binder content.

A2.4. Prepare two correction specimens at the JMF design asphalt binder content and gradation. Aggregate used for correction specimens shall be sampled from the material designated for use in production. An additional "blank" (aggregate only) specimen shall be batched at the JMF gradation. Determine an aggregate gradation in accordance with T 30 on the "blank" specimen.

A2.5. Place the freshly mixed specimens directly into the specimen basket assembly. If specimens are allowed to cool prior to placement in the specimen basket assembly, the specimens must be dried to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). Do not preheat the specimen basket assembly.

A2.6. Test the specimens in accordance with Method A or Method B of the procedure.

A2.7. Once both of the correction specimens have been burned, determine the asphalt binder content for each specimen by calculation or from the printed oven tickets, if available.

A2.8. If the difference between the asphalt binder contents of the two specimens exceeds 0.15 percent, repeat Section A2.3 through A2.7 with two more specimens and, from the four results, discard the high and low result. Determine the correction factor from the two original or remaining results as appropriate. Calculate the difference between the actual and measured asphalt binder contents for each specimen. The asphalt binder correction factor, C_F, is the average of the differences expressed as a percentage by mass of the HMA.

A2.8.1. If the asphalt binder correction factor exceeds 1.0 percent, the test temperature should be lowered to 482 ± 5°C (900 ± 8°F) for convection type furnace. If there is no improvement in the correction factor, it is permissible to use the higher temperature.

Note A2—The temperature for determining the asphalt binder content of HMA specimens by this procedure shall be the same temperature determined for the correction specimens.

A2.8.2. For the direct IR irradiation-type furnaces, the DEFAULT burn profile should be used for most materials. The operator may select burn-profile OPTION 1 or OPTION 2 to optimize the burn cycle. Option 1 is designed for aggregate that require a large aggregate correction factor (greater than 1 percent)—typically very soft aggregate (such as dolomite). Option 2 is designed for samples that may not burn completely using the DEFAULT burn profile. The burn profile for testing HMA samples shall be the same burn profile selected for correction samples.

A2.9. Perform a gradation analysis on the residual aggregate in accordance with T 30, if required. The results will be utilized in developing an aggregate correction factor and should be calculated and reported to the nearest 0.1 percent.

A2.9.1. From the gradation results, subtract the percent passing for each sieve for each specimen from the percent passing each sieve of the "blank" specimen gradation results from Section A2.4.

A2.9.2. Determine the average difference for the two values. If the difference for any single sieve exceeds the allowable difference for that sieve as listed in Table A1, then aggregate gradation correction factors (equal to the resultant average differences) for all sieves shall be applied to all acceptance gradation test results determined by T 30, prior to final rounding and reporting. If the 0.075-mm (No. 200) sieve is the only sieve outside the limits in Table A1, apply the aggregate correction factor to only the 0.075-mm (No. 200) sieve.

Table A1—Permitted Sieving Difference

Sieve	Allowable Difference
Sizes larger than or equal to 2.36 mm (No. 8)	±5.0 percent
Sizes larger than 0.075 mm (No. 200) and smaller than 2.36 mm (No. 8)	±3.0 percent
Sizes 0.075 mm (No. 200) and smaller	±0.5 percent

Standard Method of Test for

Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

AASHTO Designation: T 312-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

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1. SCOPE

1.1. This standard covers the compaction of cylindrical specimens of hot mix asphalt (HMA) using the Superpave gyratory compactor.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 275, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer
- TP 71, Evaluation of Superpave Gyratory Compactor (SGC) Internal Angle of Gyration Using Simulated Loading

2.2. *Other Standard*:

- ASME B46.1, Surface Texture, Surface Roughness, Waviness and Lay

3. SIGNIFICANCE AND USE

3.1. This standard is used to prepare specimens for determining the mechanical and volumetric properties of HMA. The specimens simulate the density, aggregate orientation, and structural characteristics obtained in the actual roadway when proper construction procedure is used in the placement of the paving mix.

3.2. This test method may be used to monitor the density of test specimens during their preparation. It may also be used for field control of an HMA production process.

4. APPARATUS

4.1. *Superpave Gyratory Compactor*—An electrohydraulic or electromechanical compactor with a ram and ram heads as described in Section 4.3. The axis of the ram shall be perpendicular to the platen of the compactor. The ram shall apply and maintain a pressure of 600 ± 18 kPa perpendicular to the cylindrical axis of the specimen during compaction (Note 1). The compactor shall tilt the specimen molds at an average internal angle of 20.2 ± 0.35 mrad (1.16 ± 0.02 degrees), determined in accordance with TP 71. The compactor shall gyrate the specimen molds at a rate of 30.0 ± 0.5 gyrations per minute throughout compaction.

Note 1—This stress calculates to 10 600 ± 310 N total force for 150-mm specimens.

4.1.1. *Specimen Height Measurement and Recording Device*—When specimen density is to be monitored during compaction, a means shall be provided to continuously measure and record the height of the specimen to the nearest 0.1 mm during compaction once per gyration.

4.1.2. The system may include a connected printer capable of printing test information, such as specimen height per gyration. In addition to a printer, the system may include a computer and suitable software for data acquisition and reporting.

4.2. *Specimen Molds*—Specimen molds shall have steel walls that are at least 7.5 mm thick and are hardened to at least a Rockwell hardness of C48. The initial inside finish of the molds shall have a root mean square (rms) of 1.60 μm or smoother when measured in accordance with ASME B46.1 (Note 2). Molds shall have an inside diameter of 149.90 to 150.00 mm and be at least 250 mm high at room temperature.

Note 2—One source of supply for a surface comparator, which is used to verify the rms value of 1.60 μm, is GAR Electroforming, Danbury, Connecticut.

4.3. *Ram Heads and Mold Bottoms*—Ram heads and mold bottoms shall be fabricated from steel with a minimum Rockwell hardness of C48. The ram heads shall stay perpendicular to their axis. The platen side of each mold bottom shall be flat and parallel to its face. All ram and base plate faces (the sides presented to the specimen) shall be flat to meet the smoothness requirement in Section 4.2 and shall have a diameter of 149.50 to 149.75 mm.

4.4. *Thermometers*—Armored, glass, or dial-type thermometers with metal stems for determining the temperature of aggregates, binder, and HMA between 10 and 232°C.

4.5. *Balance*—A balance meeting the requirements of M 231, Class G 5, for determining the mass of aggregates, binder, and HMA.

4.6. *Oven*—An oven, thermostatically controlled to ±3°C, for heating aggregates, binder, HMA, and equipment as required. The oven shall be capable of maintaining the temperature required for mixture conditioning in accordance with R 30.

4.7. *Miscellaneous*—Flat-bottom metal pans for heating aggregates, scoop for batching aggregates, containers (grill-type tins, beakers, containers for heating asphalt), large mixing spoon or small trowel, large spatula, gloves for handling hot equipment, paper disks, mechanical mixer (optional), lubricating materials recommended by the compactor manufacturer.

4.8. *Maintenance*—In addition to routine maintenance recommended by the manufacturer, check the Superpave gyratory compactor's mechanical components for wear, and perform repair, as recommended by the manufacturer.

5. HAZARDS

5.1. Use standard safety precautions and protective clothing when handling hot materials and preparing test specimens.

6. STANDARDIZATION

6.1. Items requiring periodic verification of calibration include the ram pressure, angle of gyration, gyration frequency, LVDT (or other means used to continuously record the specimen height), and oven temperature. Verification of the mold and platen dimensions and the inside finish of the mold are also required. When the computer and software options are used, periodically verify the data-processing system output using a procedure designed for such purposes. Verification of calibration, system standardization, and quality checks may be performed by the manufacturer, other agencies providing such services, or in-house personnel. Frequency of verification shall follow the manufacturer's recommendations.

6.2. The angle of gyration refers to the internal angle (tilt of mold with respect to end plate surface within the gyratory mold). The calibration of the internal angle of gyration should be verified in accordance with TP 71.

7. PREPARATION OF APPARATUS

7.1. Immediately prior to the time when the HMA is ready for placement in the mold, turn on the main power for the compactor for the manufacturer's required warm-up period.

7.2. Verify the machine settings are correct for angle, pressure, and number of gyrations.

7.3. Lubricate any bearing surfaces as needed per the manufacturer's instructions.

7.4. When specimen height is to be monitored, the following additional item of preparation is required. Immediately prior to the time when the HMA is ready for placement in the mold, turn on the device for measuring and recording the height of the specimen, and verify the readout is in the proper units, mm, and the recording device is ready. Prepare the computer, if used, to record the height data, and enter the header information for the specimen.

8. HMA MIXTURE PREPARATION

8.1. Weigh the appropriate aggregate fractions into a separate pan, and combine them to the desired batch weight. The batch weight will vary based on the ultimate disposition of the test specimens. If a target air void level is desired, as would be the case for Superpave mix analysis and performance specimens, batch weights will be adjusted to create a given density in a known volume. If the specimens are to be used for the determination of volumetric properties, the batch weights will be adjusted to result in a compacted specimen having dimensions of 150 mm in diameter and 115 ± 5 mm in height at the desired number of gyrations.

Note 3—It may be necessary to produce a trial specimen to achieve this height requirement. Generally, 4500 to 4700 g of aggregate are required to achieve this height for aggregates with combined bulk specific gravities of 2.55 to 2.70, respectively.

8.2. Place the aggregate and binder container in the oven, and heat them to the required mixing temperature.

8.2.1. The mixing temperature range is defined as the range of temperatures where the unaged binder has a viscosity of 0.17 ± 0.02 Pa·s when measured in accordance with T 316.

Note 4—Modified asphalts may not adhere to the equiviscosity requirements noted, and the manufacturer's recommendations should be used to determine mixing and compaction temperatures.

8.3. Charge the mixing bowl with the heated aggregate from one pan and dry-mix thoroughly. Form a crater in the dry-blended aggregate, and weigh the required amount of binder into the mix. Immediately initiate mixing.

8.4. Mix the aggregate and binder as quickly and thoroughly as possible to yield HMA having a uniform distribution of binder. As an option, mechanical mixing may be used.

8.5. After completing the mixture preparation, perform the required mixture conditioning in accordance with R 30.

8.6. Place a compaction mold and base plate in an oven at the required compaction temperature for a minimum of 30 minutes prior to the estimated beginning of compaction (during the time the mixture is being conditioned in accordance with R 30).

8.7. Following the mixture conditioning period specified in R 30, if the mixture is at the compaction temperature, proceed immediately with the compaction procedure as outlined in Section 9. If the compaction temperature is different from the mixture conditioning temperature used in accordance with R 30, place the mix in another oven at the compaction temperature for a brief time (maximum of 30 minutes) to achieve the required temperature.

8.7.1. The compaction temperature is the midpoint of the range of temperatures where the unaged binder has a viscosity of 0.28 ± 0.03 Pa·s when measured in accordance with T 316 (Note 4).

8.8. If loose HMA plant mix is used, the sample should be obtained in accordance with T 168. The mixture shall be brought to the compaction temperature range by careful, uniform heating in an oven immediately prior to molding.

9. COMPACTION PROCEDURE

9.1. When the compaction temperature is achieved, remove the heated mold, base plate, and upper plate (if required) from the oven. Place the base plate and a paper disk in the bottom of the mold.

9.2. Place the mixture into the mold in one lift. Care should be taken to avoid segregation in the mold. After all the mix is in the mold, level the mix, and place another paper disk and upper plate (if required) on top of the leveled material.

9.3. Load the charged mold into the compactor, and center the loading ram.

9.4. Apply a pressure of 600 ± 18 kPa on the specimen.

9.5. Apply a 20.2 ± 0.35 mrad (1.16 ± 0.02 degrees) average internal angle to the mold assembly, and begin the gyratory compaction.

9.6. Allow the compaction to proceed until the desired number of gyrations specified in R 35 is reached and the gyratory mechanism shuts off.

9.7. Remove the angle from the mold assembly, remove the ram pressure, and retract the loading ram in the order specified by the SGC manufacturer (the preceding steps may be done automatically by the compactor on some models of SGCs). Remove the mold from the compactor (if required), and extrude the specimen from the mold.

Note 5—No additional gyrations with the angle removed are required unless specifically called for in another standard referencing T 312. The extruded specimen may not be a right angle cylinder. Specimen ends may need to be sawed to conform to the requirements of specific performance tests.

Note 6—The specimens can be extruded from the mold immediately after compaction for most HMA. However, a cooling period of 5 to 10 minutes in front of a fan may be necessary before extruding some specimens to ensure the specimens are not damaged.

9.8. Remove the paper disks from the top and bottom of the specimens.

Note 7—Before reusing the mold, place it in an oven for at least 5 minutes. The use of multiple molds will speed up the compaction process.

10. DENSITY PROCEDURE

10.1. Determine the maximum specific gravity (G_{mm}) of the loose mix in accordance with T 209 using a companion sample. The companion sample shall be conditioned to the same extent as the compaction sample.

10.2. Determine the bulk specific gravity (G_{mb}) of the specimen in accordance with T 166 or T 275 as appropriate.

10.3. When the specimen height is to be monitored, record the specimen height to the nearest 0.1 mm after each revolution.

11. DENSITY CALCULATIONS

11.1. Calculate the uncorrected relative density ($\%G_{mmux}$) at any point in the compaction process using the following equation:

$$\%G_{mmux} = \frac{W_m}{V_{mx} G_{mm} G_m} \times 100 \tag{1}$$

where:

$\%G_{mmux}$ = uncorrected relative density at any point during compaction expressed as a percent of the maximum theoretical specific gravity;

W_m = mass of the specimen in g;

G_{mm} = theoretical maximum specific gravity of the mix;

G_m = unit weight of water, 1 g/cm^3;

x = number of gyrations; and

V_{mx} = volume of the specimen, in cm^3, at any point based on the diameter (d) and height (h_x) of the specimen at that point (use "mm" for height and diameter measurements).

It can be expressed as:

$$V_{mx} = \frac{\pi d^2 h_x}{4 \times 1000} \tag{2}$$

Note 8—This formula gives the volume in cm^3 to allow a direct comparison with the specific gravity.

11.2. At the completion of the bulk specific gravity test (G_{mb}), determine the relative density ($\%G_{mmx}$) at any point in the compaction process as follows:

$$\%G_{mmx} = \frac{G_{mb} h_m}{G_{mm} h_x} \times 100 \tag{3}$$

where:

$\%G_{mmx}$ = corrected relative density expressed as a percent of the maximum theoretical specific gravity;

G_{mb} = bulk specific gravity of the extruded specimen;

h_m = height in millimeters of the extruded specimen; and

h_x = height in millimeters of the specimen after x gyrations.

12. REPORT

12.1. Report the following information in the compaction report, if applicable:

12.1.1. Project name;

12.1.2. Date of the test;

12.1.3. Start time of the test;

12.1.4. Specimen identification;

12.1.5. Percent binder in specimen, nearest 0.1 percent;

12.1.6. Average diameter of the mold used (d), nearest 1.0 mm;

12.1.7. Mass of the specimen (W_m), nearest 0.1 g;

12.1.8. Maximum specific gravity (G_{mm}) of the specimen by T 209, nearest 0.001;

12.1.9. Bulk specific gravity (G_{mb}) of the specimen by T 166 or T 275, nearest 0.001;

12.1.10. Height of the specimen after each gyration (h_x), nearest 0.1 mm;

12.1.11. Relative density ($\%G_{mm}$) expressed as a percent of the theoretical maximum specific gravity (G_{mm}), nearest 0.1 percent; and

12.1.12. Gyration angle, nearest 0.2 mrad (0.01 degrees), and the method used to determine or verify the gyration angle.

13. PRECISION AND BIAS

13.1. *Precision*:

13.2. *Single Operator Precision*—The single operator standard deviations (1s limits) for relative densities at N_{ini} and N_{des} for mixtures containing aggregate with an absorption of less than 1.5 percent are shown in Table 1. The results of two properly conducted tests on the same material, by the same operator, using the same equipment, should be considered suspect if they differ by more than the d2s single operator limits shown in Table 1.

13.3. *Multilaboratory Precision*—The multilaboratory standard deviations (1s limits) for relative densities at N_{ini} and N_{des} for mixtures containing aggregate with an absorption of less than 1.5 percent are shown in Table 1. The results of two properly conducted tests on the same material, by different operators, using different equipment, should be considered suspect if they differ by more than the d2s multilaboratory limits shown in Table 1.

Table 1—Precision Estimates[a]

	1s limit Relative Density (%)	d2s limit Relative Density (%)
Single Operator Precision:		
12.5-mm nominal max agg.	0.3	0.9
19.0-mm nominal max agg.	0.5	1.4
Multilaboratory Precision:		
12.5-mm nominal max agg.	0.6	1.7
19.0-mm nominal max agg.	0.6	1.7

[a] Based on an interlaboratory study described in NCHRP Research Report 9-26 involving 150-mm diameter specimens with 4 to 5 percent air voids, 26 laboratories, two materials (a 12.5-mm mixture and a 19.0-mm mixture), and three replicates. Specimens were prepared in accordance with T 312-04. The angle of gyration was verified using Method A, external angle.

13.4. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

14. KEYWORDS

14.1. Compaction; density; gyratory.

Standard Method of Test for

Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)

AASHTO Designation: T 313-10

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)

AASHTO Designation: T 313-10

1. SCOPE

1.1. This test method covers the determination of the flexural creep stiffness or compliance of asphalt binders by means of a bending beam rheometer. It is applicable to material having a flexural stiffness value from 20 MPa to 1 GPa (creep compliance values in the range of 50 nPa–1 to 1 nPa–1) and can be used with unaged material or with material aged using T 240 (RTFOT) and/or R 28 (PAV). The test apparatus is designed for testing within the temperature range from –36 to 0°C.

1.2. Test results are not valid for beams of asphalt binder that deflect more than 4 mm, or less than 0.08 mm, when tested in accordance with this method.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- T 40, Sampling Bituminous Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 802, Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques

2.3. *Deutche Industrie Norm (DIN) Standards*:

- 43760, Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

3.1.2. *physical hardening*—a time-dependent stiffening of asphalt binder that results from the time-delayed increase in stiffness when the asphalt binder is stored at low temperatures. The increase in stiffness due to physical hardening is reversible when the temperature is raised.

3.2. *Descriptions of Terms Specific to This Standard*:

3.2.1. *flexural creep*—a test in which a simply supported asphalt binder prismatic beam is loaded with a constant load at its midpoint and the deflection of the beam is measured with respect to loading time.

3.2.2. *measured flexural creep stiffness,* $S_m(t)$—ratio obtained by dividing the maximum bending stress in the beam by the maximum bending strain.

3.2.3. *estimated creep stiffness,* $S(t)$—the creep stiffness obtained by fitting a second order polynomial to the logarithm of the measured stiffness at 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 seconds and the logarithm of time.

3.2.4. *flexural creep compliance,* $D(t)$—ratio obtained by dividing the maximum bending strain in the beam by maximum bending stress. $D(t)$ is the inverse of $S(t)$. $S(t)$ has been used historically in asphalt technology, while $D(t)$ is commonly used in studies of viscoelasticity.

3.2.5. *m-value*—absolute value of the slope of the logarithm of the stiffness curves versus the logarithm of the time.

3.2.6. *contact load*—load required to maintain positive contact between the beam and the loading shaft; 35 ± 10 mN.

3.2.7. *seating load*—load of 1-second duration required to seat the beam; 980 ± 50 mN.

3.2.8. *test load*—load of 240-second duration required to determine the stiffness of material being tested; 980 ± 50 mN.

3.2.9. *testing zero time, s*—time at which the signal is sent to the solenoid valve to switch from zero load regulator (contact load) to the testing load regulator (test load).

4. SUMMARY OF TEST METHOD

4.1. The bending beam rheometer measures the midpoint deflection of a simply supported beam of asphalt binder subjected to a constant load applied to the midpoint of the beam. The device operates only in the loading mode; recovery measurements are not obtained.

4.2. A test beam is placed in the controlled temperature fluid bath and loaded with a constant load for 240 seconds. The test load (980 ± 50 mN) and the midpoint of deflection of the beam are monitored versus time using a computerized data acquisition system.

4.3. The maximum bending stress at the midpoint of the beam is calculated from the dimensions of the beam, the span length, and the load applied to the beam for loading times of 8, 15, 30, 60, 120, and 240 seconds. The maximum bending strain in the beam is calculated for the same loading times from the dimensions of the beam and the deflection of the beam. The stiffness of the beam for the loading times specified above is calculated by dividing the maximum stress by the maximum strain.

4.4. The load and deflection at 0.0 and 0.5 seconds are reported to verify that the full-testing load (980 ± 50 mN) during the test is applied within the first 0.5 second. They are not used in the calculation of stiffness and *m*-value and should not be considered to represent material properties. The rise time of the load (time to apply full load) can be affected by improper operation of the pressure regulators, improper air bearing pressure, malfunctioning air bearing (friction), and other factors. By reporting the 0.0- and the 0.5-second signals, the user of the test results can determine the conditions of the loading.

5. SIGNIFICANCE AND USE

5.1. The test temperature for this test is related to the temperature experienced by the pavement in the geographical area for which the asphalt binder is intended.

5.2. The flexural creep stiffness or flexural creep compliance, determined from this test, describes the low-temperature, stress-strain-time response of asphalt binder at the test temperature within the linear viscoelastic response range.

5.3. The low-temperature thermal cracking performance of paving mixtures is related to the creep stiffness and the slope of the logarithm of the creep stiffness versus the logarithm of the time curve of the asphalt binder contained in the mix.

5.4. The creep stiffness and the slope of the logarithm of the stiffness versus the logarithm of the time curve are used as performance-based specification criteria for asphalt binders in accordance with M 320.

6. APPARATUS

6.1. *Bending Beam Rheometer (BBR) Test System*—A bending beam rheometer (BBR) test system consisting of (1) a loading frame which permits the test beam, supports, and the lower part of the test frame to be submerged in a constant temperature fluid bath; (2) a controlled temperature liquid bath which maintains the test beam at the test temperature and provides a buoyant force to counterbalance the force resulting from the mass of the beam; (3) a computer-controlled automated data acquisition component; (4) specimen molds; and (5) items needed to calibrate and/or verify the BBR.

6.1.1. *Loading Frame*—A frame consisting of a set of sample supports, a blunt-nosed shaft that applies the load to the midpoint of the test specimen, a load cell mounted on the loading shaft, a means for zeroing the load on the test specimen, a means for applying a constant load to the loading shaft, and a deflection measuring transducer attached to the loading shaft. A schematic of the device is shown in Figure 1.

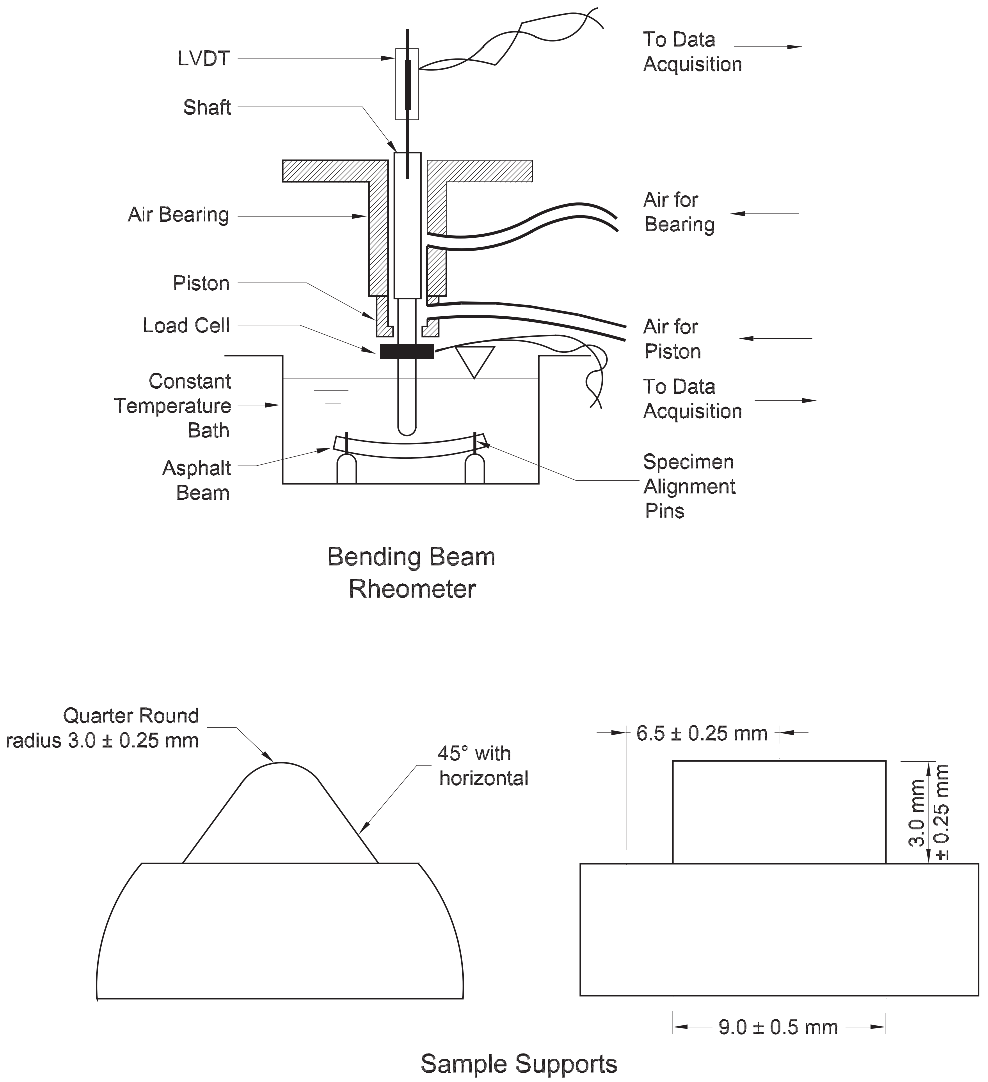


Figure 1—Schematic of the Bending Beam Rheometer

6.1.1.1. *Loading System*—A loading system that is capable of applying a contact load of 35 ± 10 mN to the test specimen and maintaining a test load of 980 ± 50 mN.

6.1.1.2. *Loading System Requirements*—The rise time for the test load shall be less than 0.5 second. The rise time is the time required for the load to rise from the 35 ± 10 mN contact load to the 980 ± 50 mN test load. During the rise time, the system shall dampen the test load to 980 ± 50 mN. Between 0.5 and 5.0 seconds, the test load shall be within ±50 mN of the average test load, and thereafter shall be within ±10 mN of the average test load.

6.1.1.3. *Sample Supports*—Sample supports with specimen support strips 3.0 ± 0.30 mm in top radius and inclined at an angle of 45 degrees with the horizontal (see Figure 1). The supports, made of stainless steel (or other corrosion-resistant metal), are spaced 102.0 ± 1.0 mm apart. The width of the supporting area of the supporting strips shall be 9.5 ± 0.25 mm. This is required to ensure that the edges of the specimen, resulting from the molding procedure, do not interfere with the mid-span deflection of the specimen measured during testing. The supports shall also include vertical alignment pins 2 to 4 mm in diameter placed at the back of each sample supports at 6.75 ± 0.25

mm from the center of the supports. These pins should be placed on the back side of the support to align the specimen on the center of the supports. See Figure 1 for details.

6.1.1.4. *Loading Shaft*—A blunt-nosed loading shaft (with a spherical contact point 6.25 (±0.30) mm in radius) continuous with a load cell and a deflection measuring transducer which is capable of applying a contact load of 35 ± 10 mN and maintaining a test load of 980 ± 50 mN. The rise time for the test load shall be less than 0.5 second where the rise time is the time required for the load to rise from the 35 ± 10 mN preload to the 980 ± 50 mN test load. During the rise time, the system shall dampen the test load after the first 5 seconds to a constant ±10-mN value.

6.1.1.5. *Load Cell*—A load cell with a minimum capacity of 2,000 mN, having a minimum resolution of 2.5 mN mounted in-line with the loading shaft and above the fluid to measure the contact load and the test load.

6.1.1.6. *Linear Variable Differential Transducer (LVDT)*—A linear variable differential transducer or other suitable mounted device mounted axially above the loading shaft capable of resolving a linear movement ≤ 2.5 μm with a range of at least 6 mm to measure the deflection of the test beam.

6.1.2. *Controlled-Temperature Fluid Bath*—A controlled-temperature liquid bath capable of maintaining the temperature at all points within the bath between –36 and 0°C within ±0.1°C. Placing a cold specimen in the bath may cause the bath temperature to fluctuate ±0.2°C from the target test temperature; consequently, bath fluctuations of ±0.2°C during isothermal conditioning shall be allowed.

6.1.2.1. *Bath Agitator*—A bath agitator for maintaining the required temperature homogeneity with agitator intensity such that the fluid current does not disturb the testing process, and mechanical noise caused by vibrations is less than the resolution specified in Sections 6.1.3 and 6.1.3.1.

6.1.2.2. *Circulating Bath (Optional)*—A circulating bath unit separate from the test frame which pumps the bath fluid through the test bath. If used, vibrations from the circulating system shall be isolated from the bath test chamber so that mechanical noise is less than the resolution specified in Sections 6.1.3 and 6.1.3.1.

6.1.3. *Data Acquisition System*—A data acquisition system that resolves loads to the nearest 2.5 mN, beam deflection to the nearest 2.5 μm, and bath fluid temperature to the nearest 0.1°C. The system shall sense the point in time when the signal is sent to the solenoid valve(s) to switch from zero load regulator (contact load) to the testing load regulator (test load). This is zero time. Using this time as a reference, the system shall provide a record of load and deflection measurements relative to this time. The system shall record the load and deflection at the loading times of 0.0, 0.5, 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 seconds. All readings shall be an average of three or more points within ±0.2 seconds from the loading time, e.g., for a loading time of 7.8, 7.9, 8.0, 8.1, and 8.2 seconds.

6.1.3.1. *Signal Filtering*—Digital or analog smoothing of the load and the deflection data may be required to eliminate electronic noise that could otherwise affect the ability of the second order polynomial to fit the data with sufficient accuracy to provide a reliable estimate of *m*-value. The load and deflection signals may be filtered with a low pass analog or digital filter that removes signals of greater than 4 Hz frequency. The averaging shall be over a time period less than or equal to ±0.2 seconds of the reporting time.

6.2. *Temperature Measuring Equipment*—A calibrated temperature transducer capable of measuring the temperature to 0.1°C over the range of –36 to 0°C mounted within 50 mm of the midpoint of the test specimen supports.

Note 1—Required temperature measurement can be accomplished with an appropriately calibrated platinum resistance thermometer (RTD) or a thermistor. Calibrations of an RTD or thermistor can be verified as per Section 6.6. An RTD meeting DIN Standard 43760 (Class A) is recommended for this purpose. The required precision and accuracy cannot be obtained unless each RTD is calibrated as a system with its respective meter or electronic circuitry.

6.3. *Test Beam Molds*—Test beam molds of suitable dimensions to yield demolded test beam 6.35 ± 0.05-mm thick by 12.70 ± 0.05-mm wide by 127 ± 2.0-mm long fabricated from aluminum flat stock as shown in Figure 2.

6.3.1. The thickness of the two spacers used for each mold (small end pieces used in the metal molds) shall be measured with a micrometer and shall not vary from each other in thickness by more than 0.05 mm.

Note 2—Small errors in the thickness of the test specimen can have a large effect on the calculated modulus because the calculated modulus is a function of the thickness, h, raised to the third power.

6.4. *Items for Calibration or Verification*—The following items are required to verify and calibrate the BBR.

6.4.1. *Stainless Steel (Thick) Beam for Compliance Measurement and Load Cell Calibration*—One stainless steel beam, 6.4 ± 0.1-mm thick by 12.7 ± 0.25-mm wide by 127 ± 5-mm long, for measuring system compliance and calibrating the load cell.

6.4.2. *Stainless Steel (Thin) Beam for Overall System Check*—One stainless steel beam, 1.3 ± 0.3-mm thick by 12.7 ± 0.1-mm wide by 127 ± 5-mm long, with an elastic modulus reported to three significant figures by the manufacturer. The manufacturer shall measure and report the thickness of this beam to the nearest 0.01 mm and the width to the nearest 0.05 mm. The dimensions of the beam shall be used to calculate the modulus of the beam during the overall system check. See Section 10.1.2.1.

6.5. *Standard Masses*—One or more standard masses are required as follows:

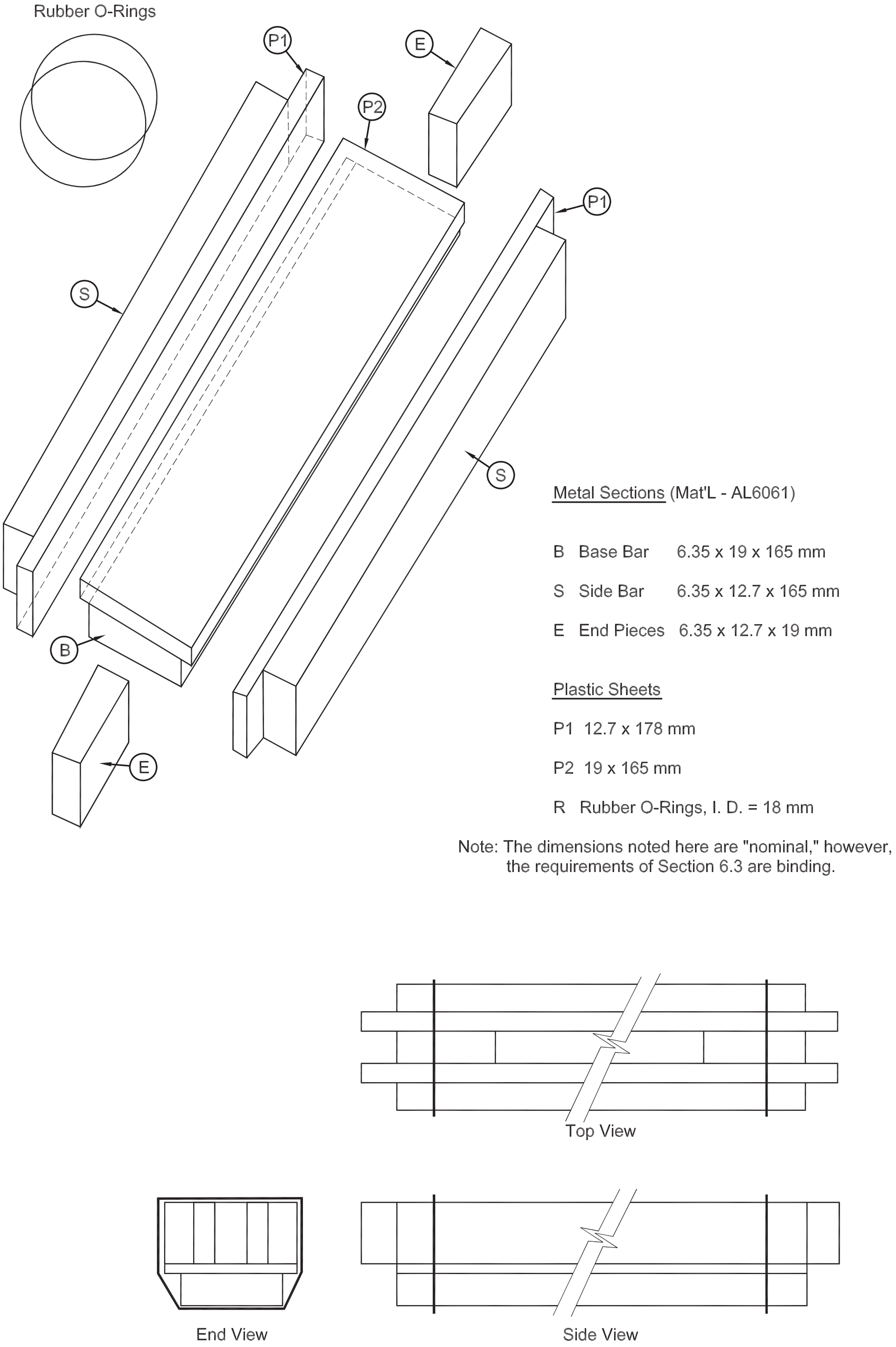
6.5.1. *Verification of Load Cell Calibration*—One or more masses totaling 100 ± 0.2 g and two masses of 2 ± 0.2 g each (see Note 3) for verifying the calibration of the load cell.

Note 3—Any suitable object may be used if the mass is confirmed to be 2 ± 0.2 g.

6.5.2. *Calibration of Load Cell*—Four masses, each of known mass ±0.2 g, and equally spaced in mass over the range of the load cell.

6.5.3. *Daily Overall System Check*—Two or more masses, each of known mass to 0.2 g, for conducting overall system check as specified by the manufacturer.

6.5.4. *Accuracy of Masses*—Accuracy of the masses in Section 6.5 shall be verified at least once each every 3 years.



Metal Sections (Mat'L - AL6061)

B Base Bar 6.35 x 19 x 165 mm

S Side Bar 6.35 x 12.7 x 165 mm

E End Pieces 6.35 x 12.7 x 19 mm

Plastic Sheets

P1 12.7 x 178 mm

P2 19 x 165 mm

R Rubber O-Rings, I. D. = 18 mm

Note: The dimensions noted here are "nominal," however, the requirements of Section 6.3 are binding.

Figure 2—Dimensions and Specifications for Aluminum Molds

6.6. *Calibrated Thermometers*—Calibrated liquid-in-glass thermometers for verification of the temperature transducer of suitable range with subdivisions of 0.1°C. These thermometers shall be partial immersion thermometers with an ice point and shall be calibrated in accordance with Test Method E 77 at least once per year. A suitable thermometer is designated 133C. An electronic thermometer of equal accuracy and resolution may be used.

6.7. *Thickness Gauge*—A stepped thickness gauge for verifying the calibrations of displacement transducer as described in Figure 3.

7. MATERIALS

7.1. *Plastic Sheeting*—Clear plastic sheeting, 0.12 ± 0.04-mm thick, for lining the interior faces of the three long aluminum mold sections. Sheeting should not be distorted by hot asphalt binder.

Note 4—Transparency film sold for use with laser printers has been found suitable.

7.2. *Petroleum-Based Grease*—A petroleum-based grease used to hold the plastic strips to the interior faces of the three long aluminum mold sections.

Note 5—Warning: Do not use any silicone-based products.

7.3. *Glycerol-Talc Mixture*—Used to coat the end pieces of aluminum molds.

Note 6—A mixture of 50 percent by weight USP grade glycerin and 50 percent USP grade talc or kaolin (china clay) is suitable for this purpose.

7.4. *Bath Fluid*—A bath fluid that is not absorbed by or does not affect the properties of the asphalt binder tested. The mass density of the bath fluid shall not exceed 1.05 g/cm^3 at testing temperatures. The bath fluid shall be optically clear at all testing temperatures. Silicone fluids or mixtures containing silicones shall not be used.

Note 7—Suitable bath fluids include ethanol, methanol, and glycol-methanol mixtures (e.g., 60 percent glycol, 15 percent methanol, 25 percent water).

8. HAZARDS

8.1. Observe standard laboratory safety procedures when handling hot asphalt binder and preparing test specimens.

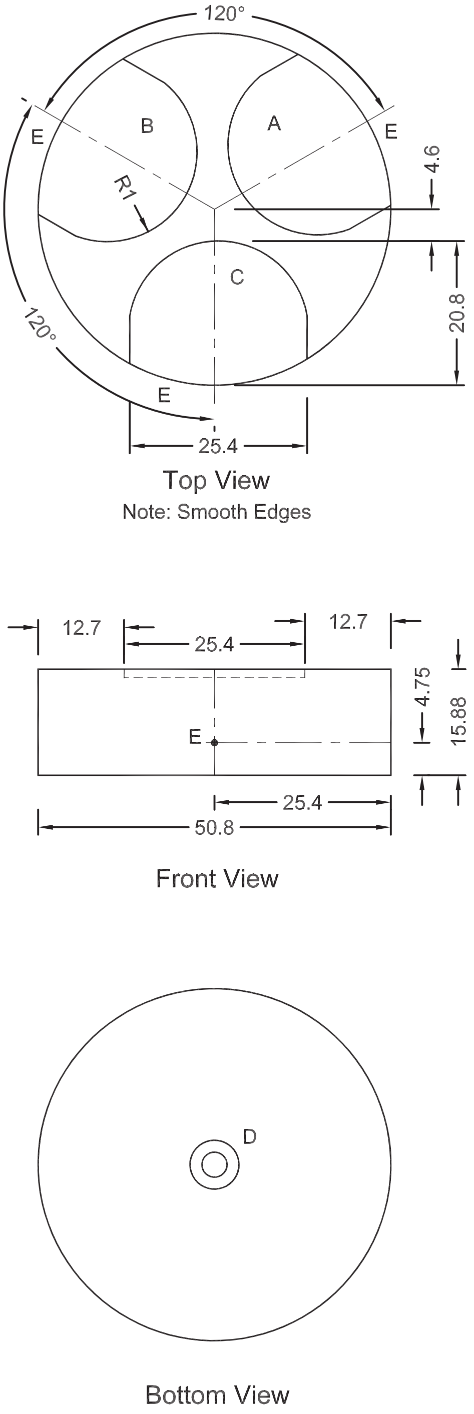
8.2. Alcohol baths are flammable and toxic. Locate the controlled temperature bath in a well-ventilated area away from sources of ignition. Avoid breathing alcohol vapors and contact of the bath fluid with the skin.

8.3. Contact between the bath fluid and skin at the lower temperatures used in this test method can cause frostbite.

9. PREPARATION OF APPARATUS

9.1. Clean the supports, loading head, and bath fluid of any particulates and coatings as necessary.

Note 8—Because of the brittleness of asphalt binder at the specified test temperatures, small fragments of asphalt binder can be introduced into the bath fluid. If these fragments are present on the supports or the loading head, the measured deflection will be affected. The small fragments, because of their small size, will deform under load and add an apparent deflection of the beam. Filtration of the bath fluid will aid in preserving the required cleanliness.



Note: Sections A, B, and C are depressions with depths from the top surface as follows:

A 1.00 mm (0.0394") ± 0.01 mm

B 3.00 mm (0.1181")

C 6.00 mm (0.2362")

Hole Sizes:

D 4 mm dia x 7.0 mm deep, Counterbore 6 mm dia x 0.8 mm deep

E Depression, 2.4 mm Ball End Mill, 1.52 mm deep. Three places in-line with corresponding top surface depressions.

Note: 1. Bottom surface is flat and parallel with top surface.
2. All dimensions are in millimeters unless otherwise indicated.

Figure 3—Typical Thickness Gauge Used to Calibrate Deflection Detector

9.2. Select the test temperature and adjust the bath fluid to the selected temperature. Wait until the temperature stabilizes and then allow the bath to equilibrate to the test temperature ±0.1°C prior to conducting a test.

9.3. Activate the data acquisition system and load the software as explained in the manufacturer's manual for the test system.

10. STANDARDIZATION

10.1. Verify the calibration of the displacement transducer, load cell, and temperature transducer as described in Sections 10.1.1 through 10.1.6. As a minimum, each of the verification steps and their frequency of performance shall be performed as described in this section. Additional verification steps may be performed at the recommendation of the manufacturer. Calibration procedures are described in the Annex. At the option of the manufacturer, the verification and calibration steps may be combined.

10.1.1. *Verification of Temperature Transducer*—On each day, before conducting tests, and whenever the test temperature is changed, verify calibration of the temperature detector by using a calibrated thermometer as described in Section 6.6. With the loading frame placed in the liquid bath, immerse the thermometer in the liquid bath close to the temperature transducer, and compare the temperature indicated by the thermometer to the temperature displayed by the data acquisition system. If the temperature indicated by the data acquisition system does not agree with the thermometer within ±0.1°C, calibration is required.

10.1.2. *Verification of Freely Operating Air Bearing*—On each day, before conducting tests, verify that the air bearing is operating freely and is free of friction. Sections 10.1.2.1 and 10.1.2.2 shall be used to verify that the shaft is free of friction. If the requirements of Sections 10.1.2.1 and 10.1.2.2 are not satisfied, friction is present in the air bearing. Clean the shaft, and adjust the clearance of the displacement transducer as per the manufacturer's instructions. If this does not eliminate the friction, discontinue use of the BBR, and consult the manufacturer.

Note 9—Friction may be caused by a poorly adjusted displacement transducer core that rubs against its housing, an accumulation of asphalt binder on the loading shaft, by oil or other particulates in the air supply, and other causes.

10.1.2.1. Place the thin steel beam (Section 6.4.2) on the sample supports, and apply a 35 ± 10-mN load to the beam using the zero load regulator. Observe the reading of the LVDT as indicated by the data acquisition system. Gently grasp the shaft, and lift it upwards approximately 5 mm by observing the reading of the LVDT. When the shaft is released, it shall immediately float downward and make contact with the beam.

10.1.2.2. Remove any beams from the supports. Use the zero load regulator to adjust the loading shaft so that it is free-floating at the approximate midpoint of its vertical travel. Gently add a 2-g mass to the loading shelf. The shaft shall slowly drop downward under the mass.

10.1.3. *Verification of Displacement Transducer*—On each day, before conducting tests, verify the calibration of the displacement transducer using a stepped gauge block of known dimensions similar to the one shown in Figure 3. With the loading frame mounted in the bath at the test temperature, remove all beams from the supports, and place the gauge block on a reference platform underneath the loading shaft according to the instructions supplied by the instrument manufacturer. Apply a 100 g ± 0.2-g mass to the loading shaft, and measure the rise of the steps with the displacement transducer. Compare the measured values as indicated by the data acquisition system with the known dimensions of the gauge. If the known dimensions as determined from the gauge block and the dimensions indicated by the data acquisition system differ by more than ±5 µm, calibration is required. Perform the calibration, and repeat Section 10.1.1. If the requirements of Section 10.1.1 cannot be met after calibration, discontinue use of the device, and consult the manufacturer.

10.1.4. *Daily Overall System Check*—On each day, before conducting tests and with the loading frame mounted in the bath, perform a check on the overall operation of the system. Place the 1.3 ± 0.3-mm-thick stainless steel (thin) beam of known modulus as described in Section 6.4.2 on the sample supports. Following the instructions supplied by the manufacturer, place the beam on the supports and apply a 50.0 or 100.0 ± 0.2-g initial mass (491 or 981 mN ± 2 mN) to the beam to ensure that the beam is seated and in full contact with the supports. Following the manufacturer's instructions, apply a second additional load of 100.0 to 300.0 ± 0.2 g to the beam. The software provided by the manufacturer shall use the change in load and associated change in deflection to calculate the modulus of the beam to three significant figures. The modulus reported by the software shall be within 10 percent of the modulus reported by the manufacturer of the beam; otherwise, the overall operation of the BBR shall be considered suspect and the manufacturer shall be consulted

10.1.5. *Verification of Load Cell*—Verify the calibration of the load cell as follows:

10.1.5.1. *Contact Load*—On each day, verify the calibration of the load cell in the range of the contact load. Place the 6.4-mm-thick stainless steel compliance beam (Section 6.4.1) on the supports. Apply a 20 ± 10-mN load to the beam using the zero load pressure regulator. Add the 2.0 ± 0.2-g mass as specified in Section 6.5.1 to the loading platform. The increase in the load displayed by the data acquisition system shall be 20 ± 5 mN. Add a second 2.0 ± 0.2-g mass to the loading platform. The increase in the load displayed by the data acquisition system shall be 20 ± 5 mN. If the increases in displayed load are not 20 ± 5 mN, calibration is required. Perform the calibration. If the requirements of Section 10.1.3.1 cannot be met after calibration, discontinue use of the device and consult the manufacturer.

10.1.5.2. *Test Load*—On each day, before conducting tests, verify the calibration of the load cell in the range of the test load. Place the 6.4-mm-thick stainless steel compliance beam (Section 6.4.1) on the supports. Use the zero load regulator (contact load) to apply a 20 ± 10-mN load to the beam. Add the 100-g mass to the loading platform. The increase in the load displayed by the data acquisition system shall be 981 ± 5 mN. Otherwise, calibrate the load cell. If the requirements of Section 10.1.3.2 cannot be met after calibration, discontinue use of the device and consult the manufacturer.

10.1.6. *Verification of Front-to-Back Alignment of Loading Shaft*—Every 6 months, check the alignment of the loading shaft with the center of the sample supports with an alignment gauge supplied by the manufacturer or by measurement as follows: Cut a strip of white paper about 25 mm in length and slightly narrower than the width of the compliance beam. Stick the paper strip to the center of the compliance beam with tape. Move the frame out of the bath, place the compliance beam on the supports, and place a small section of carbon paper over the paper. With the air pressure applied to the air bearing, push the shaft downward, causing the carbon paper to make an imprint on the white paper. Remove the beam, and measure the distance from the center of the imprint to each edge of the beam with a pair of vernier calipers. The difference between the two measurements shall be 1.0 mm or less. If this requirement is not met, contact the manufacturer of the device.

11. PREPARATION OF MOLDS AND TEST SPECIMENS

11.1. To prepare molds, spread a very thin layer of petroleum-based grease, only sufficient to hold the plastic to the aluminum, on the interior faces of the three long aluminum mold sections. Place the plastic strips over the aluminum faces and rub the plastic with firm finger pressure. Assemble the mold as shown in Figure 2 using the rubber O-rings to hold the pieces of the mold together. Inspect the mold and press the plastic film against the aluminum to force out any air bubbles. If air bubbles remain, disassemble the mold and recoat the aluminum faces with grease. Cover the inside faces of the two end pieces with a thin film of glycerol and talc to prevent the asphalt binder from sticking to the aluminum end pieces. After assembly, keep the mold at room temperature until pouring the asphalt binder.

Note 10—Thickness of the specimen is controlled by the end pieces. The thickness of the end pieces should be measured periodically to make sure that it meets the requirements of Section 6.3. The stiffness is proportional to the third power of the thickness.

11.2. If unaged binder is to be tested, obtain test sample according to T 40.

11.3. Heat the material in an oven set at the minimum temperature and for the minimum time necessary for it to be sufficiently fluid to pour.

Note 11—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. In all cases, heating time should be minimized. These precautions will help avoid oxidative hardening and volatile loss that will further harden the sample. During the heating process, the sample should be covered and stirred occasionally to ensure homogeneity.

11.4. *Molding*—Pour the binder from the one end of the mold and move toward the other end, slightly overfilling the mold. When pouring, hold the sample container 20 to 100 mm from the top of the mold and pour continuously toward the other end in a single pass. Allow the mold to cool 45 to 60 minutes to room temperature after pouring, and trim the exposed face of the cooled specimens flush with the top of the mold using a hot knife or heated spatula.

11.5. Store all test specimens in their molds at room temperature prior to testing. Schedule testing so that it is completed within 4 hours after specimens are poured.

Note 12—Time-dependent increases in stiffness can occur when asphalt binders are stored at room temperature for even short periods of time. This increase in stiffness is the result of molecular associations and is referred to as steric hardening in the literature.

11.6. Just prior to testing, cool the aluminum mold containing the test specimen in a freezer or ice bath at –5°C ± 7°C for 5 to 10 minutes, only long enough to stiffen the asphalt binder beam so that it can be readily demolded without distortion (Note 8). Some softer grades may require lower temperatures. Do not cool the molds containing the specimens in the test bath because it may cause temperature fluctuations in the bath to exceed ±0.2°C.

Note 13—Excessive cooling may cause unwanted hardening of the beam, thereby causing increased variability in the test data.

11.7. Immediately demold the specimen when it is sufficiently stiff to demold without distortion by disassembling the aluminum mold. Discard the plastic sheeting (lining the mold sections) if they become distorted.

Note 14—Minimize distortion of the specimen during demolding. If the plastic sheeting does not fully separate from the testing beam, you may remove the final portion of the sheeting as the beam is being immersed in the test bath to avoid distortion. Full contact at specimen supports is assumed in the analysis. A warped test beam yields a measured stiffness less than the actual stiffness.

12. PROCEDURE

12.1. When testing a specimen for compliance with M 320, select the appropriate test temperature from Table 1 of M 320. After demolding, immediately place the test specimen in the testing bath and condition it at the testing temperature for 60 ± 5 minutes.

Note 15—Asphalt binders may harden rapidly when held at low temperatures. This effect, which is called physical hardening, is reversible when the asphalt binder is heated to room temperature or slightly above. Because of physical hardening, conditioning time must be carefully controlled if repeatable results are to be obtained.

12.2. *Checking Contact Load and Test Load*—Check the adjustment of the contact load and test load prior to testing each set of test specimens. The 6.35-mm-thick stainless steel beam shall be used for checking the contact load and test load.

Note 16—Do not perform these checks with the thin steel beam or an asphalt test specimen.

12.2.1. Place the thick steel beam in position on the beam supports. Using the test load regulator valve, gently increase the force on the beam to 980 ± 50 mN.

12.2.2. Switch from the test load to the contact load, and adjust the force on the beam to 35 ± 10 mN. Switch between the test load and contact load four times.

12.2.3. When switching between the test load and contact load, watch the loading shaft and platform for visible vertical movement. The loading shaft shall maintain contact with the steel beam when switching between the contact load and test load while maintaining these loads at 35 ± 10 mN and 980 ± 50 mN, respectively.

12.2.4. *Corrective Action*—If the requirements of Sections 12.2.1 to 12.2.3 are not met, the device may require calibration as per the manufacturer's instructions or the loading shaft may be dirty or require alignment (see Section 10.1.2). If the requirements of Sections 12.2.1 to 12.2.3 cannot be met after calibration, cleaning, or other corrective action, discontinue use of the device and consult the equipment manufacturer.

12.3. Enter the specimen identification information, test load, test temperature, time the specimen is placed in the bath at the test temperature, and other information as appropriate into the computer which controls the test system.

12.4. After conditioning, place the test beam on the test supports, and initiate the loading sequence of the test. Maintain the bath at the test temperature ±0.1°C during testing; otherwise, the test shall be rejected.

12.5. Manually apply a 35 ± 10-mN contact load to the beam to ensure contact between the beam and the loading head for no more than 10 seconds. The specified contact load is required to ensure continuous contact between the loading shaft and support, and the specimen. Failure to establish continuous contact within the required load range gives misleading results. The contact load shall be applied by gently increasing the load to 35 ± 10 mN. While applying the contact load, the load on the beam shall not exceed 45 mN, and the time to apply and adjust the contact load shall be no greater than 10 seconds.

12.6. *Activate the automatic test system that is programmed to proceed as follows*:

12.6.1. Immediately after the application of the 35-mN contact load, increase the load from 35 ± 10 mN to the 980 ± 50-mN seating load for 1.0 ± 0.1 seconds.

Note 17—The seating loads described in Sections 12.6.1 and 12.6.2 are applied and removed automatically by the computer-controlled loading system and are transparent to the operator. Data are not recorded during the initial loading.

12.6.2. Reduce the load to 35 ± 10 mN and allow the beam to recover for 20.0 ± 0.1 seconds.

12.6.3. Apply a test load ranging as specified in Section 6.1.1.2.

Note 18—The actual load on the beam as measured by the load cell is used in calculating the stress in the beam. The 980 ± 50-mN initial seating and test load includes the 35 ± 10-mN preload.

12.6.4. Remove the test load and terminate the test.

12.6.5. At the end of the initial seating load, and at the end of the test, monitor the computer screen to verify that the load on the beam returns to 35 ± 10 mN in each case. If the beam does not return to 35 ± 10 mN, the test is invalid and the rheometer should be calibrated.

12.7. Remove the specimen from the supports and proceed to the next test.

13. CALCULATION AND INTERPRETATION OF RESULTS

13.1. See Annex.

14. REPORT

14.1. *Report data as shown in Figure 4 that describes individual test, including*:

14.1.1. Maximum and minimum temperature of the test bath measured during the 240 seconds of testing measured at 1.0-second intervals to the nearest 0.1°C;

14.1.2. Date and time when test load is applied;

14.1.3. File name of test data;

14.1.4. Name of operator;

14.1.5. Sample identification number;

```
                                   Test Information
Project:      Testing            Target Temp:   23.0°C       Conf. Test    2.199e + 008
Operator:     JSY                Actual Temp:   14.8°C       Date:         09/17/93
Specimen:     Plastic Beam B     Soak Time:     0.0 s        Load Const:   0.24
Time:         11:47:03           Beam Width:    12.70 mm     Defl Const:   0.0024
Date:         09/18/93           Thickness:     6.35 mm      Date:         09/17/93
File:         0818934.DAT

                                       Results
    t            P            d       Measured    Estimated
   Time        Force         Defl     Stiffness   Stiffness    Difference
   (s)          (N)          (mm)       (kPa)       (kPa)         (%)        m-value
     8        0.9859        0.9126     87030.0     87060.0       0.03532      0.176
    15        0.9894        1.022      77990.0     77930.0      –0.08120      0.175
    30        0.9913        1.158      68690.0     68990.0       0.04809      0.175
    60        0.9910        1.308      61110.0     61110.0       0.004487     0.174
   120        0.9908        1.475      54150.0     54150.0      –0.001551     0.174
   240        0.9906        1.664      48010.0     48000.0      –0.005077     0.174
Regression Coefficients:
a = 5.100      b = –0.1784      c = 0.001020      R^2 – 0.999996
– Cannon bending beam rheometer –                 P to print – ESC to continue
```

Figure 4—Typical Test Report

14.1.6. Time beam in bath;

14.1.7. Time test started;

14.1.8. Any flags issued by software during test;

14.1.9. Correlation coefficient, R^2, for log stiffness versus log time, expressed to nearest 0.000001;

14.1.10. Anecdotal comments (maximum 256 characters);

14.1.11. Report constants A, B, and C to three significant figures; and

14.1.12. Difference between measured and estimated stiffness calculated as:
(Estimated – Measured) × 100 percent/Measured.

14.2. Report load and deflection as for times 0.0 and 0.5 seconds.

14.3. Report data as shown in Figure 4 for time intervals of 8.0, 15.0, 30.0, 60.0, 120.0, and 240.0 seconds, including:

14.3.1. Loading time, nearest 0.1 second;

14.3.2. Load, nearest 1.0 mN;

14.3.3. Beam deflection, nearest 1 µm;

14.3.4. Measured Stiffness modulus, MPa, expressed to three significant figures;

14.3.5. Estimated Stiffness Modulus, MPa, expressed to three significant figures;

14.3.6. Difference between measured and estimated Stiffness Modulus in percent;

14.3.7. Estimated *m*-value, nearest 0.001; and

14.3.8. Regression Coefficients and least square fit R^2 value.

15. PRECISION AND BIAS

15.1. *Precision*—Criteria for judging the acceptability of creep stiffness and slope results obtained by this method are given in Table 1.

15.1.1. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

15.1.2. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

Table 1—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]	Acceptable Range of Two Test Results (d2s%)[a]
Single-Operator Precision:		
Creep Stiffness (MPa)	2.5	7.2
Slope (*m*-value)	1.0	2.9
Multilaboratory Precision:		
Creep Stiffness (MPa)	6.3	17.8
Slope (*m*-value)	2.4	6.8

[a] These values represent the 1s% and d2s% limits described in ASTM Practice C 670.

Note 19—The precision estimates given in Table 1 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 174 to 196 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). Average creep stiffness results ranged from 125.4 MPa to 236.8 MPa. Average slope results ranged from an *m*-value of 0.308 to 0.374. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 20—As an example, two tests conducted on the same material yield creep stiffness results of 190.3 MPa and 200.7 MPa, respectively. The average of these two measurements is 195.5 MPa. The acceptable range of results is then 7.2 percent of 195.5 MPa or 14.1 MPa. As the difference between 190.3 MPa and 200.7 MPa is less than 14.1 MPa, the results are within the acceptable range.

15.2. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

16. KEYWORDS

16.1. Flexural; creep stiffness; flexural creep compliance; bending beam rheometer.

ANNEX

(Mandatory Information)

A1.1 *Calibration of Displacement Transducer*—Calibrate the displacement transducer using a stepped gauge block of known dimensions similar to the one shown in Figure 3. With the loading frame mounted in the bath at the test temperature, remove all beams from the supports, and place the stepped gauge block on a reference platform underneath the loading shaft according to the instructions supplied by the instrument manufacturer. Apply a 100-g mass on the loading shaft, and follow the manufacturer's instructions to obtain a displacement transducer reading on each step. The software provided by the manufacturer shall convert the measurements to a calibration constant in terms of µm/bit to three significant figures and shall automatically enter the new constant into the software. The calibration constant should be repeatable within 10 percent from one calibration to another; otherwise, the operation of the system may be suspect.

A1.2 *Calibration of Load Cell*—Calibrate the load cell in accordance with the manufacturer's instructions using a minimum of four masses evenly distributed over the range of the load cell. The software provided by the manufacturer shall convert the measurements to a calibration constant in terms of mN/bit to three significant figures and shall automatically enter the new constant into the software. The calibration constants should be repeatable within 10 percent from one calibration to another; otherwise, the operation of the system may be suspect. Repeat the process for each test temperature.

A1.3 *Calibration of Temperature Transducer*—Calibrate the temperature detector by using a calibrated thermometer of suitable range meeting the requirements of Section 10.1.5. Immerse the thermometer in the liquid bath close to the thermal detector, and compare the temperature indicated by the calibrated thermometer to the detector signal being displayed. If the temperature indicated by the thermal detector does not agree with the thermometer within ±0.1°C, follow the manufacturer's instructions for correcting the displayed temperature to agree with the thermometer temperature.

A1.4 *Determine the System Compliance*—Determine the system compliance in accordance with the manufacturer's instructions using a minimum of four masses evenly distributed over the range of the load cell. The data acquisition software shall measure the position of the displacement transducer at each load. The compliance shall be calculated as the measured deflection per unit load. The software provided by the manufacturer shall convert the measurements to a compliance in terms of µm/N to three significant figures and shall automatically enter the compliance into the software. The compliance measurement may be performed as part of the load cell calibration or as a separate operation. The compliance measurement shall be performed each time the load cell is calibrated. The compliance value should be repeatable within 10 percent from one determination to another; otherwise, the operation of the system may be suspect. Repeat the process for each test temperature.

A1.5 *Typical Test Result*—A typical test result is shown in Figure 4. Disregard measurements obtained and the curves projected on the computer screen during the initial 8 seconds of the application of the test load. Data from a creep test obtained immediately after the application of the test load may not be valid because of dynamic loading effects and the finite rise time. Use only the data obtained between the 8- and 240-second loading time for calculating $S(t)$ and m.

A1.6 *Deflection of an Elastic Beam*—Using the elementary bending theory, the midspan deflection of an elastic prismatic beam of constant cross-section loaded in three-point loading can be obtained by applying Equations A1.1 and A1.2 as follows:

$$\delta = PL^3/48EI \qquad (A1.1)$$

where:

δ = deflection of beam at midspan, mm;
P = load applied, N;
L = span length, mm;
E = modulus of elasticity, MPa; and
I = moment of inertia, mm^4.

and:

$$I = bh^3/12 \qquad (A1.2)$$

where:

I = moment of inertia of cross-section of test beam, mm^4;
b = width of beam, mm; and
h = thickness of beam, mm.

Note A1—The test specimen has a span to depth ratio of 16:1 and the contribution of shear to deflection of the beam can be neglected.

A1.7 *Elastic Flexural Modulus*—According to elastic theory, calculate the flexural modulus of a prismatic beam of constant cross-section loaded at its midspan using the following equation:

$$E = PL^3/4bh^3\delta \qquad (A1.3)$$

where:

E = time-dependent flexural creep stiffness, MPa;
P = constant load, N;
L = span length, mm;
b = width of beam, mm;
h = thickness of beam, mm; and
δ = deflection of beam, mm.

A1.8 *Maximum Bending Stress*—The maximum bending stress in the beam occurs at the midspan at the top and bottom of the beam. Calculate σ thus:

$$\sigma = 3PL/2bh^2 \qquad (A1.4)$$

where:

σ = maximum bending stress in beam, MPa;
P = constant load, N;
L = span length, mm;

b = width of beam, mm; and
h = thickness of beam, mm.

A1.9 *Maximum Bending Strain*—The maximum bending strain in the beam occurs at the midspan at the top and bottom of the beam. Calculate ϵ using the following equation:

$$\epsilon = 6\delta h/L^2 \text{ mm/mm} \qquad (A1.5)$$

where:
ϵ = maximum bending strain in beam, mm/mm;
δ = deflection of beam, mm;
h = thickness of beam, mm; and
L = span length, mm.

A1.10 *Linear Viscoelastic Stiffness Modulus*—According to the elastic-viscoelastic correspondence principle, it can be assumed that if a linear viscoelastic beam is subjected to a constant load applied at $t = 0$ and held constant, the stress distribution is the same as that in a linear elastic beam under the same load. Further, the strains and displacements depend on time and are derived from those of the elastic case by replacing E with $1/D(t)$. Since $1/D(t)$ is equivalent to $S(t)$, rearranging the elastic solution results in the following relationship for the stiffness:

$$S(t) = PL^3/4bh^3\delta(t) \qquad (A1.6)$$

where:
$S(t)$ = time-dependent flexural creep stiffness, MPa;
P = constant load, N;
L = span length, mm;
b = width of beam, mm;
h = thickness of beam, mm;
$\delta(t)$ = deflection of beam, mm; and
$\delta(t)$ and $S(t)$ indicate that the deflection and stiffness, respectively, are functions of time.

A1.11 *Presentation of Data*:

A1.11.1 Plot the response of the test beam to the creep loading as the logarithm of stiffness with respect to the logarithm of loading time. A typical representation of test data is shown in Figure 4. Over the limited testing time from 8 to 240 seconds, the plotted data shown in Figure A1.1 can be represented by a second order polynomial as follows:

$$\log S'(t) = A + B[\log(t)] + C[\log(t)]^2 \qquad (A1.7)$$

and, the slope, m, of the logarithm of stiffness versus logarithm time curve is equal to (absolute value):

$$|m(t)| = d[\log S'(t)]/d[\log(t)] = B + 2C[\log(t)] \qquad (A1.8)$$

where:
$S'(t)$ = time-dependent flexural creep stiffness estimated using Equation A1.7, MPa;
T = time in seconds; and
A, B, and C = regression coefficients.

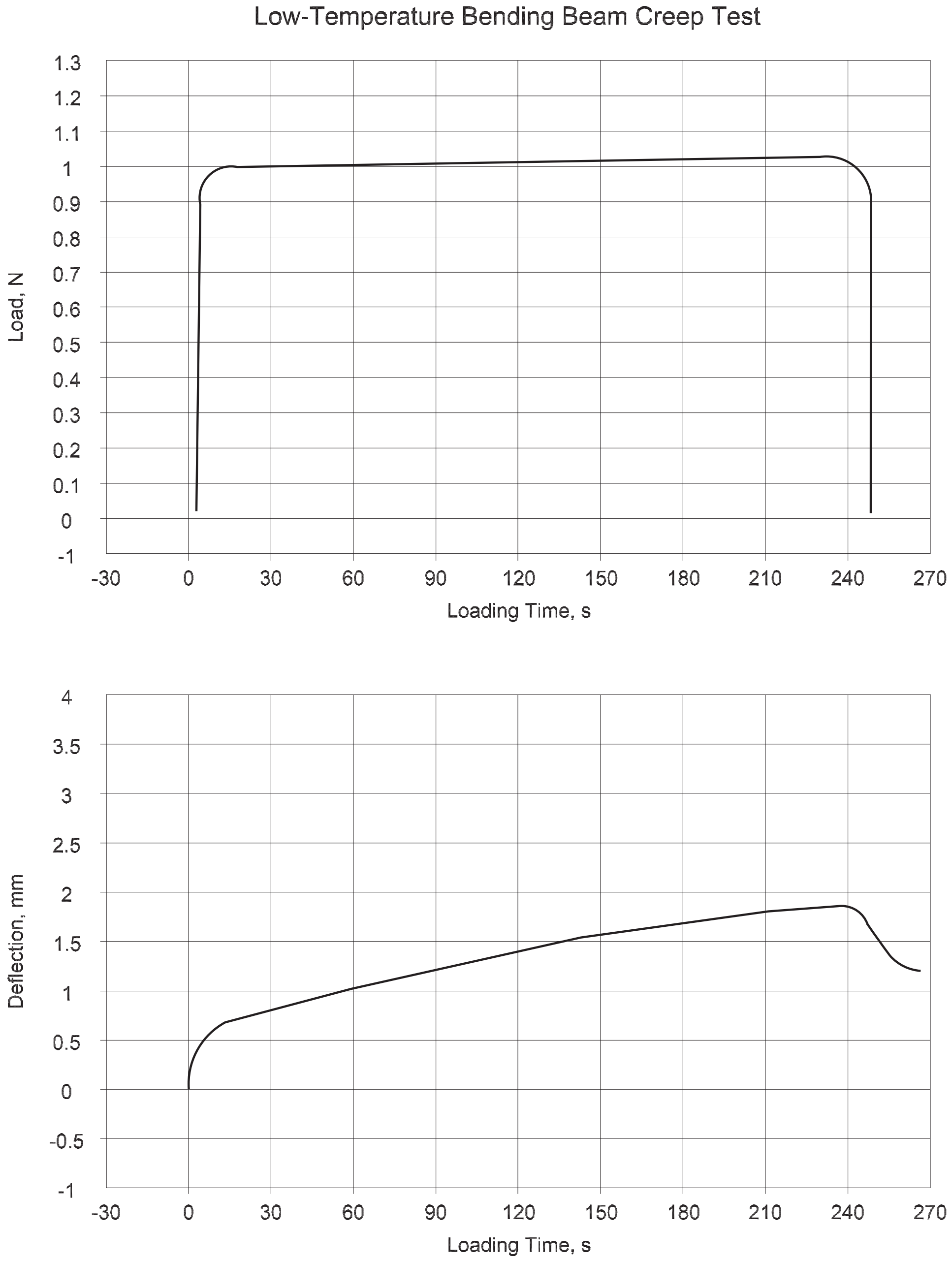


Figure A1.1—Typical Load and Deflection Plots

A1.11.2 Smoothing the data may be required to obtain smooth curves for the regression analysis as required to determine an *m*-value. This procedure can be performed by averaging five readings taken at the reported time ±0.1 and ±0.2 seconds.

A1.11.3 Obtain the constants *A*, *B*, and *C* from the least squares fit of Equation A1.7. Use data equally spaced with respect to the logarithm of time to determine the regression coefficients in Equations A1.7 and A1.8. Determine experimentally the stiffness values used for the regression to derive the coefficients *A*, *B*, and *C* and to, in turn, calculate values of *m* after loading times of 8, 15, 30, 60, 120, and 240 seconds.

A1.12 Calculation of regression coefficients, estimated stiffness values, and *m*:

A1.12.1 Calculate the regression coefficients *A*, *B*, and *C* in Equations A1.7 and A1.8 and the denominator *D* as follows:

$$A = S_y(S_{x2}S_{x4} - S_{x3}{}^2) - S_{xy}(S_{x1}S_{x4} - S_{x2}S_{x3}) + S_{xxy}(S_{x1}S_{x3} - S_{x2}{}^2)]/D \tag{A1.9}$$

$$B = [6(S_{xy}S_{x4} - S_{xxy}S_{x3}) - S_{x1}(S_yS_{x4} - S_{xxy}S_{x2}) + S_{x2}(S_yS_{x3} - S_{xy}S_{x2})]/D \tag{A1.10}$$

$$C = [6(S_{x2}S_{xxy} - S_{x3}S_{xy}) - S_{x1}(S_{x1}S_{xxy} - S_{x3}S_y) + S_{x2}(S_{x1}S_{xy} - S_{x2}S_y)]/D \tag{A1.11}$$

$$D = 6(S_{x2}S_{x4} - S_{x3}{}^2) - S_{x1}(S_{x1}S_{x4} - S_{x2}S_{x3}) + S_{x2}(S_{x1}S_{x3} - S_{x2}{}^2) \tag{A1.12}$$

where, for loading times of 8, 15, 30, 60, 120, and 240 seconds:
S_{x1} = log 8 + log 15 + ... log 240;
S_{x2} = $(\log 8)^2 + (\log 15)^2 + ...\ (\log 240)^2$;
S_{x3} = $(\log 8)^3 + (\log 15)^3 + ...\ (\log 240)^3$;
S_{x4} = $(\log 8)^4 + (\log 15)^4 + ...\ (\log 240)^4$;
S_y = log *S*(8) + log *S*(15) + ... log *S* (240);
S_{xy} = log *S*(8)(log (8)) + log *S*(15) log (15) + ... log *S*(240) log (240); and
S_{xxy} = $[\log (8)]^2 \log S(8) + [\log (15)]^2 \log S(15) + ...\ [\log (240)]^2 \log S(240)$.

A1.12.2 Calculate the estimated stiffness *S*′(*t*) at 8, 15, 30, 60, 120, and 240 seconds as follows:

$$\log S'(t) = A + B[\log(t)] + C\,[\log(t)]^2 \tag{A1.13}$$

A1.12.3 Calculate the estimated *m*-value at 8, 15, 30, 60, 120, and 240 seconds as the absolute value of

$$|m| = B + 2C\,[\log(t)] \tag{A1.14}$$

A1.12.4 Calculate $\overline{S}$ the average of the stiffness values at 8, 15, 30, 60, 120, and 240 seconds as:

$$\log \overline{S} = [\log S(8) + \ldots \log S(240)]/6 \tag{A1.15}$$

A1.12.5 Calculate the fraction of the variation in the stiffness explained by the quadratic model as:

$$R^2 = 1.00 - \left[\frac{[\log S(8) - \log S'(8)] + ...[\log S(240) - \log S'(240)]}{\left[\log S(8) - \log\left(\overline{S}\right)\right]^2 + ...\left[\log S(240) - \log\left(\overline{S}\right)\right]^2} \right] \tag{A1.16}$$

A1.12.6 Use the estimated values of the stiffness and *m* at 60 seconds for specification purposes. Measured and estimated stiffness values should agree to within 2 percent. Otherwise, the test is considered suspect.

Standard Method of Test for

Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)

AASHTO Designation: T 314-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)

AASHTO Designation: T 314-07

1. SCOPE

1.1. This test method covers the determination of the failure strain and failure stress of asphalt binders by means of a direct tension test. It can be used with unaged or aged material using T 240 (RTFOT), R 28 (PAV). The test apparatus is designed for testing within the temperature range from +6 to –36°C.

1.2. This test method is limited to asphalt binders containing particulate material having dimensions less than 250 μm.

1.3. This test method is not valid for specimens exhibiting a failure strain of greater than 10 percent considered outside the brittle-ductile range.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 49, Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders
- T 40, Sampling Bituminous Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 4, Standard Practices for Force Verification of Testing Machines
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 83, Standard Practice for Verification and Classification of Extensometer Systems

2.3. *ISO Standard*:

- ISO 10012, Measurement Management Systems—Requirements for Measurement Processes and Measuring Equipment

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of particulate organic modifiers of size less than 250 µm.

3.2. *Description of Terms Specific to This Standard*:

3.2.1. *brittle*—type of failure in a direct tension test where the stress-strain curve is essentially linear up to the point of failure and the failure is by sudden rupture of the test specimen without appreciable reduction in cross-section of the specimen.

3.2.2. *brittle-ductile*—type of failure in a direct tension test where the stress-strain curve is curvilinear and the failure is by sudden rupture of the test specimen. Limited reduction in cross-section of the specimen occurs before rupture.

3.2.3. *ductile*—type of failure in a direct tension test where the specimen does not rupture but fails by flow at large strains.

3.2.4. *tensile strain*—axial strain resulting from the application of a tensile load and calculated as the change in length of the effective gauge length caused by the application of the tensile load divided by the original unloaded effective gauge length.

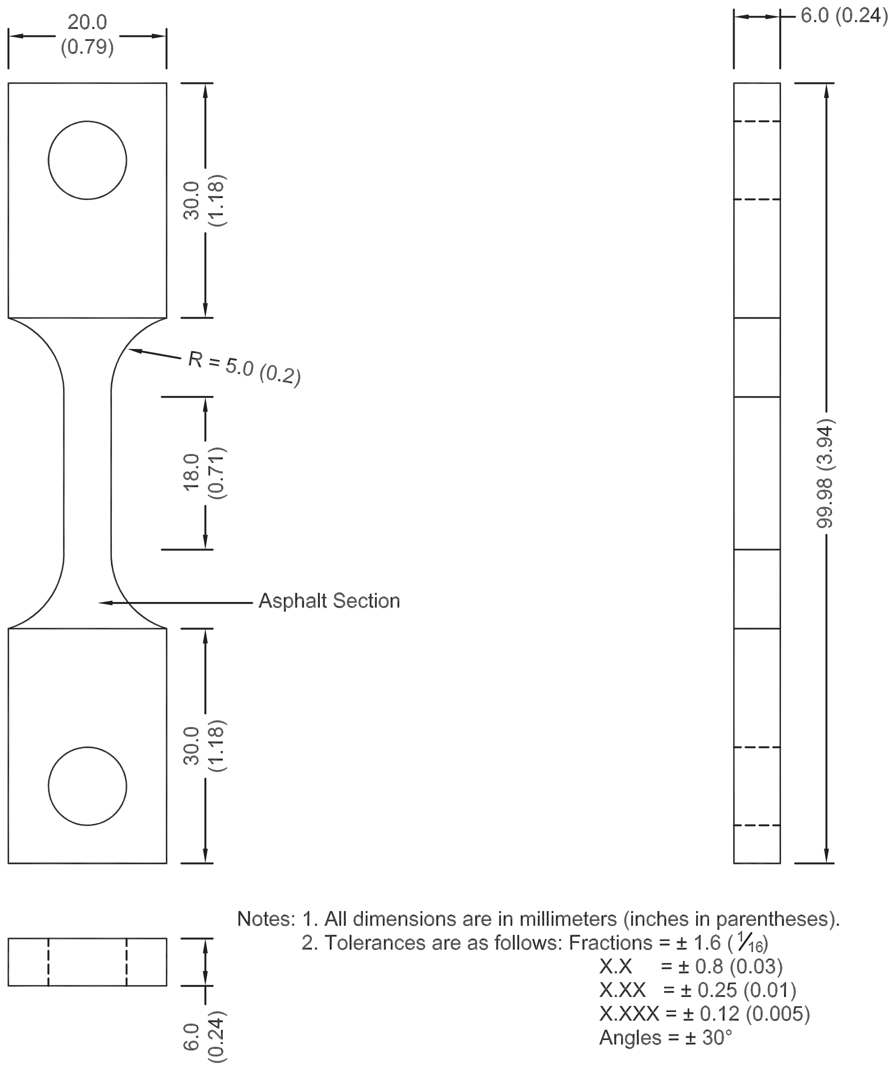
3.2.5. *tensile stress*—axial stress resulting from the application of a tensile load and calculated as the tensile load divided by the original area of cross-section of the specimen.

3.2.6. *failure*—point at which the tensile load reaches a maximum value as the test specimen is pulled at a constant rate of elongation.

3.2.7. *failure stress*—the tensile stress on the test specimen when the load reaches a maximum value during the test method specified in this standard.

3.2.8. *failure strain*—the tensile strain corresponding to the failure stress.

3.2.9. *gauge section*—the central portion of the specimen where the cross-section does not change with length. For this geometry the gauge section is 18 mm in length (see Figure 1).



Notes: 1. All dimensions are in millimeters (inches in parentheses).
2. Tolerances are as follows: Fractions = ± 1.6 ($^1\!/_{16}$)
X.X = ± 0.8 (0.03)
X.XX = ± 0.25 (0.01)
X.XXX = ± 0.12 (0.005)
Angles = ± 30°

3. Remove all sharp edges.
4. Surface finish for machined surfaces: $\sqrt[125]{}$ unless otherwise specified.

Figure 1—Superpave Direct Tension Specimen Geometry

3.2.10. *effective gauge length*—for specimens used in this test, the effective gauge length, L_e, has been determined to be 33.8 mm. This is an effective gauge length that represents the portion of the specimen that contributes to the majority of the strain.

4. SUMMARY OF TEST METHOD

4.1. This method describes the procedure used to measure the stress at failure and strain at failure in an asphalt binder test specimen pulled at a constant rate of elongation. Test specimens are prepared by pouring hot asphalt binder into a suitable mold. Two G10 phenolic end tabs are used to bond the asphalt binder during the test and to transfer the tensile load from the test machine to the asphalt binder.

4.2. This test method was developed for asphalt binders at temperatures where they exhibit brittle or brittle-ductile failure. A brittle or brittle-ductile failure will result in a fracture of the test specimen as opposed to a ductile failure in which the specimen simply stretches without fracturing. The test is not applicable at temperatures where failure is by ductile flow.

4.3. A displacement transducer is used to measure the elongation of the test specimen as it is pulled in tension at a constant rate of 1 mm/min. The load developed during the test is monitored and the tensile strain and stress in the test specimen when the load reaches a maximum are reported as the failure strain and failure stress, respectively.

5. SIGNIFICANCE AND USE

5.1. Stress at failure is used in a mechanistic pavement cracking model to compute critical cracking temperature. The procedure to compute critical cracking temperature is described in AASHTO R 49. The critical cracking temperature is then used in specifying the low temperature grade of asphalt binder in accordance with M 320.

5.2. The test is designed to measure the strength of the asphalt binder at the critical cracking temperature. The asphalt binder has limited ability to resist stress without cracking. In the asphalt binder specification failure, stress is used to determine the critical cracking temperature.

5.3. For evaluating an asphalt binder for conformance to M 320, the elongation rate of the gauge section is 1.0 mm/min and the test temperature is selected from Table 1 of M 320 according to the grade of asphalt binder. Other rates of elongation and test temperatures may be used to test asphalt binders.

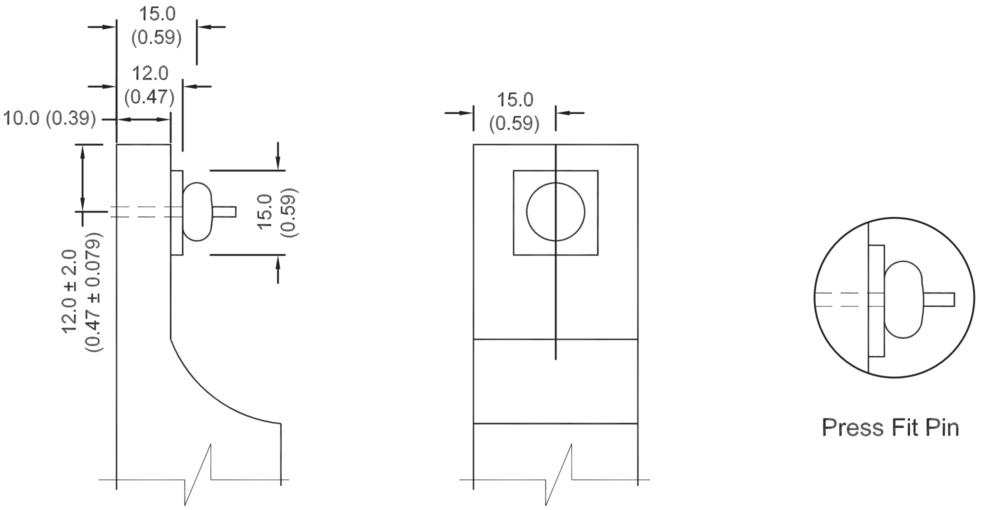
6. APPARATUS

6.1. *Direct Tension Test System*—A direct tension test system consisting of (1) a closed feedback loop displacement-controlled tensile loading machine; (2) a specimen gripping system; (3) either a fluid bath or an insulated chamber for reliable, accurate, and uniform temperature control during testing and conditioning of specimen; (4) real-time load measuring and recording devices; (5) real-time elongation measuring and recording devices; (6) a real-time temperature detection and recording device; and (7) real-time data acquisition and display devices.

The system shall have an electro-mechanical or a servo-hydraulic loading unit capable of applying and measuring tension and compression forces of at least 500 N and actuator travel of 20 mm (0.78 in.). The system stiffness shall be at least 3 mN/m including the load cell and the loading pins. The unit shall have a transducer to measure and control grip separation and provide a feedback for strain control with a displacement resolution of 1.0 μm. The system shall be capable of closed loop elongation rate control accurate to at least 1 percent of the commanded specimen elongation rate using feedback from a displacement transducer mounted between the loading pins or a non-contact extensometer measuring the elongation of the specimen.

6.1.1. *Tensile Loading Machine Equipped with Temperature Control*—A tensile loading machine with a controlled-displacement loading frame capable of producing at least a 500-N load is required. The loading frame shall be table mounted. The gripping system (loading pins and platens) shall be completely submerged under the cooling fluid if a fluid-based system is used. The gripping system shall be a minimum of 25 mm (1 in.) under the cooling fluid surface. Loading shall be accomplished by pulling directly in tension in the plane of the specimen. The distance between the load frame's loading points (between loading pins) shall accommodate specimens with total length (including the end tabs) of at least 100 mm (see Figure 1). If an air-cooled system is used, the testing frame shall be equipped with two standards (columns) with sufficient clear space between the standards so that an insulated temperature control chamber can be placed between the standards.

6.1.2. *Specimen Gripping System*—The gripping system must produce a self-aligning uniaxial test load and accept the end tabs described in Section 6.1.2.1 and be designed so that test specimens can be easily mounted in the machine. The system shall include two grips. Each grip shall include a specially shaped pin that is mounted rigidly to the loading platens of the testing machine. Figure 2 shows a typical grip and loading pin assembly. One grip shall be fixed and remain stationary during the test while the other grip is displaced at the desired elongation rate.



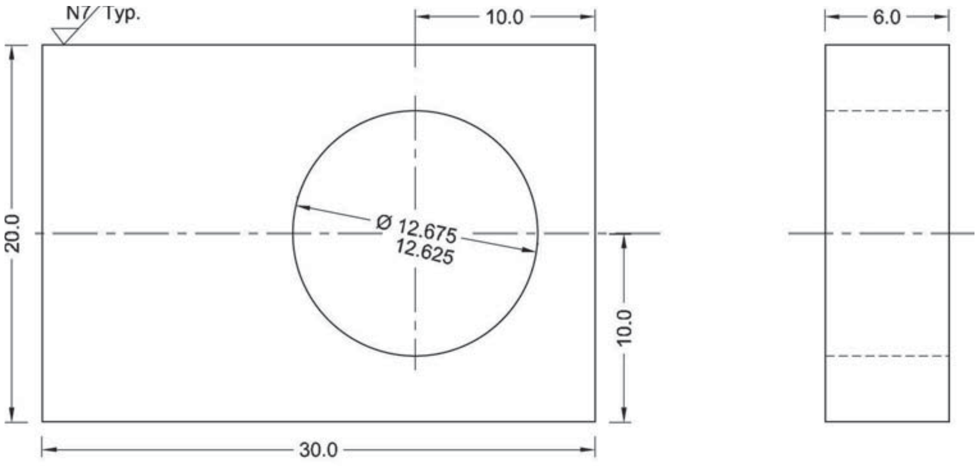
Typical Grip Showing the Pin Press-Fitted.
Two Grips Are Needed.

Notes: 1) All dimensions are in millimeters (inches in parentheses).
2) Tolerances are as follows: Fractions = ± 1.6 ($\frac{1}{16}$)
X.X = ± 0.8 (0.03)
X.XX = ± 0.25 (0.01)
X.XXX = ± 0.12 (0.005)
Angles = ± 30°

3) Remove all sharp edges.
4) Surface finish for machined surfaces: $\overset{125}{\surd}$ unless otherwise specified.

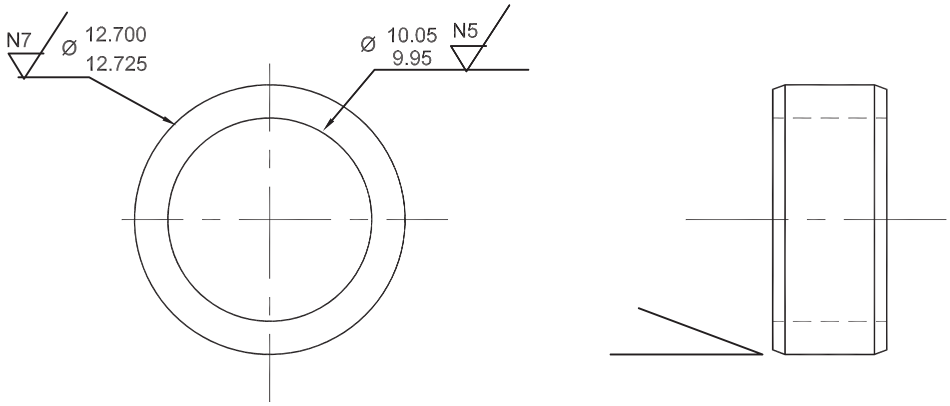
Figure 2—Loading Pin and Grip Assembly for the Superpave Direct Tension Test

6.1.2.1. *Specimen End Tabs*—End tabs made from G10 phenolic sheets having the dimensions specified in Figures 3, 4, and 5 shall be bonded to both ends of the test specimen to transfer the tensile load to the asphalt binder. The end tabs shall be machined from a standard G10 phenolic sheet. Each end tab shall contain a precisely machined hole lined with a 304 stainless steel ring. The diameter of the lined hole shall be 10 ± 0.05 mm. Gripping of the specimen is accomplished through the bond (adhesion) between the asphalt binder test specimen and the end tab. Each end tab shall be mounted on a specially shaped pin that is part of the gripping system. The specimen shall be mounted on the grips by positioning the end tabs in the test machine such that the end tabs fit onto the pins and are indexed against the face of the grips. Matching the coefficient of thermal expansion of the asphalt binder and the end tabs is necessary to reduce thermal shrinkage stresses at the interface that otherwise cause bond failures.



Notes: 1. All dimensions are in millimeters (inches in parentheses).
2. Tolerances are as follows: Fractions = ± 1.6 ($^1/_{16}$)
X.X = ± 0.6 (0.03)
X.XX = ± 0.25 (0.01)
X.XXX = ± 0.12 (0.005)
Angles = ± 30°
3. Remove all sharp edges.
4. Surface finish for machined surfaces: $\overset{125}{\surd}$ unless otherwise specified.
5. Material: G10 phenolic.
6. Also see Metal Ring and Assembly Drawings.

Figure 3—Superpave End Insert for Direct Tension Test (See Figure 4 for the Metal Ring Dimensions to Be Press Fitted into This End Insert.)



Notes: 1. All dimensions are in millimeters (inches in parentheses).

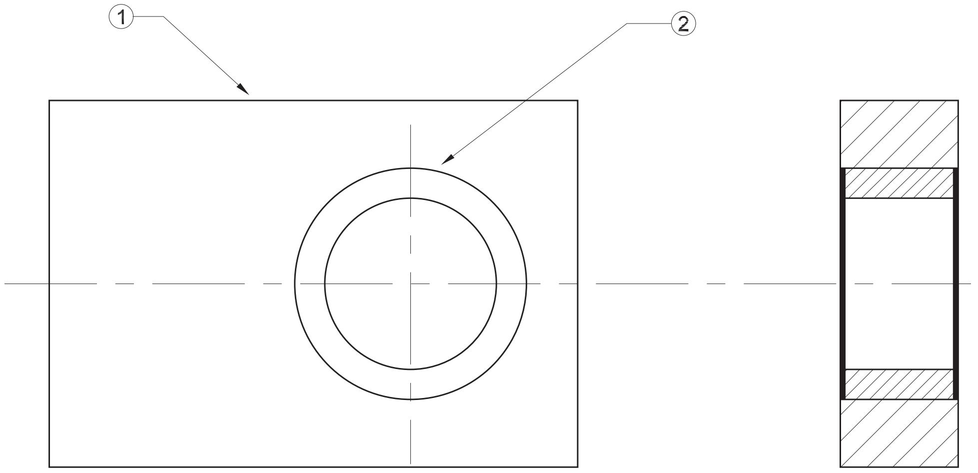
2. Tolerances are as follows: Fractions = ± 1.6 (1⁄16)
X.X = ± 0.8 (0.03)
X.XX = ± 0.25 (0.01)
X.XXX = ± 0.12 (0.005)
Angles = ± 30°

3. Remove all sharp edges.

4. Surface finish for machined surfaces: 125√ unless otherwise specified.

5. Material: Stainless Steel Type 316 or 304.
May be made from 1⁄4" schedule 40 seamless pipe.

Figure 4—Superpave End Insert Metal Ring for Direct Tension Test (See Figure 3 for Dimensions of the Insert to Be Press Fitted with This Ring.)



Press Fit Ring into hole such that ring is
flush or slightly below surface on either side.

Notes: 1. All dimensions are in millimeters (inches in parentheses).
2. Tolerances are as follows: Fractions = ± 1.6 (1/16)
X.X = ± 0.8 (0.03)
X.XX = ± 0.25 (0.01)
X.XXX = ± 0.12 (0.005)
Angles = ± 30°

3. Remove all sharp edges.
4. Surface finish for machined surfaces: 125√ unless otherwise specified.

Figure 5—Superpave End Insert for Direct Tension Test (See Figures 3 and 4.)

6.1.3. *Test Chamber for Temperature Control and Testing*—The temperature control chamber shall have sufficient space for storing at least 12 specimens. The temperature control range for the cooling chamber, without asphalt binder specimens, at all points within the bath, shall be from +6 to –36°C with temperature stability as a minimum of ± 0.1°C. Placing a room temperature specimen in the cold chamber is allowed to cause the chamber temperature between the grips to fluctuate ± 0.2°C from the target test temperature during testing and isothermal conditioning of the specimen. However, during testing the temperature gradient between the grips shall not exceed ± 0.1°C. The temperature measurement shall be accomplished with a calibrated Platinum Resistance Temperature Detector (PRTD) located in the chamber in proximity of test area (NIST Traceable, calibrated at eight temperatures in the range of +6 to –36°C). If an air-based cooling system is used, mechanical cooling or liquid nitrogen may be used to cool the chamber. It shall have a dehumidifying system with a capacity such that the formation of frost on the interior of the chamber, the test specimen, or any of the test fixtures is eliminated. The chamber shall be capable of storing a minimum of 12 test specimens on a rack which is thermally isolated from the walls and floors of the chamber such that heat conducted from the walls and floors of the chamber does not affect the temperature of the stored specimens. If an air-based cooling system is used, the chamber shall be fitted with a front-opening door for maintenance and standardization purposes and an access port that allows for insertion of the operator's hand and forearm to position test specimens on the storage shelf for conditioning and to position test specimens on the grips for testing. The access port shall be designed so that changes in chamber temperature are ± 0.2°C during an operation in which the operator's hand or forearm is inserted into or removed from the chamber. Visual access to the interior of the test chamber shall be provided to permit proper mounting of test specimens and test monitoring. The test specimen elongation is measured with an optical laser. Use of the laser requires optical glass windows on two sides of the temperature chamber so that a beam of laser light can be passed through the chamber without distorting the laser beam.

6.1.4. If fluid is used as a cooling medium, a suitable fluid for temperature control and testing has been found to be an aqueous mixture of 42 percent potassium acetate powder and 58 percent deionized water by weight. Alcohols have been found to embrittle asphalt binders (i.e., affect failure properties in presence of stress) and, therefore, shall not be used as a medium for temperature control and failure testing of asphalt binder specimen.

Note 1—Potassium acetate is commercially available in the form of a deicing fluid mixture composed of approximately 50 percent potassium acetate and 50 percent deionized water. If this commercial fluid mixture is purchased, the required 42 percent to 58 percent potassium acetate to deionized water combination may be obtained by mixing the commercially available 50:50 deicing fluid with deionized or distilled water until a specific gravity of 1.2375 ± 0.0025 is obtained. The specific gravity may be measured using a suitable hydrometer.

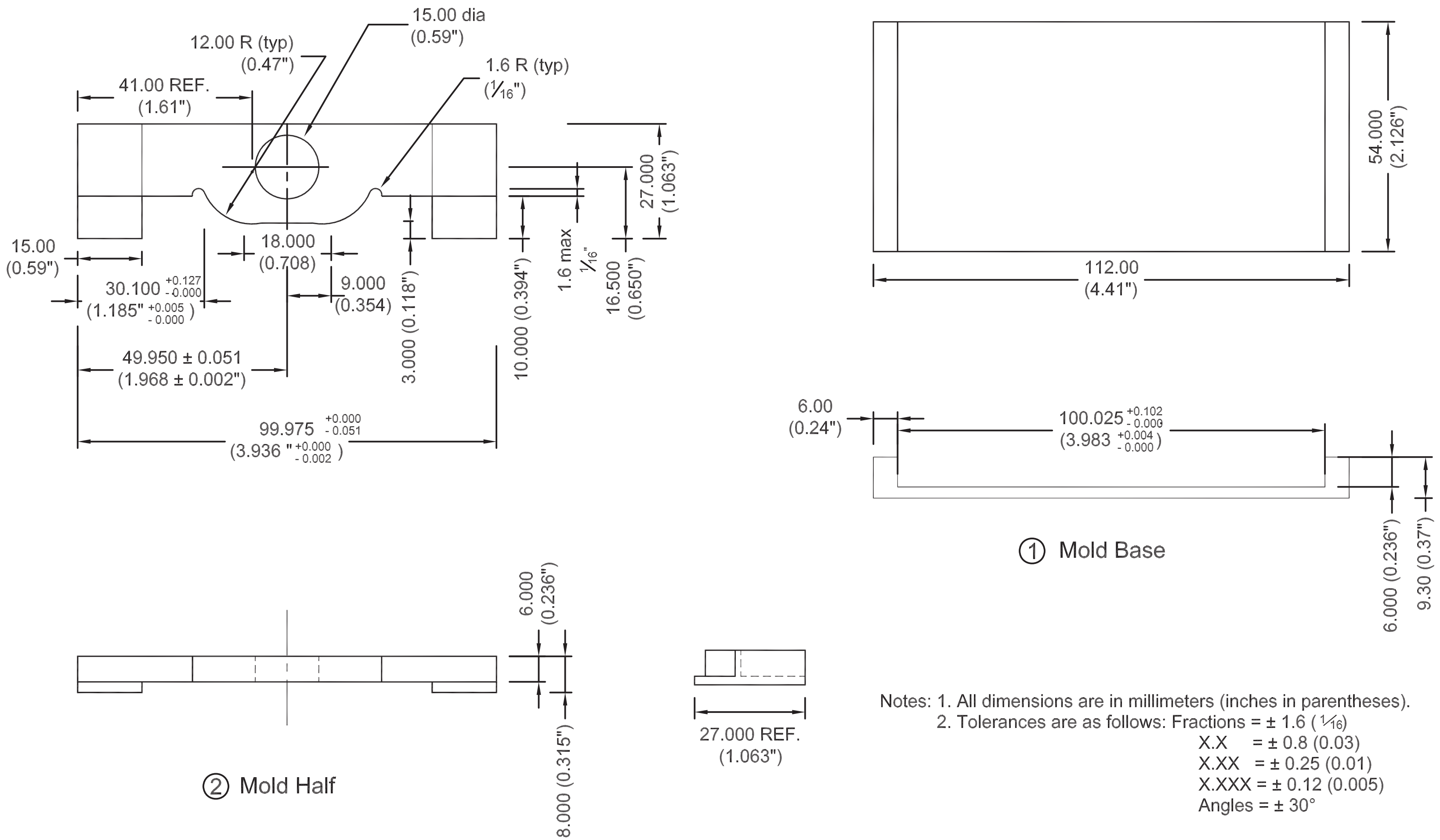
6.1.5. *Load Measuring and Recording Devices*—Load shall be measured with a load cell having a minimum capacity of 500 N and a sensitivity of 0.1 N. The load cell shall be calibrated at least annually in accordance with ASTM E 4. The load and elongation shall be monitored with the data acquisition system such that they can be resolved to 1 percent of the failure load and elongation, respectively. Once the test has started, the data acquisition system shall be able to detect the point in time when the load starts to change as a result of elongation in the sample. This shall be accomplished by monitoring the load cell signal with time. A change in the load signal equivalent to 2 ± 0.3N (threshold load) shall be used to mark the point in time where zero reading of the displacement transducer is obtained. The point in time where the peak load is obtained will be captured by the data acquisition system and the accumulated elongation from the zero reading to the elongation corresponding to the peak load shall be used to calculate the failure strain. Once the test is complete the device shall display the strain at failure. Peak loads typically range from 10 to 250 N depending on the test temperature, grade, aging, and source of the binder. Stress and strain shall be displayed to the nearest 0.1.

6.1.6. *Elongation Measuring and Recording Devices*—Specimen elongation shall be measured between the grips with a displacement transducer. The displacement transducer shall be capable of measuring and controlling grip separation and provide a feedback for elongation rate control with a displacement resolution of 1.0 µm.

6.1.6.1. If the data acquisition component consists of an IBM-compatible computer, it shall have three A/D channels, one for load, one for elongation, and one for temperature. Data shall be stored in ASCII format.

6.1.6.2. *Display of Stress-Strain Curve*—The data acquisition and display system shall be capable of displaying a stress-strain curve in units of stress (MPa) versus percent strain. This may be accomplished using the video screen of the data acquisition computer or with an x-y recorder. If a recorder is used, the units may be in volts, but in this case the test file shall contain the calibration factor in MPa/volt and percent strain/volt for both the x and y axes.

6.2. *Specimen Molds*—The specimen molds shall be manufactured from aluminum. Molds shall have the dimensions specified in Figure 6. A release agent along with a Teflon®-coated release paper, described later in Sections 7.2 and 7.3, shall be used to prevent asphalt binder from adhering to the aluminum mold sides and back plate when making the specimen. The release paper is required to prevent asphalt binder from adhering to the bottom plate of the mold.



Notes: 1. All dimensions are in millimeters (inches in parentheses).
2. Tolerances are as follows: Fractions = ± 1.6 (1⁄16)
X.X = ± 0.8 (0.03)
X.XX = ± 0.25 (0.01)
X.XXX = ± 0.12 (0.005)
Angles = ± 30°

3. Remove all sharp edges.
4. Surface finish for machined surfaces: $\sqrt[125]{}$ unless otherwise specified.

Figure 6—Superpave Direct Tension Specimen Mold

6.3. *Specimen Storage Plates*—Plexiglas™, Teflon®, or other plastic plates for transferring and storing test specimens in the air-cooled environmental chamber. These plates are not required if a fluid cooling bath is used.

6.4. *Calibrated Thermometer*—A calibrated liquid-in-glass thermometer of suitable range with subdivisions of 0.1°C is required for verification of the temperature transducer. This thermometer shall be calibrated in accordance with ASTM E 77. An ASTM 62C thermometer is suitable.

6.5. Freezer capable of maintaining a temperature of –15 ± 5°C. The freezer is only required when using the air-cooled chamber for testing.

6.6. A forced-air convection oven capable of reaching and maintaining a temperature of 160 ± 5°C for heating asphalt.

7. MATERIALS

7.1. *Fluid for temperature control in systems equipped with cooling baths*—An aqueous mixture of 42 percent potassium acetate powder and 58 percent deionized water by weight shall be used as a fluid for temperature control. Alcohols are not allowed because they have been found to lower the failure properties of all asphalts.

7.2. *Release Agent*—A mixture of 20 g of glycerin and 20 g of talc (USP) shall be used as a release agent for the aluminum molds.

7.3. *Release Paper*—A Teflon®-coated paper coated on both sides with a minimum of 0.3 micrometer of Teflon® has been found to be suitable for use as a release paper.

7.4. Solvent (Varsol™ or mineral spirits) or a degreasing spray cleaner formulated for use on asphalt for cleaning molds, end tabs, and plates.

7.5. Cleaning cloths (cotton) for wiping molds, end tabs, and plates.

8. HAZARDS

8.1. Use standard laboratory safety procedures required for handling the hot asphalt binder when preparing test specimens and required safety procedures when cleaning with solvents or degreasers.

9. CALIBRATION AND STANDARDIZATION

9.1. Verify calibration of the displacement transducer, load cell, and temperature transducer.

Note 2—Calibration is usually performed by a calibration service agency. Calibration verification, system standardization, and quality checks may be performed by the manufacturer, other agencies providing such services, or in-house personnel using the procedures described below.

9.1.1. *Load Cell and Displacement Transducer Verification*—A specially designed standard shall be used to verify the operation of both the load cell and the displacement transducer. The verification standard shall have a spring rate of approximately 135 N/mm and shall be capable of withstanding a 500-N load without damage. The verification standard shall be supplied by the manufacturer of the direct tension test system along with the stress-strain characteristics. The manufacturer shall provide a certificate with each verification standard that guarantees the NIST traceability of the equipment used to determine the stress-strain characteristics of the standard. Verify calibration of the load cell and displacement transducer at least every 6 months and when measurements are suspect.

9.1.2. *Verification of Elongation Rate*—The elongation rate shall be verified using the verification standard discussed in Section 9.1.1 To verify the elongation rate, elongation shall be plotted as a function of elapsed time. The resulting plot shall be a straight line with a slope 1.00 mm/min.

Note 3—Measurements shall be made at –18°C. Allow 10 minutes for the verification standard to achieve thermal equilibrium.

9.1.3. *Temperature Detector*—The temperature detector shall be calibrated at a minimum of once each year or sooner if it is believed the equipment may be out of calibration. The temperature shall be calibrated by a NIST-traceable device with measurement uncertainty less than one-third of the required tolerance of the measurement per ISO 10012, Section 4.3. For temperature control of ±0.1°C, the calibration device uncertainty shall be ± 0.033°C. The temperature shall be calibrated at each of the test temperatures used. Place the temperature calibration device in the environmentally controlled chamber and hold the RTD in intimate contact with the device. When the device and the temperature detection device have reached equilibrium, compare the temperature indicated on the readout for the RTD to the temperature observed by reading the calibration device. If the temperature indicated by the thermal detector does not agree with the calibration device within ± 0.1°C, apply an appropriate temperature correction to the temperature measurement indicated by the temperature detector or further calibration or maintenance is required.

10. PREPARATION OF SAMPLES AND TEST SPECIMENS

10.1. *Preparing Test Samples*—If unaged binder is to be tested, obtain test samples according to T 40.

10.1.1. Anneal the asphalt binder from which the test specimen is obtained by heating until sufficiently fluid to pour. Annealing prior to testing removes reversible molecular associations (steric hardening) that occur during normal storage at ambient temperature.

Note 4—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. The specific temperature will depend on the grade of binder and its prior aging history if any. Temperatures less than 135°C are desirable; however, temperatures above 135°C may be required for some modified asphalt binders or heavily aged binders.

10.2. Coat the specimen-forming surfaces of the two mold side plates of the aluminum mold with the release agent. The coating shall be applied so as to produce a thin uniform film on the metal surface such that no part of the metal surface is exposed. Place a single precut sheet of release paper on the bottom plate of the mold. Slide one side plate on to the bottom plate over the release paper. Place the end tabs into both ends of the mold. Slide the other side plate onto the bottom plate to complete the assembly of the mold. Place the molds and end tab assembly in the same oven that is used to heat the asphalt binder, i.e., at the same temperature for no more than 3 minutes. If molds are left in the oven for longer than 3 minutes, it will affect the release properties of the glycerin and talc coating.

10.3. Remove the mold from the oven and place it on a flat surface. Pour hot asphalt binder into the mold starting from one end of the cavity and moving across the cavity in a single pass. Pour the specimen in a continuous stream to avoid entraining air bubbles or gaps. Complete the pouring operation as quickly as possible to avoid any excessive drop in the temperature of the asphalt binder. Stop pouring when the asphalt is slightly above the top surface of the mold.

10.4. After pouring the test specimen, allow the entire assembly to cool on the bench top at ambient temperature for 30 to 60 minutes. Do not quench (quick or instantaneous cooling) the specimen to achieve ambient temperature (25°C or lower).

10.5. As soon as the specimen has cooled to room temperature, trim off the excess asphalt binder with an approximately 165°C straightedge (e.g., a flat, stiff, heavy-gauge putty knife) so that the asphalt binder is flush with the top of the mold. Use care during the trimming operation so that the asphalt binder is not pulled away from the mold and the bond between the end tabs and the asphalt binder is not damaged. Trim off the specimen in a consistent manner. Pull the hot knife along the long axis of the sample flush with the surface of the mold to remove the excess asphalt binder. After trimming, remove all debris or extraneous asphalt binder from the holes or slots in the end tab. Let the specimen sit at ambient temperature for 10 to 15 minutes after trimming.

10.6. Prior to demolding, place two side plates of an unused aluminum mold (Figure 4) into the cooling bath or air chamber and allow them to cool to the test temperature. These side plates will be used as holders for transferring the specimen to the test bath or chamber. Also prepare a specimen transfer plate as follows: Place an unused aluminum bottom plate of the mold (Figure 4) upside down on the work bench so as to form a transfer plate. Place two release papers so that they overlap lengthwise and cover the surface of the transfer plate.

10.7. Carefully demold the trimmed specimen.

10.7.1. Now demold the trimmed specimen by gently sliding the specimen and the two mold side plates towards one edge of the bottom plate until the side plate nearest to the edge is halfway across the edge. Pivot the overhanging side plate downwards using gentle pressure and demold that side. Replace the just released plate and now slide the specimen and the two side plates (one side demolded but reassembled) towards the other edge and repeat the procedure given above.

10.7.2. Next, repeat the above demolding procedure, except this time remove one side plate completely and gently mount one of the cold side plates from the cooling bath or chamber onto that side of the specimen. Now demold the other mold side plate and mount the other cold side plate from the cooling bath or chamber. At this point the specimen and mold assembly should look exactly like the trimmed specimen before demolding except the two side plates are now replaced with cold side plates that were placed in the cooling chamber or bath before the demolding process began.

10.7.3. Now turn the cold specimen mold assembly upside down by holding the mold assemble in the center between the thumb and the forefinger of each hand. Place the upside-down mold assembly on the transfer plate so as to form a cross, i.e., the mold assembly must be perpendicular to the transfer plate covered with release papers. Gently remove the bottom plate from the upside-down specimen assembly resting on the transfer plate by gently sliding it off. The release paper at the bottom of the specimen is now exposed. Hold the two side plates so as to secure the specimen while gently removing the release paper.

10.7.4. Carry the transfer plate with the upside-down but exposed specimen to the test chamber or bath. Immediately place the specimen (along with the two cold side plates) into the cooling bath or chamber onto one of the trays. Remove the two side plates after a 2-minute cool-down period. Some softer grades may require more than 2 minutes before removing the side plates.

10.7.5. Now flip the just-released specimen in the test bath or chamber so that the trimmed side is up. The specimen must always be tested with the trimmed side facing up. The transfer plate covered with the release papers should never be placed into the bath. Measurement of specimen dimensions after demolding is not necessary since dimensional tolerances are closely controlled in the molding process.

Note 5—Minimize distortion of the specimen during demolding. The variability in failure properties is increased if distorted (bent along or perpendicular to the loading axis) specimens are tested. A distorted specimen yields lower failure values.

11. SPECIMEN CONDITIONING

11.1. Set the cooling bath at the desired testing temperature and wait until it stabilizes to within ±0.1°C of the desired test temperature.

11.1.1. When testing for compliance with M 320, Table 1, use the test temperatures specified in Table 1 of M 320.

11.1.2. When testing for compliance with M 320, Table 2, use test temperatures specified in R 49.

11.2. Condition the specimens in the cooling bath or chamber at the test temperature for 60 ± 10 minutes. Adhere carefully to the time schedule to avoid testing variability due to physical hardening.

12. TEST PROCEDURE FOR SYSTEMS WITH FLUID BATH-BASED COOLING

12.1. Using rubber-tipped tongs, mount the specimen on the load frame by matching the holes on the end tabs at each end of the specimen to the loading pins on the load frame. If the holes do not match with the pins, mount one of the pins with a specimen end and adjust the load frame by moving the thumbwheel on the control box until the other end of the specimen falls into place as shown. Check the seating of the specimen by running the tongs lightly on the end tabs at each end of the specimen.

12.2. Once the specimen is on the loading pins, remove the slack between the specimen and the loading pins. Ideally the slack should be removed by setting up the test software to automatically monitor the load, zero the strain, and start the test when the load reaches a value of 2 ± 0.3 N. If such software control is not available or if the vertical test setup of an air-cooled test chamber is used, then remove the slack manually by manipulating the thumbwheel on the control box for fine adjustment. The thumbwheel is moved in the direction so as to produce tension (stretch the specimen). The thumbwheel is moved until a load of 2 ± 0.3 N is shown on the monitor screen. Once this has been accomplished, recheck the seating of the specimen with the tongs to avoid any erroneous load readings. Repeat the above manual loading procedure until a load of 2 ± 0.3 N is again obtained. Now zero the strain quickly and press the start key to start the test. If the slack is removed by setting up the software to automatically perform the slack removal, then the test is also automatically started by the software after zeroing the strain. No manual pressing of the start key is required in that case.

12.3. Set the strain rate to 3 percent/min (to allow an elongation rate of 1 mm/min) if it is not preset in the software.

13. TEST PROCEDURE FOR SYSTEMS WITH FORCED AIR BASED COOLING

13.1. After 60 ± 10 minutes, mount the specimen on the pins using the environmental chamber hand access port so that the back face of the end tab is centered on the mounting pin. Do not open the chamber door to handle or mount the specimen because that will produce excessive temperature fluctuations, which will take time to stabilize and lead to variable thermal histories. Handle the specimens with rubber surgeons' gloves to protect the operator's fingers and to minimize heating of the specimen. Handle the specimen by touching only the end tabs—do not touch the asphalt binder.

Note 6—Air currents for the circulation fan may cause the end tabs to move after being placed on the mounting pins. A silicone rubber or foam washer that remains flexible at the test temperature will help hold the end tab against the face of the grip. It is important that the end tab be centered on the pin (flush against the face of the grip) in order for the load to be applied axially through the center of the test specimen. A suitable washer may be cut from silicone rubber or foam sheeting with a cork borer. The washer may be 5- to 10-mm thick with an outer diameter of approximately 10 mm. The inside diameter of the washer should be sufficient to provide a friction fit on the 5-mm portion of the pin. The washer should slide easily on the pin providing only sufficient force to hold the end tab in place during the test.

13.2. *Loading Procedure*—Apply a preload to the test specimen by mounting the specimen as previously described and applying an elongation sufficient to develop a 1- to 2-N load; this may reduce testing variability. As soon as the 1- to 2-N load is reached, stop the movement of the platen and allow the load to relax until it is no longer detectable. The time required to relax the load will depend on the stiffness of the test specimen. Once the load has relaxed, continue the test as described in the following sections.

13.3. Select the desired strain rate and load the specimen to failure. Select a strain rate that gives an effective gauge section elongation rate of 1.00 ± 0.01 mm/min when testing for compliance with M 320. If a test specimen fails outside the gauge area of the specimen (from throat to throat), discard the test.

14. NUMBER OF REPLICATES

14.1. A total of six specimens shall be tested as described above. Fracture stress and strain are inherently variable for asphalt binders. Testing of multiple specimens may produce obvious outliers. Of six specimens tested, discard the two lowest values of failure stress, strain, and energy and recalculate the mean and standard deviation values for the four remaining failure values.

15. FAILURE IDENTIFICATION

15.1. The strain at failure is easily identified as the strain at peak load (maximum stress) when the failure is by fracture (i.e., breaks into two pieces on failure). However, when the specimen does not fracture but reaches a maximum stress and then flows without fracture the strain at failure is recorded as the strain corresponding to the maximum stress. Do not continue the test beyond 10 percent strain, and simply record the failure strain as "greater than 10 percent." If the asphalt binder can be stretched to 10 percent without fracture, it meets the requirements of M 320 at the test temperature.

15.2. If the specimen fails at the throat section, the data for failure should be recorded but it should also be noted that it failed in the throat. While the acceptable failure is in the gauge section (18-mm-long constant cross-section portion), ideally, failure should occur in the center of each specimen. The location of failure and the consistency or repeatability of failure data is directly related to straightness, how carefully the specimens are prepared, and how well they are mounted prior to testing.

16. CLEANING OF END TABS

16.1. If the end tabs are to be reused, after testing discard the asphalt portion of the spent specimen and clean the end tabs by soaking them in solvent and wiping with a soft cloth. After wiping the end tabs, use a detergent soap solution to remove any oil film residue left by the mineral spirit cleaner. Alternatively, use a degreasing spray cleaner. Clean the end tabs thoroughly. Grease-film on the asphalt bonding area can create a weak bond causing bond failures.

17. CALCULATIONS

17.1. Compute the failure stress by dividing the failure load by the original area of the test specimen cross-section (6 × 6 mm) as shown in Equation 1:

$$\sigma_f = P_f / A \tag{1}$$

where:

σ_f = failure stress, MPa;

P_f = failure load, N; and

A = original area of cross-section, m^2.

Note 7—For specimens used in this test, $A = 36 \bullet 10^{-6}$ m^2

17.2. Compute the failure strain by dividing the elongation at failure by the original gauge length, as shown in Equation 2:

$$\in_f = \delta_f / L_e \tag{2}$$

where:

$\in_f$ = failure strain, mm/mm;

δ_f = elongation at failure, mm; and

L_e = effective gauge length, mm.

Note 8—For specimens used in this test, the effective gauge length, L_e, has been determined to be 33.8 mm.

18. REPORT

18.1. Report the following information:

18.1.1. Sample identification;

18.1.2. Date and time of test;

18.1.3. Test temperature, nearest 0.1°C;

18.1.4. Rate of elongation, nearest 0.01 mm/min;

18.1.5. Failure strain, nearest 0.01 percent;

18.1.6. Failure stress, nearest 0.01 MPa;

18.1.7. Peak load, nearest N; and

18.1.8. Type of fracture observed (fracture or no fracture).

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19. PRECISION AND BIAS

19.1. *Precision*—Criteria for judging the acceptability of failure stress and strain results obtained by this method are given in Table 1.

19.2. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

19.3. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

Table 1—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]	Acceptable Range of Two Test Results (d2s%)[a]
Single-Operator Precision:		
Stress (MPa)	7.4	20.8
Strain (%)	11.4	32.2
Multilaboratory Precision:		
Stress (MPa)	18.6	52.5
Strain (%)	31.5	89.1

[a] These values represent the 1s% and d2s% limits described in ASTM Practice C 670.

Note 9—The precision estimates given in Table 1 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 34 to 61 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). Average stress results ranged from 2.79 MPa to 4.22 MPa. Average strain results ranged from 0.91 to 3.00 percent. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 10—As an example, two tests conducted on the same material yield stress results of 2.95 MPa and 3.15 MPa, respectively. The average of these two measurements is 3.05 MPa. The acceptable range of results is then 20.8 percent of 3.05 MPa or 0.63 MPa. As the difference between 2.95 MPa and 3.15 MPa is less than 0.63 MPa, the results are within the acceptable range.

19.4. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

20. KEYWORDS

20.1. Asphalt binder; direct tension; failure; failure strain; fracture; thermal cracking.

Standard Method of Test for

Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: T 315-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

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1. SCOPE

1.1. This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. It is applicable to asphalt binders having dynamic shear modulus values in the range from 100 Pa to 10 MPa. This range in modulus is typically obtained between 6 and 88°C at an angular frequency of 10 rad/s. This test method is intended for determining the linear viscoelastic properties of asphalt binders as required for specification testing and is not intended as a comprehensive procedure for the full characterization of the viscoelastic properties of asphalt binder.

1.2. This standard is appropriate for unaged material or material aged in accordance with T 240 and R 28.

1.3. Particulate material in the asphalt binder is limited to particles with longest dimensions less than 250 μm.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- T 40, Sampling Bituminous Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 2170, Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)
- D 2171, Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer

- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 563, Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
- E 644, Standard Test Methods for Testing Industrial Resistance Thermometers

2.3. *Deutsche Industrie Norm (DIN) Standards*:

- 43760, Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors

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3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

3.2. *Descriptions of Terms Specific to This Standard*:

3.2.1. *annealing*—heating the binder until it is sufficiently fluid to remove the effects of steric hardening.

3.2.2. *complex shear modulus (G^*)*—ratio calculated by dividing the absolute value of the peak-to-peak shear stress, τ, by the absolute value of the peak-to-peak shear strain, γ.

3.2.3. *calibration*—process of checking the accuracy and precision of a device using NIST-traceable standards and making adjustments to the device where necessary to correct its operation or precision and accuracy.

3.2.4. *dummy test specimen*—a specimen formed between the dynamic shear rheometer (DSR) test plates from asphalt binder or other polymer to measure the temperature of the asphalt binder held between the plates. The dummy test specimen is used solely to determine temperature corrections.

3.2.5. *loading cycle*—a unit cycle of time for which the test sample is loaded at a selected frequency and stress or strain level.

3.2.6. *phase angle (δ)*—the angle in radians between a sinusoidally applied strain and the resultant sinusoidal stress in a controlled-strain testing mode, or between the applied stress and the resultant strain in a controlled-stress testing mode.

3.2.7. *loss shear modulus (G'')*—the complex shear modulus multiplied by the sine of the phase angle expressed in degrees. It represents the component of the complex modulus that is a measure of the energy lost (dissipated during a loading cycle).

3.2.8. *storage shear modulus (G')*—the complex shear modulus multiplied by the cosine of the phase angle expressed in degrees. It represents the in-phase component of the complex modulus that is a measure of the energy stored during a loading cycle.

3.2.9. *parallel plate geometry*—refers to a testing geometry in which the test sample is sandwiched between two relatively rigid parallel plates and subjected to oscillatory shear.

3.2.10. *oscillatory shear*—refers to a type of loading in which a shear stress or shear strain is applied to a test sample in an oscillatory manner such that the shear stress or strain varies in amplitude by about zero in a sinusoidal manner.

3.2.11. *linear viscoelastic*—within the context of this specification refers to a region of behavior in which the dynamic shear modulus is independent of shear stress or strain.

3.2.12. *portable thermometer*—is an electronic device that consists of a temperature detector (probe containing a thermocouple or resistive element), required electronic circuitry, and readout system.

3.2.13. *reference thermometer*—a NIST–traceable liquid-in-glass or electronic thermometer that is used as a laboratory standard.

3.2.14. *temperature correction*—difference in temperature between the temperature indicated by the DSR and the test specimen as measured by the portable thermometer inserted between the test plates.

3.2.15. *thermal equilibrium*—is reached when the temperature of the test specimen mounted between the test plates is constant with time.

3.2.16. *verification*—process of checking the accuracy of a device or its components against an internal laboratory standard. It is usually performed within the operating laboratory.

3.2.17. *steric hardening*—see molecular association.

3.2.18. *molecular association*—a process where associations occur between asphalt binder molecules during storage at ambient temperature. Often called steric hardening in the asphalt literature, molecular associations can increase the dynamic shear modulus of asphalt binders. The amount of molecular association is asphalt specific and may be significant even after a few hours of storage.

4. SUMMARY OF TEST METHOD

4.1. This standard contains the procedure used to measure the complex shear modulus (G^*) and phase angle (δ) of asphalt binders using a dynamic shear rheometer and parallel plate test geometry.

4.2. The standard is suitable for use when the dynamic shear modulus varies between 100 Pa and 10 MPa. This range in modulus is typically obtained between 6 and 88°C at an angular frequency of 10 rad/s, dependent upon the grade, test temperature, and conditioning (aging) of the asphalt binder.

4.3. Test specimens 1 mm thick by 25 mm in diameter or 2 mm thick by 8 mm in diameter are formed between parallel metal plates. During testing, one of the parallel plates is oscillated with respect to the other at pre-selected frequencies and rotational deformation amplitudes (strain control) (or torque amplitudes (stress control)). The required stress or strain amplitude depends upon the value of the complex shear modulus of the asphalt binder being tested. The required amplitudes have been selected to ensure that the measurements are within the region of linear behavior.

4.4. The test specimen is maintained at the test temperature to within ±0.1°C by positive heating and cooling of the upper and lower plates or by enclosing the upper and lower plates in a thermally controlled environment or test chamber.

4.5. Oscillatory loading frequencies using this standard can range from 1 to 100 rad/s using a sinusoidal waveform. Specification testing is performed at a test frequency of 10 rad/s. The complex modulus (G^*) and phase angle (δ) are calculated automatically as part of the operation of the rheometer using proprietary computer software supplied by the equipment manufacturer.

5. SIGNIFICANCE AND USE

5.1. The test temperature for this test is related to the temperature experienced by the pavement in the geographical area for which the asphalt binder is intended to be used.

5.2. The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The complex shear modulus and the phase angle define the resistance to shear deformation of the asphalt binder in the linear viscoelastic region.

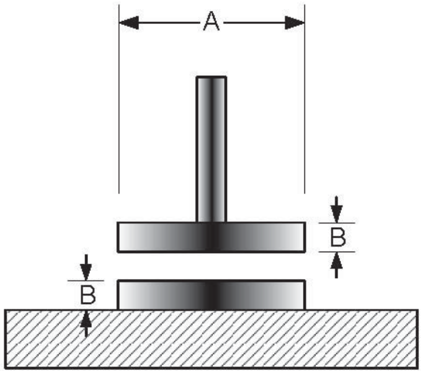
5.3. The complex modulus and the phase angle are used to calculate performance-related criteria in accordance with M 320.

6. APPARATUS

6.1. *Dynamic Shear Rheometer (DSR) Test System*—Consisting of parallel metal plates, an environmental chamber, a loading device, and a control and data acquisition system.

6.1.1. *Test Plates*—Stainless steel or aluminum plates with smooth ground surfaces. One 8.00 ± 0.02 mm in diameter and one 25.00 ± 0.05 mm in diameter (Figure 1). The base plate in some rheometers is a flat plate. A raised portion, a minimum of 1.50 mm high, with the same radius as the upper plate is required. The raised portion makes it easier to trim the specimen and may improve test repeatability.

Note 1—To obtain correct data, the upper and lower plates should be concentric with each other. At present there is no suitable procedure for the user to check the concentricity except to visually observe whether or not the upper and lower plates are centered with respect to each other. The moveable plate should rotate without any observable horizontal or vertical wobble. This operation may be checked visually or with a dial gauge held in contact with the edge of the moveable plate while it is being rotated. There are two values that determine the operating behavior of a measuring system: centricity (horizontal wobble) and runout (vertical wobble). Typically, wobble can be detected if it is greater than ±0.02 mm. For a new system, a wobble of ±0.01 mm is typical. If the wobble grows to more than ±0.02 mm with use, it is recommended that the instrument be serviced by the manufacturer.



Dimension	8-mm Nominal	25-mm Nominal
A	8 ± 0.02 mm	25 ± 0.05 mm
B	≥1.50 mm	≥1.50 mm

Figure 1—Plate Dimensions

6.1.2. *Environmental Chamber*—For controlling the test temperature, by heating or cooling (in steps or ramps), to maintain a constant specimen environment. The medium for heating and cooling the specimen in the environmental chamber shall not affect asphalt binder properties. The temperature in the chamber may be controlled by the circulation of fluid such as water, conditioned gas such as nitrogen, or by a suitable arrangement of solid state Peltier elements surrounding the sample. When forced air is used, a suitable drier must be included to prevent condensation of moisture on the plates and fixtures and, if operating below freezing temperatures, the formation of ice. The environmental chamber and the temperature controller shall control the temperature of the specimen, including thermal gradients within the sample, to an accuracy of ±0.1°C. The chamber shall completely enclose the top and the bottom plates to minimize thermal gradients.

Note 2—A circulating bath unit separate from the DSR which pumps the bath fluid through the test chamber may be required if a fluid medium is used. The flow rate of the bath media should not be modified once the temperature settings have been adjusted to the desired value. Media lines should be periodically inspected and cleaned or replaced if necessary to remove obstructions

6.1.2.1. *Temperature Controller*—Capable of maintaining specimen temperatures within ±0.1°C for test temperatures ranging from 3 to 88°C.

6.1.2.2. *Internal Temperature Detector for the DSR*—A platinum resistance thermometer (PRT) mounted within the environmental chamber as an integral part of the DSR and in close proximity to the fixed plate, with a range of 3 to 88°C, and with a resolution of 0.1°C (see Note 3). This thermometer shall be used to control the temperature of the test specimen between the plates and shall provide a continuous readout of temperature during the mounting, conditioning, and testing of the specimen. The PRT shall be calibrated as an integral unit with its respective meter or electronic circuitry.

Note 3—PTRs meeting DIN Standard 43760 (Class A) or equal are recommended for this purpose.

6.1.3. *Loading Device*—Capable of applying a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/s. If frequencies other than 10 rad/s are used, the frequency shall be accurate to one percent. The loading device shall be capable of providing either a stress controlled or strain controlled load. If the load is strain controlled, the loading device shall apply a cyclic torque sufficient to cause an angular rotational strain accurate to within 100 μ rad of the strain specified. If the load is stress controlled, the loading device shall apply a cyclic torque accurate to within 10 mN·m of the torque specified. Total system compliance at 100 N·m of torque shall be less than 2 mrad/N·m. The manufacturer of the device shall certify that the frequency, stress, and strain are controlled and measured with an accuracy of one percent or less in the range of this measurement.

6.1.4. *Control and Data Acquisition System*—Capable of providing a record of temperature, frequency, deflection angle, and torque. Devices used to measure these quantities shall meet the accuracy requirements specified in Table 1. In addition, the system shall calculate and record the shear stress, shear strain, complex shear modulus (G^*) and phase angle (δ). The system shall measure and record G^*, in the range of 100 Pa to 10 MPa, to an accuracy of 1.0 percent or less, and the phase angle, in the range of 0 to 90 degrees, to an accuracy of 0.1 degrees.

Table 1—Control and Data Acquisition System Requirements

Property	Accuracy
Temperature	0.1°C
Frequency	1%
Torque	10 mN·m
Deflection angle	100 μrad

6.2. *Specimen Mold (Optional)*—The overall dimensions of the silicone rubber mold for forming asphalt binder test specimens may vary but the thickness shall be greater than 5 mm. If the mold is a single sample mold, the following dimensions have been found suitable: For a 25-mm test plate with a 1-mm gap, a mold cavity approximately 18 mm in diameter and 2.0 mm deep. For an 8-mm test plate with a 2-mm gap, a mold cavity approximately 8 mm in diameter and 2.5 mm deep.

6.3. *Specimen Trimmer*—With a straightedge at least 4 mm wide.

6.4. *Wiping Material*—Clean cloth, paper towels, cotton swabs, or other suitable material as required for wiping the plates.

6.5. *Cleaning Solvents*—Mineral oil, citrus-based solvents, mineral spirits, toluene, or similar solvent as required for cleaning the plates. Acetone for removing the solvent residue from the surfaces of the plates is also necessary.

6.6. *Reference Thermometer*—Either NIST-traceable liquid-in-glass thermometer(s) or NIST–traceable electronic thermometric device(s). This temperature standard shall be used to standardize the portable thermometer (Section 9.3).

6.6.1. *Liquid-in-Glass Thermometer*—NIST-traceable thermometer(s) with a suitable range and subdivisions of 0.1°C. The thermometer(s) shall be a partial immersion thermometer(s) within an ice point and standardized in accordance with ASTM E 563.

6.6.1.1. *Optical Viewing Device (Optional)*—For use with liquid-in-glass thermometers that enhances readability and minimizes parallax when reading the liquid-in-glass reference thermometer.

6.6.2. *Electronic Thermometer*—Incorporating a resistive detector (Note 3) with an accuracy of ±0.05°C and a resolution of 0.01°C. The electronic thermometer shall be standardized at least once per year using a NIST–traceable reference standard in accordance with ASTM E 77.

6.7. *Portable Thermometer*—A standardized portable thermometer consisting of a resistive detector, associated electronic circuitry, and digital readout. The thickness of the detector shall be no greater than 2.0 mm such that it can be inserted between the test plates. The reference thermometer (see Section 6.6) may be used for this purpose if its detector fits within the dummy specimen as required by Section 9.4.1 or 9.4.2.

7. HAZARDS

7.1. Standard laboratory caution should be used in handling the hot asphalt binder when preparing test specimens.

8. PREPARATION OF APPARATUS

8.1. Prepare the apparatus for testing in accordance with the manufacturer's recommendations. Specific requirements will vary for different DSR models and manufacturers.

8.2. Inspect the surfaces of the test plates and discard any plates with jagged or rounded edges or deep scratches. Clean any asphalt binder residue from the plates with an organic solvent such as mineral oil, mineral spirits, a citrus-based solvent, or toluene. Remove any remaining solvent residue by wiping the surface of the plates with a cotton swab or a soft cloth dampened with acetone. If necessary, use a dry cotton swab or soft cloth to ensure that no moisture condenses on the plates.

8.3. Mount the cleaned and inspected test plates on the test fixtures and tighten firmly.

8.4. Select the testing temperature according to the grade of the asphalt binder or according to the preselected testing schedule (see Note 4). Allow the DSR to reach a stabilized temperature within ±0.1°C of the test temperature.

Note 4—M 320 and R 29 provide guidance on the selection of test temperatures.

8.5. With the test plates at the test temperature or the middle of the expected testing range, establish the zero gap level (1) by manually spinning the moveable plate, and while the moveable plate is spinning, close the gap until the removable plate touches the fixed plate (the zero gap is reached when the plate stops spinning completely), or, (2) for rheometers with normal force transducers, by closing the gap and observing the normal force and after establishing contact between the plates, setting the zero gap at approximately zero normal force.

Note 5—The frame, detectors, and fixtures in the DSR change dimension with temperature causing the zero gap to change with changes in temperature. Adjustments in the gap are not necessary when measurements are made over a limited range of temperatures. The gap should be set at the test temperature or, when tests are to be conducted over a range of temperatures, the gap should be set at the middle of the expected range of test temperatures. For most instruments, no gap adjustment is needed as long as the test temperature is within ±12°C of the temperature at which the gap is set. If the instrument has thermal gap compensation, the gap may be set at the first test temperature instead of the middle of the range of test temperatures.

8.6. Once the zero gap is established as per Section 8.5, move the plates apart to approximately the test gap and preheat the plates. Preheating the plates promotes adhesion between the asphalt binder and the plates, especially at the intermediate grading temperatures.

8.7. To preheat 25-mm plates, bring the test plates to the test temperature or the lowest test temperature if testing is to be conducted at more than one temperature. To preheat 8-mm plates, bring the plates to between 34 and 46°C. Move the plates apart and establish a gap setting of 1.05 mm (for 25-mm diameter test specimens) or 2.10 mm (for 8-mm diameter test specimens).

Note 6—In order to obtain adequate adhesion between the asphalt binder and the test plates, the plates must be preheated. Preheating is especially critical when the silicone mold is used to prepare the asphalt binder for transfer to the test plates and when the testing is conducted with the 8-mm plates. When the direct placement method is used, as long as the test plates are immediately brought in contact with the asphalt binder, the heat carried with the asphalt binder improves adhesion. The preheating temperature needed for proper adhesion will depend on the grade and nature of the asphalt binder and the test temperature (8-mm or 25-mm plates). For some of the stiffer binder grades, especially those with high levels of modification, heating the plates to 46°C may not be sufficient to ensure proper adhesion of the asphalt binder to the test plates, especially if the silicone mold is used and the testing is conducted with 8-mm plates. For highly modified asphalt binders only, higher preheat temperatures may be used.

9. VERIFICATION AND CALIBRATION

9.1. Verify the DSR and its components at least every six months and when the DSR or plates are newly installed, when the DSR is moved to a new location, or when the accuracy of the DSR or any of its components is suspect. Four items require verification—the test plate diameter, DSR torque transducer, portable thermometer, and DSR test specimen temperature. Verify the DSR temperature transducer before verifying the torque transducer.

9.2. *Verification of Plate Diameter*—Measure the diameters to the nearest 0.01 mm. Maintain a log of the measured diameters as part of the laboratory quality control program so that the measurements are clearly identified with the specific plates. Enter the actual measured dimensions into the DSR software for use in calculations. If the top and bottom plates differ in diameter, enter the smaller of the two measured diameters.

Note 7—An error of ± 0.05 mm in the diameter of the plate results in a 0.8 percent error in the complex modulus for the 25-mm plate. For the 8-mm plate, errors in diameter of ±0.01, ±0.02, and ±0.05 mm give respective errors in complex modulus of 0.5, 1.0, and 2.5 percent.

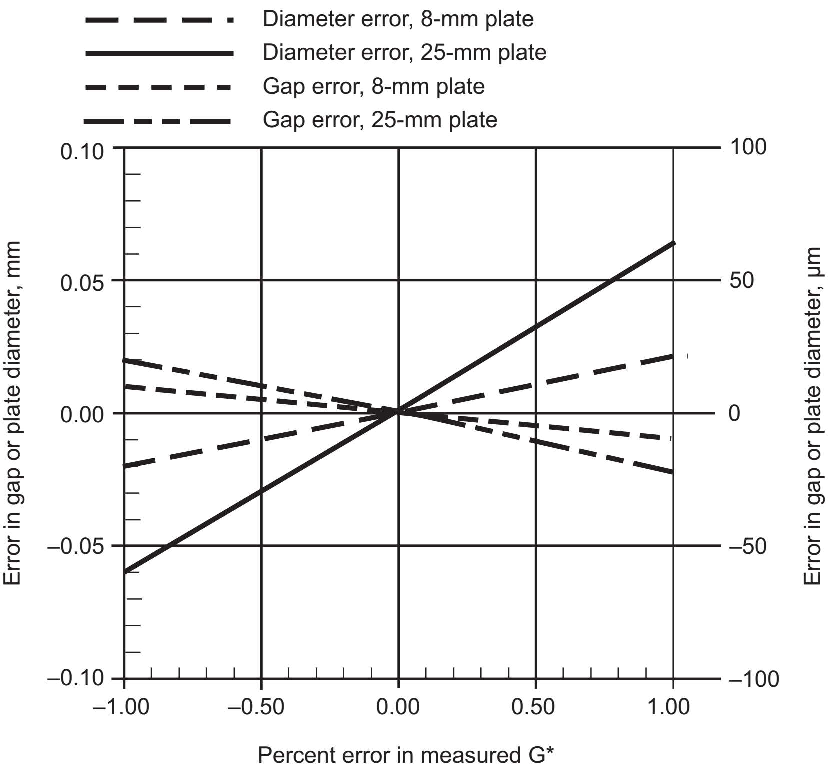


Figure 2—Effect of Error in Gap or Plate Diameter

9.3. *Verification of Portable Thermometer*—Verify the portable thermometer (used to measure the temperature between the test plates), using the laboratory reference thermometer. A portable thermometer shall be considered the combination of the meter (readout device) and the thermistor (temperature probe) as a single unit, and must be verified as such. If the reference thermometer (Section 6.6) is also used as a portable thermometer to measure the temperature between the test plates, it shall meet the requirements of Section 6.7.

9.3.1. *Recommended Verification Procedure*—Bring the reference thermometer into intimate contact with the detector from the portable thermometer and place them in a thermostatically controlled and stirred water bath (Note 8). Ensure that de-ionized water is used to prevent electrical conduction from occurring between the electrodes of the resistive temperature sensitive element. If de-ionized water is not available, encase the reference thermometer and detector of the portable thermometer in a waterproof plastic bag prior to placement in the bath. Obtain measurements at intervals of approximately 6°C over the range of test temperatures allowing the bath to reach thermal equilibrium at each temperature. If the readings of the portable thermometer and the reference thermometer differ by 0.1°C or more, record the difference at each temperature as a temperature correction, and maintain the corrections in a log as part of the laboratory quality control program.

Note 8—A recommended procedure for the high temperature range is to use a stirred water bath that is controlled within ±0.1°C such as the viscosity bath used for ASTM D 2170 or D 2171. For a low temperature bath, an ice bath or controlled temperature bath may be used. Bring the probe from the portable thermometer into contact with the reference thermometer, and hold the assembly in intimate contact. A rubber band works well for this purpose. Immerse the assembly in the water bath, and bring the water bath to thermal equilibrium. Record the temperature on each device when thermal equilibrium is reached.

Note 9—If the readings from the two devices differ by 0.5°C or more, the calibration or operation of the portable thermometer may be suspect, and it may need to be recalibrated or replaced. A continuing change in the temperature corrections with time may also make the portable thermometer suspect.

9.4. *Test Specimen Temperature Correction*—Thermal gradients within the rheometer can cause differences between the temperature of the test specimen and the temperature indicated by the DSR thermometer (also used to control the temperature of the DSR). The DSR thermometer shall be checked at an interval no greater than six months. When these differences are 0.1°C or greater, determine a temperature correction by using a thermal detector mounted in a silicone rubber wafer (Section 9.4.1) or by placing asphalt binder (dummy sample) between the plates and inserting the detector of the portable thermometer into the asphalt binder (Section 9.4.2).

9.4.1. *Method Using Silicone Rubber Wafer*—For the entire range of test temperatures, place the wafer between the 25-mm test plates, and close the gap to bring the wafer into contact with the upper and lower plate so that the silicone rubber makes complete contact with the surfaces of the upper and lower plates. If needed, apply a thin layer of petroleum grease or anti-seize compound (see Note 10) to completely fill any void space between the silicone rubber and the plates. Complete contact is needed to ensure proper heat transfer across the plates and silicone rubber wafer. Determine any needed temperature correction as per Section 9.4.3.

Note 10—Anti-seize compound available by that name at hardware and auto supply stores is much less apt to contaminate the circulating water than petroleum grease.

Note 11—The thickness of the silicone wafer should be measured with calipers to identify the actual thickness. The thickness can be used to set the gap for temperature.

9.4.2. *Method Using Dummy Test Specimen*—The dummy test specimen shall be formed from asphalt binder or other polymer that can be readily formed between the plates. Mount the dummy test specimen between the test plates, and insert the detector (probe) of the portable thermometer into the dummy test specimen. Close the gap to the test gap (1 mm for 25-mm plates and 2 mm for 8-mm plates) keeping the detector centered vertically and radially in the dummy test specimen. Heat the plates as needed to allow the dummy test specimen to completely fill the gap between the test plates. It is not necessary to trim the dummy test specimen but avoid excessive material around the edges of the plates. Determine any needed temperature correction as per Section 9.4.3.

Note 12—Silly putty can leave a residue of silicone oil on the surfaces of the plates, and for this reason, its use as a dummy specimen is not recommended.

9.4.3. *Determination of Temperature Correction*—Obtain simultaneous temperature measurements with the DSR thermometer and the portable thermometer at 6°C increments to cover the range of test temperatures. At each temperature increment, after thermal equilibrium has been reached, record the temperature indicated by the portable thermometer and the DSR thermometer to the nearest 0.1°C. Temperature equilibrium is reached when the temperature indicated by both the DSR thermometer and the portable thermometer do not vary by more than 0.1°C over a 5 min period. Obtain additional measurements to include the entire temperature range that will be used for measuring the dynamic shear modulus.

9.4.4. *Plot Correction versus Specimen Temperature*—Using the data obtained in Section 9.4, prepare a plot of the difference between the two temperature measurements versus the temperature measured with the portable thermometer (Figure 3). This difference is the temperature correction that must be applied to the DSR temperature controller to obtain the desired temperature in the test specimen between the test plates. Report the temperature correction at the respective test temperature from the plot and report the test temperature between the plates as the test temperature. Alternatively, the instrument software may be written to incorporate these temperature corrections.

Note 13—The difference between the two temperature measurements may not be a constant for a given rheometer but may vary with differences between the test temperature and the ambient laboratory temperature as well as with fluctuations in ambient temperature. The difference between the two temperature measurements is caused in part by thermal gradients in the test specimen and fixtures.

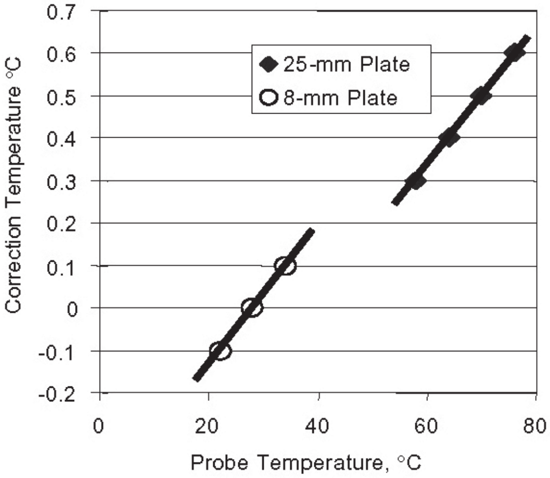


Figure 3—Determination of Temperature Correction

9.5. *Verification of DSR*—Verify the accuracy of the torque transducer and angular displacement transducer.

Note 14—A newly installed or reconditioned instrument should be verified on a weekly basis using the procedures in Section 9.5 until acceptable verification has been demonstrated. Maintaining the data in the form of a control chart where the verification measurements are plotted versus calendar date is recommended (see Appendix X2).

9.5.1. *Verification of Torque Transducer*—Verify the calibration of the torque transducer a minimum of once every six months using a reference fluid or manufacturer-supplied fixtures when the calibration of the torque transducer is suspect or when the dynamic viscosity, as measured for the reference fluid, indicates that the torque transducer is not in calibration.

9.5.1.1. *Verification of Torque Transducer with Reference Fluid*—The complex viscosity measured with the DSR shall be within three percent of the capillary viscosity as reported by the manufacturer of the reference fluid; otherwise, the calibration of the torque transducer shall be considered suspect. Calculate the complex viscosity as the complex modulus, *G**, divided by the angular frequency in rad/s. Recommended practice for using the reference fluid is given in Appendix X3.

$$\textit{Percent Variance} = [(\eta a - \eta b)/\eta a] * 100 \qquad (1)$$

where:

ηa = the standard capillary viscosity as reported by the supplier of the reference fluid; and

ηb = the measured viscosity as calculated from the complex modulus, *G**, divided by the angular frequency in rad/s.

Note 15—A suitable reference fluid is available from Cannon Instrument Company as Viscosity Standard Number N2700000SP. The viscosity of the standard is reported in mPa•s. Convert the viscosity measurements to mPa•s before calculating the percent variance.

9.5.1.2. *Verification of Torque Transducer with Fixtures*—Verify the calibration of the torque transducer using the manufacturer-supplied fixtures in accordance with the instructions supplied by the manufacturer. Suitable manufacturer-supplied fixtures are not widely available. If suitable fixtures are not available, this requirement shall be waived.

9.5.2. *Verification of Angular Displacement Transducer*—If manufacturer-supplied fixtures are available, verify the calibration every six months or when the calibration of the DSR is suspect. If suitable fixtures are not available, this requirement shall be waived.

9.5.3. If the DSR cannot be successfully verified according to Section 9.5, it shall not be used for testing in accordance with this standard until it has been successfully calibrated by the manufacturer or other qualified service personnel.

10. PREPARING SAMPLES AND TEST SPECIMENS

10.1. *Preparing Test Samples*—If unaged binder is to be tested, obtain test samples according to T 40.

10.1.1. Anneal the asphalt binder from which the test specimen is obtained by heating until sufficiently fluid to pour the required specimens. Annealing prior to testing removes reversible molecular associations (steric hardening) that occur during normal storage at ambient temperature. Avoid heating the binder samples above a temperature of 163°C; however, with some modified or heavily aged asphalt binders, pouring temperatures above 163°C may be required. Loosely cover the sample, and stir it occasionally during the heating process to ensure homogeneity and to remove air bubbles. Minimize the heating temperature and time to avoid hardening the sample.

Note 16—For neat asphalt binders, minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended.

Note 17—For PAV aged samples, asphalt binder may be placed in a vacuum oven set at a maximum of 175°C for 40 minutes. Due to the poor heat transfer in the vacuum oven, the asphalt binder will not be overheated.

10.1.2. Cold material from storage containers must be annealed prior to usage. Structure developed during storage can result in overestimating the modulus by as much as 50 percent.

10.2. *Preparing Test Specimens*—Zero the gap as specified in Section 8. Carefully clean and dry the surfaces of the test plates so that the specimen will adhere to both plates uniformly and strongly. Heat the chamber to 34 to 46°C when using the 8-mm specimens. Heat the chamber to the test temperature or the beginning of the range (Note 6) when using 25-mm specimens. This requirement is to preheat the upper and lower plates to allow specimen adhesion to both plates. Prepare a test specimen using one of the methods specified in Section 10.3.1, 10.3.2, or 10.3.3.

10.3. Transfer asphalt binder to one of the test plates through pouring (Section 10.3.1), direct transfer (Section 10.3.2), or by use of a silicone mold (Section 10.3.3). Use a sufficient amount of asphalt binder so that trimming is required.

Note 18—Direct transfer and pouring are the preferred methods because the test results are less likely to be influenced by steric hardening than with the silicone mold method. Direct transfer and direct pouring result in higher asphalt binder temperatures when the plates and asphalt binder are brought into contact, thereby improving adhesion. For this reason, it is also important to bring the asphalt binder and plates into contact promptly after pouring or direct transfer.

10.3.1. *Pouring*—Only when using rheometers that are designed for removal of the plates without affecting the zero setting, remove the removable plate and, while holding the sample container approximately 15 mm above the test plate surface, pour the asphalt binder in the center of the upper test plate continuously until it covers the entire plate except for an approximate 2-mm wide strip at the perimeter (Note 19). Wait only long enough for the specimen to stiffen, to prevent movement, and then mount the test plate in the rheometer for testing.

Note 19—An eye dropper or syringe may be used to transfer the hot asphalt binder to the plate.

10.3.2. *Direct Transfer*—Transfer the hot asphalt binder to one of the plates using a glass or metal rod, spatula, or similar tool. Immediately after transferring the hot asphalt binder to one of the plates, proceed to Section 10.4 to trim the specimen and form the bulge.

Note 20—A small, narrow stainless steel spatula of the type used to weigh powders on an analytical balance has been found suitable for transferring the asphalt hot binder. When using a rod, form the test specimen with a twisting motion, using a mass of sufficient size. The twisting motion seems to keep the mass on the rod in control. A 4- to 5-mm diameter rod is suitable. The glass rod technique is especially useful for the 8-mm plate.

10.3.3. *Silicone Mold*—Pour the hot asphalt binder into a silicone rubber mold that will form a pellet having dimensions as required in Section 6.2. Allow the silicone rubber mold to cool to room temperature. Testing shall be initiated within 2 hours of pouring the specimen into the silicone rubber mold. The molds shall be covered while cooling to eliminate contamination. The specimen may be mounted to either the upper or lower plate. To mount the specimen to the lower plate, remove the specimen from the mold and center the pellet on the lower plate of the DSR. To mount the specimen to the upper plate, center the specimen on the upper plate while it is still in the silicone rubber mold,. Gently press the specimen to the upper plate and then carefully remove the silicone rubber mold leaving the specimen adhered to the upper plate.

10.3.3.1. The filled mold should be cooled at room temperature by placing the mold on a flat laboratory bench surface without chilling. Cooling to temperatures below room temperature results in an unknown thermal history that may affect the measured values of modulus and phase angle. Cooling may also result in the formation of moisture on the surface of the specimen that will interfere with adhesion of the specimen to the plates.

Note 21—Solvents should not be used to clean the silicone rubber molds. Wipe the molds with a clean cloth to remove any asphalt binder residue. With use, the molds will become stained from the asphalt binder, making it difficult to remove the binder from the mold. If sticking becomes a problem, discard the mold.

Note 22—Some binder grades cannot be removed from the silicone mold without cooling. Materials such as PG 52-34, PG 46-34, and some PG 58-34 grades do not lend themselves to being removed from the mold at ambient temperatures. If the binder specimen cannot be removed from the mold without cooling, the direct transfer or pouring method may be used, or the filled mold may be chilled in a freezer or refrigerator for a maximum of 10 min to facilitate demolding the specimen.

10.4. *Trimming Test Specimen*—Immediately after the specimen has been placed on one of the test plates as described above, move the test plates together until the gap between the plates equals the testing gap plus the gap closure required to create the bulge. (See Section 10.5 for gap closure required to create the bulge.) Trim excess binder by moving a heated trimming tool around the edges of the plates so that the asphalt binder is flush with the outer diameter of the plates.

Note 23—The trimming tool should be at a temperature that is sufficiently hot as to allow trimming but not excessively hot as to burn the edge of the specimen. The trimming tool should also not be excessively cool as to snag or damage the edge of the test specimen.

Note 24—The gap should be set at the starting test temperature (Section 11.1.1) or at the middle of the expected range of test temperatures (Section 11.1.2). See Note 5 for guidance on setting the gap. Typically, reliable test results may be obtained with a single sample using temperatures within 12°C of the temperature at which the gap is set.

10.5. *Creating Bulge*—Immediately after the trimming is complete, decrease the gap by the amount required to form a slight bulge at the outside face of the test specimen. The gap required to create a bulge is rheometer specific and depends upon factors such as the design of the rheometer and the difference between the trimming temperature and test temperature. Recommended closure values for creating the gap are 0.05 mm for the 25-mm plate and 0.10 mm for the 8-mm plate. A recommended practice for verifying the gap closure required to produce an appropriate bulge is given in Appendixes X8, X9, and X10.

Note 25—The complex modulus is calculated with the assumption that the specimen diameter is equal to the plate diameter. If the asphalt binder forms a concave surface at its outer edges this assumption will not be valid and the modulus will be underestimated. The calculated modulus is based upon the radius of the plate raised to the fourth power. A slight bulge equal to approximately one-quarter of the gap is recommended. A procedure for determining the closure required to form an acceptable gap is given in Appendixes X8, X9, and X10.

11. PROCEDURE

11.1. Bring the specimen to the test temperature ±0.1°C. See Note 4.

Note 26—The gap should be set at the starting test temperature (Section 11.1.1) or at the middle of the expected range of test temperatures (Section 11.1.2). See Note 5 for guidance on setting the gap. Typically, reliable test results may be obtained with a single sample, in an 8-mm to 25-mm plate, using temperatures within 12°C of the temperature at which the gap is set.

11.1.1. When testing a binder for compliance with M 320, select the test temperature from the appropriate table in M 320.

11.1.2. When conducting a temperature sweep, start at a midrange test temperature and increase or decrease the test temperature to cover the desired range of test temperatures. (See Sections 6 and 7 in R 29.)

11.2. Set the temperature controller to the desired test temperature, including any offset as required by Section 9.4.4. Allow the temperature indicated by the RTD to come to the desired temperature. The test shall be started only after the temperature has remained at the desired temperature ±0.1°C for at least 10 minutes.

Note 27—It is impossible to specify a single equilibration time that is valid for DSRs produced by different manufacturers. The design (fluid bath or air oven) of the environmental control system and the starting temperature will dictate the time required to reach the test temperature. The method for determining the correct thermal equilibration time is described in Appendix X12.

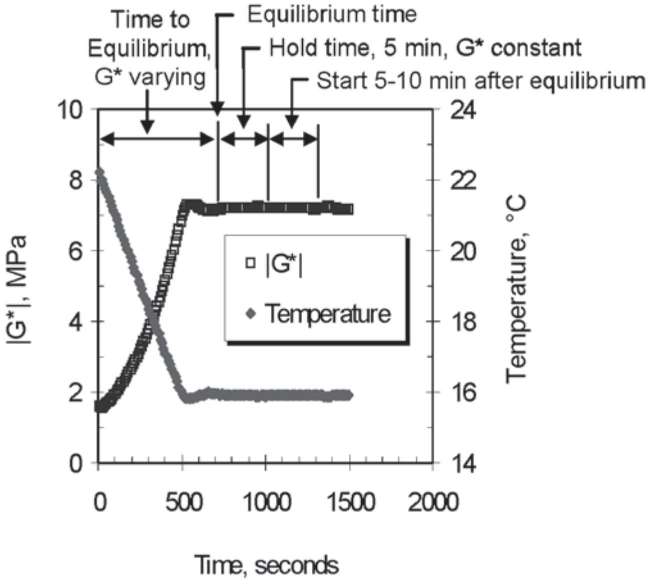


Figure 4—Determining Thermal Equilibrium Time

11.3. *Strain Control Mode*—When operating in a strain controlled mode, determine the strain value according to the value of the complex modulus. Control the strain within 20 percent of the target value calculated by Equation 2.

$$\gamma,\ \text{percent} = 12.0/(G^*)^{0.29} \tag{2}$$

where:

γ = shear strain in percent, and

G^* = complex modulus in kPa.

11.3.1. When testing specimens for compliance with M 320, select an appropriate strain value from Table 2. Software is available with the dynamic shear rheometers that will control the strain automatically without control by the operator.

Table 2—Target Strain Values

		Strain, percent	
Material	kPa	Target Value	Range
Original binder	1.0 $G^*/\sin\delta$	12	9 to 15
RTFO residue	2.2 $G^*/\sin\delta$	10	8 to 12
PAV residue	5000 $G^*\sin\delta$	1	0.8 to 1.2

11.4. *Stress Control Mode*—When operating in a stress controlled mode, determine the stress level according to the value of the complex modulus. Control the stress within 20 percent of the target value calculated by Equation 3.

$$\tau = 12.0\left(G^*\right)^{0.71} \tag{3}$$

where:

τ = shear stress in kPa, and

G^* = complex modulus in kPa.

11.4.1. When testing specimens for compliance with M 320 select an appropriate stress level from Table 3. Software is available with the dynamic shear rheometers that will control the stress level automatically without control by the operator.

Table 3—Target Stress Levels

Material	kPa	Stress, kPa Target Level	Range
Original binder	1.0 *G**/sin δ	0.12	0.09 to 0.15
RTFO residue	2.2 *G**/sin δ	0.22	0.18 to 0.26
PAV residue	5000 *G**sin δ	50.0	40.0 to 60.0

11.5. When the temperature has equilibrated, condition the specimen by applying the required strain for a recommended 10 cycles or a required range of 8 to 16 cycles at a frequency of 10 rad/s (see Note 28). Obtain a test measurement by recording data for an additional recommended 10 cycles or a range of 8 to 16 cycles. Reduce the data obtained for the second set of cycles to produce a value for the complex modulus and phase angle. Typically a Fast Fourier Transform (FFT) is used to reduce the data. Multiple measurements may be obtained to verify that the sample is properly prepared. Disbonding between the plates and the binder or fracture in the sample can result in a decrease in the modulus with repeat measurements. Some asphalt binders may exhibit a reduced modulus with continued application of shear stresses (multiple measurements). The data acquisition system automatically acquires and reduces the data when properly activated. When conducting tests at more than one frequency, start testing at the lowest frequency and increase to the highest frequency.

Note 28—The standard frequency of 10 rad/s is used when testing binder for compliance with M 320.

11.6. The data acquisition system specified in Section 6.1.4 automatically calculates *G** and δ from test data acquired when properly activated.

11.7. Initiate the testing immediately after preparing and trimming the specimen. The testing at subsequent temperatures should be done as quickly as possible to minimize the effect of molecular associations (steric hardening) that can cause an increase in modulus if the specimen is held in the rheometer for a prolonged period of time. When testing at multiple temperatures all testing should be completed within four hours.

12. INTERPRETATION OF RESULTS

12.1. The dynamic modulus and phase angle depend upon the magnitude of the shear strain; the modulus and phase angle for both unmodified and modified asphalt binder decrease with increasing shear strain as shown in Figure 5. A plot such as that shown in Figure 5 can be generated by gradually increasing the load or strain amplitude, thereby producing a strain sweep. It is not necessary to generate such sweeps during normal specification testing; however, such plots are useful for verifying the limits of the linear region.

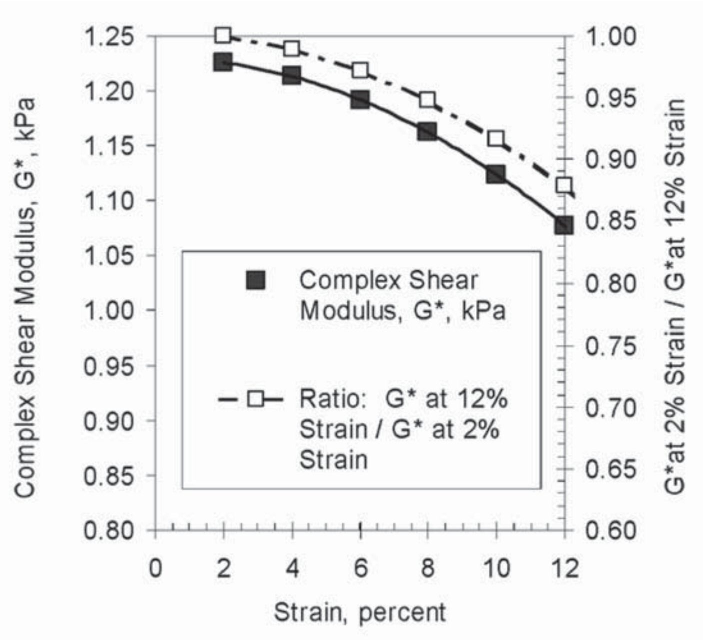


Figure 5—Example of Strain Sweep

12.2. A linear region may be defined at small strains where the modulus is relatively independent of shear strain. This region will vary with the magnitude of the complex modulus. The linear region is defined as the range in strains where the complex modulus is 95 percent or more of the zero-strain value.

12.3. The shear stress varies linearly from zero at the center of the plates to a maximum at the extremities of the plate perimeter. The shear stress is calculated from the applied or measured torque, measured or applied strain, and the geometry of the test specimen.

13. REPORT

13.1. A sample report format is given in Appendix X13. Provide a complete identification and description of the material tested including name, grade, and source.

13.2. Describe the instrument used for the test including the model number.

13.3. The strain and stress levels specified in Tables 2 and 3 have been selected to ensure a common reference point that has been shown to be within the linear region for neat and modified asphalt binders. Some systems may not be linear within this region. When this situation is observed, report the modulus at the recommended stress or strain levels but also report that the test conditions were outside the linear region.

13.4. *For each test, report the following*:

13.4.1. Test plate diameter, nearest 0.1 mm, and test gap, nearest 1 µm;

13.4.2. Test temperature, nearest 0.1°C;

13.4.3. Test frequency, nearest 0.1 rad/s;

13.4.4. Strain amplitude, nearest 0.01 percent, or torque, nearest mN·m;

13.4.5. Complex modulus (G^*) for the 10 measurements, kPa to three significant figures;

13.4.6. Phase angle (δ) for the second 10 cycles, nearest 0.1 degrees; and

13.4.7. $G^*/\sin\delta$, nearest 0.01 kPa, or $G^*\sin\delta$, nearest whole number.

14. PRECISION AND BIAS

14.1. *Precision*—Criteria for judging the acceptability of dynamic shear results obtained by this method are given in Table 4.

14.1.1. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 4 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 4, Column 3.

14.1.2. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 4 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 4, Column 3.

Table 4—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]	Acceptable Range of Two Test Results (d2s%)[a]
Single-Operator Precision:		
Original Binder: $G^*/\sin\delta$ (kPa)	2.3	6.4
RTFO Residue: $G^*/\sin\delta$ (kPa)	3.2	9.0
PAV Residue: $G^*\cdot\sin\delta$ (kPa)	4.9	13.8
Multilaboratory Precision:		
Original Binder: $G^*/\sin\delta$ (kPa)	6.0	17.0
RTFO Residue: $G^*/\sin\delta$ (kPa)	7.8	22.2
PAV Residue: $G^*\cdot\sin\delta$ (kPa)	14.2	40.2

[a] These values represent the 1s% and d2s% limits described in ASTM Practice C 670.

Note 29—The precision estimates given in Table 4 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 185 to 208 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). Average original binder results for $G^*/\sin\delta$ ranged from 1.067 kPa to 2.342 kPa. Average RTFO residue results for $G^*/\sin\delta$ ranged from 2.274 kPa to 7.733 kPa. Average PAV residue results for $G^*\cdot\sin\delta$ averaged from 1100 kPa to 4557 kPa. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 30—As an example, two tests conducted on the same PAV residue yield results of 1200 kPa and 1300 kPa, respectively. The average of these two measurements is 1250 kPa. The acceptable range of results is then 13.8 percent of 1250 kPa or 173 kPa. As the difference between 1200 kPa and 1300 kPa is less than 173 kPa, the results are within the acceptable range.

14.2. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

15. KEYWORDS

15.1. Dynamic shear rheometer; DSR; complex modulus; asphalt binder.

APPENDIXES

(Nonmandatory Information)

X1. TESTING FOR LINEARITY

X1.1. *Scope*:

X1.1.1. This procedure is used to determine whether an unaged asphalt binder exhibits linear or non-linear behavior at the upper grading temperature, e.g., 52, 58, 64, 70, 76, or 82°C. The determination is based on the change in complex shear modulus at 10 rad/s when the strain is increased from 2 to 12 percent.

X1.2. *Procedure*:

X1.2.1. Verify the DSR and its components in accordance with Section 9 of this standard.

X1.2.2. Prepare the DSR in accordance with Section 10 of this standard.

X1.2.3. Prepare a test specimen for testing with 25-mm plates as per Section 11 of this standard. Select the test temperature as the upper grading temperature for the binder in question.

X1.2.4. Determine the complex shear modulus at 2 and 12 percent strain following the test procedure described in Section 12 except as noted below. Always start with the lowest strain and proceed to the next larger strain.

X1.3. *Strain Controlled Rheometers*—If the software provided with the DSR will automatically conduct tests at multiple strains, program the DSR to obtain the complex shear modulus at strains of 2, 4, 6, 8, 10, and 12 percent. If this automatic feature is not available, test by manually selecting strains of 2, 4, 6, 8, 10, and 12 percent strain.

X1.4. For stress controlled rheometers, compute the starting stress based on the complex shear modulus, G^*, and shear stress, τ, as determined at the upper grading temperature during the grading of the binder. At this temperature the complex modulus, G^*, will be greater than or equal to 1.00 kPa and the shear stress, τ, will be between 0.090 and 0.150 kPa (see Table 2). Calculate the starting stress as τ /6.00 kPa. Increase the stress in five increments of τ /6.00 kPa.

Note X1—*Sample calculation*: Assume a PG 64-22 asphalt binder with G^* = 1.29 kPa at 64°C and τ = 0.135 kPa. The starting stress will be 1.35kPa/6 = 0.225 kPa. Test at 0.225, 0.450, 0.675, 0.900, 1.13, and 1.35 kPa, starting with 0.225 kPa.

X1.5. *Plot of Complex Modulus Versus Strain*—Prepare a plot of complex shear modulus versus percent strain as shown in Figure 5. From the plot, determine the complex shear modulus at 2 and 12 percent strain.

X1.6. *Calculations*:

X1.6.1. Calculate the modulus ratio as the complex shear modulus at 12 percent strain divided by the complex shear modulus at 2 percent strain.

X1.7. *Report*:

X1.7.1. *Report the following*:

X1.7.1.1. Complex shear modulus (*G**) to three significant figures,

X1.7.1.2. Strain, nearest 0.1 percent,

X1.7.1.3. Frequency, nearest 0.1 rad/s, and

X1.7.1.4. The ratio calculated by dividing the modulus at 12 percent strain by the modulus at 2 percent strain.

X1.8. *Data Interpretation*:

X1.8.1. The measurement was performed in the non-linear range of the material if the modulus ratio as calculated in Section X1.11 is <0.900 and linear if ≥0.900. If the measurement was performed in the non-linear range of the material, the results obtained under this standard will be considered as invalid for grading a binder according M 320.

X2. CONTROL CHART

X2.1. *Control Charts*:

X2.1.1. Control charts are commonly used by various industries, including the highway construction industry, to control the quality of products. Control charts provide a means for organizing, maintaining and interpreting test data. As such, control charts are an excellent means for organizing, maintaining, and interpreting DSR verification test data. Formal procedures based on statistical principles are used to develop control charts and the decision processes that are part of statistical quality control.

A quality control chart is simply a graphical representation of test data versus time. By plotting laboratory measured values for the reference fluid in a control chart format, it is easy to see when:

- The measurements are well controlled and both the device and the operator are performing properly.
- The measurements are becoming more variable with time, possibly indicating a problem with the test equipment or the operator.
- The laboratory measurements for the fluid are, on the average above or below the target (reference fluid) value.

Many excellent software programs are available for generating and maintaining control charts. Some computer-based statistical analysis packages contain procedures that can be used to generate control charts. Spreadsheets such as Microsoft's Excel can also be used to generate control charts and, of course, control charts can be generated manually. (See Table X3.1 as an example print-out.)

X2.2. *Care in Selecting Data*:

X2.2.1. Data used to generate control charts should be obtained with care. The idea of randomness is important but need not become unnecessarily complicated. An example will show why a random sample is needed—a laboratory always measures the reference fluid at the start of the shift or workday. These measurements could be biased by start-up errors such as a lack of temperature stability when the device is first turned on. The random sample ensures that the measurement is representative of the process or the material being tested. Said another way, a random sample has an equal chance of being drawn as any other sample. A measurement or sample always taken at the start or end of the day, or just before coffee break, does not have this chance.

X3. EXAMPLE

X3.1. The power of the control chart is illustrated in Table X3.1 using the verification data obtained for the DSR. Other DSR verification data suitable for a quality control chart presentation includes measurements for determining the temperature correction, calibrating the electronic thermometer, and maintaining data from internally generated asphalt binder reference samples. For this example, the reported viscosity for the reference fluid is 271 Pa·s; hence, the calculated value for G^* is 2.71 kPa. This value for G^* is labeled as "G^* from Reference Fluid" in Figure X3.1. The laboratory should obtain this value on average if there is no laboratory bias.

Table X3.1—Sample Test Data

Week	Measured G^*, kPa
1	2.83
2	2.82
3	2.77
4	2.72
5	2.69
6	2.72
7	2.77
8	2.75
9	2.71
10	2.82
11	2.66
12	2.69
13	2.75
14	2.69
15	2.73
16	2.77
17	2.72
18	2.67
19	2.66
20	2.78
21	2.74
22	2.69
Average	2.73
Std. Dev.	0.051
CV %	1.86

X3.2. *Comparison of 22-Week Laboratory Average for G* with Value Calculated from Reference Fluid*:

X3.2.1. The 22-Week average of the laboratory measurements is labeled as "22-Week Laboratory Average" in Figure X3.1. Over the 22 weeks, for which measurements were made, the average was 2.73 kPa. This value compares favorably with the calculated reference value, 2.71 kPa, differing on the average by only 0.7 percent. There appears to be little laboratory bias in this data.

Comparison of CV of Laboratory Measurements with Round Robin CV:

X3.2.2. From a previous round robin study, the within laboratory standard deviation (d1s) for the fluid was reported as 0.045 (CV = 1.67 percent). The 22-week standard deviation for the measured values of *G** is 0.051 CV = 1.86 percent), as compared to 0.045 (CV =1.67 percent) reported from the round robin. However, it should be pointed out that the 22-week CV, 1.86 percent, also includes day-to-day variability, a component of variability not included in the round-robin d1s value. Based on this information the variability of the laboratory measurements are acceptable.

X3.3. *Variability of Measured Values*:

X3.3.1. In Figure X3.1, the value of *G** calculated from the reference fluid is shown as a solid line. Also shown are two dotted lines that represent the *G** calculated from the reference fluid ±2 d1s where d1s is the value from the round robin. The calculated reference value for the fluid is 2.71 kPa, and the standard deviation is 0.045. Thus, a deviation of 2 d1s gives values of:

$$2.71\text{kPa} \pm (2)\,(0.045) = 2.80\text{ kPa}, 2.62\text{ kPa} \qquad (X3.1)$$

If the laboratory procedures are under control, the equipment is properly calibrated, and there is no laboratory bias, 95 percent of the measurements should fall within the limits 2.62 kPa and 2.80 kPa. Laboratory measurements outside this range are suspect, and the cause of the outlier should be investigated. The outlier may be the result of either testing variability or laboratory bias. The measurement from Week 10 in Figure X3.1 falls outside the ±2 d1s limits and is cause for concern such that testing procedures and verification should be investigated.

If a measurement deviates from the target, in this case *G** from the reference fluid, by more than ±3 d1s, corrective action should be initiated. The ±3 d1s limits 99.7 percent of the measured values if the laboratory procedures are under control and the equipment is properly calibrated.

X3.4. *Trends in Measured Value*:

X3.4.1. The control chart can also be used to identify unwanted trends in the data. For example, from weeks one to five, a steady decrease in the measured value is observed. This is cause for concern and the reason for the trend should be investigated. More sophisticated rules for analyzing trends in control charts can be found elsewhere.

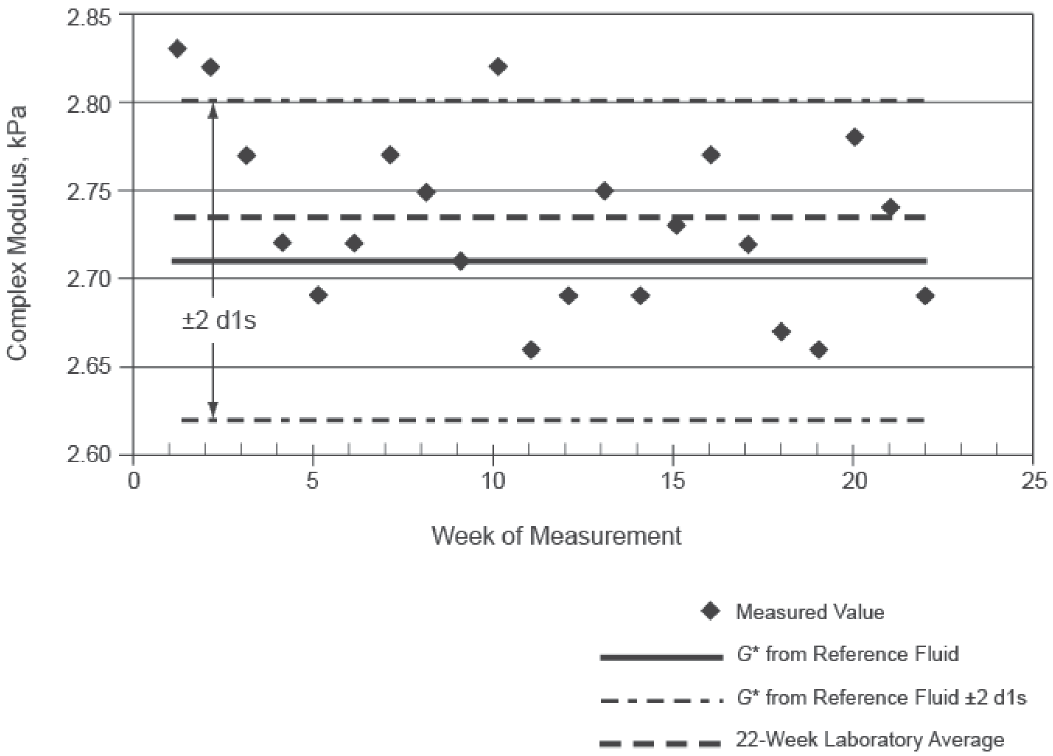


Figure X3.1—Control Chart

X4. USE OF REFERENCE FLUID

X4.1. *Source of Reference Fluid*:

X4.2. An organic polymer produced by Cannon Instrument Company as Viscosity Standard N2700000SP has been found suitable as reference fluid for verifying the calibration of the DSR. The viscosity of the fluid, as determined from NIST–traceable capillary viscosity measurements, is approximately 270 Pa·s at 64°C. However, the viscosity of the fluid varies from one lot to the next. The lot-specific viscosity is printed on the label of the bottle.

X5. CAUTIONS IN USING REFERENCE FLUID

X5.1. Some items of caution when using the reference fluid are:

- The fluid cannot be used to verify the accuracy of the phase angle measurement.
- The fluid must not be heated as heating can degrade the fluid causing a change in its viscosity.
- The fluid should be used for verification only after the DSR temperature measurements are verified.
- The fluid cannot be used to calibrate the torque transducer. The manufacturer or other qualified service personnel using a calibration device designed specifically for the rheometer should perform the calibration. These calibration devices are typically not available in operating laboratories.
- When tested at 10 rad/s, the reference fluid should only be used at 64°C and above. At lower temperatures, the fluid is viscoelastic; hence, the viscosity, η, reported on the certificate by Cannon will not match the complex viscosity $\eta^* = G^*/10$ rad/s determined from the measurement.

- Bubbles in the fluid will have a dramatic effect on the measured value of G^*. The fluid in the bottle should be free of bubbles and care must be taken not to introduce bubbles when preparing test specimens. Recommended procedures for preparing test specimens are given in Appendix X6.

X6. CALCULATION OF *G** FROM STEADY-STATE VISCOSITY MEASUREMENTS

X6.1. Among the different methods for converting between dynamic and steady-state viscosity of polymers, the most popular and most successful is the so-called Cox-Merz empirical rule. The rule leads, in simplified terms, to the following approximation.

$$G^*/\omega \sim \eta \qquad (X6.1)$$

where:

G^* = the complex modulus,

ω = the angular frequency in radians/s, and

η = the shear rate independent capillary viscosity as reported by the supplier of the reference fluid.

For this rule to apply the measurements must be in the viscous region where the phase angle approaches 90 degrees. The value of the complex modulus is then simply 10 times the value of the capillary viscosity. For example, if the capillary viscosity is 270,000 mPa·s the complex modulus is:

$$G^*\text{, kPa} \approx (270{,}000\ \text{mPa·s})(1\ \text{kPa}/1{,}000{,}000\ \text{mPa})(10\ \text{rad/s}) = 2.70\ \text{kPa·rad} \qquad (X6.2)$$

The reference fluid behaves as a viscous fluid at 64°C and above and provides very accurate estimates of G^* above 64°C. At temperatures below 58°C the fluid gives incorrect values for G^* with the error increasing as the temperature departs from 64°C. At 64°C and above G^* divided by the frequency in radians per second should be no more than three percent different than the viscosity printed on the bottle label. If this is the case, then the torque calibration should be considered suspect.

X7. METHODS FOR TRANSFERRING THE FLUID TO THE TEST PLATES

X7.1. Three different methods are recommended for transferring the fluid to the test plates:

X7.2. The glass rod method (Section X7.1), the spatula method (Section C4.3), and a direct method where a removable test plate is held in direct contact with the fluid in the bottle (Section C4.4).

X7.3. *Glass Rod Method (Figure X7.1)*:

X7.3.1. In this method, a glass rod is inserted into the fluid and rotated (Step 1) while in the fluid. Continue rotating the rod, and pull it slowly from the fluid (Step 2) carrying a small mass of the fluid with the rod. Touch the mass to the plate (Step 3) to transfer the fluid to the plate. See Figure X7.1.

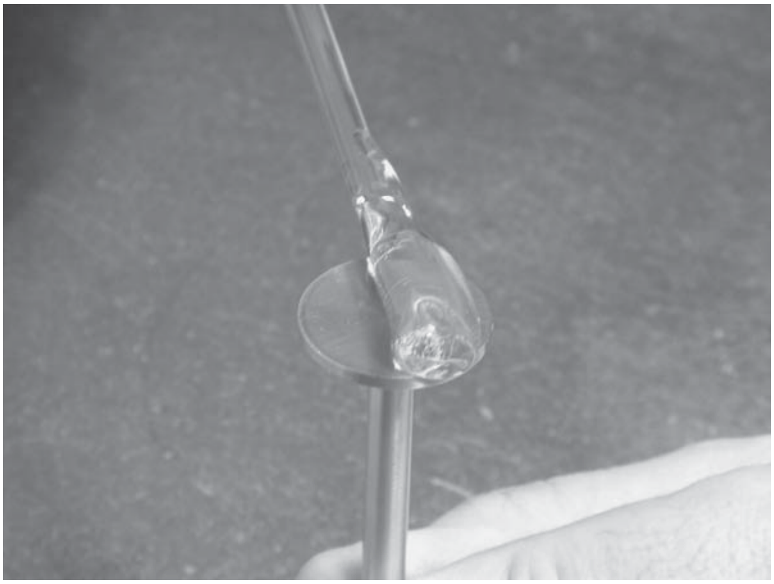


Figure X7.1—Using a Glass Rod to Place the Reference Fluid on the Plate

X7.4. *Spatula Method (Figure X7.2)*:

X7.5. When carefully used a spatula may be used to transfer the fluid. Special care must be taken not to trap air as the material is scooped from the bottle, Step 1. Smear the mass on the spatula onto the plate (Step 2) and cut the mass from the spatula by drawing the spatula across the edge of the plate (Step 3). This method appears to be the most difficult to implement and is the least recommended of the three methods.

Figure X7.2—Using a Spatula to Place the Reference Fluid on the Plate

X7.6. *Direct Touch Method (Figure X7.3)*—If the rheometer is equipped with plates that may be removed and reinstalled without affecting the gap reference, remove one of the plates and touch the surface of the plate to the surface of the fluid in the bottle (Step 1). Pull the plate from the bottle, bringing a mass of the fluid along with the plate (Step 2). Invert the plate and allow the fluid to flow out into a mushroom shape (Step 3).

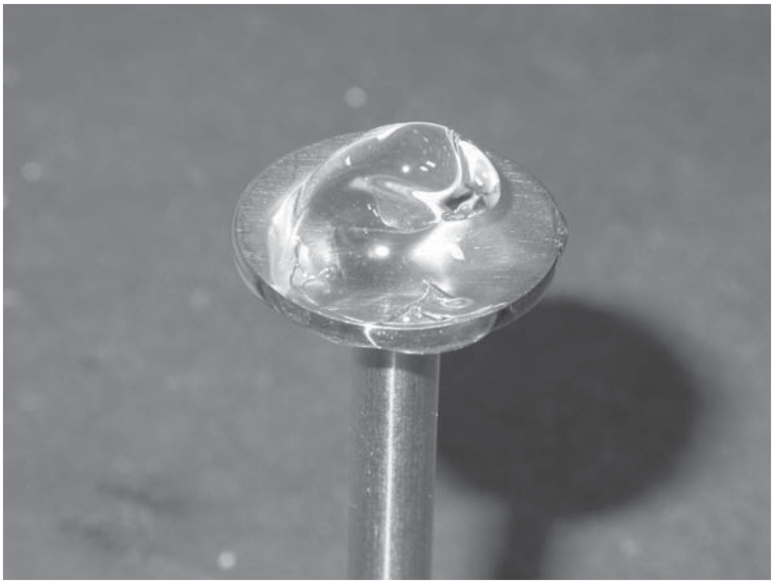


Figure X7.3—Direct Touch Method to Place the Reference Fluid on the Plate

Proceed immediately to Section 10.5 to trim the reference fluid specimen and form the bulge.

Proceed with testing the reference fluid specimen as described in Section 11.

X8. SELECTION OF GAP CLOSURE TO OBTAIN BULGE

X8.1. *Need for Accurate Measurement of Specimen Diameter*:

X8.2. The accuracy of the DSR measurements depends upon an accurate measurement of the diameter of the test specimen. The diameter of the test specimen is assumed equal to the diameter of the test plates. For this reason, the trimming of excess binder and the final closure of the gap to produce a slight bulge in the test specimen are critical steps in the DSR test procedure. When the gap is closed to its final dimension, the bulge must be of sufficient size to compensate for any shrinkage in the binder and consequently avoiding a concave surface as shown in Figure X8.1. The diameter of the test specimen in Figure X8.1 approaches d, rather than d', the diameter of the plate. The modulus, G^*, is calculated according to the following equation:

$$|G^*| = (2h/\pi r^4)\bullet(\tau/\Theta) \qquad (X8.1)$$

where:

G^* = Complex modulus

τ = Torque applied to test specimen

h = Thickness of test specimen

Θ = Angular rotation, radians

r = radius of test plate

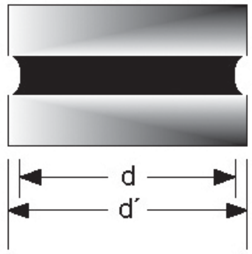


Figure X8.1—Concave Surface Resulting from Insufficient Closure after Trimming

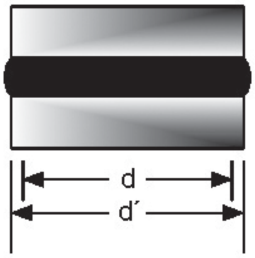


Figure X8.2—Proper Bulge

X8.3. According to Equation X8.1, the modulus depends upon the radius (or diameter) raised to the fourth power. Therefore, a small concavity in the outer surface of the test specimen, as shown in Figure X8.1, will have a large effect on the measured modulus because the actual specimen diameter will be less than the plate diameter. For a given amount of concavity, the effect on the measured modulus is greater for the 8-mm plate than the 25-mm plate. A more desirable result is a slight bulge as illustrated in Figure X8.2. Shear stresses are not transferred directly from the plate to the overhanging binder; therefore, the effect of a slight bulge on the measured modulus is much less than a slight concavity. It should be noted that errors in the diameter of the test specimen do not affect the measured values of the phase angle.

X9. RECOMMENDED GAP CLOSURE VALUES

X9.1. Recommended values for the gap closure required to form a bulge at the test temperature similar to the bulge illustrated in Figure X8.2 are given in Section 10.5 as 50 µm and 100 µm for the 25-mm and 8-mm plates, respectively. Although these values may be appropriate for many rheometers, they may not be appropriate for all rheometers. The applicability of these values to a specific rheometer may be determined by preparing a test specimen using the recommended closure and observing the shape of the bulge after the final closure of the gap and after the test specimen is at the test temperature. If the recommended closure values do not give an appropriate bulge, the recommended closure values should be adjusted as appropriate.

Proper and improper bulges are shown in Figures X10.1 through X10.3. A magnifying glass is useful for examining the shape of the bulge. Regardless of the closure required to produce a desirable bulge, the actual gap should be used in the calculations.

X10. FACTORS AFFECTING BULGE DEVELOPMENT

X10.1. A number of factors can affect the bulge formed at the test temperature. These include:

- The amount of closure used to create the bulge.
- The difference in temperature between the trimming temperature, the temperature at which the bulge is created, and the test temperature.
- Thermal expansion-contraction characteristics of the rheometer.
- Thermal contraction and expansion of the asphalt binder.

A concave surface is more likely to form at the intermediate temperatures, than at the upper test temperatures (8-mm plate rather than the 25-mm plate). In fact, at the higher test temperatures excessive material can be squeezed from the plates as shown in Figure X10.3. This situation should also be avoided and may require gap closures somewhat less than the recommended values.

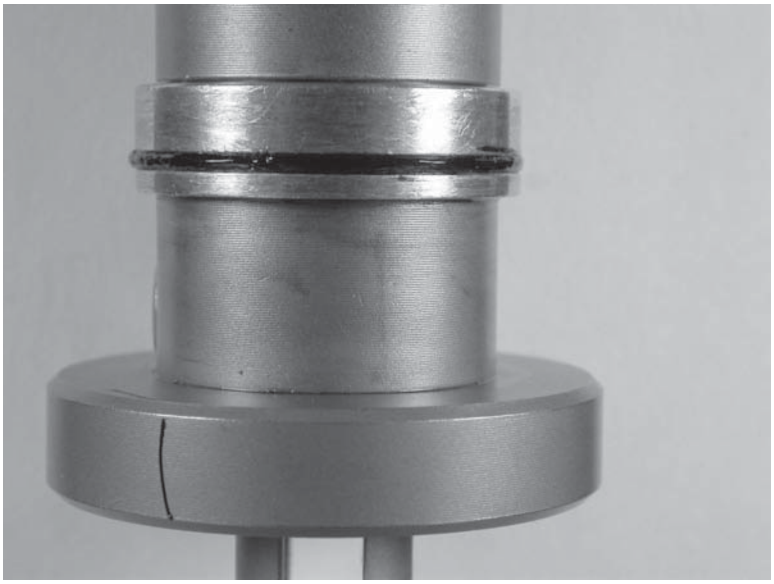


Figure X10.1—Good Bulge Size

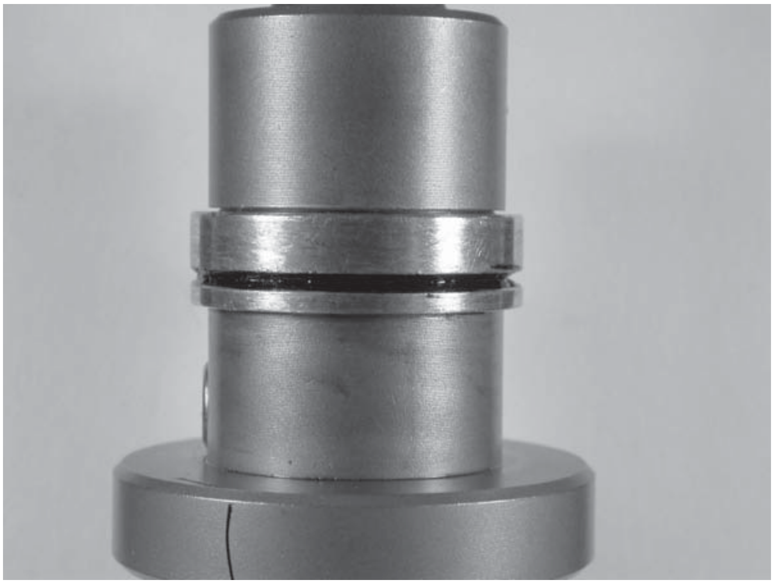


Figure X10.2—Concave Bulge

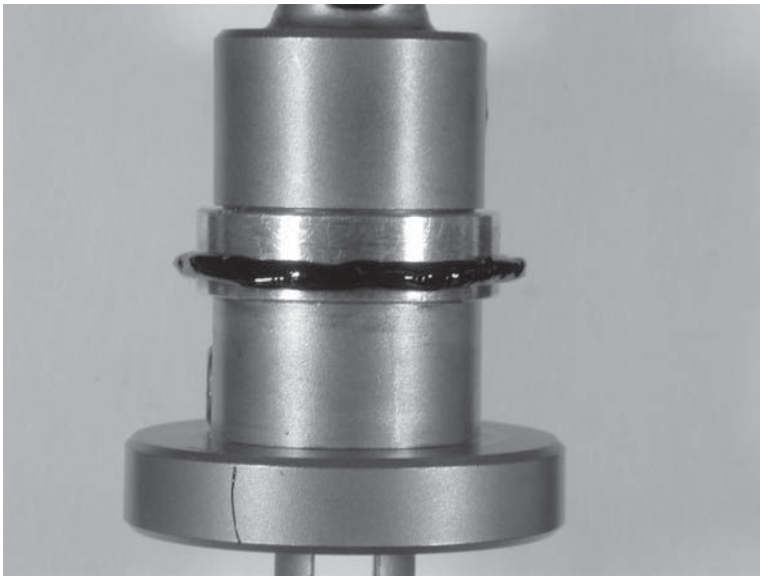


Figure X10.3—Oversized Bulge

X11. DETERMINATION OF TIME TO THERMAL EQUILIBRIUM

X11.1. *Reason for Determining Time Required to Obtain Thermal Equilibrium*:

X11.1.1. After the test specimen has been mounted in the DSR, it takes some time for the asphalt binder between the test plates to reach thermal equilibrium. Because of thermal gradients within the test plates and test specimen, it may take longer for the test specimen to come to thermal equilibrium than the time indicated by the DSR thermometer. Therefore, it is necessary to experimentally determine the time required for the test specimen to reach thermal equilibrium.

X11.1.2. The time required to obtain thermal equilibrium varies for different rheometers. Factors that affect the time required for thermal equilibrium include:

X11.1.3. Design of the rheometer and whether air or liquid is used as a heating-cooling medium;

X11.1.4. Difference between ambient temperature and the test temperature, different when testing below room temperature, and above room temperature;

X11.1.5. Difference in temperature between the trimming and test temperature; and

X11.1.6. Plate size, different for the 8-mm and 25-mm plate.

X11.2. It is not possible to specify a single time as the time required to obtain thermal equilibrium. For example, thermal equilibrium is reached much quicker with liquid-controlled rheometers than with air-cooled rheometer. This requires that the time to thermal equilibrium be established for individual rheometers, typical trimming and testing temperatures, and testing conditions.

X12. METHOD TO DETERMINE THE TIME REQUIRED TO OBTAIN THERMAL EQUILIBRIUM

X12.1. A reliable estimate of the time required for thermal equilibrium can be obtained by monitoring the DSR temperature and the complex modulus of a sample mounted between the test plates. Because the modulus is highly sensitive to temperature, it is an excellent indicator of thermal equilibrium. The following procedure is recommended for establishing the time to thermal equilibrium:

X12.2. Mount a binder sample in the DSR and trim in the usual manner. Create a bulge and bring the test chamber or fluid to the test temperature.

X12.3. Operate the rheometer in a continuous mode at 10 rad/s using an unmodified asphalt binder—one that does not change modulus with repeated shearing. Use the smallest strain value that gives good measurement resolution.

X12.4. Record the modulus at 30 s time intervals, and plot the modulus versus time (Figure 4).

X12.5. The time to reach thermal equilibrium is the time required to reach a constant modulus. Typically, this time will be greater than the time required to reach a constant reading on the DSR thermometer.

X12.6. Because the time required to reach thermal equilibrium will vary with the test temperature and testing conditions, the time to thermal equilibrium should be established separately for both intermediate and high-temperature measurements. Once the time to thermal equilibrium has been established, it does not have to be repeated unless the test conditions change.

X13. SAMPLE REPORT

Header Information:

Item	Data Group 1	Item	Data Group 2
Operator's Name:	24 Alpha-Numeric	Date of Test (dd/mm/yy):	__/__/__
Test Specimen ID No.:	18 Alpha	Time of Test (hr:min):	__:__
Project ID No.:	12 Alpha-Numeric	DSR Manufacturer:	12 Alpha-Numeric
File Name:	12 Alpha-Numeric	DSR Model:	12 Alpha-Numeric
Test Plate Diameter, Nearest 0.01 mm:	00.00	DSR Serial Number or Other Identifying ID No.:	18 Alpha-Numeric
Test Frequency, rad/s:	0.00	Software Version:	12 Alpha-Numeric
Test Gap, 0.01 mm:	00.00		

Test Results for Grading (Use separate column for each test temperature):

Measurements	Data Group 3	Data Group 4	Data Group 5	Data Group 6
Test Specimen Temperature, 0.1°C	0.00	0.00	0.00	0.00
Temperature Correction at Test Temperature, 0.1°C	0.00	0.00	0.00	0.00
Stress Amplitude, kPa	0.00	0.00	0.00	0.00
Strain Amplitude, percent	0.00	0.00	0.00	0.00
Complex Modulus, *G**, kPa	0.00	0.00	0.00	0.00
Phase Angle, degrees	00.0	00.0	00.0	00.0
Complex Modulus/sin(Phase Angle)	0.00	0.00	0.00	0.00
Complex Modulus × sinδ (Phase Angle)	00.0	00.0	00.0	00.0
Comments generated by DSR software (Example: "This material passes.")				
At end of file, 276 alphanumeric field for operator comments and comments, if any, generated by DSR software.				

Test Results for Linearity Determination:

Measurements	Data Group 7
Test Specimen Temperature, 0.1°C	0.00
Temperature Correction at Test Temperature, 0.1°C	0.00

	Data Group 8	Data Group 9	Data Group 10	Data Group 11	Data Group 12	Data Group 13
Measurements		0.00	0.00	0.00	0.00	0.00
Stress Amplitude, kPa	0.00	0.00	0.00	0.00	0.00	0.00
Strain Amplitude, percent	0.00	0.00	0.00	0.00	0.00	0.00
Complex Modulus, *G**, kPa	0.00	00.0	00.0	00.0	00.0	00.0
Phase Angle, degrees	00.0	00.0	00.0	00.0	00.0	00.0
At end of file, 276 alphanumeric field for operator comments and comments, if any, generated by DSR software.						

X14. REFERENCES

X14.1. Anderson, D. A. and M. Marasteanu. "*Manual of Practice for Testing Asphalt Binders in Accordance with the Superpave PG Grading System.*" The Pennsylvania Transportation Institute, The Pennsylvania State University, PTI 2K07, November 1999 (Revised February 2002).

X14.2. Wadsworth, H., ed. *Handbook of Statistical Methods for Engineers and Scientists.* McGraw-Hill, New York, NY, 1990.

X14.3. Anderson, D. A., C. E. Antle, K. Knechtel, and Y. Liu. *Interlaboratory Test Program to Determine the Inter- and Intra-Laboratory Variability of the SHRP Asphalt Binder Tests*. FHWA, 1997.

X14.4. Cox, W. P. and E. H. Merz. Correlation of Dynamic and Steady Flow Viscosities, *Journal of Polymer Science*, Volume 28, 1958, *pp*. 619–622.

Standard Method of Test for

Viscosity Determination of Asphalt Binder Using Rotational Viscometer

AASHTO Designation: T 316-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Viscosity Determination of Asphalt Binder Using Rotational Viscometer

AASHTO Designation: T 316-10

1. SCOPE

1.1. This test method outlines the procedure for measuring the viscosity of asphalt binders at elevated temperature from 60 to over 200°C using a Rotational Viscometer apparatus as specified by M 320 and R 29.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the application of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 320, Performance-Graded Asphalt Binder
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- T 40, Sampling Bituminous Materials

2.2. *ASTM Standards*:
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. TERMINOLOGY

3.1. *viscosity*—the ratio between the applied shear stress and the rate of shear is called the coefficient of viscosity. This coefficient is a measure of the resistance to flow of the liquid. It is commonly called the viscosity. The SI unit of viscosity is the Pascal second (Pa·s).

4. SUMMARY OF METHOD

4.1. This test method can be used to measure the viscosity of asphalt at application temperatures. The torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in an asphalt sample at a constant temperature is used to measure the relative resistance to rotation. The torque and speed are used to determine the viscosity of the binder in Pascal seconds.

5. SIGNIFICANCE AND USE

5.1. This test method can be used to measure the apparent viscosity of asphalt at application temperatures.

5.2. The measured viscosity at elevated temperatures can be used to determine whether the asphalt binder can be handled and pumped at the refinery, terminal, or hot mix plant facility. Measured viscosity from this procedure can be used to develop temperature viscosity charts for estimating mixing and compaction temperatures for use in hot mix asphalt mix design.

6. APPARATUS

6.1. *Oven*—An oven capable of maintaining any desired temperature setting from room temperature to 260°C to within ±3°C.

6.2. *Thermometers*—Thermometers having a range from 60 to over 200°C and readable to 0.2°C.

6.3. *Balance*—A balance with a capacity of 2000 g readable to 0.1 g for determining the mass of asphalt binder.

6.4. *Cylindrical Spindles* of various sizes for measurement of asphalt binders of different viscosities.

6.5. *Rotational Viscometer* capable of measuring the torque required to rotate the selected spindle at a selected constant speed while submerged in asphalt at constant desired test temperature and should display the viscosity in Pascal seconds automatically.

6.6. *Temperature Controller*—A proportional temperature controller capable of maintaining the specimen temperatures ±1.0°C for test temperatures ranging from 60 to 165°C or greater.

7. MATERIALS

7.1. Solvent (such as Mineral Spirits or Varsol) or a degreasing spray cleaner formulated for cleaning the sample holder, spindles and accessories.

8. HAZARDS

8.1. Use standard laboratory safety procedures required for handling the hot asphalt binder and required safety procedures when cleaning with solvents or degreasers.

9. PREPARATION OF APPARATUS

9.1. The rotational viscometer must be leveled to function properly. A bubble-type level is normally located on top of the viscometer and is adjusted by using leveling screws located on the base. If the torque controller and thermal chamber are separate units, both should be leveled.

10. CALIBRATION AND STANDARDIZATION

10.1. The accuracy of the rotary transducer is checked using a reference fluid (Newtonian fluid) of known viscosity at various temperatures. The reference fluid shall be certified to be Newtonian in behavior over the full range of expected test temperatures and shear rates. The viscosity measured should be within ±2 percent or the rotary transducer requires recalibration.

10.2. The accuracy of the temperature reading of the temperature controller is checked by placing an asphalt sample in the testing chamber and equilibrating to a given temperature. The indicated temperature shall be verified by using a NIST traceable measuring device as defined by ASTM E 1.

11. PREPARATION OF SAMPLES AND TEST SPECIMENS

11.1. *Preparing Test Samples*—Unaged asphalt and modified asphalt binders are obtained according to T 40.

11.1.1. Anneal the asphalt binder from which the specimen is obtained by heating until sufficiently fluid to pour. Annealing prior to testing removes reversible molecular associations (steric hardening) that may occur during normal storage at ambient temperature.

Note 1—Minimum pouring temperature that produces a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. The specific temperature will depend on the grade of binder and its prior aging history, if any. Temperatures less than 135°C are desirable; however, temperatures above 135°C may be required for some modified asphalt binders or heavily aged binders.

12. PROCEDURE

12.1. Read and understand the information in the rotational viscometer manufacturer’s operating manual before proceeding.

12.2. Turn on the rotational viscometer and proportional temperature controller unit.

12.3. Preheat the sample holder with the sample chamber and the selected cylindrical spindle according to the manufacturer’s recommendation.

12.4. Set the proportional temperature controller to desired test temperature.

12.5. Heat the required amount of asphalt binder as recommended by the manufacturer for testing according to Section 11.1.1.

12.6. When the proportional temperature controller reads the desired test temperature, remove the sample holder, and add the required amount of asphalt into the sample chamber.

12.7. Insert the sample chamber into the proportional temperature controller unit.

12.8. Insert a preheated spindle and attach it to the viscometer using the necessary coupling. Gently lower the spindle into the asphalt so that asphalt covers the upper conical portion of the spindle. This procedure may vary based on the manufacturer’s recommendations.

12.9. Bring the asphalt sample to the desired temperature within approximately 30 minutes. Set the viscometer speed at 20 rpm and set the display to read the viscosity in Pascal seconds (Pa·s). This operation may be done manually or by using a software program.

12.10. Allow the asphalt sample to equilibrate at the desired test temperature for a minimum of 10 minutes. Begin the spindle rotation during the 10 minute temperature equilibration period. Allow the readings to stabilize before recording any viscosity measurements. If the observed torque is out of range for the selected spindle and speed, change the spindle and or speed based on the manufacturer's recommendations for the anticipated viscosity. Restart the test with a new sample.

12.11. Start the test after the asphalt sample has reached the specified temperature and equilibrated and the viscosity readings have stabilized, as required in Sections 12.9 and 12.10.

12.12. Measure the viscosity at one-minute intervals for a total of three minutes.

12.13. Follow the procedure in Sections 12.1 to 12.12 for other temperatures.

13. CALCULATION OF RESULTS

13.1. The viscosity is reported as the average of three readings. If the digital output of the rotational viscometer viscosity is in units of centipoise (cP), the following factor is used to convert to Pascal-seconds:

$$10\ \mathrm{P} = 1\ \mathrm{Pa{\cdot}s} \qquad (1)$$

$$1\ \mathrm{cP} = 1\ \mathrm{mPa{\cdot}s} \qquad (2)$$

Multiply viscosity in centipoise by 0.001 to obtain the viscosity in Pa·s.

14. REPORT

14.1. *Report the following information*:

14.1.1. Report the date and time of the test;

14.1.2. Report the test temperature to the nearest 1°C;

14.1.3. Report the speed in rpm;

14.1.4. Report the size of the spindle used;

14.1.5. Report the torque in percent; and

14.1.6. Report the average viscosity in Pa·s.

15. PRECISION AND BIAS

15.1. *Precision*—Criteria for judging the acceptability of viscosity results obtained by this method are given in Table 1.

15.1.1. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

15.1.2. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

Table 1—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]	Acceptable Range of Two Test Results (d2s%)[a]
Single-Operator Precision:		
Average Viscosity (Pa·s)	1.2	3.5
Multilaboratory Precision:		
Average Viscosity (Pa·s)	4.3	12.1

[a] These values represent the 1s% and d2s% limits described in ASTM Practice C 670.

Note 2—The precision estimates given in Table 1 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 142 to 202 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). Unmodified binder average viscosity results ranged from 0.272 Pa·s to 0.719 Pa·s. The modified binder average viscosity results ranged from 1.621 Pa·s to 1.638 Pa·s. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 3—As an example, two tests conducted on the same material yield viscosity results of 0.500 Pa·s and 0.510 Pa·s, respectively. The average of these two measurements is 0.505 Pa·s. The acceptable range of results is then 3.5 percent of 0.505 Pa·s or 0.018 Pa·s. As the difference between 0.500 Pa·s and 0.510 Pa·s is less than 0.018 Pa·s, the results are within the acceptable range.

15.2. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

16. KEYWORDS

16.1. Asphalt binder; viscosity.

Standard Method of Test for

Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

AASHTO Designation: T 319-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

AASHTO Designation: T 319-08

1. SCOPE

1.1. This standard describes a procedure for the extraction and recovery of asphalt binder from asphalt mixtures [both hot mix asphalt (HMA) and reclaimed asphalt pavement (RAP)] that have a minimal effect on the physical and chemical properties of the asphalt binder recovered. This standard is intended for use when the physical or chemical properties, or both, of the recovered asphalt binder are to be determined. It can also be used to determine the quantity of asphalt binder in the HMA or RAP. Recovered aggregate may be used for sieve analysis or other aggregate testing.

1.2. This method is applicable to HMA sampled from the pavement, RAP sampled from the pavement or stockpile, HMA plant production, or laboratory fabricated HMA.

1.3. *This procedure may involve hazardous materials, operations, and equipment. This procedure does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 110, Moisture or Volatile Distillates in Hot Mix Asphalt (HMA)
- T 168, Sampling Bituminous Paving Mixtures
- T 329, Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

2.2. *ASTM Standards*:

- D 96, Standard Test Methods for Water and Sediment in Crude Oil by Centrifuge Method (Field Procedure) (Withdrawn 2000)
- D 5361, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing

3. TERMINOLOGY

3.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

4. SUMMARY OF METHOD

4.1. The asphalt mixture is repeatedly washed and filtered with solvent in an extraction/filtration apparatus. Each filtrate is distilled under vacuum in a rotary evaporator with the asphalt remaining in the flask. After recovery of the final filtrate, the solution is concentrated to about 300 mL and centrifuged to remove the aggregate fines. The decanted solution is distilled under vacuum to remove the extraction solvents. Nitrogen gas is introduced during the final phase of distillation to drive off any remaining traces of solvents. The quantity of asphalt binder in the asphalt mixture is calculated (optional) and the recovered asphalt (distillation residue) sample is subjected to further physical and chemical testing as required. The recovered aggregate can then be used for sieve analysis or other aggregate testing, if desired.

5. SIGNIFICANCE AND USE

5.1. This method is used for obtaining recovered asphalt binder residue samples from asphalt mixture samples for further physical and chemical analyses, and for the optional calculation of asphalt binder content.

6. APPARATUS

6.1. *Extraction Vessel*[1]—The extraction vessel shall be a device as shown in Figure 1, and shall have a 130-mm long piece of 150-mm I.D. Schedule 80 aluminum pipe or Schedule 80, Grade 304 stainless steel pipe (Figure 2) with removable top and bottom 13-mm thick aluminum or stainless steel plates. The top plate (Figure 3) shall have a mixing motor mount and 19-mm port for adding solvent. The bottom plate (Figure 4) shall be equipped with a quick-connect fitting. Four 100-mm by 25-mm baffles (Figure 5) shall be mounted in the extraction vessel followed by a 3-mm aluminum ring, 2-mm (No. 10) mesh screen, spacer (Figure 6), 0.3-mm (No. 50) mesh screen, another spacer, 0.075-mm (No. 200) mesh screen, then another 2-mm (No. 10) mesh screen, as shown in Figure 1.

Note 1—A vessel available from Pass Industries (133 MacArthur Court, Nicholasville, KY 40356, Telephone Number 859-881-0205) has proven acceptable for these requirements.

6.2. *In-Line Filter*—The in-line fine filter apparatus shall be a cartridge type with 20-μm retention and at least 820 cm^3 of effective filter area. The filter apparatus shall be able to be removed from the system to accommodate weighing before and after the procedure. The filter shall be capable of withstanding heat up to 135°C without degradation in order to accommodate oven drying of the filter apparatus.

Note 2—Whatman Polycap™ 75 HD (Catalog Number 6703-7521) or equivalent is a suitable filter. (Whatman Inc., 9 Bridewell Place, Clifton, NJ 07014)

6.3. *Filtrate Flasks with Tubulation*, 1000 mL (two required).

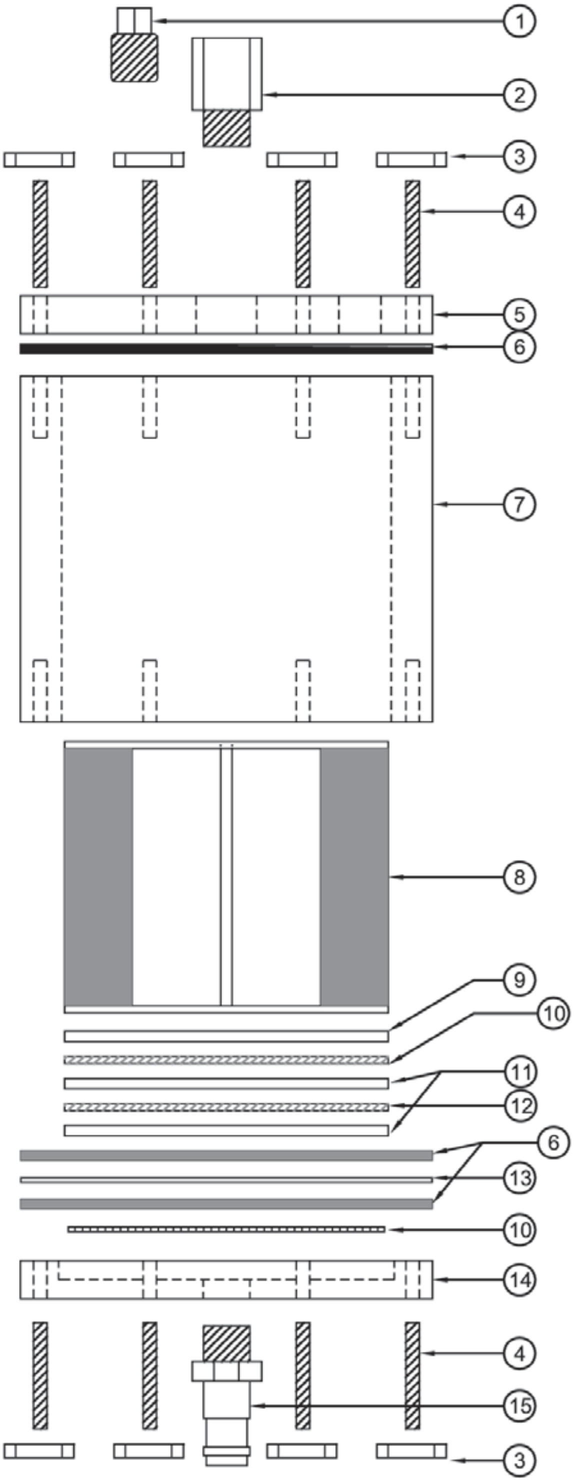
6.4. *Round-Bottom Flasks*, 1000 mL, with cork stands.

6.5. *Gas Flowmeter*, capable of indicating a gas flow up to 1000 mL/minute.

6.6. *Rotary Evaporator Device*, with transfer and purge tubes, capable of holding a recovery flask in oil at a 15° angle and rotating at 40 r/min.

Note 3—The Buchi Rotavapor RE-120 has proven acceptable for these requirements (Buchi, Labortechnik AG, Postfach, 9230 Flach 1, Switzerland).

6.7. *Hot Oil Bath*, capable of heating oil to 180°C.



(1) 2-ISO 12 RT (¾-in. NPT) plug.
(2) ISO 8 RT (½ in.-NPT) fitting with 16-mm I.D. hole for motor shaft.
(3) 12 M5 × 0.5 wing nuts.
(4) 12 M5 × 0.5 × 50 mm studs.
(5) Extraction vessel top.
(6) 3 vision gaskets 3 mm thick, 16 mm width with holes to fit over studs.
(7) Extraction vessel housing.
(8) Aluminum baffle.
(9) Aluminum ring, 3 mm thick, 148 mm O.D. ,10 mm width.
(10) Stainless steel screens, 10 mesh.
(11) Metal spacers.
(12) #50 Screen.
(13) #200 Screen.
(14) Extraction vessel bottom.
(15) ISO 4 RT (¾ -in. NPT) quick-connect fitting.

Figure 1—Extraction Vessel

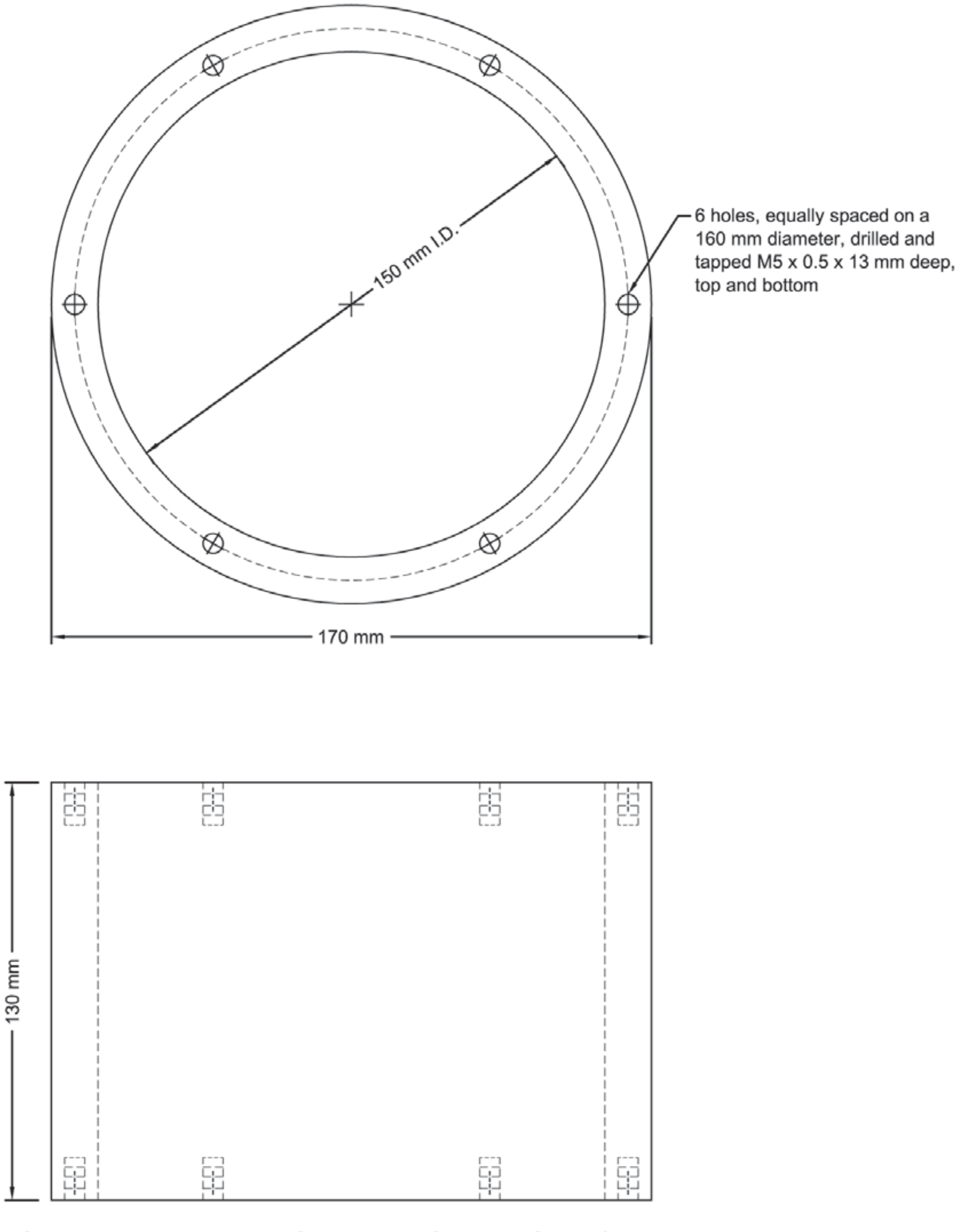
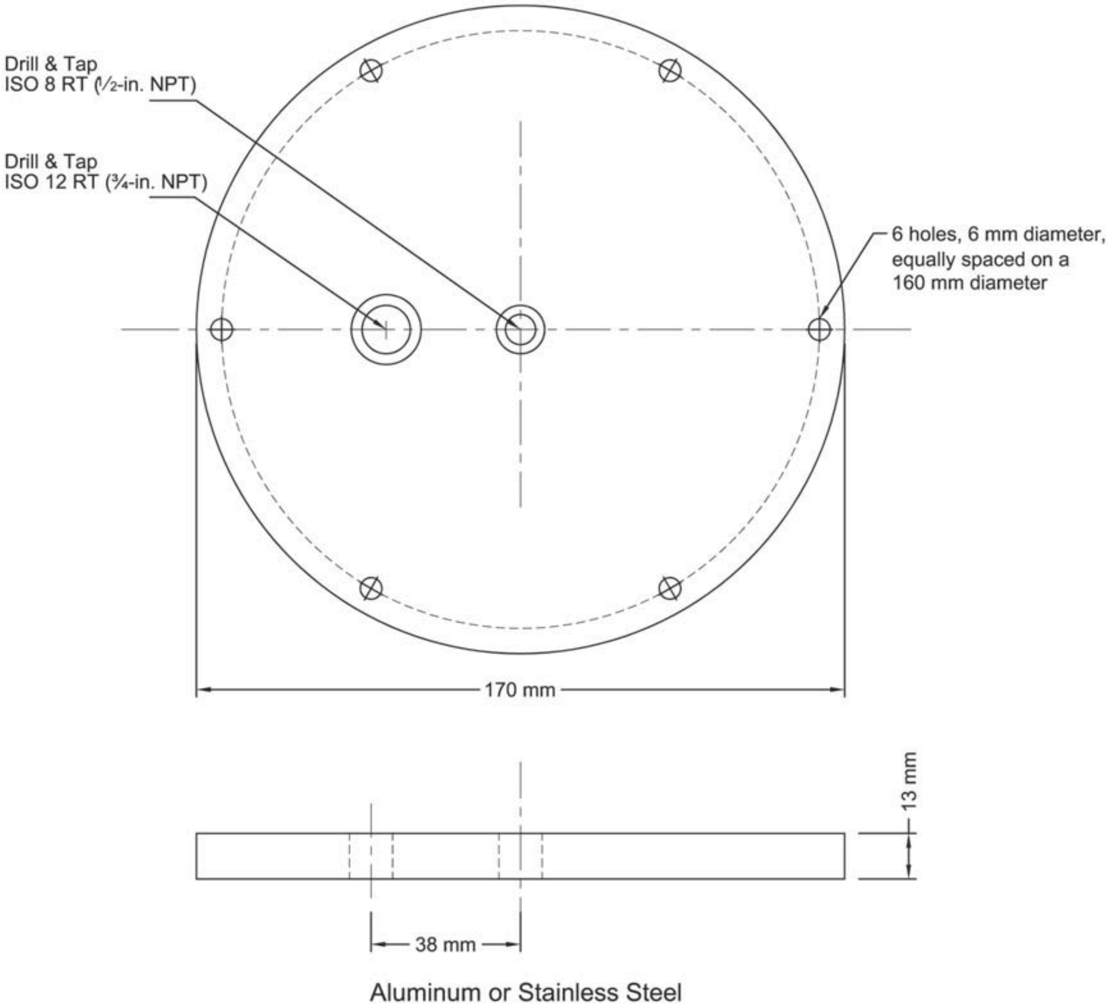
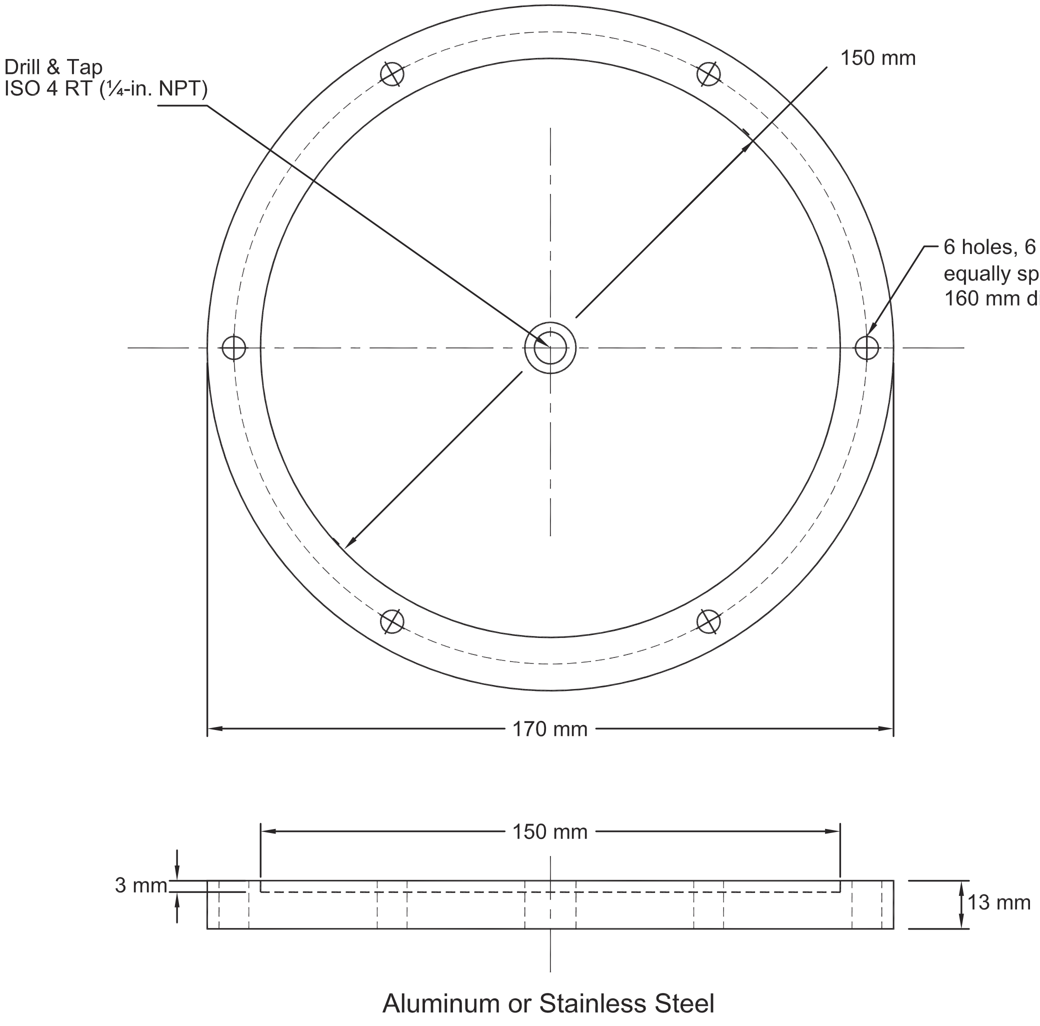


Figure 2—Extraction Vessel Housing



Notes: 1. Not to scale.
2. Assume a tolerance of 0.2 mm unless otherwise noted.

Figure 3—Extraction Vessel Top Plate



Notes: 1. Not to scale.
2. Assume a tolerance of 0.2 mm unless otherwise noted.

Figure 4—Extraction Vessel Bottom Plate

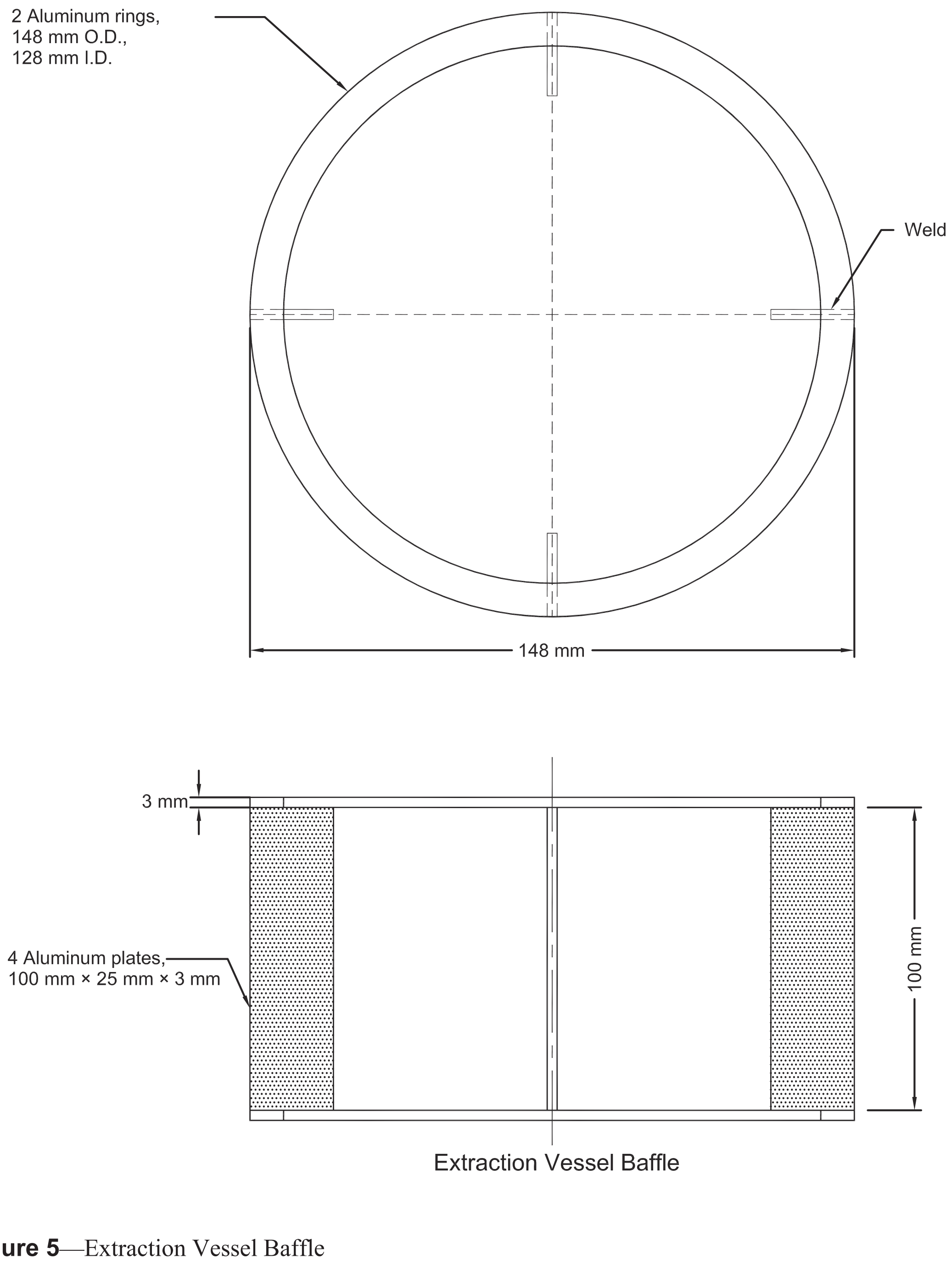


Figure 5—Extraction Vessel Baffle

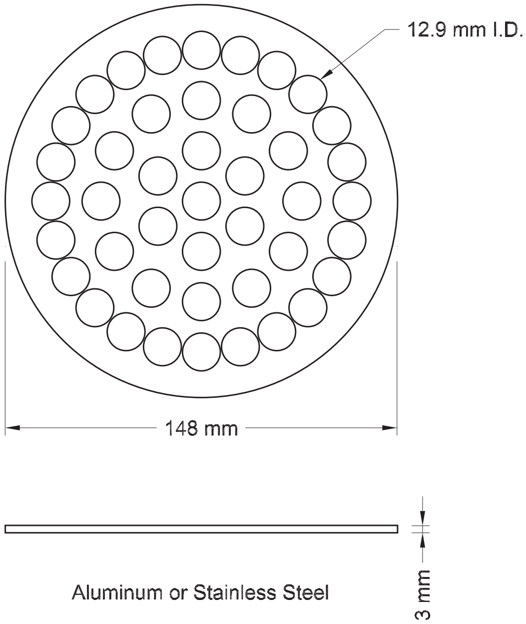


Figure 6—Extraction Vessel Spacer

6.8. *Single-Speed Mixing Motor*, 150 W ($^1/_5$ hp), 30 r/min.

6.9. *Centrifuge*, batch unit capable of exerting a minimum centrifugal force of 770 times gravity.

6.10. *Wide-Mouth Centrifuge Bottles*, 250 mL.

6.11. *Oven*, capable of maintaining a temperature of 110 ± 5°C.

6.12. *Balance*, of suitable capacity, meeting the requirements of M 231 for Class G 2 balances.

6.13. *Thermometer*, having a range of 30°C to 300°C.

6.14. *Utilities*—Vacuum source and cooling water source.

6.15. *Scale (optional)*—Having a capacity of 12 kg or more, sensitive to 0.1 g or less, and accurate within 0.1 percent of the test load at any point within the range of use for this test. Within any 100-g range of test load, a difference between readings shall be accurate within 0.1 g.

6.16. *6-mm Diameter Polypropylene Tubing*—varying length, for transferring solution throughout the procedure.

Note 4—To avoid contamination of the sample due to solvent degradation of the tubing, do not substitute Nalgene or rubber tubing for the polypropylene tubing specified.

6.17. *Copper Tubing*, of an amount and size adequate to connect the apparatus as shown in Figure 7.

7. MATERIALS AND REAGENTS

7.1. *Solvent* (n-Propyl Bromide or Trichloroethylene, reagent grade; or Toluene, reagent grade)—If using Toluene, combine with Ethanol, absolute, in proportions of 85 percent Toluene and 15 percent Ethanol after the third wash (Section 12.2).

7.2. *Nitrogen Gas*, at least 99.95 percent pure, in a pressurized tank with a pressure-reducing regulator valve.

8. HAZARDS

8.1. Use solvents only under a fume hood or with an effective surface exhaust system in a well-ventilated area. Observe the manufacturer's recommended safety precautions when using compressed nitrogen.

9. SAMPLING

9.1. Obtain asphalt mixture samples in accordance with T 168. When sampling from a compacted roadway, remove specimens from the roadway in accordance with ASTM D 5361. When sampling RAP, refer to T 2 for aggregate sampling.

10. PREPARATION OF APPARATUS

10.1. *Preparing the Extraction Vessel*—Install the baffle piece and other internal parts in the order shown in Figure 1. Tightly and evenly fasten the bottom end piece (with the quick connect fitting) of the vessel with wing nuts or hexagonal nuts.

10.2. *Preparing the Rotary Evaporator*—Turn on the cooling water. Turn on the oil bath, and set the temperature to 100 ± 2.5°C. Place six 3-mm glass boiling beads in a 1000-mL round-bottom flask. Attach this recovery flask to the rotary evaporator, and immerse approximately 38 mm of the flask into the oil bath. Set the angle of the recovery flask, from the horizontal to the bath, at 15°. Set the flask rotation at 40 r/min. Clamp the empty condensate flask onto the condenser. Attach the transfer tube inside the neck of the rotary evaporator. Attach the filtrate transfer line to the external fitting on the neck of the rotary evaporator.

11. STANDARDIZATION

11.1. At least every six months, verify the calibration of the oil bath temperature detector by using a certified mercury-in-glass thermometer of suitable range that is accurate to ±0.2°C. Immerse the thermometer in the oil bath close to the thermal detector, and compare the temperature indicated by the certified thermometer to the temperature setting for the oil bath. If the temperature indicated by the thermal detector does not agree with the certified thermometer within ±0.5°C, perform additional calibration or maintenance.

11.2. At least every six months, use a mercury manometer or other certified pressure measurement device to verify calibration of the vacuum indicator. If the vacuum indicator and the certified pressure measurement device do not agree within ±0.1 kPa, perform additional calibration or maintenance.

11.3. At least every six months, verify the rotational velocity of the rotary evaporator.

11.4. At least every six months, verify the flow rate of the nitrogen flowmeter.

12. PROCEDURE

12.1. *Sample Preparation*:

12.1.1. If a sample of asphalt mixture is not sufficiently soft to separate with a spatula or trowel, place the sample in a large, flat pan, and warm it in an oven at 110 ± 5°C only until it can be handled or mixed.

12.1.2. Split or quarter the loose asphalt mixture sample until an amount of the sample that will yield approximately 50 to 60 g of extracted asphalt binder is obtained. Typically 1000 g of asphalt mixture is sufficient.

Note 5—This procedure works best when recovering less than 60 g of asphalt binder. Therefore, if the asphalt binder content of the mix is already known, then the mass of the original sample required is that which yields about 50 to 60 g of asphalt binder.

Note 6—The maximum aggregate size in the test specimen will affect the calculated asphalt content. If the calculated results from this standard are used to represent the asphalt content of the asphalt mixture from which the sample was obtained, use a minimum mass of test specimens for calculations that will ensure that inclusion or removal of one maximum size particle will not change the calculated asphalt content by more than 0.05 percent. This restriction may require testing multiple test specimens.

12.1.3. If the asphalt binder content is to be determined, obtain a separate test specimen from the asphalt mixture sample. Determine the moisture content in accordance with T 110 or T 329 and record the mass percent of water in the test specimen.

12.2. *Extraction and Filtration*:

12.2.1. Place the asphalt mixture sample in the extraction vessel. Put the gasket and the upstream end piece on the vessel, and fasten the wing nuts tightly and evenly, creating a secure seal.

12.2.2. Charge 600 mL of solvent through the 19-mm port on the upstream end of the extractor. Blanket the interior of the extraction vessel by injecting nitrogen through the upstream port at a rate of 1000 mL/min for 1 min. Close the port with the threaded plug. Attach the extractor to the motor. Start the motor, and mix for 5 ± 1 minutes at 30 r/min. Turn off the motor.

12.2.3. Remove the extractor; place it on a stand, and attach the quick-connect fitting to the first filtrate-receiving flask. Ensure the filtrate transfer line is closed. Remove the upstream port, and blanket the extractor with nitrogen at a rate of 400 mL/min while drawing the asphalt/solvent solution into the first flask. Apply a vacuum of 93.3 ± 0.7 kPa (700 ± 5 mm Hg) to the first filtrate-receiving flask in order to draw the material from the vessel. Continue drawing the solution into the first flask until there is no noticeable amount of solution exiting the vessel. Turn off the vacuum.

12.2.4. Filtering through the in-line cartridge filter, switch the vacuum to the second filtrate-receiving flask, and apply a vacuum of 93.3 ± 0.7 kPa Filter until there is no noticeable amount of solution remaining in the first flask or the filter. Turn off the vacuum.

12.2.5. After filtration, open the filtrate transfer valve on the second receiving flask and allow the solution to flow from the filtrate-receiving flask to the recovery flask. Continue the transfer until the filtrate-receiving flask is empty or the recovery flask is about two-thirds full; then, begin the primary distillation.

12.2.6. After the distillation is started, disconnect the extractor from the quick-connect fitting. Repeat the extraction procedure. For the second wash, use 400 ± 10 mL of solvent, and mix/rotate for

10 ± 1 minutes. For subsequent washes (Note 7), use 400 ± 10 mL of solvent, and mix for 30 to 35 min.

Note 7—After the third wash, the condensate from the primary distillation step may be used for extraction solvent. Recycling solvent in this manner allows the entire procedure to use approximately 1500 mL of solvent.

12.2.7. Proceed to the final recovery step (Section 12.4) if the filtrate flowing through the transfer tube, after a 30-min wash, is a light brown color. A minimum of three washes is required.

12.3. *Primary Distillation*:

12.3.1. Close the filtrate transfer valve line, distill solvent at 100 ± 2.5°C (oil bath temperature), and at a vacuum of 93.3 ± 0.7 kPa.

12.3.2. If after the primary distillation step the condensate flask is over half full, empty the flask. Save this solvent for use in subsequent washes (Note 7). After primary distillation of each filtrate, maintain vacuum, temperature, flask rotation, and cooling water. Repeat the primary distillation after each filtration (Note 8).

Note 8—It is important to concentrate the asphalt in the recovery flask after each wash and at a low temperature. This procedure minimizes the temperature and the time spent in the dilute solution and, therefore, minimizes asphalt hardening in the solvent.

12.4. *Final Extraction and Recovery*:

12.4.1. Distill the contents of the recovery flask until it is about one-third full.

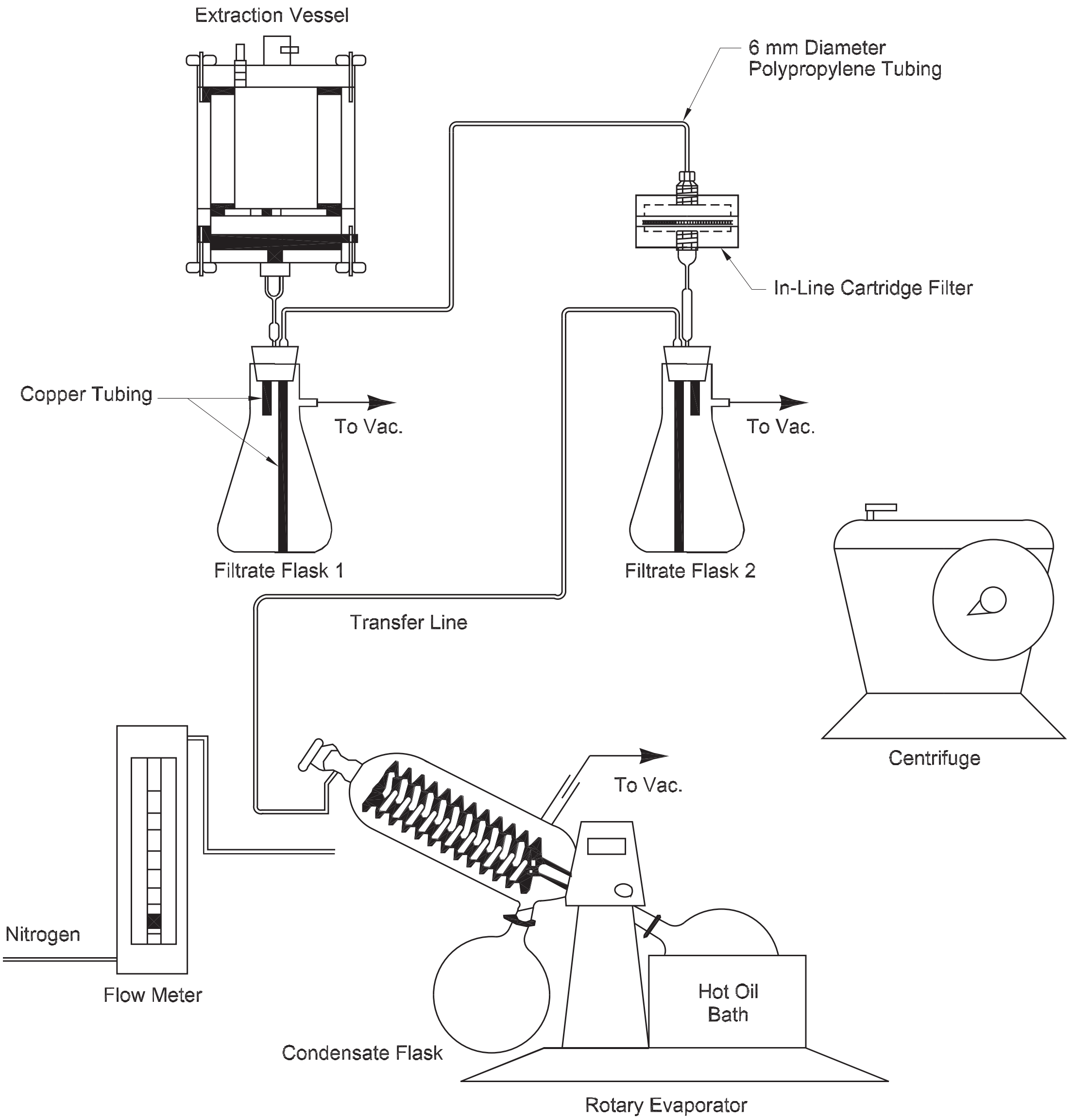


Figure 7—Extraction and Recovery Apparatus

12.4.2. Turn off the vacuum then clean and disconnect the recovery flask, and pour the contents into the centrifuge bottles using a funnel and screen to prevent the boiling beads from entering the bottles. Fill the bottles so that their masses are equal. Wash any remaining residue from the recovery flask into the centrifuge bottles. Increase the oil bath temperature to 174 ± 2.5°C. Centrifuge the bottles at 3600 r/min for 25 minutes.

12.4.3. Empty the centrifuge bottles back into the recovery flask, and add six 3-mm diameter glass boiling beads. Reattach the flask to the rotary evaporator. Disconnect the transfer tube from the rotary evaporator, and replace it with the gas purge tube. Disconnect the filtrate transfer line from the external rotary evaporator neck fitting, and replace it with the nitrogen gas line. Apply a vacuum of 93.3 ± 0.7 kPa. Lower the flask approximately 38 mm into the oil bath.

12.4.4. Distill the solvent.

12.4.5. When the condensation rate falls below one drop every 30 seconds, introduce nitrogen gas at a rate of 1000 mL/minute. Maintain the gas flow, vacuum, and bath temperature for 30 ± 1 minutes to reduce the residual solvent concentration to near zero. Complete removal of residual solvent is very important for obtaining accurate asphalt properties.

12.4.6. Shut down the oil bath, flask rotation, vacuum, gas flow, and cooling water. Remove the evaporating flask. If the asphalt binder content is to be determined, determine and record the mass of the recovered asphalt binder to the nearest 0.1 g. Pour the asphalt into a sample tin using a screen to prevent the boiling beads from entering the tin.

13. DETERMINATION OF ASPHALT BINDER CONTENT (OPTIONAL)

13.1. When a determination of asphalt binder content is desired, use the following procedure:

13.1.1. *Before Section 12.2.1, do the following*:

13.1.1.1. Determine the mass of the mixture sample;

13.1.1.2. Determine the mass of the cartridge filter; and

13.1.1.3. Determine the mass of the centrifuge bottles.

13.1.2. *Before Section 12.4.3, do the following*:

13.1.2.1. Dry the centrifuge bottles, in-line filter, and opened vessel (including inserts) to constant mass;

13.1.2.2. Determine the mass of fine material in the centrifuge bottles (dry original);

13.1.2.3. Determine the mass of fine material in the filter (dry original); and

13.1.2.4. Determine the mass of all aggregate material in the vessel (scrape/brush all screens, etc.);

13.1.2.5. Determine the asphalt content using the following equation:

$$\frac{\text{Asphalt content \%} = \text{Original sample} - (\text{Recovered aggregate} + \Delta\text{Bottles} + \Delta\text{Filter}}{\text{Original Sample}} \times 100$$

14. REPORT

14.1. *Report the following information*:

14.1.1. Source of the test sample.

14.2. *Report the following information if the asphalt binder content is to be determined*:

14.2.1. Mass of the test specimen to the nearest gram;

14.2.2. Mass percent of water in the companion test specimen to the nearest 0.01 percent;

14.2.3. Mass of asphalt binder in the test specimen to the nearest gram; and

14.2.4. Percent of asphalt binder in the test sample to the nearest 0.01 percent.

15. PRECISION AND BIAS

15.1. *Precision*—The research required to develop precision values has not been conducted.

15.2. *Bias*—The research required to establish the bias of this method has not been conducted.

16. KEY WORDS

16.1. Asphalt binder; extraction; recovery; rotary evaporator.

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[1] An "International" No. 2 Centrifuge operating at 1900 r/min or an "SMM Continuous Centrifuge" exerting a force of 3000 times gravity at 9000 r/min has been found satisfactory for this purpose.

Standard Method of Test for

Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)

AASHTO Designation: T 320-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)

AASHTO Designation: T 320-07

1. SCOPE

1.1. This standard provides performance-related test procedures for the determination of stiffness and permanent shear strain of asphalt mixtures using the Superpave Shear Tester (SST). Modified and unmodified asphalt mixtures can be tested and analyzed using this standard.

1.2. This standard is applicable to specimens prepared in a laboratory or cored from a pavement for post-construction analysis. It is intended for use with specimens having the following minimum dimensions:

Nominal Maximum Aggregate Size in Asphalt Mixture, mm	Specimen Diameter	Specimen Height
19	150	50
12.5, 9.5, 4.75	150	38

Note 1—*Nominal maximum aggregate size* is defined in R 35 as the sieve greater than the first sieve to retain more than 10 percent of the total aggregate. Asphalt mixtures with a nominal maximum aggregate size greater than 19 mm can be tested using this procedure, but it is not recommended. The larger aggregate sizes may significantly interfere with the material response, thereby affecting the repeatability of the test.

Note 2—The SST is only capable of testing specimens with a maximum diameter of 150 mm. The specimen height of 50 mm is preferred, but may not be available in roadway cores where layer thickness may only be 38 mm. Specimen heights less than 38 mm usually cannot be tested because of equipment constraints.

Note 3—The diameter-to-height ratio for shear test specimens should be 3:1 or greater. This effectively eliminates the use of 100-mm diameter specimens (because of minimum height requirement for testing discussed in Note 2).

1.3. *This practice may involve hazardous materials, operations, and equipment. It does not purport to address all the safety concerns associated with its use. It is the responsibility of the user of this practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)

- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- T 2, Sampling of Aggregates
- T 40, Sampling Bituminous Materials
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2. *ASTM Standards*:

- D 3549, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 5361, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing

3. SIGNIFICANCE AND USE

3.1. The test procedures and associated analysis techniques described in this method can be used to determine shear stiffness and permanent shear strain of asphalt mixtures. The shear frequency sweep test at constant height can be used to determine mixture stiffness. The simple shear test at constant height can be used to determine shear deformation from the application of a static shear load. The repeated shear test at constant height can be used with corresponding analysis procedures to estimate the rutting susceptibility of an asphalt mixture.

4. EQUIPMENT AND MATERIALS

4.1. *Shear Test System*—The shear test system shall consist of a loading device, specimen deformation measurement equipment, an environmental chamber, and a control and data acquisition system. It shall accommodate test specimens 150 mm in diameter and 50 mm in height.

4.1.1. *Loading Device*—The loading device shall be capable of simultaneously applying both vertical and horizontal loads to a specimen. It shall also be capable of applying static, ramped (increasing or decreasing), and repetitive loads of various waveforms. As a minimum, the loading device shall be capable of applying horizontal shear load pulses in a haversine waveform with a load duration of 0.1 s with 0.6 s between load pulses. Loading shall be provided by two hydraulic actuators (one each horizontal and vertical) and shall be controlled by closed-loop feedback using either stress or strain control throughout the entire range of frequencies and temperatures. The loading device shall be capable of meeting the minimum requirements specified in Table 1.

Table 1—Minimum Test System Requirements

Measurement and Control Parameters	Range	Resolution	Accuracy
Load (N)	0 to 31,000	2	5
Axial LVDT (mm)	0 to 5	0.0025	0.005
Shear LVDT (mm)	0 to 0.05	0.001	0.002
Temperature (˚C)	0 to 80	0.25	0.5

4.1.2. *Environmental Chamber*—The environmental chamber shall be capable of maintaining the temperature of the test specimen as specified in Table 1 during the testing sequence.

4.1.3. *Data Acquisition and Control System*—The data acquisition and control system shall automatically control user-selected measurement parameters, within the accuracy specified in Table 1, during the testing sequence. The system shall record load cycles, applied horizontal and vertical loads, specimen deformation in two directions (vertical and horizontal), environmental conditions, and the required frequency of data sampling. At the conclusion of the test, the data acquisition and control system shall provide all applicable test data.

4.2. *Conditioning Chamber*—The conditioning chamber shall be capable of maintaining the specimen conditioning temperatures as specified in Table 1.

4.3. *Platen-Specimen Assembly Device (optional)*—The platen-specimen assembly device is used to facilitate bonding the specimen to the loading platens with adhesive. The device shall maintain the platens in a parallel position (relative to each other) during the gluing operation. The platens must remain parallel so that stresses do not develop in the specimen when the specimen-platen assembly is clamped in the test system. The device shall be capable of testing specimens with a maximum diameter of 150 mm and maximum height of 50 mm.

4.4. *Aluminum Loading Platens*—Top and bottom aluminum loading platens at least 6.35 mm greater in diameter than the diameter of the specimen to be tested and at least 20 mm thick. The bearing face of each platen shall be plane to 0.025 mm.

4.5. *Adhesive*—Quickset adhesive with a minimum hardened stiffness modulus of 2000 MPa for bonding the platens to the specimen ends.

Note 4—Devcon™ 5-Minute Plastic Steel Epoxy Cement[3] is satisfactory for tests conducted at 20°C or higher.

4.6. *Solvent* —Acetone, kerosene, or other equivalent solvent for cleaning the platens after testing.

Note 5—Most of the epoxy and samples can be removed by heating and scraping the platens. The solvent is used only for a final cleaning.

5. STANDARDIZATION

5.1. The testing system shall be standardized prior to initial use and at least once every 12 months thereafter.

5.1.1. Verify the capability of the environmental control chamber to maintain the required temperature within the accuracy specified in Table 1.

5.1.2. Verify the calibration of all measurement components [such as load cells and linear variable differential transducers (LVDTs)] of the testing system.

5.1.3. If any of the verifications yield data that do not comply with the accuracy requirements specified in Table 1, correct the problem prior to proceeding with testing. Appropriate action may involve correction of menu entries, maintenance of system components, calibration of system components (using an independent calibration service, manufacturer service, or in-house resources), or replacement of system components.

6. SAMPLING AND SPECIMEN PREPARATION

6.1. Five test specimens are preferred, and a minimum of three specimens are required, for performing the repeated shear test at constant height. Three test specimens are preferred for performing the shear frequency sweep test at constant height and the simple shear test at constant height.

6.2. *Laboratory-Mixed, Laboratory-Compacted (LMLC) Specimens*—Sample asphalt binder and aggregates in accordance with T 40 and T 2, respectively. Use the appropriate proportions of asphalt binder and aggregates according to the final asphalt mix design.

6.2.1. Prepare aggregate batches of the appropriate size to produce a compacted specimen that will be 150 mm in diameter and 75 mm in height. Heat the aggregate batches to the appropriate mixing temperature.

Note 6—The Appendix contains information on the calculation of the appropriate aggregate batch weight to achieve the correct specimen dimension at the proper percentage of air voids.

6.2.2. Heat the asphalt binder to the appropriate mixing temperature. Mix the correct proportions of asphalt binder and combined aggregates to match the asphalt mix design.

6.2.3. After mixing, condition the asphalt mixture for 4.0 ± 0.1 h at 135 ± 5°C in accordance with "Short-Term Conditioning for Mixture Mechanical Property Testing," R 30.

6.2.4. Compact the HMA mixture in accordance with T 312 to obtain a specimen with the appropriate percentage of air voids as follows:

Test	Air Voids, %
Repeated Shear Test	3.0 ± 0.5
Simple Shear Test	7.0 ± 0.5
Shear Frequency Sweep Test	7.0 ± 0.5

Note 7—Other compaction procedures than the Superpave™ gyratory compactor (T 312) and other target air void percentages may be used. However, caution is needed to prevent comparisons between asphalt mixtures with different target air voids or compaction. The test procedures and analyses are sensitive to both the percentage of air voids and the compaction procedure.

Note 8—Specimens are often compacted to a target air void percentage that is higher than the anticipated percentage of air voids in the cut test specimen. This is done because cutting the top and bottom of a compacted specimen removes lower density material, thereby raising the density (lowering the air voids) of the test specimen. The magnitude of the difference between the target percentage of air voids for the compacted specimen and the target percentage of air voids for the test specimen is dependent upon the nominal maximum aggregate size of the mixture and the mixture gradation. Coarse mixes, and/or mixes with a larger nominal maximum aggregate size, tend to have greater differences between the compacted specimen air voids and the test specimen air voids. In general, a 1.0 percent offset (compact to a target of 4.0 percent air voids or 8.0 percent air voids) should be sufficient to achieve the appropriate percentage of air voids in the test specimen.

6.2.5. Cool the compacted specimen to room temperature. Cut the compacted specimen to a height of 50 mm with two parallel faces. Determine and record the height of the cut specimen at the least and greatest heights. If the difference in the least and the greatest height is more than 2 mm, then discard the specimen and prepare another.

6.2.6. Determine the percentage of air voids in the test specimens in accordance with T 269. Determine the height and diameter of the test specimens in accordance with ASTM D 3549.

6.3. *Field-Mixed, Laboratory-Compacted (FMLC) Specimens*—Obtain HMA samples in accordance with T 168. Compact specimens in accordance with T 312 to the appropriate percentage of air voids. (See Section 6.2.4 and Notes 7 and 8.)

6.3.1. Cool the compacted specimen to room temperature. Cut the compacted specimen to a height of 50 mm with two parallel faces. Determine and record the height of the cut specimen at the least and greatest heights. If the difference in the least and the greatest height is more than 2 mm, then discard the specimen and prepare another.

6.3.2. Determine the percentage of air voids in the test specimens in accordance with T 269. Determine the height and diameter of the test specimens in accordance with ASTM D 3549.

6.4. *Field-Mixed, Field-Compacted (FMFC), or Pavement Core Specimens*—Obtain asphalt pavement specimens having a diameter of 150 mm and a minimum thickness of 38 mm in accordance with ASTM D 5361.

6.4.1. Cut the specimens to the proper test dimensions. Cool the compacted specimen to room temperature. Cut the compacted specimen to a height of 50 mm with two parallel faces. Determine and record the height of the cut specimen at the least and greatest heights. If the difference in the least and the greatest height is more than 2 mm, then discard the specimen and prepare another.

6.4.2. Determine the percentage of air voids in the test specimens in accordance with T 269. Determine the height and diameter of the test specimens in accordance with ASTM D 3549.

6.5. *Preparing the Specimens for Testing*—The following steps discuss the bonding of the test specimen to the platens for testing in the shear tester.

6.5.1. Ensure that the platens are clean, aligned, and clamped in place in the platen-specimen assembly device (optional) or shear test device.

6.5.2. Prepare the adhesive. If using an epoxy, proportion and mix the resin and hardener together in accordance with the manufacturer's instructions (Note 4).

6.5.3. Apply a thin coating of the adhesive to the top of the test specimen and to the bottom platen. Center the test specimen on the bottom platen and lower the top platen onto the specimen. Rotate the specimen slightly to ensure good bonding.

Note 9—Approximately 135 g of epoxy cement has been found suitable to provide bonding without excess waste. Half of the epoxy cement should be used on the bottom platen and the other half on the top of the specimen.

6.5.4. Bond the specimen to the platens using a light pressure (approximately 35 kPa) for 5 minutes. Begin removing excess adhesive from the sides of the test specimen by trimming as soon as the light pressure is applied.

6.5.5. After the adhesive has stabilized, remove the test assembly (specimen with attached platens) from the platen-specimen assembly device (optional) or shear test device and allow the adhesive to cure for the minimum time recommended by the manufacturer.

7. PROCEDURE A—SHEAR FREQUENCY SWEEP TEST AT CONSTANT HEIGHT (STIFFNESS)

7.1. Turn on the hydraulic system at least 1 hour before starting the test to allow sufficient warm-up time. Warm up the actuators and hydraulic oil by using a sinusoidal waveform in stroke control.

7.2. Determine the lowest temperature at which the specimen will be tested and precondition the test specimens from 2 to 4 hours (Note 11) at the required test temperature ±0.5°C. Set the temperature for the environmental chamber of the shear test device at the required test temperature.

Note 10—Many specimens are tested at multiple temperatures depending on the desired data. For example, stiffness at an intermediate temperature (such as 20°C) may be desired to provide inputs to a fatigue analysis procedure. Stiffness at a higher temperature (such as 40°C) may be desired to provide an indication of the expected high temperature stiffness of an asphalt mixture. Because of equipment constraints, testing can only be conducted at temperatures where the mixture stiffness is less than approximately 3000 MPa (435 ksi). Because of nonlinear responses, testing should also be confined to temperatures no higher than 12°C below the high-temperature grade of the asphalt binder (i.e., 52°C for a PG 64-22 asphalt binder).

Note 11—A conditioning chamber is preferred since it allows the shear test device to be free to perform tests rather than be occupied for temperature conditioning.

7.3. After the conditioning period, remove the specimen (attached to platens) from the conditioning chamber. Quickly attach the shear and vertical linear variable differential transducers (LVDTs) to the specimen platens. Open the environmental chamber of the shear tester and place the sample with the attached LVDTs on the shear table.

7.4. Ensure that the LVDTs are plugged into the proper data acquisition ports within the shear tester's environmental chamber. Zero the shear and vertical LVDTs.

7.5. Confirm that the vertical test system heads are positioned to allow the platen-specimen assembly to slide between the bottom horizontal and top vertical heads. Confirm that the horizontal test head is positioned such that the top and bottom test heads are aligned vertically. Center the specimen between the heads and secure the platens. Close the environmental chamber.

7.6. Confirm that the environmental chamber temperature control is activated and on the proper setting to maintain the required test temperature with a tolerance of ±0.5°C. Allow the specimen temperature to stabilize for a minimum of 20 minutes and a maximum of 60 minutes. This stabilization time allows the specimen to reacquire the proper test temperature (lost during LVDT instrumentation) and for the LVDTs to stabilize after the temperature change.

7.7. Execute the shear frequency sweep test at constant height.

7.7.1. Precondition the specimen by applying a sinusoidal shear strain consisting of a peak-to-peak amplitude of 0.0001 mm/mm (0.01 percent) at 10 Hz for 100 cycles. During the loading cycle, maintain the specimen height constant, within ±0.013 mm, by applying sufficient axial stress during the loading cycle. This is accomplished by controlling the vertical actuator using closed-loop feedback from the axial LVDT.

7.7.2. Perform the shear frequency sweep test by applying a sinusoidal shear strain of 0.0001 mm/mm (0.01 percent) at each of the following frequencies –10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, and 0.01 Hz. Use 50 cycles each for the 10 Hz and 5 Hz frequencies. Use 20 cycles each for the 2 Hz and 1 Hz frequencies. Use 7 cycles each for the 0.5, 0.2, and 0.1 Hz frequencies. Use 4 cycles each for the 0.05, 0.02, and 0.01 Hz frequencies.

7.7.3. Record the axial and shear deformations (from the LVDTs) and axial and shear loads. Record at a minimum rate of 50 data points per second for the number of cycles specified for each frequency in Section 8.7.2.

7.7.4. At the conclusion of the test, release the loads and return the actuators to the pretest position. Switch the control back to the actuators (from the axial LVDT) and disconnect the LVDTs.

Note 12—Since the shear frequency sweep test is executed in the (theoretically) linear viscoelastic region, the same specimen can be tested using either the simple shear test at constant height (Procedure B) or repeated shear test at constant height (Procedure C). At high temperatures (40°C and higher), the simple shear test at constant height will induce sufficient permanent shear strain to affect further mixture properties. The repeated shear test at constant height should always induce sufficient permanent shear strain to affect mixture properties. Both tests should be considered "destructive" tests. Therefore, it is recommended that shear frequency sweep testing not be conducted on specimens that have been subjected to "destructive" testing.

7.8. Remove the specimen from the test chamber.

Note 13—The shear frequency sweep test at constant height takes approximately 45 minutes to execute from the time the specimen is removed from the conditioning chamber until the test is completed and the specimen is removed from the shear tester.

7.9. If stiffness will be determined at other test temperatures, either: (a) return the specimen to the conditioning chamber and change the temperature of the SST and conditioning chamber to the next desired temperature; or (b) set the specimen aside without cleaning and wait until the temperature of the SST chamber can be adjusted.

7.10. Once stiffness has been determined at all desired temperatures, clean the specimen from the platens by placing the specimen-platen assembly in an oven at approximately 135°C for 60 minutes to debond the specimen and adhesive from the platens. Scrape the platens clean with a scraper. Use acetone or other suitable solvent to remove any remaining adhesive.

8. PROCEDURE B—SIMPLE SHEAR TEST AT CONSTANT HEIGHT

8.1. Turn on the hydraulic system at least 1 hour before starting the test to allow sufficient warm-up time. Warm up the actuators and hydraulic oil by using a sinusoidal waveform in stroke control.

8.2. Determine the lowest temperature at which the specimen will be tested (Note 14) and precondition the test specimens from 2 to 4 hours (Note 11) at the required test temperature ±0.5°C. Set the temperature for the environmental chamber of the shear test device at the required test temperature.

Note 14—Specimens may be tested at multiple temperatures. However, since this test does induce some permanent shear strain, the same specimen should not be tested at temperatures of 40°C or higher. At temperatures less than 40°C, the permanent shear strain should be sufficiently small to allow the specimen to be tested at other temperatures.

8.3. After the conditioning period, remove the specimen (attached to platens) from the conditioning chamber. Quickly attach the shear and vertical linear variable differential transducers (LVDTs) to the specimen platens. Open the environmental chamber of the shear tester and place specimen on the shear table.

8.4. Ensure that the LVDTs are plugged into the proper data acquisition ports within the shear tester's environmental chamber. Zero the shear and vertical LVDTs.

8.5. Confirm that the vertical test system heads are positioned to allow the platen-specimen assembly to slide between the bottom horizontal and top vertical heads. Confirm that the horizontal test head is positioned such that the top and bottom test heads are aligned vertically. Center the specimen between the heads and secure the platens to the heads. Close the environmental chamber.

8.6. Confirm that the environmental chamber temperature control is activated and on the proper setting to maintain the required test temperature with a tolerance of ±0.5°C. Allow the specimen temperature to stabilize for a minimum of 20 minutes and a maximum of 60 minutes. This stabilization time allows the specimen to reacquire the proper test temperature (lost during LVDT instrumentation) and for the LVDTs to stabilize after the temperature change.

8.7. Execute the simple shear test at constant height.

8.7.1. Determine the specified shear stress level for the test. Perform the test by increasing the shear stress at a rate of 70 kPa/s to: 345 ± 5 kPa (4°C); 105 ± 5 kPa (20°C); or 35 ± 1 kPa (40°C). Maintain the stress at the specified level for 10 ± 1 s. Reduce the shear stress to 0 kPa at a rate of 25 ± 1 kPa/s. Continue the test at a stress level of 0 kPa for an additional 10 ± 1 s. During the test, maintain the specimen height constant, within ±0.013 mm, by applying sufficient axial stress during the loading cycle. This is accomplished by controlling the vertical actuator using closed-loop feedback from the axial LVDT.

8.7.2. Record the axial and shear deformations (from the LVDTs) and axial and shear loads. Record at a minimum rate of 50 data points per second.

8.7.3. At the conclusion of the test, release the loads and return the actuators to the pretest position. Switch the control back to the actuators (from the axial LVDT) and disconnect the LVDTs.

8.8. Remove the specimen from the test chamber.

Note 15—The simple shear test at constant height takes approximately 30 minutes to execute from the time the specimen is removed from the conditioning chamber until the test is completed and the specimen is removed from the shear tester.

8.9. If the simple shear test will be executed at other test temperatures, either: (a) return the specimen to the conditioning chamber and change the temperature of the SST and conditioning chamber to the next desired temperature; or (b) set the specimen aside without cleaning and wait until the temperature of the SST chamber can be adjusted.

8.10. Once the simple shear test has been executed at all desired temperatures, clean the specimen from the platens by placing the specimen-platen assembly in an oven at approximately 135°C for 60 minutes to debond the specimen and adhesive from the platens. Scrape the platens clean with a scraper. Use acetone or other suitable solvent to remove any remaining adhesive.

9. PROCEDURE C—REPEATED SHEAR TEST AT CONSTANT HEIGHT

9.1. Turn on the hydraulic system at least one hour before starting the test to allow sufficient warm-up time. Warm up the actuators and hydraulic oil by using a sinusoidal waveform in stroke control.

9.2. Determine the test temperature (Note 15) and precondition the test specimens from 2 to 4 hours at the required test temperature ±0.5°C (Note 11). Set the temperature for the environmental chamber of the shear test device at the required test temperature.

Note 16—The test temperature can be determined in many ways, but is most commonly calculated as the 7-day maximum pavement temperature (at a depth of 50 mm) for the project location. If the mixture in question is the wearing (surface) course, and the thickness of the layer is less than 50 mm, then the actual layer thickness (e.g., 38 mm) may be used as the depth for calculating the test temperature. Information on calculating pavement temperatures is available in SHRP A-648A and LTPP's LTPPBind software.

9.3. After the conditioning period, remove the specimen (attached to platens) from the conditioning chamber. Quickly attach the shear and vertical linear variable differential transformers to the specimen platens. Open the environmental chamber of the shear tester and place the specimen on the shear table.

9.4. Ensure that the LVDTs are plugged into the proper data acquisition ports within the shear tester's environmental chamber. Zero the shear and vertical LVDTs.

9.5. Confirm that the vertical test system heads are positioned to allow the platen-specimen assembly to slide between the bottom horizontal and top vertical heads. Confirm that the horizontal test head is positioned such that the top and bottom test heads are aligned vertically. Center the specimen between the heads and secure the platens to the heads. Close the environmental chamber.

9.6. Confirm that the environmental chamber temperature control is activated and on the proper setting to maintain the required test temperature with a tolerance of ±0.5°C. Allow the specimen temperature to stabilize for a minimum of 20 minutes and a maximum of 60 minutes. This stabilization time allows the specimen to reacquire the proper test temperature (lost during LVDT instrumentation) and for the LVDTs to stabilize after the temperature change.

9.7. Execute the repeated shear test at constant height.

9.7.1. Apply a repeated haversine shear stress to the test specimen consisting of 69 ± 5 kPa (approximately 1220 N shear load for a 150-mm diameter test specimen) for 0.1 s followed by a 0.6-s rest period. During the loading cycle, maintain the specimen height constant, within ±0.013 mm, by applying sufficient axial stress during the loading cycle. This is accomplished by controlling the vertical actuator using closed-loop feedback from the axial LVDT.

9.7.2. Continue the test sequence for 5000 cycles or until the shear LVDT exceeds its range (usually at 2.5-mm or 5 percent shear strain), whichever comes first.

9.7.3. Record the axial and shear deformations (from the LVDTs) and axial and shear loads. Record at a minimum rate of 50 data points per second during the intervals specified in Table 2.

Table 2—Required Interval Ranges for Recording Data for Procedure B and C

Data	Cycles
1 through 10	1599 through 1601
19 through 21	1799 through 1801
29 through 31	1999 through 2001
49 through 51	2249 through 2251
79 through 81	2499 through 2501
99 through 101	2749 through 2751
199 through 201	2999 through 3001
299 through 301	3249 through 3251
399 through 401	3499 through 3501
499 through 501	3749 through 3751
599 through 601	3999 through 4001
799 through 801	4249 through 4251
999 through 1001	4499 through 4501
1199 through 1201	4749 through 4751
1399 through 1401	4999 through 5000

9.7.4. At the conclusion of the test, release the loads and return the actuators to the pretest position. Switch the control back to the actuators (from the axial LVDT) and disconnect the LVDTs.

9.8. Remove the specimen from the test chamber.

Note 17—The repeated shear test at constant height takes approximately 90 minutes to execute from the time the specimen is removed from the conditioning chamber until the test is completed and the specimen is removed from the shear tester.

9.9. Clean the specimen from the platens by placing the specimen-platen assembly in an oven at approximately 135°C for 60 minutes to debond the specimen and adhesive from the platens. Scrape the platens clean with a scraper. Use acetone or other suitable solvent to remove any remaining adhesive.

10. DATA ANALYSIS

10.1. *Procedure A (Shear Frequency Sweep Test at Constant Height)*—For each specimen, determine the complex shear modulus (G^*) and phase angle (δ) at each frequency. These values are usually calculated by software programs from the measured values of shear load, axial load, shear displacement, and axial displacement.

10.2. *Procedure B (Simple Shear Test at Constant Height)*—For each specimen, calculate the maximum shear strain achieved in Equations 1 and 2:

$$\gamma_{\text{max}} = \frac{\delta_{\text{shear, maximum}} - \delta_{\text{shear, initial}}}{h} \qquad (1)$$

where:

γ_{max} = maximum shear strain;

$\delta_{\text{shear, maximum}}$ = maximum recorded deformation by the shear LVDT;

$\delta_{\text{shear, initial}}$ = initial shear deformation at the start of the test (nominally zero); and

H = specimen height (platen-to-platen measurement only).

10.2.1. The recovery can also be calculated as follows:

$$\text{Recovery} = \frac{\delta_{\text{shear, maximum}} - \delta_{\text{shear, final}}}{\delta_{\text{shear, maximum}}} \qquad (2)$$

where:

Recovery = calculated recovery of the specimen;

$\delta_{\text{shear, maximum}}$ = maximum recorded deformation by the shear LVDT; and

$\delta_{\text{shear, final}}$ = final recorded shear deformation at the end of the test.

10.3. *Procedure C (Repeated Shear Test at Constant Height)*—For each specimen, determine the permanent shear strain at the end of the test (nominally 5000 cycles). The permanent shear strain (γ_p) is calculated as the change in shear deformation from the start of the test to the end of the test divided by the gauge length (nominally 50 mm when using platen-to-platen measurement) in Equation 3:

$$\gamma_p = \frac{\delta_{\text{shear, final}} - \delta_{\text{shear, initial}}}{h} \qquad (3)$$

where:

γ_p = permanent shear strain;

$\delta_{\text{shear, final}}$ = final recorded deformation by the shear LVDT at the end of the test;

$\delta_{\text{shear, initial}}$ = initial shear deformation at the start of the test (nominally zero); and

H = specimen height (platen-to-platen measurement only).

10.3.1. The permanent shear strain can also be expressed as a percentage by multiplying by 100.

11. REPORT

11.1. *Report the following information for each test specimen*:

11.1.1. Mixture identification and specimen identification;

11.1.2. Percentage of air voids in the test specimen, or bulk specific gravity;

11.1.3. Conditioning time and temperature (within 0.1°C);

11.1.4. Equilibration or stabilization time, minutes;

11.1.5. Measured temperature during the test (within 0.1°C);

11.1.6. Note any deviations from the test procedures for each specimen (i.e., shear loads out of tolerance, etc.).

11.2. *Report the following information for Procedure A (Shear Frequency Sweep Test at Constant Height)*:

11.2.1. For each specimen, report the complex shear modulus (G^*) and phase angle (δ) at each frequency.

11.3. *Report the following information for Procedure B (Simple Shear Test at Constant Height)*:

11.3.1. For each specimen, report the maximum shear strain obtained (usually expressed in terms of microns, or 10^{-6} mm/mm) and recovery (expressed as a percentage).

11.4. *Report the following information for Procedure C (Repeated Shear Test at Constant Height)*:

11.4.1. For each specimen, report the permanent shear strain obtained at 5000 cycles. If the test stops before 5000 cycles, report the permanent shear strain and the number of cycles.

12. PRECISION AND BIAS

12.1. *Precision*—The research required to develop precision estimates for the shear frequency sweep, simple shear, and repeated shear test procedures has not been formally conducted.

12.2. *Bias*—The research required to determine the bias of the procedures has not been conducted.

13. KEYWORDS

13.1. Frequency sweep; permanent strain; repeated shear; shear testing; simple shear; stiffness.

APPENDIX

(Nonmandatory Information)

X1. CALCULATING AGGREGATE BATCH WEIGHT FOR LABORATORY-MIXED, LABORATORY-COMPACTED SPECIMENS

X1.1. Calculate the aggregate batch weight required for laboratory-mixed, laboratory-compacted (LMLC) specimens, using Equation X1.1 (valid for 150-mm diameter specimens):

$$\text{Mass} = \frac{17.671 \times \text{Height} \times G_{mm} \times \left(1 - AV\right)}{\left(1 - AC\right)} \quad (X1.1)$$

where:

Mass = aggregate batch weight, g;

Height = target compacted height of the specimen, mm;

G_{mm} = maximum theoretical specific gravity (T 209) of the mixture;

AV = percentage of air voids desired, expressed as a decimal (i.e., 0.04 rather than 4.0 percent); and

AC = asphalt binder content of the mix, expressed as a decimal (i.e., 0.045 rather than 4.5 percent).

Example: A mixture with a 5.2 percent asphalt binder content and a G_{mm} of 2.533 is intended to be evaluated in the repeated shear test to estimate rutting susceptibility. The technician desires the test specimen to have 4.0 ± 0.5 percent air voids. Therefore, anticipate compacting a specimen to a height of 75 mm and allowing a 1 percent offset in air voids between the compacted specimen and the cut test specimen (Note 8). Using Equation X1.1, the aggregate batch weight is determined:

$$\text{Mass} = \frac{17.671 \times 75 \times 2.533 \times \left(1 - 0.05\right)}{\left(1 - 0.052\right)} = 3364 \text{ g} \quad (X1.2)$$

X2. CALCULATING MIXTURE SAMPLE WEIGHT FOR FIELD-MIXED, LABORATORY-COMPACTED SPECIMENS

X2.1. Calculate the mixture sample weight required for field-mixed, laboratory-compacted (FMLC) specimens, using Equation X2.1 (valid for 150-mm diameter specimens):

$$\text{Mass} = 17.671 \times \text{Height} \times G_{mm} \times \left(1 - AV\right) \qquad (X2.1)$$

where:

Mass = aggregate batch weight, g;

Height = target compacted height of the specimen, mm;

G_{mm} = maximum theoretical specific gravity (T 209) of the mixture; and

AV = percentage of air voids desired, expressed as a decimal (i.e., 0.04 rather than 4.0 percent).

X2.2. Alternatively, determine the compacted specimen height if the sample mass is known:

$$\text{Height} = \frac{\text{Mass}}{17.671 \times G_{mm} \times \left(1 - AV\right)} \qquad (X2.2)$$

Example: A mixture sample of 4220 g is obtained. The G_{mm} of the mixture is determined to be 2.471. To produce a test specimen having approximately 4.0 ± 0.5 percent air voids, the target compacted height should be calculated as follows:

$$\text{Height} = \frac{4220}{17.671 \times 2.47 \times \left(1 - 0.05\right)} = 101.7 \text{ mm} \qquad (X2.3)$$

Standard Method of Test for

Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending

AASHTO Designation: T 321-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending

AASHTO Designation: T 321-07

1. SCOPE

1.1. This standard provides procedures for determining the fatigue life and fatigue energy of 380 mm long by 50 mm thick by 63 mm wide hot mix asphalt (HMA) beam specimens sawed from laboratory or field compacted HMA and subjected to repeated flexural bending until failure.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- PP 3, Preparing Hot Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor[1]
- T 2, Sampling of Aggregates
- T 40, Sampling Bituminous Materials
- T 168, Sampling Bituminous Paving Mixtures
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

2.2. *ASTM Standards*:

- D 3202, Standard Practice for Preparation of Bituminous Mixture Beam Specimens by Means of the California Kneading Compactor
- D 3549, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 5361, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1. *Definitions:*

3.1.1. *failure point*—the load cycle at which the specimen exhibits a 50 percent reduction in stiffness relative to the initial stiffness.

4. SIGNIFICANCE AND USE

4.1. The fatigue life and failure energy determined by this standard can be used to estimate the fatigue life of HMA pavement layers under repeated traffic loading. The performance of HMA can be more accurately predicted when these properties are known.

5. APPARATUS

5.1. *Test System*—The test system shall consist of a loading device, an environmental chamber (optional), and a control and data acquisition system. The test system shall meet the minimum requirements specified in Table 1.

Table 1—Test System Minimum Requirements

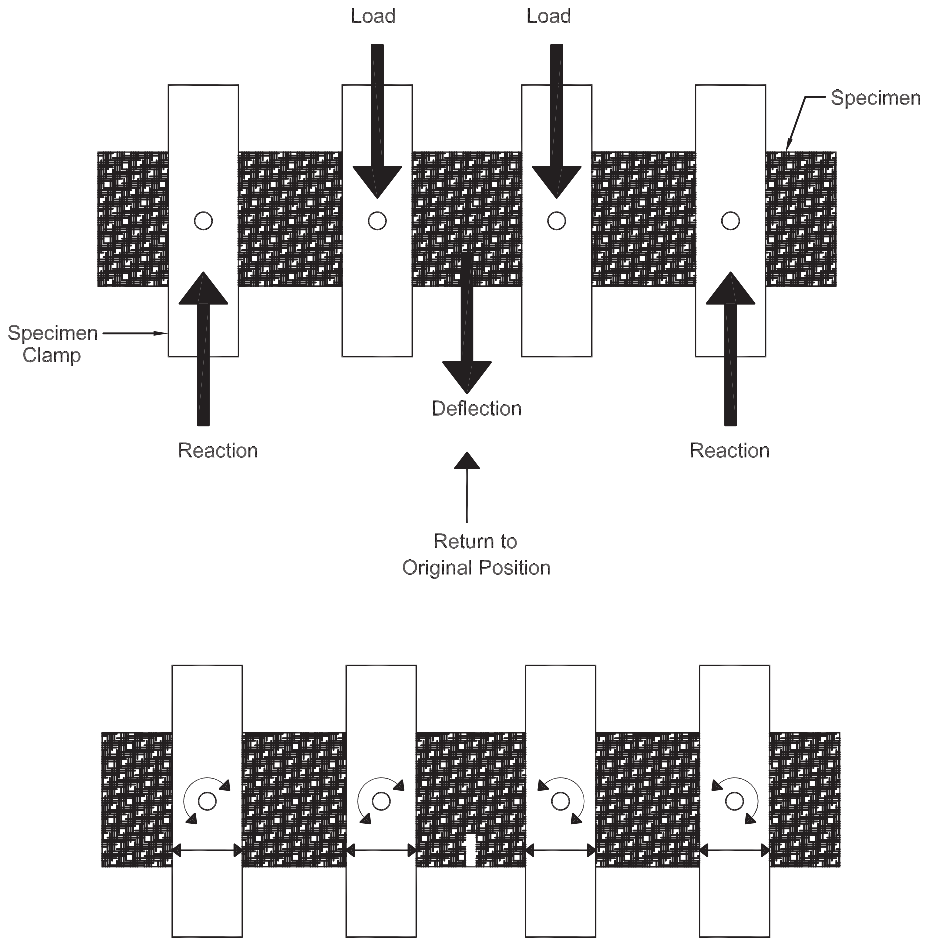
Load Measurement and Control	Range:	0 to 5 kN
	Resolution:	2 N
	Accuracy:	5 N
Displacement Measurement and Control	Range:	0 to 5 mm
	Resolution:	2 µm
	Accuracy:	5 µm
Frequency Measurement and Control	Range:	5 to 10 Hz
	Resolution:	0.005 Hz
	Accuracy:	0.01 Hz
Temperature Measurement and Control	Range:	–10 to 25˚C
	Resolution:	0.25˚C
	Accuracy:	±0.5˚C

5.1.1. *Loading Device*—The test system shall include a closed-loop, computer controlled loading component which, during each load cycle in response to commands from the data processing and control component, adjusts and applies a load such that the specimen experiences a constant level of strain during each load cycle. The loading device shall be capable of (1) providing repeated sinusoidal loading at a frequency range of 5 to 10 Hz; (2) subjecting specimens to four-point bending with free rotation and horizontal translation at all load and reaction points; and (3) forcing the specimen back to its original position (i.e., zero deflection) at the end of each load pulse. (Figure 1 illustrates the loading conditions.)

5.1.2. *Environmental Chamber (Optional)*—The environmental chamber shall enclose the entire specimen and maintain the specimen at 20.0 ± 0.5°C during testing. An environmental chamber is not required if the temperature of the surrounding environment can be maintained within the specified limits.

5.1.3. *Control and Data Acquisition System*—During each load cycle, the control and data acquisition system shall be capable of measuring the deflection of the beam specimen, computing the strain in the specimen, and adjusting the load applied by the loading device such that the specimen experiences a constant level of strain on each load cycle. In addition, it shall be capable of recording load cycles, applied loads, and beam deflections and computing and recording the maximum tensile stress, maximum tensile strain, phase angle, stiffness, dissipated energy, and cumulative dissipated energy at load cycle intervals specified by the user.

5.2. *Miscellaneous Apparatus and Materials*—A suitable saw for cutting the beams and a mechanism for setting proper clamp spacing. For loading devices that require a glued nut for deformation measurement, a screw, nut (suggested size M 8 by 1) and block assembly for referencing the linear variable differential transducer (LVDT) to the neutral axis of the specimen, and epoxy for attaching the nut to the specimen are also needed.



Free Translation and Rotation

Figure 1—Load and Freedom Characteristics of Fatigue Test Apparatus

6. HAZARDS

6.1. Observe standard laboratory safety precautions when preparing and testing HMA specimens.

7. SAMPLING AND SPECIMEN PREPARATION

7.1. *Laboratory-Mixed and Compacted Specimens*—Sample asphalt binder in accordance with T 40 and sample aggregate in accordance with T 2. Prepare three replicate hot mix asphalt beam specimens, from slab(s) or beam(s) compacted in accordance with PP 33 or ASTM D 3202.

Note 1—The type of compaction device may influence the test results. It is recommended to cut beams from a large slab compacted by a vibratory roller.

Note 2—Normally, test specimens are compacted using a standard compactive effort. However, the standard compactive effort may not reproduce the air voids of roadway specimens measured according to T 269. If specimens are to be compacted to a target air void content, the compactive effort to be used should be determined experimentally.

7.2. *Plant-Mixed, Laboratory-Compacted Specimens*—Obtain HMA samples in accordance with T 168. Prepare three replicate hot mix asphalt beam specimens, from slab(s) or beam(s) compacted in accordance with PP 3 or ASTM D 3202. (See Notes 1 and 2.)

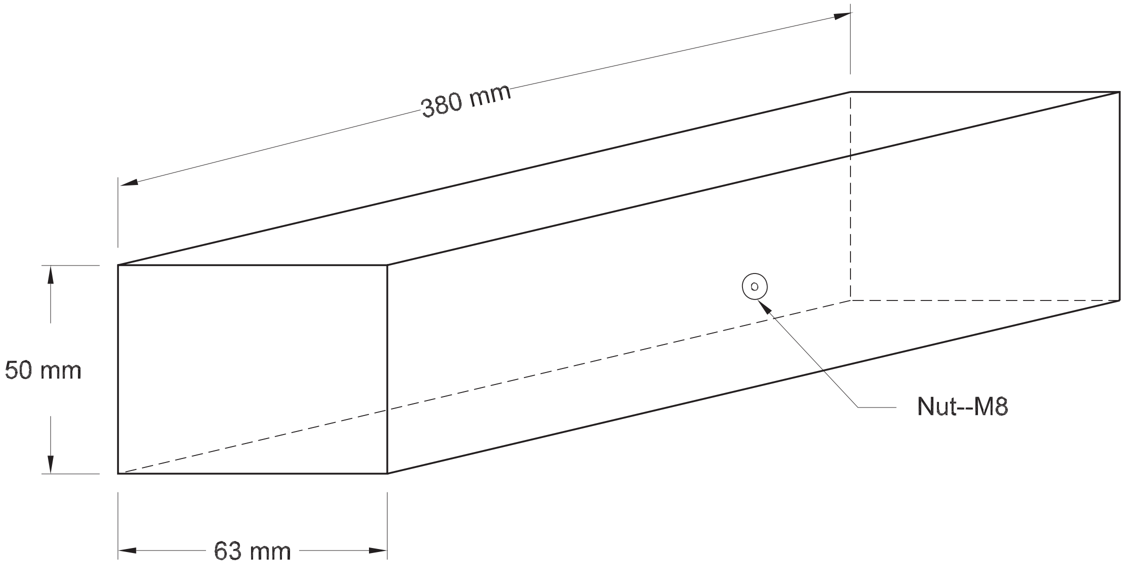
7.3. *Roadway Specimens*—Obtain compacted HMA samples from the roadway in accordance with ASTM D 5361.

7.4. Saw at least 6 mm from both sides of each test specimen to provide parallel (saw-cut) surfaces to eliminate high air void sections on the specimen surface. For loading devices that require gluing a nut for deformation measurement, these cut surfaces provide smooth surfaces for mounting the measurement gauges. The final required dimensions, after sawing, of the specimens are 380 ± 6 mm in length, 50 ± 6 mm in height, and 63 ± 6 mm in width.

8. PROCEDURE

8.1. *Specimen Measurement*—Measure the height and width of the specimen to the nearest 0.01 mm at three different points along the middle 100 mm of the specimen length in accordance with applicable sections of ASTM D 3549. Determine the average of the three measurements for each dimension and record the averages to the nearest 0.1 mm.

8.2. *Epoxying Nut to Neutral Axis of Specimen*—Locate the center of a specimen side. Apply epoxy in a circle around this center point and place the nut on the epoxy such that the center of the nut is over the center point. Avoid applying epoxy such that it fills the center of the nut. Allow the epoxy to cure before moving the specimen. (Figure 2 illustrates a nut epoxied to the neutral axis of the specimen.)



Note: Not to scale.

Figure 2—Nut Epoxied to the Neutral Axis

8.3. Place the specimen in an environment which is at 20.0 ± 0.5°C for 2 hours to ensure the specimen is at the test temperature prior to beginning the test.

8.4. Open the clamps and slide the specimen into position (Figures 3, 4, and 5). Use the jig to ensure proper horizontal spacing of the clamps, 119 mm center-to-center. When the specimen and clamps are in the proper positions, close the outside clamps by applying sufficient pressure to hold the specimen in place. Next, close the inside clamps by applying sufficient pressure to hold the specimen in place.

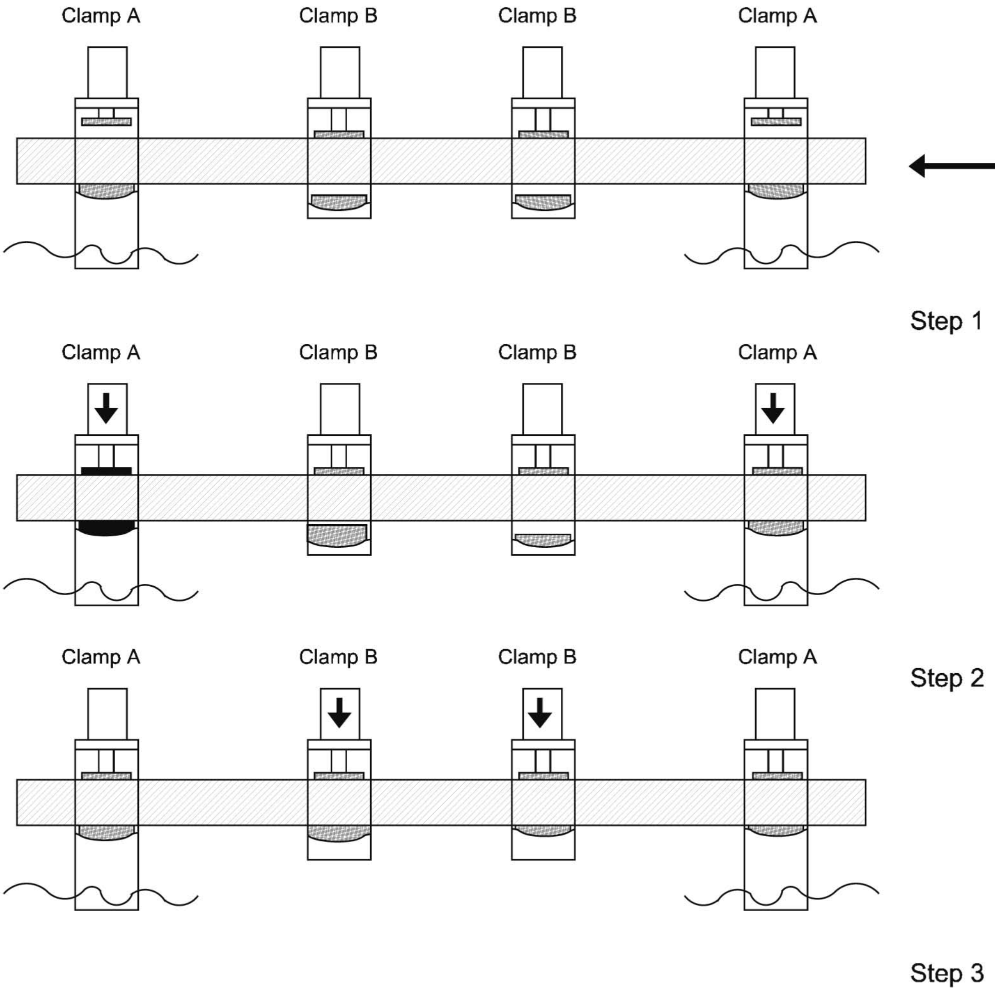


Figure 3—Specimen Clamping Procedure

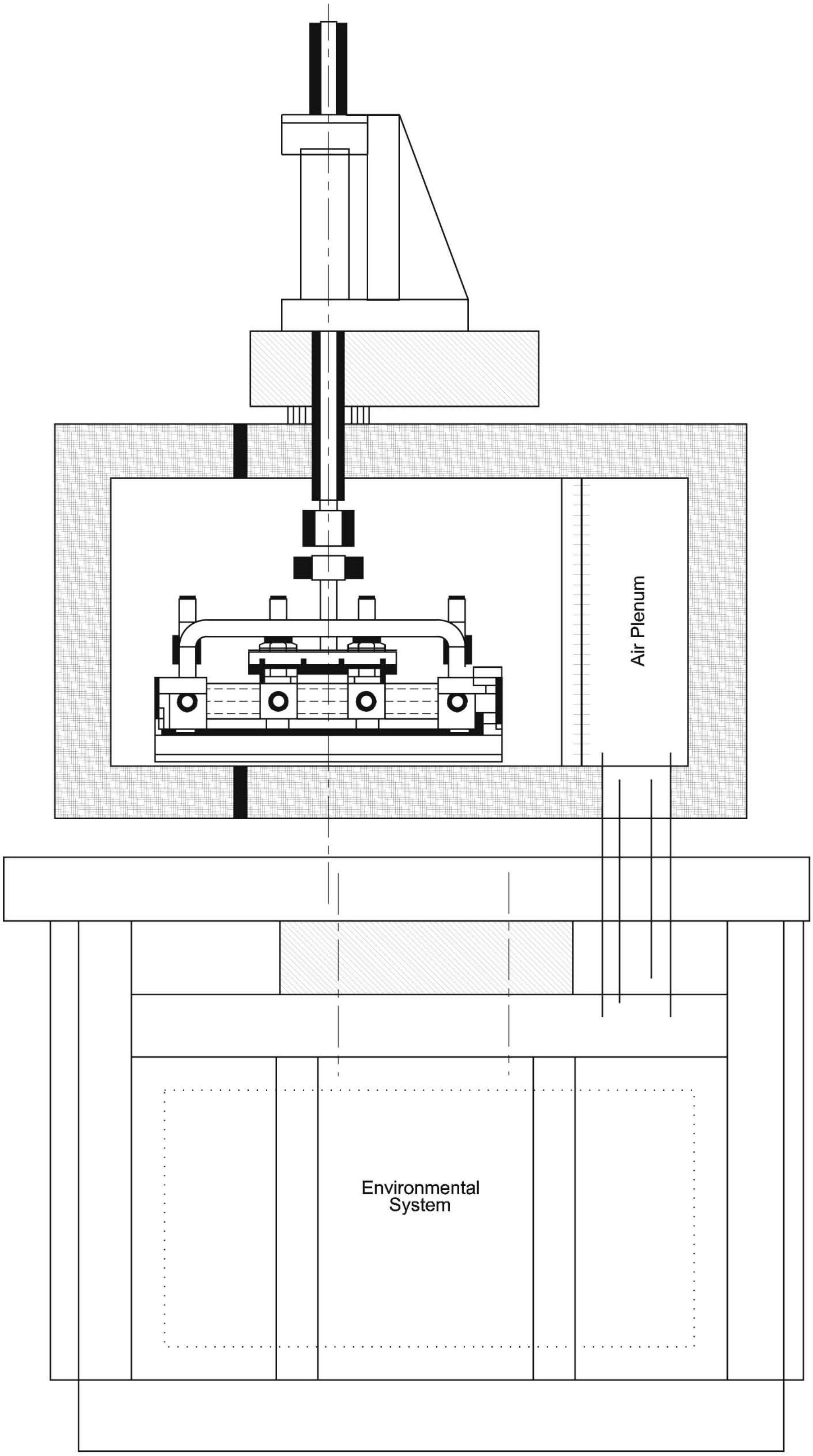


Figure 4—Schematic of Flexural Beam Fatigue Test Apparatus, Side View

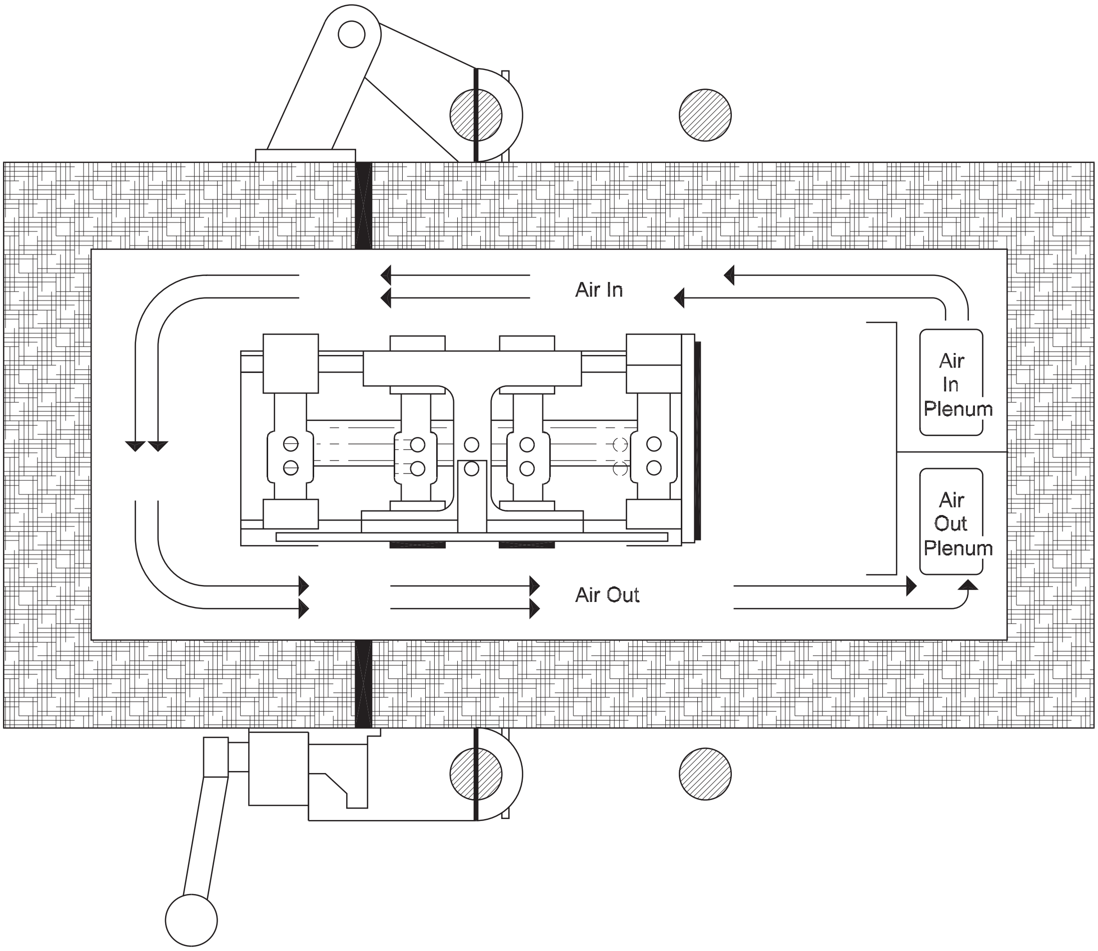


Figure 5—Schematic of Flexural Beam Fatigue Test Apparatus, Top View

8.5. Attach the LVDT block to the specimen by screwing the screw into the nut epoxied on the specimen. (Figure 4 illustrates the connection of the screw/nut/block assembly and the LVDT such that beam deflections at the neutral axis will be measured.) Clamp the LVDT into position such that the LVDT probe rests on top of the block and the LVDT is reading close to zero.

8.6. Select the desired initial strain (250 to 750 microstrain) and loading frequency, and the load cycle intervals at which test results are recorded and computed and enter them into the recording and control component's test program. Set the loading frequency within a range of 5 to 10 Hz.

Note 3—Selection of load cycle intervals at which test results are computed and recorded may be limited by the amount of memory available for storing data.

8.7. Apply 50 load cycles at a constant strain of 250 to 750 microstrain. Determine the specimen stiffness at the 50th load cycle. This stiffness is an estimate of the initial stiffness, which is used as a reference for determining specimen failure.

8.8. Select a deflection level (strain level) such that the specimen will undergo a minimum of 10,000 load cycles before its stiffness is reduced to 50 percent or less of the initial stiffness. A stiffness reduction of 50 percent or more represents specimen failure. A minimum of 10,000 load cycles ensures that the specimen does not decrease in stiffness too rapidly.

8.9. After selecting the appropriate test parameters, begin the test. Activate the recording and control components so that the test results at the selected load cycle intervals are monitored and recorded, ensuring that the test system is operating properly. When the specimen has experienced greater than 50 percent reduction in stiffness, terminate the test.

9. CALCULATIONS

9.1. Perform the following calculations at the operator-specified load cycle intervals:

9.1.1. *Maximum Tensile Stress (Pa)*:

$$\sigma_t = (0.357P)/(bh^2) \tag{1}$$

where:
P = load applied by actuator, in newtons;
b = average specimen width, in meters; and
h = average specimen height, in meters.

9.1.2. *Maximum Tensile Strain (m/m)*:

$$\in_t = (12\delta\, h)/(3L^2 - 4a^2) \tag{2}$$

where:
δ = maximum deflection at center of beam, in m;
a = space between inside clamps, 0.357/3 m, (0.119 m); and
L = length of beam between outside clamps, 0.357 m.

9.1.3. *Flexural Stiffness (Pa)*:

$$S = \sigma_t / \in_t \tag{3}$$

9.1.4. *Phase Angle* (deg):

$$\varphi = 360 fs \tag{4}$$

where:
f = load frequency, in Hz; and
s = time lag between $P_{\max}$ and $\delta_{\max}$, in seconds.

Note 4—When automated testing software is used in the recording and control component of the test system, φ is approximated by an algorithm contained in the automated testing software.

9.1.5. *Dissipated Energy (J/m^3) per cycle*:

$$D = \pi\sigma_t \in_t \sin(\varphi) \tag{5}$$

9.1.6. *Cumulative Dissipated Energy*, *J/m^3*:

$$\sum_{i=1}^{i=n} D_i \tag{6}$$

where:

D_i = D for the i^{th} load cycle.

Note 5—It may not be possible to calculate dissipated energy D for every load cycle due to memory limitations of the recording and control component. Therefore, dissipated energy may be plotted against load cycles for the particular load cycles at which data was collected (i.e., the load cycles selected by the operator) up to the load cycle of interest. The area under the curve represents the cumulative dissipated energy. See Figure 6 for a typical dissipated energy versus load cycle plot.

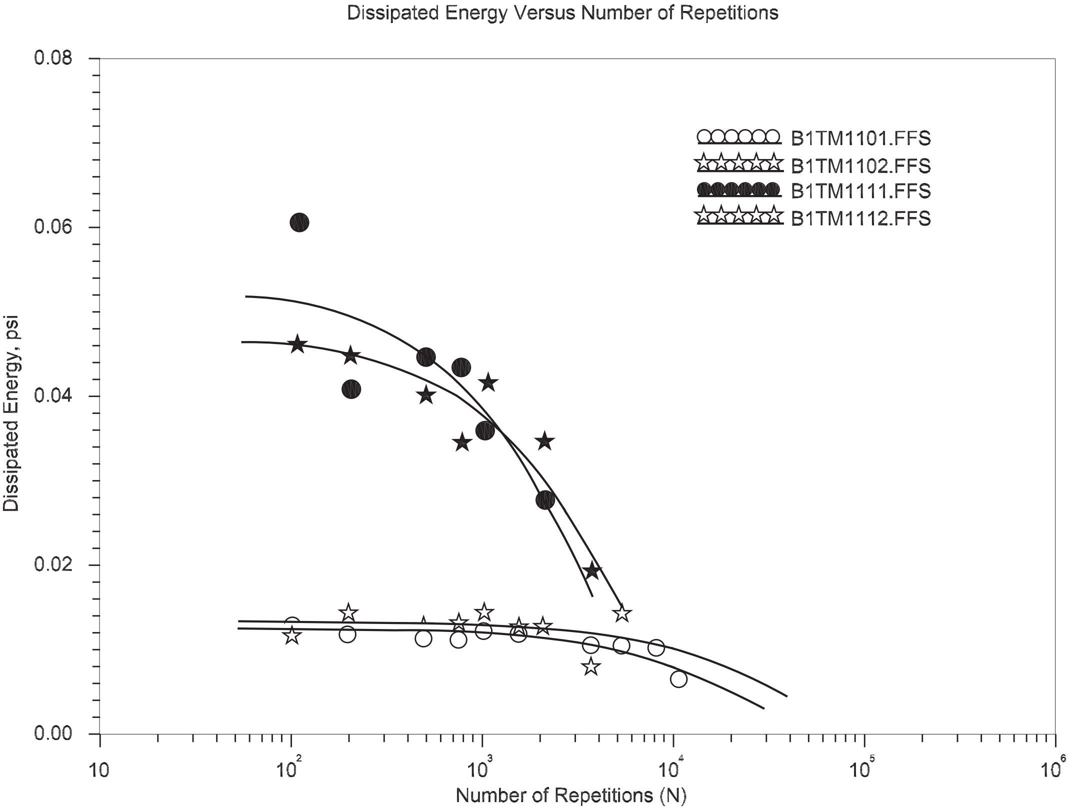


Figure 6—Dissipated Energy Versus Load Cycles (Repetitions)

9.1.7. *Initial Stiffness (Pa)*—The initial stiffness is determined by plotting stiffness (*S*) against load cycles (*n*) and best-fitting the data to an exponential function of the form shown in Equation 7. Figure 7 presents a typical plot of stiffness versus load cycles. The constant *A* represents the initial stiffness.

$$S = Ae^{bn} \quad (7)$$

where:

e = natural logarithm to the base e;
A = constant; and
b = constant.

9.1.8. *Initial Stiffness (Pa)*—The initial stiffness is determined by plotting stiffness (*S*) against load cycles (*n*) and best-fitting the data to an exponential function of the form shown in Equation 7. Figure 7 presents a typical plot of stiffness versus load cycles. The constant *A* represents the initial stiffness.

$$S = Ae^{bn} \quad (8)$$

where:

e = natural logarithm to the base e;
A = constant; and
b = constant.

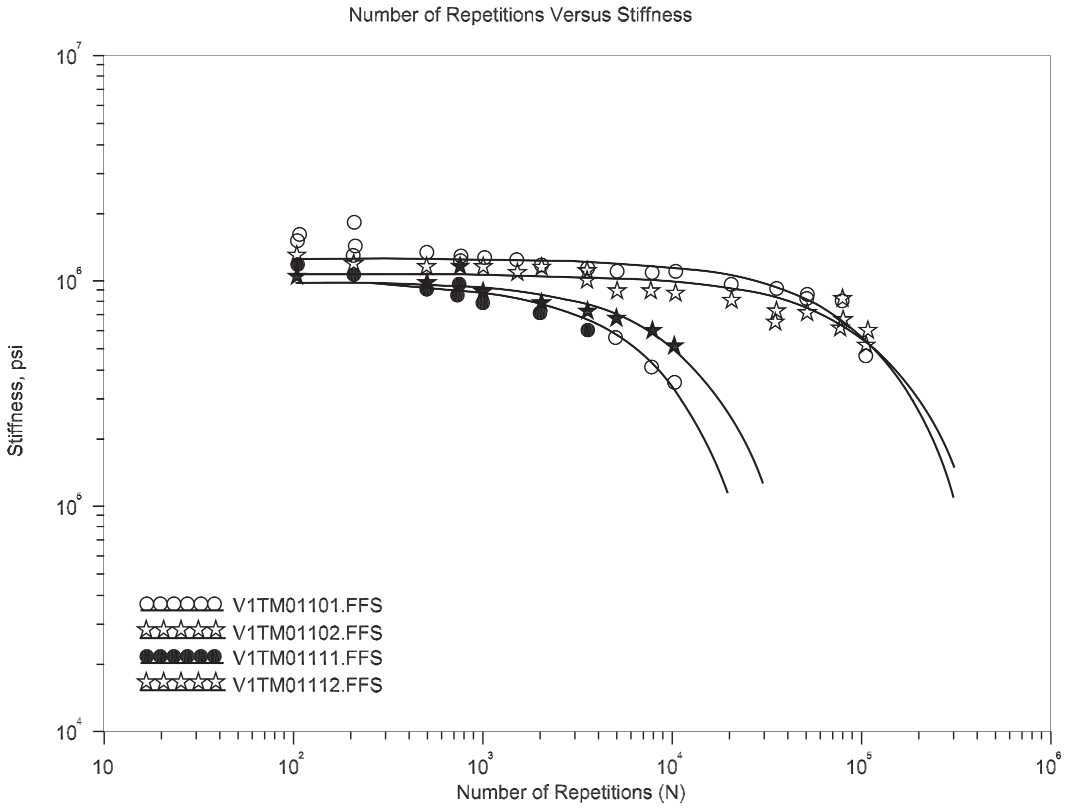


Figure 7—Stiffness Versus Load Cycles (Repetitions)

9.1.9. *Cycles to Failure*—Failure is defined as the point at which the specimen stiffness is reduced to 50 percent of the initial stiffness. The load cycle at which failure occurs is computed by solving for *n* from Equation 7, or simply:

$$n_{f,50} = \left[\ln\left(S_{f,50} / A\right)\right] / b \qquad (9)$$

where:

$S_{f,50}$ = stiffness, 50 percent of initial stiffness, in Pa; and
$S_{f,50}/A$ = 0.5, by definition.

9.1.10. *Cumulative Dissipated Energy to Failure (J/m^3)*:

$$\sum_{i=1}^{i=n_{f,50}} D_i \qquad (10)$$

Note 6—It is not necessary to measure the dissipated energy for every load cycle; however, the automated testing software used to control the fatigue test systematically determines the dissipated energy at specified load cycles during the test. The total dissipated energy to failure is summarized as part of the output.

10. REPORT

10.1. *Hot Mix Asphalt Description*—Report the binder type, binder content, aggregate gradation, and air void percentage.

10.2. *Specimen Dimensions*—Report the specimen length, average specimen height, and average specimen width in meters, to four significant figures.

Note 7—See E 29 for information on determination of significant figures in calculations.

10.3. Report the average test temperature to the nearest 0.2°C.

10.4. Report the test results listed in Table 2 for each load cycle interval selected by the operator to three significant figures.

Table 2—Test Results

Load Cycle	Applied Load	Beam Deflection	Tensile Stress	Tensile Strain	Flexural Stiffness	Phase Angle	Dissipated Energy	Cumulative Dissipated Energy
	N	m	Pa	m/m	Pa	degree	J/m^3	J/m^3

10.5. Report the initial flexural stiffness in pascals.

10.6. Report the cycles to failure.

10.7. Prepare a plot of stiffness versus load cycles as shown in Figure 7.

10.8. Prepare a plot of dissipated energy versus load cycles as shown in Figure 6.

11. PRECISION AND BIAS

11.1. *Precision*—The research required to develop precision values has not been conducted.

11.2. *Bias*—The research required to establish the bias of this method has not been conducted.

12. KEYWORDS

11.1.

12.1. Fatigue life; flexural bending; hot mix asphalt fatigue; hot mix asphalt flexural testing; hot mix asphalt tensile testing; hot mix asphalt stiffness; hot mix asphalt energy dissipation.

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[1] PP 3-94 (1996) was last printed in the May 2002 edition of the *AASHTO Provisional Standards*.

Standard Method of Test for

Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device

AASHTO Designation: T 322-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device

AASHTO Designation: T 322-07

1. SCOPE

1.1. This standard provides procedures for determining the tensile creep compliance at different loading times, tensile strength and Poisson's ratio of hot mix asphalt (HMA) using indirect loading techniques.

1.2. The procedures described in this standard provide the data required to conduct the thermal cracking analysis. These procedures apply to test specimens having a maximum aggregate size of 38 mm or less. Specimens shall be 38 to 50 mm high and 150 ± 9 mm in diameter.

1.3. *This test may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- PP 3, Hot Mix Asphalt (HMA) Specimens by Means of the Rolling Wheel Compactor[1]
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 320, Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)

2.2. *ASTM Standards*:

- D 3549, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 5361, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing

2.3. *Other Document*:

- *The Superpave™ Mix Design Manual for New Construction and Overlays*

3. TERMINOLOGY

3.1. *Definitions*:

3.2. *creep*—the time-dependent part of strain resulting from stress.

3.3. *creep compliance*—the time-dependent strain divided by the applied stress.

3.4. *tensile strength*—the strength shown by a specimen subjected to tension, as distinct from torsion, compression, or shear.

3.5. *Poisson's ratio (ν)*—the absolute value of the ratio of transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

4. SUMMARY OF METHOD

4.1. This standard describes the procedure for determining the tensile creep and tensile strength to be determined on the same specimen for thermal cracking analyses.

4.2. The tensile creep is determined by applying a static load of fixed magnitude along the diametral axis of a specimen. The horizontal and vertical deformations measured near the center of the specimen are used to calculate a tensile creep compliance as a function of time. Loads are selected to keep horizontal strains in the linear viscoelastic range (typically below a horizontal strain of 500×10^{-6} mm/mm) during the creep test. By measuring both horizontal and vertical deformations in regions where the stresses are relatively constant and away from the localized nonlinear effects induced by the steel loading strips, Poisson's ratio can be more accurately determined. Creep compliance is sensitive to Poisson's ratio measurements.

4.3. The tensile strength is determined immediately after determining the tensile creep or separately by applying a constant rate of vertical deformation (or ram movement) to failure.

5. SIGNIFICANCE AND USE

5.1. Tensile creep and tensile strength test data are required for Superpave mixtures to determine the master relaxation modulus curve and fracture parameters. This information is used to calculate the thermal cracking of HMA. The master relaxation modulus curve controls thermal crack development while the fracture parameter defines a mixture's resistance to fracture.

5.2. The values of creep compliance, tensile strength, and Poisson's ratio determined with this method can be used in linear viscoelastic analysis to calculate the low temperature thermal cracking potential of asphalt concrete.

5.3. Tensile creep data may be used to evaluate the relative quality of materials.

5.4. This procedure is applicable to newly prepared mixtures, reheated, and recompacted mixtures. Reheated and recompacted mixtures will have lower creep compliance values than newly prepared mixtures when measured under these specific loading conditions and temperatures.

5.5. This procedure is applicable for mixtures with a maximum aggregate size of 38 mm or less.

6. APPARATUS

6.1. *Indirect Tensile Test System*—The indirect tensile test system shall consist of an axial loading device, a load measuring device, specimen deformation measurement devices, an environmental chamber, and a control and data acquisition system.

6.1.1. *Axial Loading Device*—The loading device shall be capable of providing a fixed or constant load of 100 kN with a resolution of at least 20 N and constant rate of ram displacement of at least 12 mm/minute.

6.1.2. *Load Measuring Device*—The load measuring device shall consist of an electronic load cell, designed for placement between the loading platen and piston, with a sensitivity of 20 N, and a minimum capacity of 100 kN.

6.1.3. *Specimen Deformation Measurement Devices*—The specimen deformation measurement devices shall consist of four displacement transducers with a range of at least 25 mm, reducible to 0.25 mm through software, and a minimum resolution throughout the range of 0.10 μm.

6.1.4. *Environmental Chamber*—The environmental chamber shall be equipped with temperature conditioners and controls capable of generating test temperatures between –30 and +10°C inside the chamber and maintaining the desired test temperature to within ±0.5°C. The internal dimensions of the environmental chamber shall be sufficient to hold a minimum of three test specimens for a period of 12 hours prior to testing.

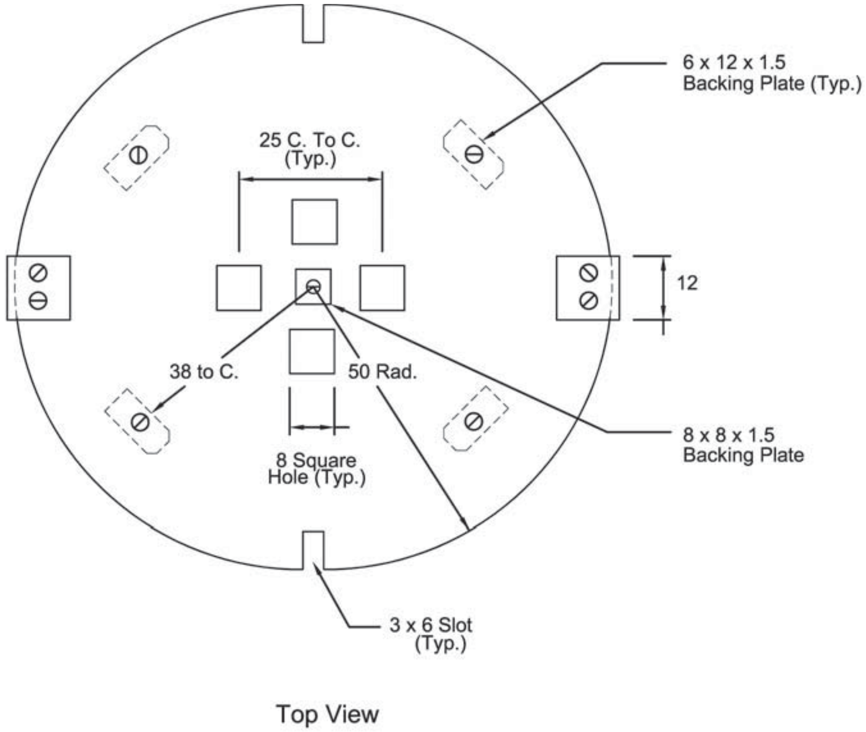
6.1.5. *Control and Data Acquisition System*—Specimen behavior in the creep compliance test is evaluated from time records of applied load and specimen deformation. These parameters shall be recorded on an analog to digital data acquisition device.

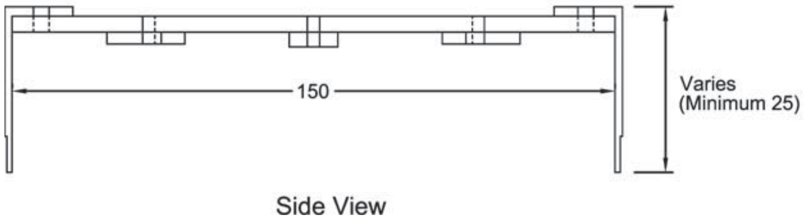
6.1.5.1. When determining the 100-second tensile creep for Superpave, digital data acquisition devices shall provide a sampling frequency of 10 Hz for the first 10 seconds and 1 Hz for the next 90 seconds. When determining the 1000-second tensile creep, digital data acquisition devices shall provide a sampling frequency of 10 Hz for the first 10 seconds, 1 Hz for the next 90 seconds, and 0.1 Hz for the rest of 900 seconds. When determining the tensile strength test, digital data acquisition devices shall provide a sampling frequency of 20 Hz through the entire test. A 16-bit A/D board is normally required to obtain the resolution needed when determining the tensile creep and the range needed when determining the tensile strength.

6.1.6. *Gauge Points*—Eight brass gauge points having a diameter of 8 mm and a height of 3.2 mm are required per specimen.

6.1.7. *Mounting Template*—A mounting template for placing and mounting the brass gauge points to each side of the test specimen (four per side) which have been used successfully are shown in Figures 1 and 2. An example of a template for use with 150-mm diameter specimens is shown in Figure 1. Other similar and comparable systems such as those used in T 320 can be used.

6.1.8. *Test Specimen Loading Frame*—The specimen load frame shall be as described in ASTM D 4123-82(95) and capable of delivering test loads coincident with the vertical diametral plane of the test specimen and with less than 20 N frictional resistance in guides and/or bearings. Often a smaller guide frame with special alignment capabilities is used in conjunction with the larger loading frame to accomplish this. The frame may be configured with two support columns or four support columns (Figure 2).





Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Tolerances ±0.2 mm unless otherwise noted.
3. Not to scale.

Figure 1—150-mm Gauge Point Template

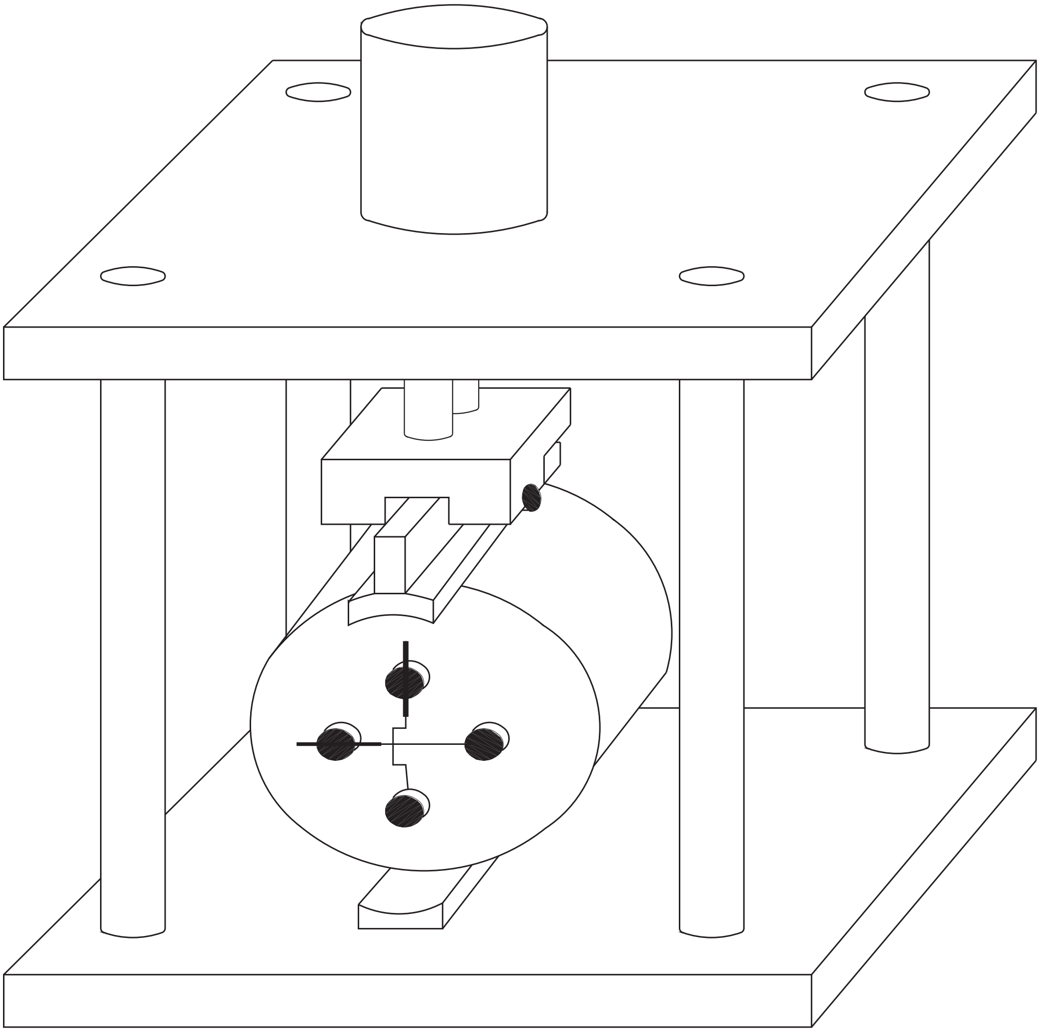


Figure 2—Specimen Loading Frame

7. HAZARDS

7.1. Observe standard laboratory safety precautions when preparing and testing HMA specimens.

8. STANDARDIZATION

8.1. Calibrate the testing system prior to initial use and at least once a year thereafter.

8.1.1. Calibrate the environmental control component to maintain the required temperature within the accuracy specified.

8.1.2. Calibrate all measurement components (such as load cells and displacement transducers) of the testing system.

8.1.3. If any of the verifications yield data that do not comply with the accuracy specified, correct the problem prior to proceeding with testing. Appropriate action may include correction of menu entries, maintenance on system components, calibration of system components (using an independent calibration agency, or service by the manufacturer, or in-house resources), or replacement of system components.

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9. SAMPLING

9.1. *Laboratory Molded Specimens*—Prepare a minimum of three replicate laboratory molded specimens, in accordance with T 312 or PP 3. If PP 3 is used, use a suitable core drill to cut specimens from the sample after compaction.

9.2. *Roadway Specimens*—Obtain roadway specimens from the pavement in accordance with ASTM D 5361. Prepare cores with smooth and parallel surfaces that conform to the height and diameter requirements specified in Section 10.2. Prepare a minimum of three replicate cores.

---

10. SPECIMEN PREPARATION AND PRELIMINARY DETERMINATIONS

10.1. Saw at least 6 mm from both sides of each test specimen to provide smooth, parallel (saw-cut) surfaces for mounting the measurement gauges.

Note 1—Measurements taken on cut faces yield more consistent results, and gauge points can be attached with much greater bonding strength.

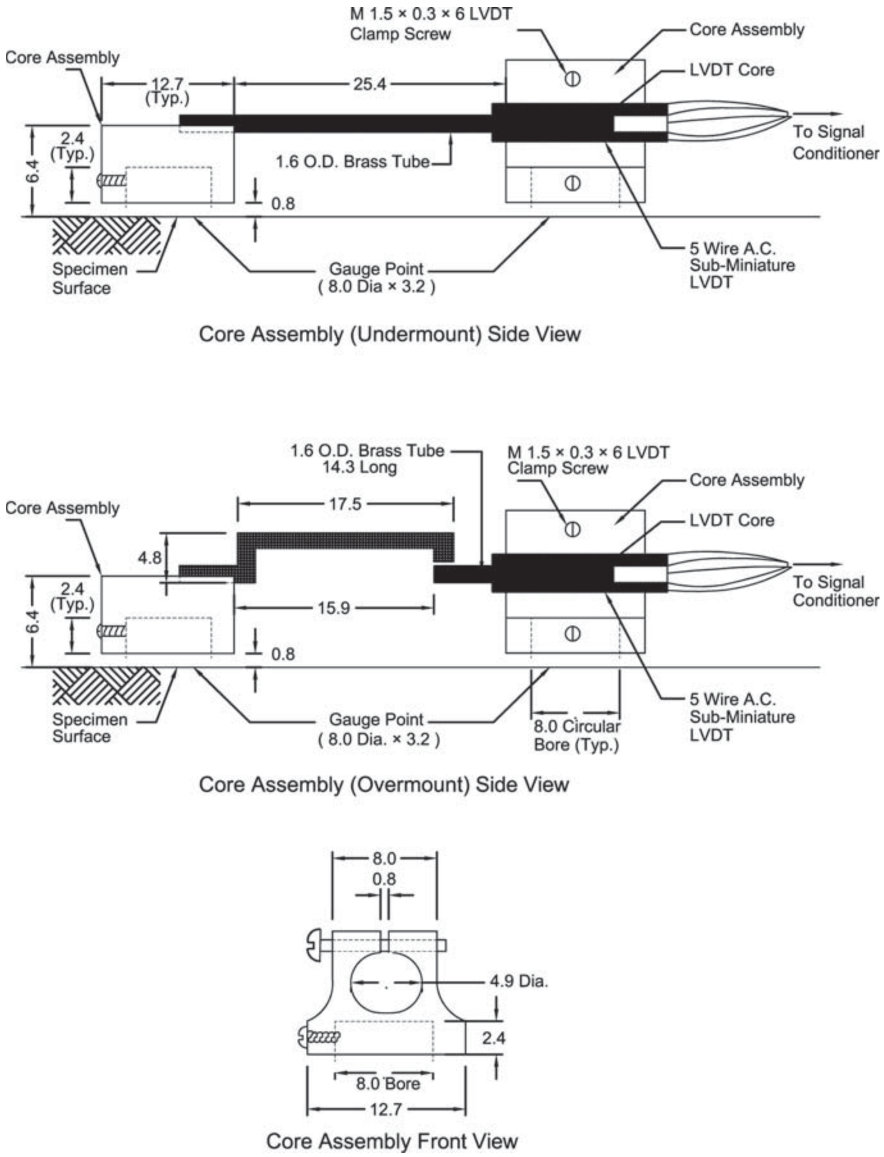
10.2. *Specimen Size*—Prepare specimens with a height of 38 to 50 mm and a diameter of 150 ± 9 mm.

10.3. *Determining Specimen Height and Diameter*—Determine and record the diameter and height (thickness) of each specimen in accordance with ASTM D 3549, to the nearest 1 mm.

10.4. *Determining the Bulk Specific Gravity*—Determine the specific gravity of each specimen in accordance with T 166, except that if the water absorbed by the specimen exceeds 2 percent, substitute a thin, adherent plastic wrap membrane that is water-resistant instead of the paraffin coating.

10.5. *Specimen Drying*—If specimens were immersed directly into the water, after determining the bulk specific gravity, allow each specimen to dry at room temperature to a constant mass.

10.6. *Mounting Displacement Tranducers*—Attach four brass gauge points with epoxy to each flat face of the specimen (four per face). On each flat face of the specimen, two gauge points shall be placed along the vertical and two along the horizontal axes with a center to center spacing of 38.0 ± 0.2 mm for a specimen diameter of 150 ± 9 mm. The placement and location of the gauge points on each face shall produce a mirror image of each other. Mount the displacement tranducers on the gauge points such that the transducer's center line is 6.4 mm above the specimen's surface. Figure 3 shows a system for mounting linear variable transducers that has been successfully used for IDT creep measurements at low temperature.



Core Assembly (Undermount) Side View

Core Assembly (Overmount) Side View

Core Assembly Front View

Notes: 1. All dimensions shown in millimeters unless otherwise noted.
2. Tolerances ±0.2 mm unless otherwise noted.
3. Not to scale.

Figure 3—Cross Section of LVDT Mounting System for 150-mm Specimen

11. TENSILE CREEP/STRENGTH TESTING (THERMAL CRACKING ANALYSIS)

11.1. Determine the tensile creep compliance of each of the three specimens at three measurements at 10°C intervals. The following test temperatures are recommended:

- For mixtures made using binder grades PG XX-34 or softer: −30, −20, and −10°C
- For mixtures made using binder grades PG XX-28 and PG XX-22, or mixtures for which binder grade is unknown: −20, −10, and 0°C

- For mixtures made using binder grades PG XX-16 or harder: −10, 0, and +10°C
- For mixtures subjected to severe age hardening, the test temperatures should be increased by 10°C

Note 2—The original Superpave mixture analysis procedures specified test temperatures of 0, –10, and –20°C.

11.2. Lower the temperature of the environmental chamber to the test temperature and, once the test temperature ±0.5°C is achieved, allow each specimen to remain at the test temperature from 3 ± 1 hours prior to testing. Under no circumstances shall the specimen be kept at 0°C or less for more than 24 hours.

11.3. Zero or rebalance the electronic measuring system and apply a static load of fixed magnitude (±2 percent) without impact to the specimen for 100 ± 2 seconds. If a complete analysis is required, a period of 1000 ± 20.5 seconds has been found suitable. Use a fixed load that produces a horizontal deformation of 0.00125 mm to 0.0190 mm for 150-mm diameter specimens. If either limit is violated, stop the test and allow a recovery time of 5 minutes before restarting with an adjusted load. Comply strictly with these limits to prevent both nonlinear response, characterized by exceeding the upper limit, and significant problems associated with noise and drift inherent in sensors, when violating the lower deformation limit.

11.4. After the creep tests have been completed at each temperature, determine the tensile strength by applying a load to the specimen at a rate of 12.5 mm of ram (vertical) movement per minute. Record the vertical and horizontal deformations on both ends of the specimen and the load until the load starts to decrease. The tensile strength should normally be determined at the middle temperature used for the creep tests.

Note 3—In some cases, it is acceptable to unload the specimen between the creep compliance and strength tests. This will facilitate control on certain testing machines.

12. CALCULATIONS

12.1. Calculate the air voids for each test specimen in accordance with T 269.

12.2. *Creep Compliance—Mathematical Model*:

12.2.1. The three reference specimens are analyzed simultaneously to reduce variability in determining Poisson's ratio and, therefore, creep compliance.

12.2.2. Obtain average thickness and diameter in mm and creep load in kN for the three replicates:

$$D_{avg} = \frac{\sum_{n=1}^{3} b_n}{3} \tag{1}$$

$$D_{avg} = \frac{\sum_{n=1}^{3} D_n}{3} \tag{2}$$

$$P_{avg} = \frac{\sum_{n=1}^{3} P_n}{3} \tag{3}$$

where:

Σ = sum of the three specimens, values for thickness, diameter, creep load, in kN;

b_{avg}, D_{avg}, P_{avg} = average thickness, diameter, and creep load of three replicate specimens; and

b_n, D_n, P_n = thickness, diameter, and creep load of specimen n (n = 1 to 3).

12.2.3. Compute normalized horizontal and vertical deformation arrays for each of the six specimen faces (three specimens, two faces per specimen).

$$\Delta X_{n,i,t} = \Delta X_{i,t} \times \frac{b_n}{b_{avg}} \times \frac{D_n}{D_{avg}} \times \frac{P_{avg}}{P_n} \tag{4}$$

$$\Delta Y_{n,i,t} = \Delta Y_{i,t} \times \frac{b_n}{b_{avg}} \times \frac{D_n}{D_{avg}} \times \frac{P_{avg}}{P_n} \tag{5}$$

where:

$\Delta X_{n,i,t}$ = normalized horizontal deformation for face i (i = 1 to 6) at time t (t = 0 to t_{final}, where t_{final} is the total creep time);

$\Delta Y_{n,i,t}$ = normalized vertical deformation for face i at time t;

$\Delta X_{i,t}$ = measured horizontal deformation for face i at time t; and

$\Delta Y_{i,t}$ = measured vertical deformation for face i at time t.

12.2.4. Obtain the average horizontal and vertical deformations $\Delta X_{a,i}$ and $\Delta Y_{a,i}$ at a time corresponding to one half the total creep test time for each of the six specimen faces. Thus, for a 100-second creep test, obtain the deformations corresponding to t = 50 seconds.

$$\Delta X_{a,i} = \Delta X_{n,i,t_{mid}} \tag{6}$$

$$\Delta Y_{a,i} = \Delta Y_{n,i,t_{mid}} \tag{7}$$

where:

$\Delta X_{a,i} + \Delta Y_{a,i}$ = average horizontal and vertical deformations for face i;

$\Delta X_{n,i,t_{mid}}$ = normalized horizontal deformation at a time corresponding to half the total creep test time for face i; and

$\Delta Y_{n,i,t_{mid}}$ = normalized vertical deformation at a time corresponding to half the total creep test time for face i.

12.2.5. Obtain the trimmed mean of the deflections ΔX_t and ΔY_t. This is accomplished by numerically ranking the six $\Delta X_{a,i}$ and $\Delta Y_{a,i}$ values and averaging the four middle values. Thus, the highest and lowest values of horizontal and vertical deformation are not included in the trimmed mean. Compute:

$$\Delta X_t = \frac{\sum_{j=2}^{5} \Delta X_{r,j}}{4} \tag{8}$$

$$\Delta Y_t = \frac{\sum_{j=2}^{5} \Delta Y_{r,j}}{4} \tag{9}$$

where:

$\Delta X_{r,j}$ = $\Delta X_{a,i}$ values sorted in ascending order;

$\Delta Y_{r,j}$ = $\Delta Y_{a,i}$ values sorted in ascending order;

ΔX_t = trimmed mean of horizontal deformations; and

ΔY_t = trimmed mean of vertical deformations.

12.2.6. Obtain the ratio of the horizontal to vertical deformations, X/Y, as follows:

$$\frac{X}{Y} = \frac{\Delta X_t}{\Delta Y_t} \tag{10}$$

12.2.7. Compute the trimmed mean, $\Delta X_{tm,t}$, of the six horizontal deformation arrays.

$$\Delta X_{tm,t} = \frac{\sum_{j=2}^{5} \Delta X_{r,j,t}}{4} \tag{11}$$

where:

$\Delta X_{r,j,t}$ = $\Delta X_{i,t}$ arrays sorted, where the $i = 6$ arrays are sorted according to the sorting order already established in Section 13.3.5 for $\Delta X_{r,j}$; and

$\Delta X_{tm,t}$ = Trimmed mean of the $\Delta X_{i,t}$ arrays.

12.2.8. Compute creep compliance, $D(t)$:

$$D(t) = \frac{\Delta X_{tm,t} \times D_{avg} \times b_{avg}}{P_{avg} \times GL} \times C_{cmpl} \tag{12}$$

where:

$D(t)$ = creep compliance at time t (kPa); and

GL = gauge length in meters (38×10^{-3} for 150-mm diameter specimens); and

$$C_{cmpl} = 0.6354 \times \left(\frac{X}{Y}\right)^{-1} - 0.332 \tag{13}$$

$$\left[0.704 - 0.213\left(\frac{b_{avg}}{D_{avg}}\right)\right] \le C_{cmpl} \le \left[1.566 - 0.195\left(\frac{b_{avg}}{D_{avg}}\right)\right]$$

12.2.9. Poisson's ratio, ν, may be computed as:

$$\nu = -0.10 + 1.480\left(\frac{X}{Y}\right)^2 - 0.778\left(\frac{b_{avg}}{D_{avg}}\right)^2\left(\frac{X}{Y}\right)^2 \tag{14}$$

where:

$0.05 \le \nu \le 0.50$

12.3. *Tensile Strength—Mathematical Model*:

12.3.1. Calculate tensile strength for each specimen, $S_{t,n}$, as:

$$S_{t,n} = \frac{2 \times P_{f,n}}{\pi \times b_n \times D_n} \tag{15}$$

where:

$P_{f,n}$ = maximum load observed for specimen, n;

$S_{t,n}$ = tensile strength of specimen, n.

12.3.2. Compute the average tensile strength:

$$S_t = \frac{\sum_{n=1}^{3} S_{t,n}}{3} \qquad (16)$$

where:

S_t = average tensile strength of mixture.

---

13. REPORT

13.1. *Report the following information*:

13.1.1. Bulk specific gravity of each specimen tested to the nearest 0.001;

13.1.2. Maximum specific gravity of the asphalt concrete mixture to the nearest 0.001;

13.1.3. Air voids of each specimen to the nearest 0.1 percent;

13.1.4. Height and diameter of all test specimens to the nearest millimeter;

13.1.5. Test temperature to the nearest 0.5°C, and for creep testing the load levels used during the test to the nearest 5 N;

13.1.6. Tensile creep compliance values $D(t)$; and

13.1.7. Tensile strength (σ_t) of the mixture to the nearest pascal as computed.

14. PRECISION AND BIAS

14.1. *Precision*—The research required to develop precision estimates has not been conducted.

14.2. *Bias*—The research required to establish the bias of this method has not been conducted.

15. KEYWORDS

15.1. Creep compliance; diametral creep compliance; linear variable differential transducer; tensile creep test; tensile failure test; tensile strength.

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[1] PP 3-94 (1996) was last printed in the May 2002 edition of the *AASHTO Provisional Standards*.

Standard Method of Test for

Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)

AASHTO Designation: T 324-04 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)

AASHTO Designation: T 324-04 (2008)

1. SCOPE

1.1. This test method describes a procedure for testing the rutting and moisture-susceptibility of hot mix asphalt (HMA) pavement samples in the Hamburg Wheel-Tracking Device.

1.2. The method describes the testing of submerged, compacted HMA in a reciprocating rolling-wheel device. This test provides information about the rate of permanent deformation from a moving, concentrated load. A laboratory compactor has been designed to prepare slab specimens. Also, the Superpave™ Gyratory Compactor (SGC) has been designed to compact specimens in the laboratory. Alternatively, field cores of large diameter, 255 mm (10 in.) or 300 mm (12 in.), or saw-cut slab specimens may be tested.

1.3. The test method is used to determine the premature failure susceptibility of HMA due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage. This test method measures the rut depth and number of passes to failure.

1.4. The potential for moisture damage effects are evaluated since the specimens are submerged in temperature-controlled water during loading.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

3. SIGNIFICANCE AND USE

3.1. This test measures the rutting and moisture susceptibility of an HMA specimen.

4. SUMMARY OF METHOD

4.1. A laboratory-compacted specimen of HMA, a saw-cut slab specimen, or a core taken from a compacted pavement is repetitively loaded using a reciprocating steel wheel. The specimen is submerged in a temperature-controlled water bath of 40 to 50ºC (104 to 122ºF) or a temperature specified for the binder being used. The deformation of the specimen, caused by the wheel loading, is measured.

4.2. The impression is plotted as a function of the number of wheel passes. An abrupt increase in the rate of deformation coincides with stripping of the asphalt binder from the aggregate in the HMA specimen.

5. APPARATUS

5.1. *Hamburg Wheel-Tracking Machine*—An electrically powered machine capable of moving a 203.2-mm (8-in.) diameter, 47-mm (1.85-in.) wide steel wheel over a test specimen. The load on the wheel is 705 ± 4.5 N (158 lb ± 1.0 lb). The wheel shall reciprocate over the specimen, with the position varying sinusoidally over time. The wheel shall make approximately 50 passes across the specimen per minute. The maximum speed of the wheel shall be approximately 0.305 m/s (1 ft/s) and will be reached at the midpoint of the specimen.

5.2. *Temperature Control System*—A water bath capable of controlling the temperature within ±1.0ºC (1.8ºF) over a range of 25 to 70ºC (77 to 158ºF). This bath shall have a mechanical circulating system to stabilize the temperature within the specimen tank.

5.3. *Impression Measurement System*—An LVDT device capable of measuring the depth of the impression of the wheel within 0.01 mm (0.0004 in.), over a minimum range of 0 to 20 mm (0.8 in.). The system shall be mounted to measure the depth of the impression at the midpoint of the wheel's path on the slab specimen. The impression shall be measured at least every 400 passes of the wheel. This system must be capable of measuring rut depth without stopping the wheel. This measurement must be referenced to the number of wheel passes.

5.4. *Wheel Pass Counter*—A non-contacting solenoid that counts each wheel pass over the specimen. The signal from this counter shall be coupled to the wheel impression measurement, allowing for the rut depth to be expressed as a function of the wheel passes.

5.5. *Specimen Mounting System*—A stainless steel tray that can be mounted rigidly to the machine. This mounting must restrict shifting of the specimen to within 0.5 mm (0.02 in.) during testing. The system shall suspend the specimen, allowing for free circulation of the water bath on all sides. The mounting system shall be designed to provide a minimum of 20 mm (0.8 in.) of free circulating water on all sides of the specimen.

5.6. *Balance*—Balance of 12,000 g capacity, accurate to 0.1 g.

5.7. *Ovens*—Ovens for heating aggregate and asphalt binders.

5.8. *Superpave Gyratory Compactor*—Superpave Gyratory Compactor (SGC) and molds conforming to T 312.

5.9. Bowls, spoon, spatula, etc.

6. SPECIMEN PREPARATION

6.1. *Number of Test Specimens*—There shall be two test specimens prepared for each test. Specimens may either be slab specimens or cylinders.

6.2. *Laboratory-Produced HMA*:

6.2.1. Mixture proportions are batched in accordance with the desired job mix formula.

6.2.2. The temperature to which the asphalt binder must be heated to achieve a viscosity of 170 ± 20 cSt shall be the mixing temperature. For modified asphalt binders, use the mixing temperature recommended by the binder manufacturer.

6.2.3. Dry-mix the aggregates and mineral admixture (if used) first; then add the correct percentage of asphalt binder. Mix the materials until all aggregates are thoroughly coated. (Wet-mix the aggregates if a lime slurry or other wet materials are used.)

6.2.4. Test samples shall be conditioned at the appropriate compaction temperature in accordance with the short-term conditioning procedure in R 30.

6.2.5. The temperature to which the asphalt binder must be heated to achieve a viscosity of 280 ± 30 cSt shall be the compaction temperature. For modified asphalt binders, use the compaction temperature recommended by the binder manufacturer.

6.2.6. *Laboratory Compaction of Specimens*—Specimens compacted in the laboratory shall be either compacted slab specimens or SGC specimens.

6.2.6.1. *Compacting Slab Specimens*—Material shall be compacted into slab specimens using a Linear Kneading Compactor (or equivalent) and shall be 320 mm (12.5 in.) long and 260 mm (10.25 in.) wide. A slab specimen thickness of 38 mm (1.5 in.) to 100 mm (4 in.) can be used. The slab specimen thickness shall be at least twice the nominal maximum aggregate size. Compacted slab specimen shall be cooled at normal room temperature on a clean, flat surface until the specimen is cool to the touch.

6.2.6.2. *Compacting SGC Specimens*—Material shall be compacted into specimens using an SGC according to T 312. A specimen thickness of 38 mm (1.5 in.) to 100 mm (4 in.) can be used. The specimen thickness shall be at least twice the nominal maximum aggregate size. Two 150-mm (6-in.) diameter specimens are needed. Compacted specimens shall be cooled at normal room temperature on a clean, flat surface until the specimen is cool to the touch.

6.3. *Field-Produced HMA—Loose Mix*:

6.3.1. Obtain a sample of HMA according to T 168.

6.3.2. *Laboratory Compaction of Specimens*—Specimens compacted in the laboratory shall be either compacted slab specimens or SGC specimens.

6.3.2.1. *Compacting Slab Specimens*—Material shall be compacted into slab specimens using a Linear Kneading Compactor (or equivalent) and shall be 320 mm (12.5 in.) long and 260 mm (10.25 in.) wide. A slab specimen thickness of 38 mm (1.5 in.) to 100 mm (4 in.) can be used. The slab specimen thickness shall be at least twice the nominal maximum aggregate size. Compacted slab specimens shall be cooled at normal room temperature on a clean, flat surface until the specimen is cool to the touch.

6.3.2.2. *Compacting SGC Specimens*—Material shall be compacted into specimens using an SGC according to T 312. A specimen thickness of 38 mm (1.5 in.) to 100 mm (4 in.) can be used. The specimen thickness shall be at least twice the nominal maximum aggregate size. Compacted specimens shall be cooled at normal room temperature on a clean, flat surface until the specimen is cool to the touch.

6.4. *Field-Produced HMA*—Field Compacted (Core/Slab Specimen):

6.4.1. *Cutting*—Field cores or field slab specimens shall consist of wet saw-cut compacted specimens taken from HMA pavements. Field cores shall be 250 mm (10 in.) in diameter. Field slab specimens shall be wet saw-cut to approximately 260 mm (10.25 in.) wide and 320 mm (12.5 in.) long. A slab specimen thickness of 38 mm (1.5 in.) to 100 mm (4 in.) may be used. The height of a field core or field slab specimen is typically 38 mm (1.5 in.), but may be adjusted to fit the specimen mounting system by wet saw-cutting.

Note 1—Care should be taken to load the sample so it is level to the surface of the mold. The sample must be trimmed if it is too tall or shimmed up if it is too short (support with plaster if needed). The down pressure from the wheel is calibrated to be 705 N (158 lb) at the center, level to the top of the mold position. Even a small change in elevation will change the down pressure significantly.

7. DETERMINING AIR VOID CONTENT

7.1. Determine the bulk specific gravity of the specimens in accordance with T 166.

7.2. Determine the maximum specific gravity of the mixture in accordance with T 209.

7.3. Determine the air void content of the specimens in accordance with T 269. It is recommended, for laboratory-compacted specimens, that the target air void content be 7.0 ± 2.0 percent. Field specimens may be tested at the air void content at which they are obtained.

8. PROCEDURE

8.1. *Specimen Mounting*—Use plaster of paris to rigidly mount the specimen in the mounting trays. The plaster shall be mixed at approximately a 1:1 ratio of plaster to water. Pour the plaster to a height equal to that of the specimen so that the air space between the specimen and the tray is filled. The plaster layer underneath the specimen shall not exceed 2 mm (0.08 in.). Allow the plaster at least 1 hour to set. If other mounting material is used, it should be able to withstand 890 N (200 lb) of load without cracking.

8.2. *Selecting the Test Temperature*—The test temperature shall be selected based upon the applicable specifications.

8.3. Be sure the drain valve(s) is closed. Fill the wheel-tracking device with hot water until the float device floats to a horizontal position. The water temperature may vary and should be adjusted if necessary.

8.4. When the water has reached the test temperature for 30 minutes, lower the wheels onto the specimens. Ensure that the micro-control unit's LVDT readout reads between 10 mm (0.4 in.) and 18 mm (0.7 in.). To adjust the LVDT height, loosen the two screws on the LVDT mount, and slide the LVDT up or down to the desired height. Tighten the screws.

8.5. Start the test.

8.6. The wheel-tracking device shall shut off when 20 000 passes have occurred. The device will also shut off if the average LVDT displacement (read from the micro-control unit, not the screen) is 40.90 mm (1.6 in.) or greater for an individual specimen. Note that the screen readout subtracts the initial LVDT reading from the total displacement.

8.7. Turn off the machine and the main power supply. To drain the baths, open the valve(s) beneath the tanks. Raise the wheels and remove the rutted specimens and the spacers.

8.8. Clean the water baths, heating coils, wheels, and temperature probe with water and scouring pads or as per the manufacturer's recommendations. Use a wet-dry vacuum to remove particles that have settled to the bottom of the baths. Clean the filter element and spacers after every test.

8.9. Turn the steel wheels after each test so the same section of the steel wheel surface is not in contact with the test specimen from test to test. This rotation will provide for even wear over the entire wheel. The test should run with a smooth movement across the test specimen.

9. CALCULATIONS

9.1. Plot the rut depth versus number of passes for each test. A typical plot of the output produced by the Hamburg Wheel-Tracking Device is shown in Figure 1. From this plot, obtain the following values:

Slope and intercept of the first steady-state portion of the curve.

Slope and intercept of the second steady-state portion of the curve.

9.2. Calculate the following test parameters:

All of the test parameters below are expressed in "Passes."

$$\text{Stripping Inflection Point (SIP)} = \frac{\text{Intercept (second portion)} - \text{Intercept (first portion)}}{\text{Slope (first portion)} - \text{Slope (second portion)}} \qquad (1)$$

where:

Failure Rut Depth is the specified maximum allowable rut depth for the test.

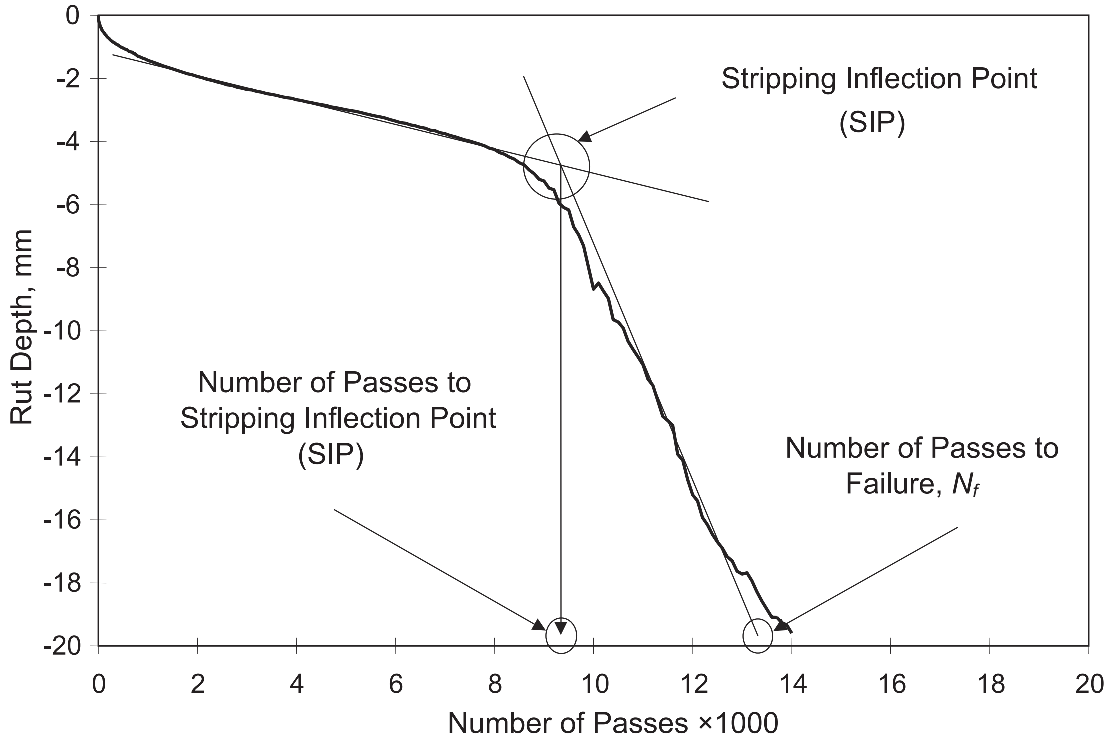

Figure 1—Hamburg Curve with Test Parameters

10. REPORT

10.1. *The report shall include the following parameters*:

10.2. HMA Production (Field or Lab);

10.3. Compaction method (slab or SGC specimen);

10.4. Number of passes at maximum impression;

10.5. Maximum impression;

10.6. Test temperature;

10.7. Specimen(s) air voids;

10.8. Type and amount of anti-stripping additive used;

10.9. Creep slope;

10.10. Strip slope; and

10.11. Stripping inflection point.

11. PRECISION AND BIAS

11.1. Work is under way to develop precision and bias statements for this standard.

12. KEYWORDS

12.1. Compacted hot mix asphalt; moisture-susceptibility; rutting; wheel-track testing.

APPENDIXES

(Nonmandatory Information)

X1. MAINTENANCE

X1.1. All eight of the grease fittings shall be greased with fresh grease every 20 tests (not to exceed 2 months) per the manufacturer's recommendations.

X2. CALIBRATION/EQUIPMENT VERIFICATION

X2.1. Verify that the water bath temperature is within ±1.0ºC (1.8ºF) of the temperature readout on the micro-control unit every 6 months.

X2.2. Verify that the LVDT height is within ±0.05 mm (0.002 in.) between the three (10, 20, and 30 mm) (0.4. 0.8, and 1.2 in.) calibration blocks.

X2.3. Verify that the load on the wheel, in the middle of the stroke on the sample, at the correct level elevation, to be 705 ± 4.5 N (158 ±1.0 lb). A calibrated load cell, accurate to 0.4 N (0.1 lb) is sufficient for this check.

X2.4. Verify that the steel wheel is reciprocating back and forth on the test sample at 50 ± 5 passes per minute.

Standard Method of Test for

Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

AASHTO Designation: T 329-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

AASHTO Designation: T 329-08

1. SCOPE

1.1. This method is intended for the determination of moisture content of hot mix asphalt (HMA) by drying in an oven.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 168, Sampling Bituminous Paving Mixtures

3. TERMINOLOGY

3.1. *constant mass*—shall be defined as the mass at which further drying does not alter the mass by more than 0.05 percent.

4. SUMMARY OF TEST METHOD

4.1. A test specimen of HMA is dried in a forced-air, ventilated, or convection oven to constant mass.

5. APPARATUS

5.1. *Balance or Scale*—2-kg (4.4-lb) capacity, readable to at least 0.1 g and conforming to the requirements of M 231.

5.2. *Forced-Air, Ventilated, or Convection Oven*—capable of maintaining the temperature surrounding the sample at 163 ± 14°C (325 ± 25°F).

5.3. *Sample Container*—the container in which the sample is dried shall be of sufficient size to contain the sample without danger of spilling and to allow the sample to be evenly distributed in a manner that will allow completion of the test in an expeditious manner.

6. SAMPLE

6.1. A sample of HMA shall be obtained in accordance with T 168.

6.2. The sample shall be reduced in size in accordance with R 47. The size of the test sample shall be a minimum of 1000 g.

7. PROCEDURE

7.1. Determine and record the mass of the sample container to the nearest 0.1 g.

7.2. Place the test sample in the sample container. Determine and record the temperature of the test sample. To facilitate drying, evenly distribute the test sample in the sample container.

7.3. Determine and record the total mass of the sample container and moist test sample to the nearest 0.1 g.

7.4. Preheat the oven to drying temperature. The drying temperature shall fall within the Job Mix Formula mixing temperature range. If a mixing temperature range is not supplied, a temperature of 163 ± 14 °C (325 ± 25°F) will be used.

Note 1—For repeatability between operators and or laboratories the difference between drying temperatures for samples should not exceed 9°C (15°F).

7.5. Calculate the mass of the initial, moist test sample by subtracting the mass of the sample container determined in Section 7.1 from the total mass of the sample container and moist test sample determined in Section 7.3.

7.6. The sample shall initially be dried for 90 ± 5 minutes and its mass determined. Then dry the sample at 30 ± 5-minute intervals until a constant mass is reached.

Note 2—The moisture content of test samples and the number of test samples in the oven will affect the rate of drying at any given time. Placing wet test samples in the oven with nearly dry test samples could affect the drying process.

7.7. Cool the sample container and test sample to approximately the same temperature as determined in Section 7.2.

7.8. Determine and record the total mass of the sample container and dry test sample to the nearest 0.1 g.

Note 3—Do not attempt to remove the test sample from the sample container for the purposes of determining the dry mass of the test sample.

7.9. Calculate the mass of the final, dry test sample by subtracting the mass of the sample container determined in Section 7.1 from the total mass of the sample container, and dry test sample determined in Section 7.7.

8. CALCULATIONS

8.1. *Calculate moisture content as follows*:

$$\text{Moisture Content,\%} = \frac{M_i - M_f}{M_f} \times 100 \qquad (1)$$

where:

M_i = mass of the initial, moist test sample, g; and

M_f = mass of the final, dry test sample, g.

Example: M_i = 1134.9 g

M_f = 1127.3 g

$$\text{Moisture Content,\%} = \frac{1134.9\text{ g} - 1127.3\text{ g}}{1134.9\text{ g}} \times 100 = 0.67\%$$

9. REPORT

9.1. Report the moisture content to the nearest 0.01 percent.

10. KEYWORDS

10.1. Hot mix asphalt; moisture content; oven-drying.

Standard Method of Test for

Bulk Specific Gravity and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method

AASHTO Designation: T 331-10[1]
ASTM Designation: D 6752-03$^{\epsilon 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Bulk Specific Gravity and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method

AASHTO Designation: T 331-10[1]

ASTM Designation: D 6752-03$^{\epsilon 1}$

1. SCOPE

1.1 This method covers the determination of bulk specific gravity of specimens of compacted hot mix asphalt (HMA) mixtures.

1.2 This method should be used with samples that contain open or interconnecting voids and/or absorb more than 2.0 percent of water by volume, as determined by T 166. An agency may specify this method as an alternative to T 275.

1.3 The bulk specific gravity of the compacted HMA may be used in calculating the unit mass of the mixture.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- T 275, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2 *ASTM Standards*:

- D 6752, Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method
- D 7227, Standard Practice for Rapid Drying of Compacted Asphalt Specimens Using Vacuum Drying Apparatus
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

2.3 *Other Documents*:

- FHWA-IF-02-044, *NCAT Report No. 02-11: Bulk Specific Gravity Round-Robin Using the CoreLok*$^{\text{TM}}$ *Vacuum Sealing Device*

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3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 *bulk specific gravity (of solids)*—the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.

The form of the expression shall be:

$$\text{Bulk specific at gravity } x/y\,^{\circ}\text{C} \qquad (1)$$

where:

x = temperature of the material; and

y = temperature of the water.

3.1.2 *constant mass*—shall be defined as the mass at which further drying does not alter the mass by more than 0.05 percent when the mass is determined at 2-h intervals.

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4. TEST SPECIMENS

4.1 Test specimens may be either laboratory-compacted HMA mixtures or sampled from HMA pavements. The mixtures may be surface or wearing course, binder or leveling course, or hot mix base.

4.2 *Size of Specimens*—Specimens shall conform to the requirements of T 166.

4.3 Specimens shall be taken from pavements with a core drill, diamond or carborundum saw, or by other suitable means.

4.4 Care shall be taken to avoid distortion, bending, or cracking of specimens during and after the removal from the pavement or mold. Specimens shall be stored in a safe, cool place.

4.5 Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.

4.6 If desired, specimens may be separated from other pavement layers by sawing or other suitable means. Care should be exercised to ensure sawing does not damage specimens. Jagged edges or sharp aggregates may puncture the plastic bag. Specimen ends or planar edges may require sawing if the bag does not conform to the specimen in a uniform manner.

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5. APPARATUS

5.1 *Bag Cutter*—A knife, scissors, or other types of clipping devices may be used to quickly open bags.

5.2 *Oven*—The oven shall be capable of maintaining the appropriate temperature for drying specimens to a constant mass.

5.3 *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231. The weighing device shall be equipped with a suitable suspension apparatus and holder to determine the mass of the specimen while suspended from the center of the scale pan of the weighing device.

5.4 *Plastic Bags*—The two most commonly used sizes of bags are designated as small and large size bags. The small bags shall have a minimum opening of 235 mm (9.25 in.) and a maximum opening of 260 mm (10.25 in.) with a mass of less than 35 g. The large bags shall have a minimum opening of 375 mm (14.75 in.) and a maximum opening of 394 mm (15.5 in.) with a mass of 35 g or more. The bags shall be made of a plastic material that will not adhere to asphalt film, puncture resistant, capable of withstanding sample temperatures of up to 70ºC (158ºF), impermeable to water, and contain no air channels for evacuation of air from the bag. The bags shall have a minimum thickness of 0.100 mm (0.004 in.) and a maximum thickness of 0.152 mm (0.006 in.). The manufacturer shall provide the apparent specific gravity of the bags (usually located in the operator's manual). See the manufacturer's recommendations to ensure proper handling of bags.

5.5 *Specimen Sliding Plates*—Level and smooth-sided planar filler plates shall be inserted into the chamber to keep the samples of various heights level with the seal bar while being sealed. The plates shall be removable and of the appropriate dimensions to easily fit into the vacuum chamber. A smooth-sided specimen supporting plate shall easily slide on top of the smooth-sided plates. The opposite side of the smooth-sided specimen supporting plate shall have a cushioning membrane to help prevent tears in the plastic bag. The plate shall be large enough to fully support the specimen but small enough to allow movement during the sealing process.

5.6 *Suspension Apparatus*—The wire suspending the container shall be of the smallest practical size to minimize any possible effects of a variable immersed length. The suspension apparatus shall be constructed to enable the container to be immersed to a depth sufficient to cover it and the test sample during weighing.

5.7 *Thermometer*—ASTM 17°C (17°F), having a range of 19 to 27°C (66 to 80°F), graduated and conforming to ASTM E 1. An electronic temperature measuring device, such as a resistance thermometer or thermocouple, may be used.

5.8 *Vacuum Chamber*—The pump shall be capable of evacuating the sealed and enclosed chamber to 5 mm Hg in 60 s at sea level. The chamber shall be large enough to seal samples of 150 mm by 350 mm by 150 mm (6 in. by 14 in. by 6 in.) thick. A sealing bar of sufficient length to fully seal small and large size bags shall be located inside the chamber. The heat setting shall be set according to the manufacturer's recommendations and bag composition. The device shall automatically seal the plastic bag and exhaust air back into the chamber in a controlled manner to ensure proper conformance of the plastic bag to the specimen. The air exhaust and vacuum operation time should be calibrated to bring the chamber to atmospheric pressure in 80 to 120 s after completion of the vacuum operation. The vacuum system should be provided with a latch to control chamber door opening.

5.9 *Vacuum Gauge (Calibrated)*—The calibrated vacuum gauge shall be capable of being placed inside the automatic vacuum sealing device to verify vacuum performance and seal integrity. The gauge shall have a minimum range of 10 to 0 mm Hg (10 to 0 torr) and readable to 1 mm Hg (1 torr) increments as a minimum.

5.10 *Water Bath*—For immersing the specimen in water while suspended under the weighing device, equipped with an overflow outlet for maintaining a constant water level and thermostatically controlled so as to maintain the bath at 25 ± 1°C (77 ± 1.8°F). A heater and circulator may be attached. The circulator shall not be in use while recording sample masses. It is important that the water bath be of sufficient size to ensure sufficient space for the sample and the plastic bag suspension. A water bath with suggested minimum dimensions (length by width by depth) of 610 mm by 460 mm by 460 mm (24 in. by 18 in. by 18 in.) or a large cylindrical container has been found to work well for this test method.

Note 1—A cushioned holder located inside water bath for water displacement of the sample; should not have sharp edges. Holders without sufficient cushioning have been found to puncture the bags. A clip may be attached to the container to hold the bag underwater and to keep bag edges from touching water bath edges. Water baths at eye level may help prevent tears in bags and assist in ease of use.

6. PROCEDURE

6.1 *Initial Mass of Specimen in Air*—Dry the specimen to a constant mass at a temperature of 52 ± 3°C (125 ± 5°F), or vacuum-dry the specimen according to ASTM D 7227. Samples saturated with water shall initially be dried overnight and then the mass determined at 2-h drying intervals. Recently compacted laboratory samples, which have not been exposed to moisture, do not require drying. Cool the specimen to room temperature at 25 ± 5°C (77 ± 9°F), and record the initial dry mass as A. It is important that the sample contain less than 5 g of water before it is exposed to vacuum. At high vacuum, water will evaporate, potentially causing the bag around the sample to loosen due to trapped gas, thus resulting in a higher volume determination and a lower bulk specific gravity result.

Note 2—Bulk specific gravity determined by this method may be lower, and air voids higher, than the results obtained by T 166. The differences may be more pronounced for coarse and absorptive mixtures. Users of this test method are cautioned to evaluate any alteration in asphalt content or aggregate gradation for mix designs with a positive performance history. If this procedure will be used for control or assurance testing, users are cautioned to follow this procedure during the laboratory mix design.

Note 3—Laboratory-compacted specimens of 3000 to 6000 g may be considered at room temperature equilibrium after 2 h of cooling under a fan. The cooling time may be reduced for smaller specimens or if verified to have no significant differences in properties from those cooled to room temperature equilibrium.

Note 4—Some steps may be performed in conjunction with T 166.

6.2 *Sealing the Specimen*—Select an appropriately sized bag for the specimen. Specimens of 100 mm (4 in.) and 150 mm (6 in.) up to 50 mm (2 in.) in thickness are usually tested with the small bag. Specimens of 150 mm (6 in.) in diameter by 50 mm (2 in.) or greater in thickness will usually be tested with a large bag.

6.2.1 Set the heat sealing bar temperature according to the bag manufacturer’s recommendations.

6.2.2 Inspect the bag for holes and irregularities, record the bag mass. Place the bag inside the vacuum chamber on top of the specimen sliding plate.

6.2.3 Insert the specimen into the bag with the smoothest plane of the specimen on the bottom. This operation may be done inside the chamber while holding the bag open with one hand over the sliding plate and gently inserting the specimen with the other hand. There should be about 25 mm (1 in.) of slack between the presealed bag end and the specimen.

6.2.4 If needed, filler plates should be added or removed prior to inserting the specimen. Grab the unsealed end of the bag on each side, and gently pull and center it over the seal bar, overlapping the bag at least 25 mm (1 in.).

6.2.5 Ensure that there are no wrinkles in the bag along the seal bar just prior to closing the lid.

6.2.6 Close the lid, and engage the lid-retaining latch. The vacuum pump light will illuminate “red,” and the vacuum gauge on the exterior of the chamber will become active, or a digital reading will show the vacuum state. It is normal for the bag to expand or “puff up” during this process.

6.2.7 Once sealed, the “de-vac” valve will open, and air will enter the chamber, causing atmospheric pressure to collapse the bag around the specimen.

6.2.8 Disengage the lid-retaining latch, and carefully remove the sealed specimen from the chamber. Gently pull on the bag at any areas that appear loose. Loose areas indicate a poor seal and the process must then be restarted at Section 6.1 with a new bag and a new initial mass.

6.3 *Sealed Specimen Mass*—Calculate the mass of the sealed specimen in air by summing the masses recorded in Sections 6.1 and 6.2.2. Designate this mass as *B*.

6.4 *Mass of Sealed Specimen in Water*—Quickly weigh the sealed specimen in a water bath at 25 ± 1ºC (77 ± 1.8ºF). Fully submerge the specimen and bag to ensure no trapped air bubbles exist under the specimen. Ensure that the bag is completely underwater and that it is not touching the edges of the water bath. Designate this mass as *E*.

Note 5—The time between the lid opening after sealing and the time to placement of the specimen into the water bath should not exceed 1 min to reduce the potential for bag leaks.

6.5 *Check*—To ensure a tight seal in the bag, remove the sample from the water, and cut the bag open. Remove the sample from the bag, and determine its mass. Designate this mass as *C*. Compare this mass with initial dry mass determined in Section 6.1 as *A*. If *A* is more than 5 g from the mass of dry specimen *C*, the results from this method may not be accurate. The check passes if less than 0.08 percent is lost or no more than 0.04 percent is gained. A loss indicates sample material loss, and a gain indicates a possible bag leakage problem. Remove the bag, and restart the process at Section 6.1 if this check fails.

6.6 If the specimen may be needed for referee testing, oven-dry the specimen as described in Method C of T 166 or vacuum-dry it according to ASTM D 7227.

6.7 If the specimen will not be needed for referee testing, oven-dry the specimen as described in Method A of T 166, or vacuum-dry it according to ASTM D 7227.

7. CALCULATION

7.1 Calculate the bulk specific gravity of the specimen as follows. Round and report the value to the nearest 0.001.

$$G_{mb} = \frac{A}{\left[C + (B - A)\right] - E - \left[\frac{B - A}{F}\right]}$$

where:

G_{mb} = specimen bulk specific gravity;

A = initial mass of the dried specimen in air, g;

B = calculated mass of the dry, sealed specimen, g;

C = final mass of the specimen after removal from the sealed bag, g;

E = mass of the sealed specimen underwater, g; and

F = apparent specific gravity of the plastic sealing material at 25° C (77°F), provided by the manufacturer.

7.2 Calculate the density of the specimen as follows. Round and report the value to the nearest 1 kg/m³ (lb/ft³).

$\tilde{n} = G_{mb} (\tilde{a})$

where:

G_{mb} = bulk specific gravity of the specimen;
ñ = density of the specimen, kg/m^3 or lb/ft^3 (pcf); and
ã = density of water at 25ºC (77ºF), (997.0 kg/m^3, 0.997 g/cm^3, or 62.2 lb/ft^3, pcf).

8. VERIFICATION

8.1 *Vacuum System Verification*:

8.1.1 The vacuum settings of the device shall be verified once every 3 months, after repairs, and after shipment or relocation as a minimum.

8.1.2 Verification shall be performed with an absolute vacuum gauge capable of being placed inside the chamber and reading the vacuum setting of the sealing device.

8.1.3 Place the gauge inside the chamber and record the setting. The gauge should indicate a reading of 10 mm Hg (10 torr) or less. The unit should not be used if the gauge reading is above 10 mm Hg (10 torr).

8.2 *Plastic Bag Verification*:

8.2.1 The apparent specific gravity of the plastic bag provided by the manufacturer shall be verified periodically.

8.2.2 Compact a specimen of 4.75-mm (No. 4) nominal-maximum aggregate size HMA with a Marshall compactor or gyratory compactor (according to T 245 or T 312, respectively) to minimum dimensions of 100 mm (4 in.) in diameter by 60 mm (2.4 in.) thick. The sample should be compacted to produce air voids of 4.0 ± 1.0 percent.

8.2.3 Using three bags from the same size set of plastic bags and the compacted specimen from Section 8.2.2 follow Section 6, as appropriate; determine the bulk specific gravity of the compacted specimen for each individual bag.

8.2.4 Average the three bulk specific gravities (or densities) obtained with each bag.

8.2.5 Determine the bulk specific gravity of the same compacted specimen, by T 166.

8.2.6 The average bulk specific gravity (or density) calculated for the HMA specimen using the plastic bags shall be within ±0.020 g/cm^3 (20 kg/m^3) of the bulk specific gravity (or density) as determined by T 166 for the same HMA specimen. If the difference between T 166 and T 331 bulk specific gravities is outside of the required tolerance, dry the sample per the procedures in Section 6.1, and repeat the above verification test. Average the values for the first and second verification tests, and ensure that the difference is less than or equal to 0.02 g/cm^3. Contact the manufacturer if this verification test fails.

8.2.7 This section shall be repeated for each bag size.

9. PRECISION

9.1 Criteria for judging the acceptability of bulk specific gravity results obtained by this test method are given in Table 1:

Table 1—Acceptability of Bulk Specific Gravity[a]

Test and Type Index	Standard Deviation	Acceptable Range of Two Results
Single-Operator Precision	0.0124	0.035
Multilaboratory Precision	0.0135	0.038

[a] The precision estimates were obtained from *Bulk Specific Gravity Round-Robin Using the CoreLok*^{TM} *Vacuum Sealing Device* report. The FHWA pooled-fund study report number was FHWA-IF-02-044, NCAT Report No. 02-11.

9.2 The figures given in Column 2 are the standard deviations that have been found to be appropriate for the conditions of the test described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between results of two properly conducted tests.

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[1] Similar, but not identical, to ASTM D 6752-03$^{\in 1}$.

Standard Method of Test for

Determining Rutting Susceptibility of Hot Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA)

AASHTO Designation: T 340-10

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Determining Rutting Susceptibility of Hot Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA)

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1. SCOPE

1.1. This method describes a procedure for testing the rutting susceptibility of hot mix asphalt (HMA) using the Asphalt Pavement Analyzer (APA).

1.2. Annex A1 contains procedures for calibration checks for several APA components and related equipment.

1.3. Appendix X1 presents specifications for, and discussion concerning, several options for APA testing parameters often employed by APA users.

1.4. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2. *ASTM Standard*:

- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. APPARATUS

3.1. *APA*—A thermostatically controlled device designed to test the rutting susceptibility of HMA by applying repetitive linear loads to compacted test specimens through pressurized hoses via wheels.

3.1.1. The APA shall be thermostatically controlled to maintain the test temperature and conditioning chamber at any set point between 4 and 72°C (40 and 160°F) within 1°C (2°F).

3.1.2. The APA shall be capable of independently applying loads up to 578 N (130 lbf) to the wheels. The loads shall be calibrated to the specified test load by an external-force transducer.

3.1.3. The APA shall be capable of adjusting the pressure in the test hoses and maintaining up to 862 kPa (125 psi) in the test hoses.

3.1.4. The APA shall be capable of testing six cylindrical specimens.

3.1.5. The test molds shall be rectangular in shape, be composed of ultra-high molecular weight (UHMW) polyethylene, fit snugly within the testing position in the APA testing chamber, and contain two holes in which to insert the specimens. The dimensions of each hole shall be 150 ± 2.0 mm (5.91 ± 0.08 in.) in diameter by 75.0 ± 2.0 mm (2.95 ± 0.08 in.) tall.

3.1.6. The APA shall have a programmable master cycle counter that can be preset to the desired number of cycles for a test. The APA shall be capable of automatically stopping the test at the completion of the programmed number of cycles.

3.1.7. The test hoses shall be composed of a nylon tube with high-tensile textile cord reinforcement and a synthetic rubber cover. The nominal inside diameter of the hoses shall be 19.0 mm (0.75 in.); the nominal outside diameter of the hoses shall be 29.5 mm (1.16 in.). The maximum working pressure (WP) of the hoses shall be 5.17 MPa (750 psi). The hoses should be replaced when any of the outer rubber casing exhibits significant wear. Follow the APA manufacturer's instructions for the technique on replacing hoses.

Note 1—A Gates 77B Paint Spray and Chemical hose has been found to be satisfactory. This hose is available from the Gates Corporation (Product No. 3207-0296).

3.1.8. When electing to manually measure rut depths, a rut depth measurement template is required. This template shall be machined aluminum plate [approximately 31.7 to 38.1 mm (1.25 to 1.50 in.) thick] and have the following dimensions: 400.0 mm (15.75 in.) long by 152.4 mm (6 in.) wide. The rut depth measurement template shall contain five openings, spaced along the length of the template, in which the ruts are measured. The locations of the openings on the template will coincide with the locations utilized by the automatic measurement system. Each of the five openings shall be approximately 11 mm (0.43 in.) wide.

Note 2—Manual rut depth measurements on specimens that are rutted significantly may result in erroneous data. The rut depth measurement template may rest on the displaced material rather than on the test mold. In these cases, the rut depth measurement template should be modified with a channel removed from the bottom side of the template in order to span the displaced material and ensure that the template rests on the test mold.

3.1.9. The APA shall be calibrated in accordance with Annex A1.

3.2. *Ovens for maintaining temperature of plant-produced HMA and preheating specimens.*

3.3. *Compaction device and molds*:

3.3.1. Superpave gyratory compactor (SGC) and compaction molds conforming to T 312, or

3.3.2. Vibratory compactor and compaction molds.

3.3.2.1. *Vibratory compactor*—A steel-frame device mounted on noise-absorbing isolators and supports that utilizes adjustable vibratory compression forces to consolidate and compact HMA to produce cylindrical specimens for further testing. The device shall be timer-controlled and capable of compacting the specimens to a specified height and extracting the specimens after compaction. The vibratory compactor shall have a control panel separate from the compaction unit. The panel shall contain a mode switch to control specimen compaction and extraction and a timer to control the compaction-time cycle.

3.3.2.2. The compaction molds used for specimens produced in the vibratory compactor shall be composed of steel with the following dimensions:

- inside diameter of 149.9 ± 0.5 mm (5.90 ± 0.02 in.);
- inside height of 133.4 ± 0.5 mm (5.25 ± 0.02 in.);
- overall height of 152.7 ± 0.5 mm (6.01 ± 0.02 in.);
- wall thickness of 7.81 ± 0.5 mm (0.31 ± 0.02 in.); and
- bottom plate diameter of 149.0 ± 0.5 mm (5.87 ± 0.02 in.).

4. PREPARATION OF TEST SPECIMENS

4.1. *Number and dimensions of test specimens*—Six cylindrical specimens, 150 mm (5.91 in.) in diameter by 75 ± 2 mm (3.0 ± 0.1 in.) tall.

4.2. *Roadway Core Specimens*:

4.2.1. Roadway core specimens shall be 140 to 152 mm (5.5 to 6.0 in.) in diameter and a minimum of 50 mm (2 in.) tall with all surfaces of the perimeter perpendicular to the surface of the core within 5 mm (0.2 in.). Cores taller than the desired height shall be trimmed with a saw to a height of 75 ± 2 mm (3.0 ± 0.1 in.). For cores with diameters between 140 and 152 mm (5.5 and 6.0 in.) or heights between 50 and 73 mm (2.0 and 2.9 in.), plaster of paris or comparable material may be used to achieve the proper testing height of 75 ± 2 mm (3.0 ± 0.1 in.) and to ensure that specimens with small diameters fit snugly within the testing mold. Testing shall be conducted on the uncut face of the core.

4.3. *Plant-Produced (HMA)*:

4.3.1. Samples of plant-produced HMA shall be obtained in accordance with T 168. HMA samples shall be reduced to the appropriate test size and compacted while the HMA is within the compaction temperature range as determined by the specifying agency. Reheating of loose plant HMA should be avoided.

4.3.2. When using an SGC, compact specimens conforming to the dimensional requirements of Section 4.1 to 7.0 ± 0.5 percent air voids in accordance with T 312.

4.3.3. When using a vibratory compactor, compact specimens conforming to the dimensional requirements of Section 4.1 to 7.0 ± 0.5 percent air voids in accordance with the following procedure:

4.3.3.1. Attach and level the appropriate compaction head to the vibrating assembly in accordance with the manufacturer's instructions. Verify that the compaction head is correctly attached and arranged to produce a specimen of the desired height. Check the position of the compaction head against the specimen mold in accordance with the manufacturer's instructions.

4.3.3.2. Adjust the compaction force and vibration time settings in accordance with the manufacturer's instructions.

4.3.3.3. Heat and charge the specimen mold in accordance with the manufacturer's instructions.

4.3.3.4. Operate the vibratory compactor in order to compact and extrude the specimen in accordance with the manufacturer's instructions.

4.3.4. Compacted specimens should remain at room temperature, approximately 25°C (77°F), to allow the entire specimen to cool, for a minimum of 3 hours.

4.4. *Laboratory-Prepared (HMA)*:

4.4.1. Prepare the ingredient materials and mix the HMA specimens in accordance with T 312.

4.4.2. When using an SGC, compact specimens conforming to the dimensional requirements of Section 4.1 to 7.0 ± 0.5 percent air voids in accordance with T 312.

4.4.3. When using a vibratory compactor, compact specimens conforming to the dimensional requirements of Section 4.1 to 7.0 ± 0.5 percent air voids in accordance with the procedure given in Sections 4.3.3.1 through 4.3.3.4.

4.4.4. Compacted specimens should remain at room temperature, approximately 25°C (77°F), to allow the entire specimen to cool, for a minimum of 3 hours.

5. DETERMINING THE AIR VOID CONTENT

5.1. Determine the bulk specific gravity of the HMA specimens in accordance with T 166. In the case of sawn specimens as described in Section 4.2.1, determine the bulk specific gravity of the specimens after sawing.

5.2. Determine the maximum specific gravity of the loose HMA in accordance with T 209.

5.3. Determine the air void content of the HMA specimens in accordance with T 269.

6. SELECTING THE TEST TEMPERATURE

6.1. The test temperature shall be set to the high temperature of the standard Superpave performance-graded (PG) binder identified by the specifying agency for the project that the HMA is intended. For circumstances where the high-temperature binder grade has been increased, the APA test temperature will remain at the standard PG binder high temperature.

7. SPECIMEN PREHEATING

7.1. Place the specimens in the test molds.

7.2. Specimens shall be preheated at the test temperature in the temperature-calibrated APA test chamber or a separate calibrated oven for a minimum of 6 hours. Specimens should not be held at the test temperature for more than 24 hours prior to testing.

8. PROCEDURE

8.1. Set the hose pressure gap reading to 690 ± 35 kPa (100 ± 5 psi). Set the load cylinder pressure reading for each wheel to achieve a load of 445 ± 22 N (100 ± 5 lbf).

8.2. Stabilize the testing chamber temperature at the temperature selected in Section 6.

8.3. Secure the preheated, molded specimens in the APA. The preheated APA chamber should not be open for more than 6 minutes when securing the test specimens into the machine. Close the chamber doors and allow a minimum of 10 minutes for the temperature to stabilize prior to starting the test.

8.4. *Manual Rut-Depth Measurement*:

8.4.1. Apply 25 cycles to seat the specimens before taking the initial measurements. Make adjustments to the hose pressure as needed during these 25 cycles.

8.4.2. Open the chamber doors; unlock and pull out the sample holding tray.

8.4.3. Place the rut-depth-measurement template conforming to Section 3.1.8 over the specimen. Ensure that the rut-depth-measurement template is properly seated and firmly rests on top of the testing mold.

8.4.4. Zero the measuring gauge. Take initial readings at each of the four outside locations on the template; the center measurement is not used. Measurements shall be determined by placing the measuring gauge in the template slots and sliding the gauge slowly across each slot. Record the smallest measurement for each location to the nearest 0.01 mm (0.0004 in.).

8.4.5. Repeat Sections 8.4.3 and 8.4.4 for each set of cylinders in the testing position. All measurements shall be completed within 6.0 ± 0.5 minutes.

8.4.6. Push the sample holding tray in and secure it. Close the chamber doors and allow a minimum of 10 minutes for the temperature to stabilize.

8.4.7. Set the preset counter to 8000 cycles.

8.4.8. Start the test. When the test reaches 8000 cycles, the APA will stop and the load wheels will automatically retract.

8.4.9. Repeat Sections 8.4.2 through 8.4.5 to obtain the final measurements.

8.5. *Automatic Rut-Depth Measurement*:

Note 3—Some APA users have reported significant differences in rut depths between automatic measurements and manual measurements.

8.5.1. Initialize the APA computer software. Using the APA computer software or on the APA as appropriate, enter the applicable test parameters and project information prior to starting the test.

8.5.2. Ensure that the cycle-countdown mechanism is set to a value that will permit the specimens to be seated, a complete test of 8000 cycles to be performed, and the computer program to be disengaged at the end of the test. Normally, this value is between 8050 and 8100 cycles.

8.5.3. Using the APA computer software or on the APA as appropriate, start the test.

8.5.4. The APA will stop when the test is complete, and the wheels will automatically retract. Save the rut-depth data file to the computer. Print the data if desired.

9. CALCULATIONS

9.1. Determine the average rut depth for each of the three test positions.

9.1.1. When utilizing manual rut-depth measurement, determine the rut depth at each location by subtracting the final measurement from the initial measurement. Use the rut depth for all four locations to calculate the average rut depth for each of the three test positions.

9.1.2. When utilizing automatic rut-depth measurement, obtain the rut depths from the three test positions as displayed on the APA computer software.

9.2. *Outlier Evaluation*—Calculate the sample standard deviation for the three test positions. If the sample standard deviation of the three test positions is greater than or equal to 2.0 mm (0.08 in.), then the position with the rut depth farthest from the average may be discarded. The testing procedure, device calibration, and test specimens should be investigated to determine possible causes for the excessive variation.

9.3. The APA rut depth for the HMA is the overall average rut depth for the three test positions, less any outliers, from the six cylindrical specimens.

10. REPORT

10.1. *The test report shall include the following information*:

10.1.1. The laboratory name, technician name, and date of the test;

10.1.2. The HMA type and description;

10.1.3. The type of test specimens (cylinders or cores);

10.1.4. For cylinders, the type of compaction device (SGC or vibratory compactor);

10.1.5. The average air void content of the test specimens;

10.1.6. The test temperature;

10.1.7. The method utilized to measure rut depth (manual or automatic); and

10.1.8. The average rut depth for each of the three test positions, and the overall average rut depth for the HMA, to the nearest 0.1 mm (0.0004 in.).

11. PRECISION AND BIAS

11.1. Work is underway to develop precision and bias statements for this standard.

ANNEX

(Mandatory Information)

A1. CALIBRATION

A1.1. The following items should be checked for calibration no less than once per year: (1) preheating oven; (2) APA temperature; (3) APA wheel load; and (4) APA hose pressure. Instructions for each of these calibration checks are included in this section. For APAs equipped with the automatic rut-depth measurement system, calibrate the horizontal and vertical components of the data-acquisition system according to the manufacturer's schedule and instructions.

A1.2. *Temperature calibration of the preheating oven*:

A1.2.1. The preheating oven must be calibrated with a NIST-traceable thermometer [an ASTM No. 65C (65F) calibrated thermometer conforming to ASTM E 1 is recommended] and a metal thermometer well to avoid rapid heat loss when checking the temperature.

A1.2.2. *Temperature Stability*:

A1.2.2.1. Set the oven to the chosen temperature [e.g., 64°C (147°F)]. Place the thermometer in the well, and place the thermometer and well on the center of the shelf where the samples and molds will be preheated. It usually takes an hour or so for the oven chamber, well, and thermometer to stabilize. After 1 hour, open the oven door and read the thermometer without removing it from the well. Record this temperature. Close the oven door.

A1.2.2.2. Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Record this temperature.

A1.2.2.3. If the readings from Sections A1.2.2.1 and A1.2.2.2 are within 0.4°C (0.8°F), average the readings. If the readings differ by more than 0.4°C (0.8°F), continue to take readings every 30 minutes until the temperature stabilizes within 0.4°C (0.8°F) on two consecutive readings.

A1.2.3. *Temperature Uniformity*:

A1.2.3.1. To check the uniformity of the temperature in the oven chamber, move the thermometer and well to another location in the oven so that they are on a shelf where the samples and molds will be preheated, but as far as possible from the first location. Take and record readings of the thermometer at the second location every 30 minutes until two consecutive readings at the second location are within 0.4°C (0.8°F).

A1.2.3.2. Compare the average of the two readings at the first location from Section A1.2.2.3 with the average of the stabilized temperature at the second location. If the average temperatures from the two locations are within 0.4°C (0.8°F), the oven temperature is relatively uniform, and it is suitable for use in preheating APA samples. If the average of the readings at the two locations differs by more than 0.4°C (0.8°F), another oven that will maintain this level of uniformity and meet calibration must be utilized.

A1.2.4. *Temperature Accuracy*:

A1.2.4.1. Average the temperatures from the two locations (Section A1.2.2.3 and A1.2.3.2.). If that average temperature is within 0.4°C (0.8°F) of the set-point temperature on the oven, the oven is reasonably accurate and calibration is complete.

A1.2.4.2. If the set point differs from the average temperature by more than 0.4°C (0.8°F), adjust the oven set point appropriately to raise or lower the temperature inside the oven chamber so that the thermometer and well will be at the desired temperature [e.g., 64°C (147°F)].

A1.2.4.3. Place the thermometer and well on the center of the shelf. At 30-minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4°C (0.8°F), and the average of the two consecutive readings is within 0.4°C (0.8°F) of the desired test temperature [e.g., 64°C (147°F)], the oven has been properly adjusted and calibration is complete. If these two conditions are not satisfied, repeat Sections A1.2.4.2 and A1.2.4.3.

A1.3. *APA Temperature Calibration*:

A1.3.1. The APA must be calibrated with a NIST-traceable thermometer [an ASTM No. 65C (65F) calibrated thermometer conforming to ASTM E 1 is recommended] and a metal thermometer well to avoid rapid heat loss when checking the temperature.

A1.3.2. *Temperature Stability*:

A1.3.2.1. Turn on the APA main power, and set the chamber temperature controller so that the inside of the testing chamber is at the anticipated testing temperature [e.g., 64°C (147°F)]. Also, if applicable, set the water temperature controller to achieve the anticipated testing temperature.

Note A1—Due to possible variability in the APA temperature controller, the thermometer reading should always be considered as the chamber temperature.

A1.3.2.2. Place the thermometer in the well, and place the thermometer and well on the left side of the APA where the samples are tested.

Note A2—It may be helpful to remove the hose rack from the APA during the temperature calibration to avoid breaking the thermometer.

A1.3.2.3. It usually takes about 5 hours for the APA temperature to stabilize. After the temperature display on the controller has stabilized, open the chamber doors and read the thermometer without removing it from the well. Record this temperature. Close the chamber doors.

A1.3.2.4. Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Record this temperature.

A1.3.2.5. If the readings from Sections A1.3.2.3 and A1.3.2.4 are within 0.4°C (0.8°F), average the readings. If the readings differ by more than 0.4°C (0.8°F), continue to take readings every 30 minutes until the temperature stabilizes within 0.4°C (0.8°F) on two consecutive readings.

A1.3.3. *Temperature Uniformity*:

A1.3.3.1. To check the uniformity of the temperature in the APA chamber, move the thermometer and well to the right side of the APA where the samples are tested. Take and record readings of the thermometer at the second location every 30 minutes until two consecutive readings at the second location are within 0.4°C (0.8°F).

A1.3.3.2. Compare the average of the two consecutive readings obtained in Sections A1.3.2.5 and A1.3.3.1. If the average temperatures from the two locations are within 0.4°C (0.8°F), the APA temperature is relatively uniform, and it is suitable for use. If the average of the readings at the two locations differs by more than 0.4°C (0.8°F), consult the manufacturer on improving the temperature uniformity.

A1.3.4. *Temperature Accuracy*:

A1.3.4.1. Average the temperatures from the two locations (Sections A1.3.2.5 and A1.3.3.2.). If that average temperature is within 0.4°C (0.8°F) of the desired test temperature [e.g., 64°C (147°F)], the APA temperature is reasonably accurate and calibration is complete.

A1.3.4.2. If the average temperature differs from the desired test temperature [e.g., 64°C (147°F)] by more than 0.4°C (0.8°F), adjust the APA temperature controller so that the thermometer and well will be at the desired test temperature.

Note A3—It is advisable to keep the water bath set at the same temperature as the test chamber.

A1.3.4.3. Place the thermometer and well on the center of the shelf. At 30-minute intervals, take readings of the thermometer. When two consecutive readings are within 0.4°C (0.8°F), and the average of the two consecutive readings is within 0.4°C (0.8°F) of the desired test temperature [e.g., 64°C (147°F)], the APA temperature has been properly adjusted and calibration at that temperature is complete. Record the current set points on the temperature controllers for later reference. If these two conditions are not satisfied, repeat Sections A1.3.4.2 and A1.3.4.3.

A1.4. APA wheel load calibration of the air cylinders at the three test positions.

A1.4.1. Check the APA wheel loads with the calibrated load cell provided with the APA. Check and adjust the loads one at a time while the other wheels are in the "down" position and bearing on a dummy sample or wooden block of approximately the same height as a test sample. Calibration of the wheel loads should be accomplished with the APA at room temperature.

A1.4.1.1. Remove the hose rack from the APA.

A1.4.1.2. "Jog" the wheel carriage until the wheels are over the center of the sample tray when the wheels are in the "down" position.

A1.4.1.3. Raise and lower the wheels 20 times to heat up the cylinders.

A1.4.1.4. Adjust the bar on top of the load cell until the total height of the load cell/load bar assembly is 105 ± 5 mm (4.1 ± 0.2 in.).

A1.4.1.5. Position the load cell under one of the wheels. Place wooden blocks or dummy samples under the other two wheels.

A1.4.1.6. Zero the load cell.

A1.4.1.7. Lower all wheels by turning the cylinder switch to "CAL."

A1.4.1.8. If the load cell is not centered left-to-right beneath the wheel, then raise the wheel and adjust the position of the load cell. To determine if the load cell is centered front-to-back beneath the wheel, unlock the sample tray and move it SLOWLY until the wheel rests in the indentation on the load-cell bar (where the screw is located).

A1.4.1.9. After the load cell has been properly centered, adjust the pressure in the cylinder to obtain 445 ± 5 N (100 ± 1 lbf). Allow 3 minutes for the load-cell reading to stabilize between adjustments. Record the pressure and load.

A1.4.1.10. With the wheel on the load cell remaining in the "down" position, raise and lower the other wheels one time. Allow 3 minutes for the load-cell reading to stabilize. Record the pressure and load.

A1.4.1.11. With the other wheels remaining in the "down" position, raise and lower the wheel over the load cell. Allow 3 minutes for the load-cell reading to stabilize. Record the pressure and load.

A1.4.1.12. Repeat Sections A1.4.1.5 through A1.4.1.11 for each wheel/cylinder.

A1.4.1.13. Return the load cell to the first wheel and repeat Sections A1.4.1.5 through A1.4.1.11.

A1.4.1.14. Place the load cell under the second wheel and repeat Sections A1.4.1.5 through A1.4.1.11.

A1.4.1.15. Place the load cell under the third wheel and repeat Sections A1.4.1.5 through A1.4.1.11. The current cylinder pressures will be used to set the wheel loads to 445 N (100 lbf).

A1.5. *Replacement of the APA hoses*:

A1.5.1. New hoses shall be placed in service in accordance with Section 3.1.7.

A1.5.1.1. Remove the hose rack from the APA.

A1.5.1.2. Remove the used hoses from the hose rack. For each position, place the new hose on the barbed nipples and secure it with the hose clamps.

A1.5.1.3. Position each new hose in the rack, ensuring that any curvature in the hose is aligned vertically (concave down toward the specimen) without any curvature in the horizontal direction. Tighten the nuts at the ends of the hoses only until the hoses are secure. Over-tightening will affect the contact pressure and hose life.

A1.5.1.4. Place the hose rack back into the APA and ensure that the hoses are aligned beneath the wheels.

A1.5.1.5. Prior to formal testing, "break in" the new hoses by running 8000 cycles on a set of previously tested samples at a temperature of 55°C (131°F) or higher.

A1.6. *APA hose pressure check*:

A1.6.1. The air pressure in the APA test hoses shall be checked with a NIST-traceable test gauge or transducer with a suitable range while the APA is operating. Since the hoses are connected in series, it is satisfactory to connect the test gauge to the end of the right-most hose. The pressure should not fluctuate outside of the range of 690 ± 35 kPa (100 ± 5 psi) during normal operation. Adjust the pressure as necessary with the hose-pressure regulator.

Note A4—The Ashcroft test gauge, Model 450182As02L200#, has been found to be satisfactory for this purpose. This gauge is available through Grainger (Stock No. 2F008).

APPENDIX

(Nonmandatory Information)

X1. OPTIONAL APA TESTING PARAMETERS

X1.1. The numerous testing parameters involved when utilizing the APA (e.g., hose pressure/wheel load, specimen air-void content, specimen height, etc.) present a great opportunity for multiple combinations. Accordingly, very few APA users employ the same set of testing parameters. One reason for this diversity is that the use of the APA predated the development of a standard for the APA. Most users developed their own method based on the manufacturer's instructions, accumulated substantial data with that method, and in some cases, implemented a specification based on those data. Understandably, many APA users are hesitant to modify their testing parameters at this point.

X1.2. This standard establishes a set of APA testing parameters for the sake of consistency and development of precision and bias statements. The parameters specified are based on the general experience of numerous APA users and are widely accepted within the industry. In fact, the specified test conditions represent the majority of APA users. However, the parameters established in this standard do not agree with the recommendations from NCHRP 9-17 (*NCHRP Report 508*) in every case. The NCHRP 9-17 study attempted to identify the APA test parameters that best correlate with field rutting performance.

X1.3. Due to the diversity involved with the APA testing parameters throughout the community of users, this appendix presents specifications for, and discussion concerning, other test-condition options often employed by APA users.

X1.4. *Beam Specimens*:

X1.4.1. Some APA users test HMA beam specimens, rather than cylindrical specimens, for rut depth. Beam specimens can only be prepared by using the vibratory compactor. NCHRP 9-17 (*NCHRP Report 508*) included beam specimens as part of the research effort. When utilizing beam specimens in the APA, the following additional specifications are recommended:

X1.4.1.1. The APA shall be capable of testing cylindrical or beam specimens.

X1.4.1.2. The test molds for beam specimens shall be rectangular in shape, be composed of UHMW polyethylene, fit snugly within the testing position in the APA testing chamber, and contain one hole in which to insert the specimen. The dimensions of the hole shall be 75.0 ± 2.0 mm (2.95 ± 0.08 in.) tall by 125.0 ± 2.0 mm (4.92 ± 0.08 in.) wide by 300.0 ± 2.0 mm (11.81 ± 0.08 in.) long.

X1.4.1.3. The compaction molds used for beam specimens shall be composed of steel and reinforced with 25.4 mm (1.00 in.) by 28.6 mm (1.13 in.) angle mounted 25.4 mm (1.00 in.) from the top of the mold. The molds shall conform to the following dimensions:

- inside length of 299.9 ± 0.5 mm (11.81 ± 0.02 in.);
- inside width of 124.5 ± 0.5 mm (4.90 ± 0.02 in.);
- inside height of 133.5 ± 0.5 mm (5.26 ± 0.02 in.);
- overall height of 152.5 ± 0.5 mm (6.00 ± 0.02 in.);
- wall thickness of 6.25 ± 0.5 mm (0.25 ± 0.02 in.);
- bottom plate length of 297.4 ± 0.5 mm (11.71 ± 0.02 in.); and
- bottom plate width of 122.2 ± 0.5 mm (4.81 ± 0.02 in.).

X1.4.1.4. For either laboratory-prepared or plant-produced HMA, compact three beam specimens per test in accordance with the procedure given in Sections 4.3.3.1 through 4.3.3.4. Ensure the beam specimens conform to the following dimensions: 75 ± 2 mm (3.0 ± 0.1 in.) tall by 125 mm (4.92 in.) wide by 300 mm (11.81 in.) long.

X1.4.1.5. When performing manual rut-depth measurement for beam specimens, take initial readings at each of the five locations on the rut-depth-measurement template conforming to Section 3.1.8. Otherwise, obtain manual rut-depth measurements in accordance with Section 8.4.

X1.4.1.6. When calculating the rut depth from manual rut-depth measurements for beam specimens, use the rut depth for all five locations to calculate the average rut depth for each of the three test positions. The APA rut depth for the HMA is the overall average rut depth for the three test positions, less any outliers as described in Section 9.2, from the three beam specimens.

X1.4.1.7. Report that beam specimens were the type of test specimens utilized to evaluate the HMA rut depth.

X1.5. *115-mm Cylindrical Specimens*:

X1.5.1. Some APA users test cylindrical specimens with a specimen height of 115 mm, rather than a specimen height of 75 mm, for rut depth. NCHRP 9-17 (*NCHRP Report 508*) did not include cylindrical specimens with a specimen height of 115 mm as part of the research effort. Additional research is needed to compare rut depths between the two sample heights (75 mm and 115 mm) for cylindrical specimens. When utilizing cylindrical specimens with a specimen height of 115 mm in the APA, the following additional specifications are recommended:

X1.5.1.1. The dimensions of each of the two holes in the test molds for cylindrical specimens shall be 150.0 ± 2.0 mm (5.91 ± 0.08 in.) in diameter by 115.0 ± 2.0 mm (4.53 ± 0.08 in.) tall.

X1.5.1.2. The number and dimensions of test specimens shall be as follows: six cylindrical specimens, 150 mm (5.91 in.) in diameter by 115 ± 2 mm (4.5 ± 0.1 in.) tall.

X1.5.1.3. Report that cylindrical specimens with a specimen height of 115 mm were the type of test specimens utilized to evaluate the HMA rut depth.

X1.6. *Lower Target Air Void Content*:

X1.6.1. Some APA users test cylindrical specimens compacted to 4.0 percent air voids or beam specimens compacted to 5.0 percent air voids rather than using a target air void content of 7.0 percent. When desiring a lower target air void content, beam specimens are normally compacted to 5.0 percent air voids rather than 4.0 percent due to a frequent inability to compact beam specimens to 4.0 percent.

X1.6.2. NCHRP 9-17 (*NCHRP Report 508*) evaluated these lower air void targets during the course of the research and found that the lower targets more closely related to field rutting performance than cylindrical and beam specimens compacted to 7.0 percent air voids. However, the vast majority of APA users utilize a target air void content of 7.0 percent.

X1.6.3. When utilizing cylindrical specimens compacted to 4.0 percent air voids or beam specimens compacted to 5.0 percent air voids, the following additional specifications are recommended:

X1.6.3.1. When producing either laboratory-prepared or plant-produced HMA specimens using an SGC, compact cylindrical specimens conforming to the dimensional requirements of Section 4.1 or Section X1.5.1.2 to 4.0 ± 0.5 percent air voids in accordance with T 312.

X1.6.3.2. When producing either laboratory-prepared or plant-produced HMA specimens using a vibratory compactor, compact cylindrical specimens conforming to the dimensional requirements of Section 4.1 or Section X1.5.1.2 to 4.0 ± 0.5 percent air voids. Alternatively, compact beam specimens conforming to the dimensional requirements of Section X1.4.1.4 to 5.0 ± 0.5 percent air voids. In both cases, compact the specimens in accordance with the procedure given in Sections 4.3.3.1 through 4.3.3.4.

X1.7. *Higher Wheel Load and Hose Pressure*:

X1.7.1. Some APA users test specimens using a wheel load of 534 N (120 lbf) and a hose pressure of 830 kPa (120 psi) rather than 445 N (100 lbf) and 690 kPa (100 psi), respectively. NCHRP 9-17 (*NCHRP Report 508*) evaluated the higher load and pressure during the course of the research. However, the vast majority of APA users utilize a wheel load of 445 N (100 lbf) and a hose pressure of 690 kPa (100 psi) when testing APA specimens. Additional research is needed to compare rut depths between the two loading conditions. When utilizing a wheel load of 534 N (120 lbf) and a hose pressure of 830 kPa (120 psi), the following additional specifications are recommended:

X1.7.1.1. Set the hose pressure gap reading to 830 ± 35 kPa (120 ± 5 psi). Set the load cylinder pressure reading for each wheel to achieve a load of 534 ± 22 N (120 ± 5 lbf).

X1.7.1.2. Report that a wheel load of 534 N (120 lbf) and a hose pressure of 830 kPa (120 psi) were utilized to evaluate the HMA rut depth.

X1.7.1.3. When calibrating the APA wheel load, after the load cell has been properly centered, adjust the pressure in the cylinder to obtain 534 ± 5 N (120 ± 1 lbf). Otherwise, calibrate the APA wheel load for each test position in accordance with Section A1.4. Use the current cylinder pressures to set the wheel loads to 534 N (120 lbf) as described in Section A1.4.1.15.

X1.7.1.4. When checking the APA hose pressure, ensure that the pressure does not fluctuate outside the range of 830 ± 35 kPa (120 ± 5 psi) during normal operation. If necessary, adjust the pressure with the hose-pressure regulator.

Standard Method of Test for

Helical Continuously Welded Seam Corrugated Steel Pipe

AASHTO Designation: T 241-95 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Helical Continuously Welded Seam Corrugated Steel Pipe

AASHTO Designation: T 241-95 (2008)

1. SCOPE

1.1. This method describes the procedure to be used in determining the quality of the seam or helical, continuously welded seam, corrugated steel pipe. The procedure to be used involves distorting a short length of welded seam by using a 25-mm diameter, hemispherical punch and a 38-mm inside diameter contoured die. The resulting distorted weld area will hereafter be called the "cup."

1.2. At the option of the engineer, or in the event of a disagreement between the engineer and fabricator, the referee test described in Section 4 will be performed.

2. APPARATUS

2.1. *Die*—A die having an inside diameter of 38 mm and machined to conform to the corrugation of the sample. (See Figure 1.)

2.2. *Punch*—A punch consisting of a 25-mm steel ball attached to a section of 19-mm diameter steel rod. (See Figure 1.)

2.3. *Bending Test Device*—Bending jig with roller bending edges, adjustable supports, and 13-mm diameter mandrel. (See Figure 2.)

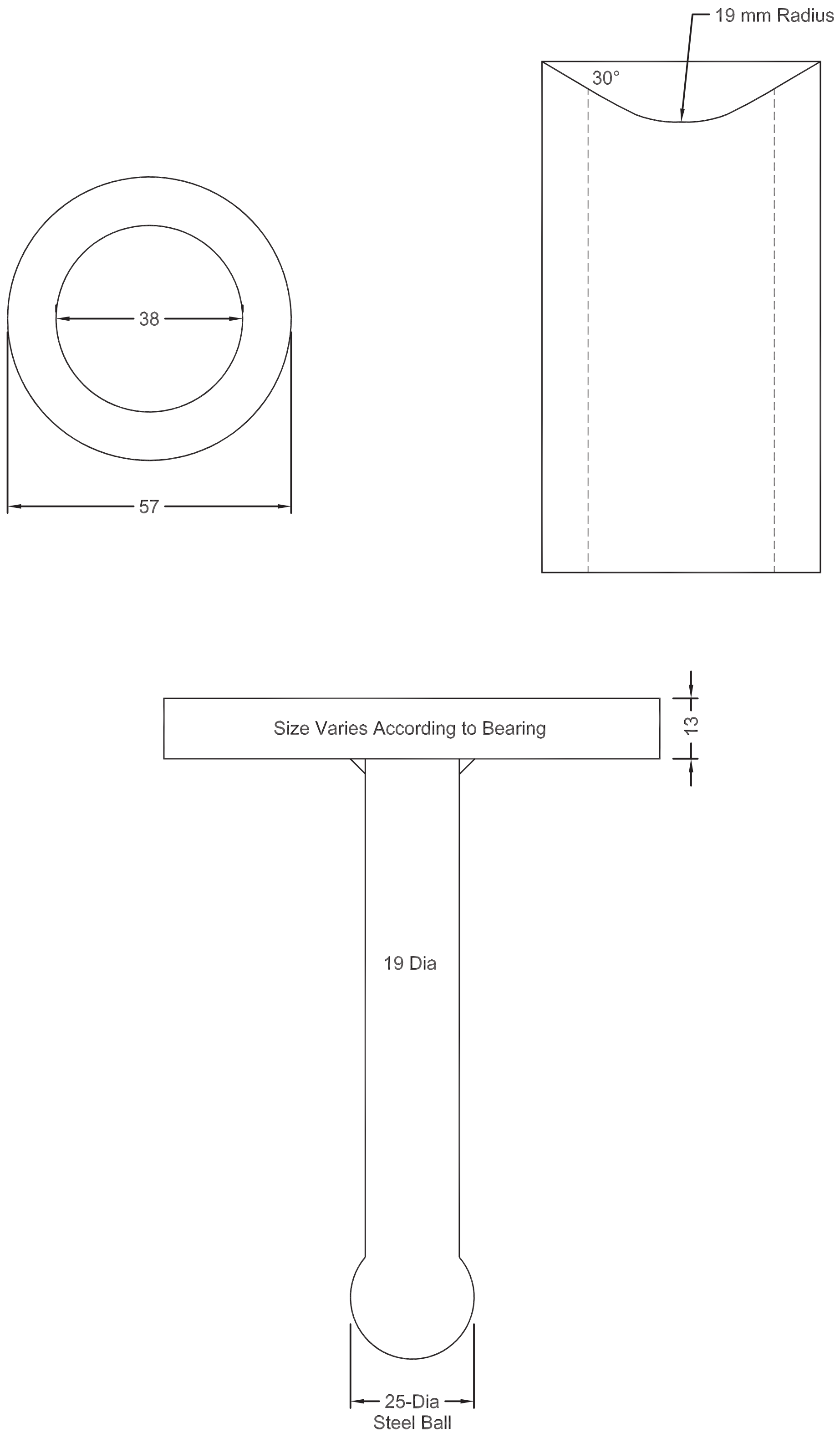
2.4. *Gauge*—Figure 3 shows a gauge recommended for use in measuring various dimensions in connection with the cup test, and also for checking acceptable width of the area burned by welding. It is used in the following manner:

2.4.1. The projections at the top of the gauge are dimensioned horizontally in accordance with the widths of burned area (three times thickness of metal) acceptable under the specification for each indicated gauge of metal.

2.4.2. The 76.2-mm overall length dimension is used to check the positioning of the test.

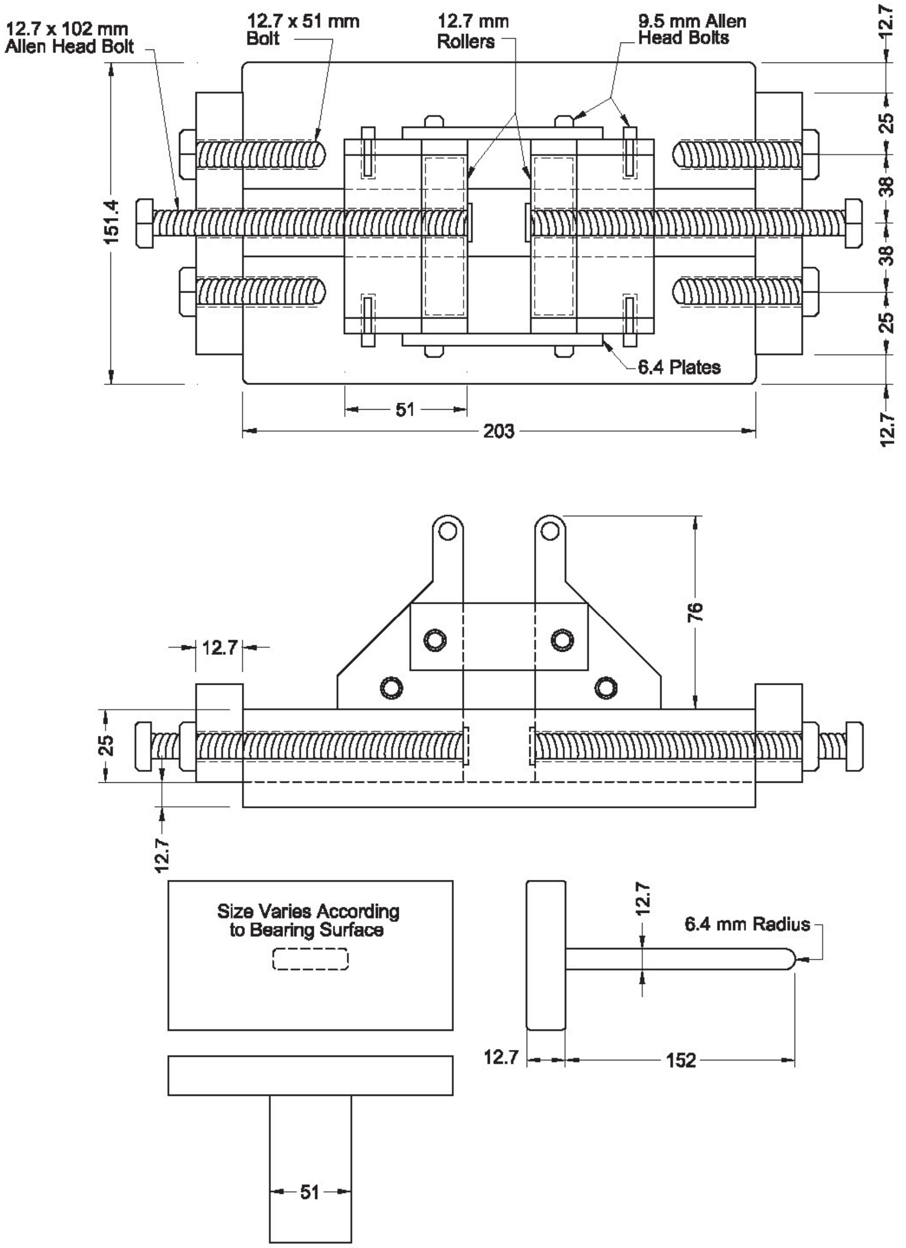
2.4.3. When the gauge is positioned on the pipe so that the bottom legs straddle the convex side of the cup, the 10.31-mm projection should always touch the cup. The interval corresponds to the minimum allowable depth of the cup after relaxation.

2.4.4. The 6.35-mm side projection can be used to check conformance to the limits set forth in Section 3.3.



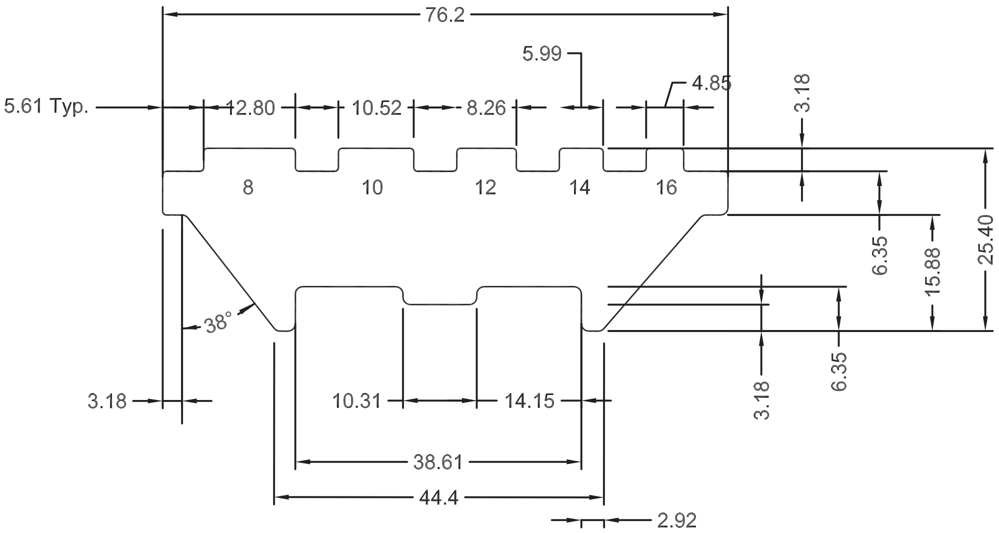
Note: All dimensions shown in millimeters unless otherwise noted.

Figure 1—Die and Punch for Cup Test



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 2—Bend Test Apparatus



Material—2.38 mm Stainless Steel

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 3—Cup Gauge

2.5. *Loading Device*—The loading device may be either a hydraulic or a screw-type testing machine with sufficient opening between the upper bearing surface and the lower bearing surface of the machine to permit the introduction of the specimen to be tested, or any suitable device that is capable of applying sufficient load to cause the die to penetrate the weld to the depth specified.

3. CUP TEST PROCEDURE

3.1. Position the punch on one side and center over the welded seam at the desired testing location. The direction of the cup shall be with the concavity of the corrugation. Tests shall be made not less than 75 mm from the end of the pipe and the minimum distance between tests shall be 75 mm.

3.2. Center the punch opposite the die, on the other side of the pipe wall, and, using the loading device described in Section 2.5, force the punch into the weld to a nominal depth under load of 5 mm. The resulting cup after relaxation must be at least 3 mm in depth.

3.3. For a length of a pipe to be acceptable, the sum of the lengths of cracks or other defects on either side of the cup shall be not more than 6 mm.

3.3.1. If the first cup indicates a failure, punch a second cup at another location on the weld not less than 76 mm or more than 300 mm from the first cup and in the direction of the center of the pipe. If this second cup test indicates a failure, the pipe shall be rejected.

3.4. *Report*—No formal test report is necessary for the cup test. This test will be part of the routine quality control and inspection procedure for acceptance of the pipe.

4. REFEREE TEST METHOD

4.1. The referee test consists of destructive tests requiring two 600- by 600-mm samples of pipe containing approximately 600-mm length of weld running through the center. No reformed corrugations will be allowed in the samples.

4.2. Each sample shall be cut into test specimens of the number and type shown in Table 1.

Table 1—Number and Type of Specimens

Number of Test Specimens Required	Type
3	Tensile test across the weld
3	Tensile test of the base metal above the weld
3	Tensile test of the base metal below the weld
3	Face bends
3	Root bends
3	Cup test of the weld
3	Cup test of base metal

4.3. *Tensile Test Specimens*—The tensile test specimens will be prepared in accordance with T 244, Figure 3. The grip of each specimen area will be flattened with care to prevent damage to the welds. The ultimate strength of the across-the-weld test specimens shall be equal to 90 percent of the ultimate strength of the lowest base metal test specimen.

4.4. In determining the mechanical properties, the base metal thickness of the specimen shall be measured after stripping the coating from the ends of the specimen contacting the grips of the testing machine, before testing.

4.5. *Bend Test*—All face and root bend specimens shall have a 5.0-mm gauge length on their appropriate sides across the weld area. The face bend specimen corrugations shall be flattened before testing. The test shall be performed by centering the weld on a 13-mm mandrel and bending the specimen 180 degrees. The root bend test shall be performed by forcing the corrugated specimen to a flat position. Any visible cracks in the weld resulting from the bend tests will be cause for rejection. The data resulting from the bend tests shall be the percent elongation of the gauge length.

4.5.1. *Bend Test Specimen*—The bend specimens shall be 150 mm long and 25 mm wide cut across the welded seam.

4.6. *Report*—The following elements are essential in reporting results of referee tests:

4.6.1. Ultimate strength of base metal and weld specimens,

4.6.2. Percentage of ultimate strength of weld metal compared with lowest ultimate strength of base metal,

4.6.3. Results of bend tests,

4.6.4. Results of cup tests of both the weld and base metal, and

4.6.5. Evaluation of test data.

Standard Method of Test for

Helical Lock Seam Corrugated Pipe

AASHTO Designation: T 249-03 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Helical Lock Seam Corrugated Pipe

AASHTO Designation: T 249-03 (2007)

1. SCOPE

1.1. This method of test is to be followed in ascertaining the quality of the seam of a helical lock seam corrugated pipe.

VISUAL METHOD

2. PROCEDURE

2.1. Determine lock seam quality by examining samples of the lock seam cross section sawed from the pipe. See Figure 1 for location of sample. See Figure 2 for the cross section of the sample.

2.2. The manufacturer will saw a triangular sample from the seam at one end of a length of pipe so as to show the cross section normal to the seam. The base of the triangular sample shall be of sufficient width to show complete lock seam profile. (See Figure 1.)

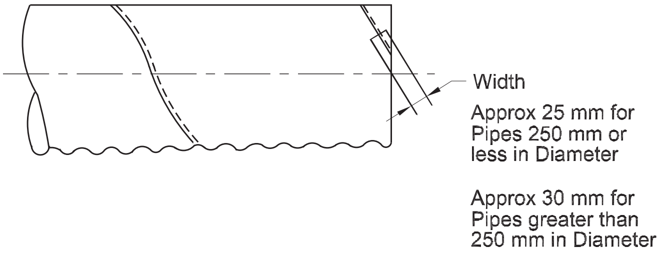


Figure 1—Location of Sample

2.3. The edges of the sheets within the cross section of the lock seam shall lap at least 4.0 mm for pipe 250 mm or less in diameter and at least 7.9 mm for pipe greater than 250 mm in diameter, with an occasional tolerance of –10 percent of lap width allowable. The lapped surfaces shall be in tight contact. There shall be no visible cracks in the metal, loss of metal-to-metal contact, or excessive angularity on the interior of the 180-degree fold of metal at the completion of forming the lock seam. Measure the seam lap and retaining offset distances (Figure 2) for conformance with specified maximum or minimum dimensions. See Figure 3 for examples of unacceptable seam cross sections.

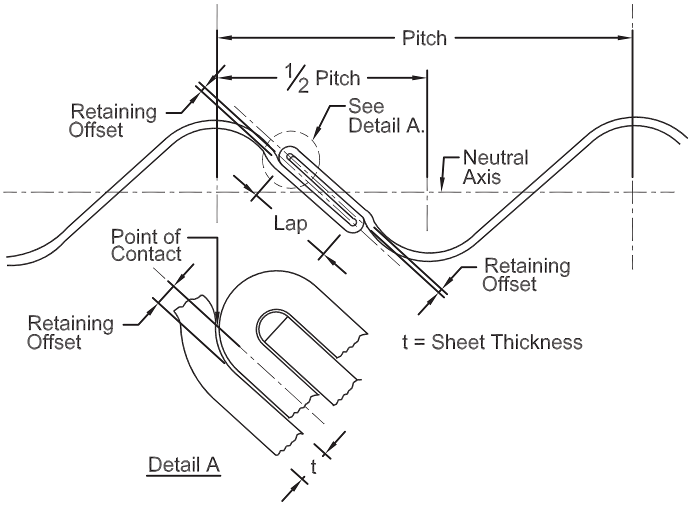


Figure 2A—Type I Lock Seam Cross Section

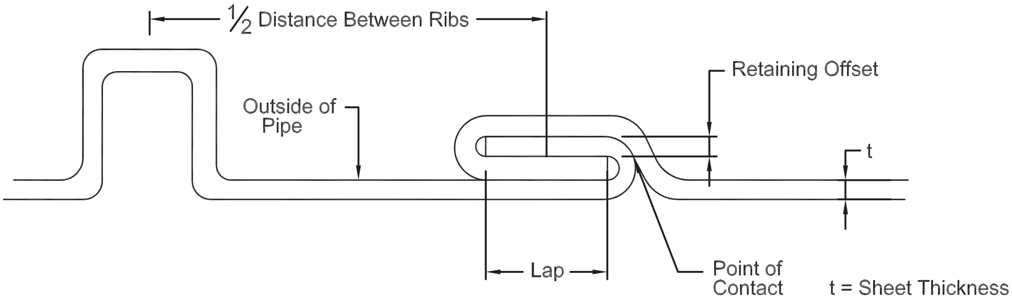


Figure 2B—Type IR Lock Seam Cross Section

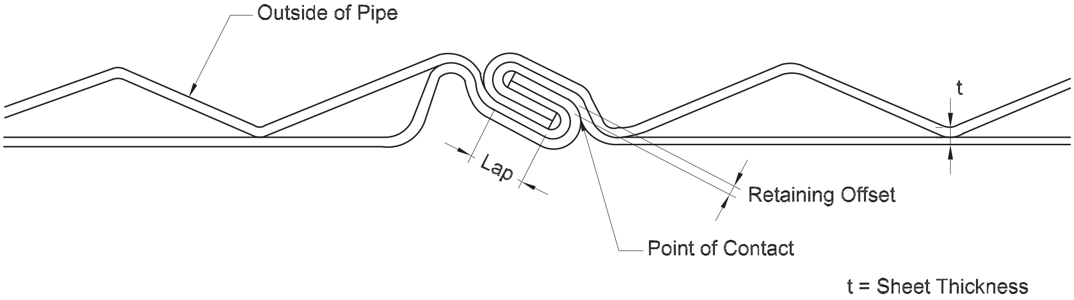


Figure 2C—Type IA Lock Seam Cross Section

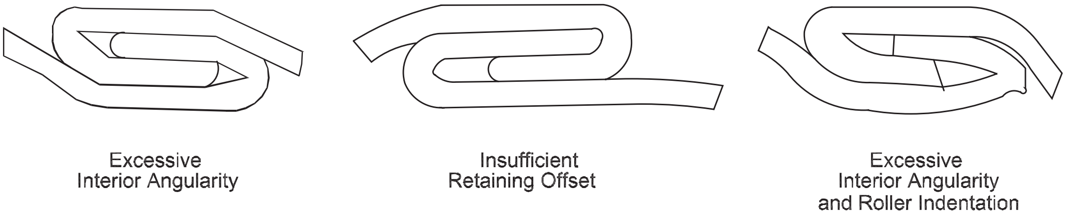


Figure 3—Examples of Unacceptable Seams

TENSION TEST METHOD

3. APPARATUS

3.1. A standard calibrated tensile testing machine.

4. TEST SPECIMEN

4.1. Cut a sample from the end of a fabricated pipe by sawing or burning, with dimensions at least 100 mm parallel to the lock seam and 150 mm perpendicular to the lock seam. If the ends of the pipe have been rerolled to form annular corrugations, take the sample from an area that has not been rerolled unless it is specifically intended to test for the seam strength after rerolling.

4.2. Trim the edges of the sample by sawing to provide a test specimen 25 mm wide (measured parallel to the lock seam), with the edges parallel. (See Figure 4.)

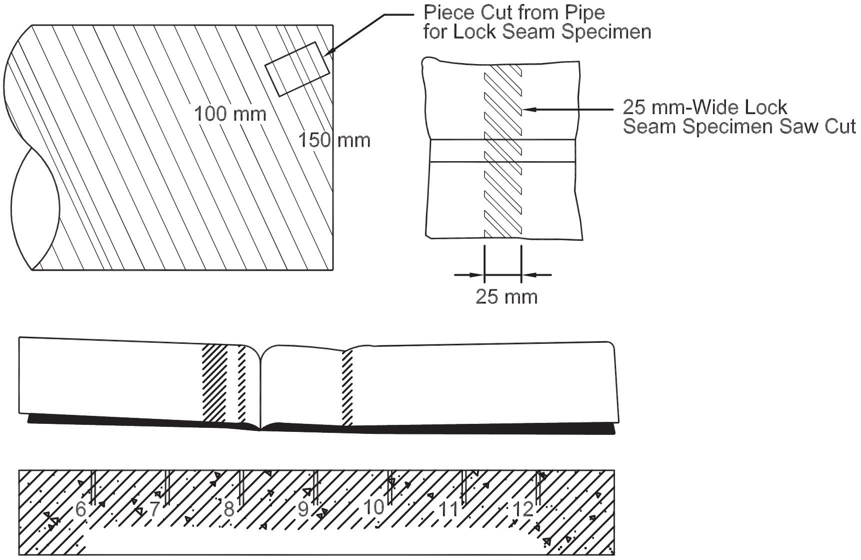


Figure 4—Type of Lock Seam Coupon Tension Specimen

4.3. Flatten the ends of the specimen for gripping in the testing machine, using a vise or similar tool. Insert one end at a time into the vise to 13 mm from the lock seam. As the vise flattens the corrugations, the unrestrained end will rotate. Realign the lock seam with the flattened ends by use of a crescent wrench (or similar) tightened over the lock seam to prevent distortion of the seam itself while bending the strip back into line.

5. PROCEDURE

5.1. Measure the width of the specimen at the lock seam to the nearest 0.2 mm. Measure the thickness of the sheet to the nearest 0.02 mm to determine the nominal sheet thickness.

5.2. Insert the specimen in the testing machine and apply a tensile load until the specimen separates at the lock seam. Record the maximum load.

6. CALCULATION AND REPORT

6.1. Determine the lock seam tensile strength by dividing the maximum load by the width of the specimen. Report the results as kilonewtons per meter (kN/m), and indicate whether the specimen is from an area where the corrugations have been rerolled.

Standard Method of Test for

Concrete Pipe, Manhole Sections, or Tile

AASHTO Designation: T 280-06[1]
ASTM Designation: C 497-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Concrete Pipe, Manhole Sections, or Tile

AASHTO Designation: T 280-06[1]
ASTM Designation: C 497-05

1. SCOPE

1.1. These test methods cover testing of concrete pipe, manhole sections, and tile. The test methods described are used in production testing and acceptance testing to evaluate the properties provided for in the specifications.

1.2. The test methods appear in the following order:

	Section
External load crushing strength	4
Flat slab tops	5
Core strength	6
Absorption	7
Hydrostatic	8
Permeability	9
Manhole step	10
Cylinder strength	11
Gasket lubricant	12
Joint shear	13
Alkalinity	14
Gasket measurement	15
Off-center hydrostatic joint test	16

1.3. The test specimens shall not have been exposed to a temperature below 4ºC [40ºF] for the 24 hours immediately preceding the test.

1.4. If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it shall be discarded and another specimen taken.

1.5. Specimens shall be selected in accordance with the specifications for the type of pipe or tile being tested.

1.6. The values stated in SI units are to be regarded as the standard.

1.7. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- M 262, Concrete Pipe and Related Products
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 231, Capping Cylindrical Concrete Specimens

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 1231/C 1231M, Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders
- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- E 4, Standard Practices for Force Verification of Testing Machines

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. For definitions of terms relating to concrete pipe, see M 262.

4. EXTERNAL LOAD CRUSHING STRENGTH TEST BY THE THREE-EDGE-BEARING TEST METHOD

4.1. *Summary of Test Method*—The test specimen is tested in a machine designed to apply a crushing force upon the specimen in a plane through the vertical axis extending along the length of the specimen.

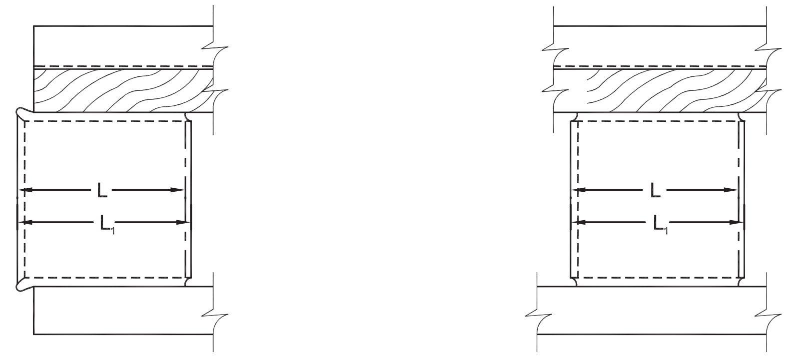
4.2. *Significance and Use*—The crushing test shall be either a quality-control test performed to establish that the finished, shippable pipe has sufficient strength to withstand the crushing loads stated in the specifications or a proof of design test performed to prove the adequacy of design.

4.3. *Apparatus*:

4.3.1. The testing machine shall be of any type of sufficient capacity and shall be capable of providing the rate of loading prescribed in Section 4.5.3.

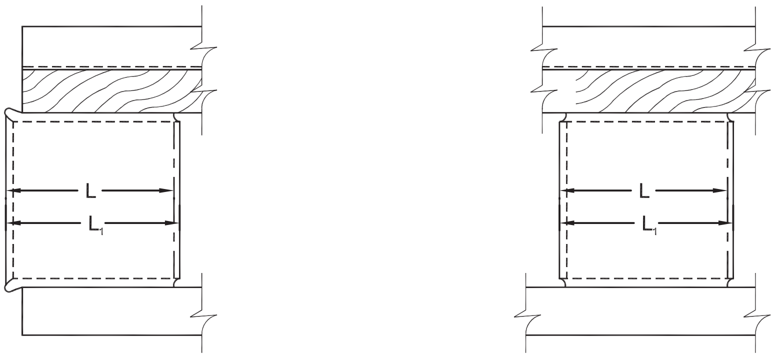
4.3.2. The testing machine shall be substantial and rigid throughout, so that the distribution of the load will not be affected appreciably by the deformation or yielding of any part.

4.3.3. The three-edge-bearing method of loading shall be used. The test specimen shall be supported on a lower bearing of two parallel longitudinal strips and the load applied through an upper bearing (Figures 1, 2, 3, and 4). At the option of the manufacturer, either or both the lower bearing and the upper bearing beam shall extend the full length or any portion of the length of the specimen (Figure 5).



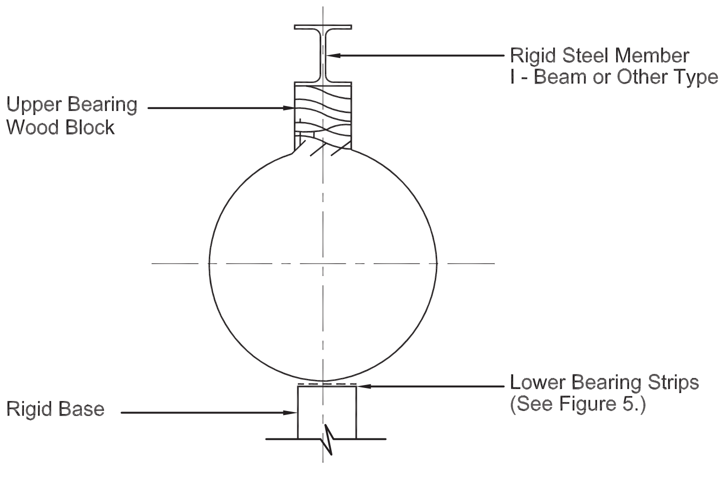
Modified Tongue and Groove Pipe

Tongue and Groove Pipe



Bell and Spigot Pipe

Plain End or Cut Pipe

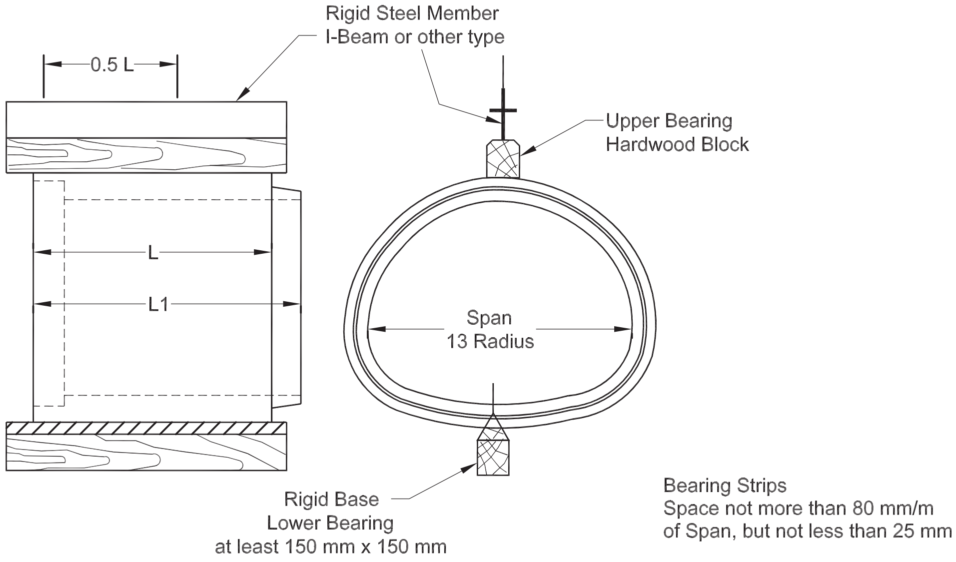


Note: The figures illustrate a method of applying the load to the pipe.

Figure 1—Three-Edge-Bearing Test, Circular Pipe

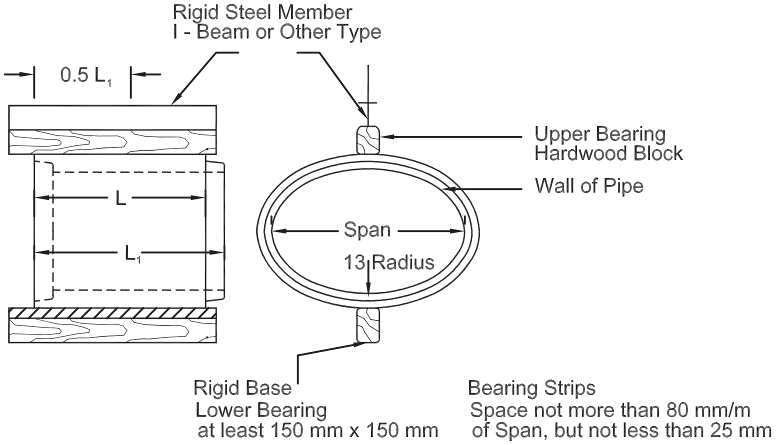
SI Equivalents for Values in Figures 1–13

0.3 mm	0.01 in.	80 mm/m	1 in./ft
1.5 mm	$^{1}/_{16}$ in.		
3 mm	$^{1}/_{8}$ in.	0.25 mm/mm	$^{1}/_{4}$ in./in.
13 mm	$^{1}/_{2}$ in.		
25 mm	1 in.	250 mL/min	0.07 gal/min
50 mm	2 in.		
75 mm	3 in.	26.25 kN	1800 lb
100 mm	4 in.	58.33 kN	4000 lb
125 mm	5 in.		
150 mm	6 in.	21°C	70°F
600 mm	2 ft		



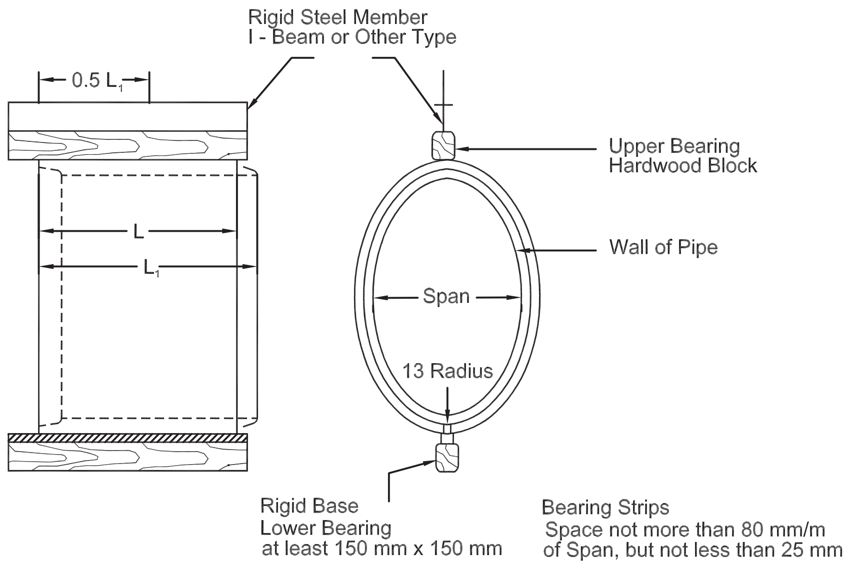
Note: The figures illustrate a method of applying the load to the pipe.

Figure 2—Three-Edge-Bearing Test, Arch Pipe



Note: The figure illustrates a method of applying the load to the pipe.

Figure 3—Three-Edge-Bearing Test, Horizontal Elliptical Pipe



Note: The figure illustrates a method of applying the load to the pipe.

Figure 4—Three-Edge-Bearing Test, Vertical Elliptical Pipe

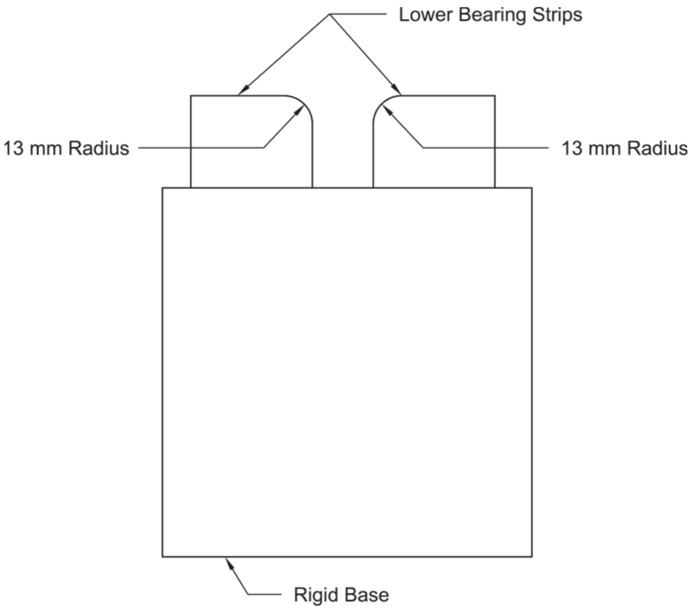


Figure 5—Lower Bearing Strip Detail

4.3.4. The lower bearings shall consist of wood or hard rubber strips. Wooden strips shall be straight, have a cross section of not less than 50 mm [2 in.] in width and not less than 25 mm [1 in.] nor more than 38 mm [1$^1/_2$ in.] in height and shall have the top inside corners rounded to a radius of 13 mm [$^1/_2$ in.]. Hard rubber strips shall have a durometer hardness of not less than 45, nor more than 60. They shall be rectangular in cross section, having a width of not less than 50 mm [2 in.], a thickness of not less than 25 mm [1 in.] nor more than 38 mm [1$^1/_2$ in.], and shall have the top inside corner rounded to a radius of 13 mm [$^1/_2$ in.].

4.3.5. The lower bearing strips shall be fastened to a wooden or steel beam or directly to a concrete base, any of which shall provide sufficient rigidity so that deflection is not greater than $^1/_{720}$ of the specimen length when the maximum load is applied. The rigid base shall be at least 150 mm [6 in.] wide. The interior vertical sides of the strips shall be parallel and spaced a distance apart of not more than 90 mm/m [1 in./ft] of specimen diameter, but in no case less than 25 mm [1 in.]. The bearing faces of the lower strips shall not vary from a straight line vertically or horizontally by more than 2.5 mm/m [$^1/_{32}$ in./ft] of length under no load.

4.3.6. The upper bearing shall be a rigid wood beam with or without an attached hard rubber strip. The wood block shall be sound, free of knots, and straight and true from end to end. It shall be fastened to a steel or wood-faced steel beam of such dimensions that deflections under maximum load will not be greater than $^1/_{720}$ of the specimen length. The bearing face of the upper bearing block shall not deviate from a straight line by more than 2.5 mm/m [$^1/_{32}$ in./ft] of length. When a hard rubber strip is used on the bearing face it shall have a durometer hardness of not less than 45 nor more than 60, and shall have a width of not less than 50 mm [2 in.] and a thickness of not less than 25 mm [1 in.] nor more than 38 mm [$1^1/_2$ in.] and shall be secured to a wood beam meeting the above requirements.

4.3.7. If mutually agreed upon by the manufacturer and the owner prior to the test, before the specimen is placed, a fillet of plaster of paris not exceeding 25 mm [1 in.] in thickness shall be cast on the surface of the upper and lower bearings. The width of the fillet cap, upper or lower, shall not be more than 80 mm/m [1 in./ft] of the specimen diameter, but in no case less than 25 mm [1 in.].

4.3.8. The equipment shall be so designed that the load will be distributed about the center of the overall length (L_1) of the specimen (Figures 1, 2, 3, and 4). At the option of the manufacturer, the center of the load shall be applied at any point of the overall length (L_1) of the specimen. The load shall be applied either at a single point or at multiple points dependent on the length of the specimen being tested and the rigidity of the test frame.

Note 1—The user of these test methods is advised that multiple points of load applications to the upper bearing will permit use of lighter beams without excess deflection.

4.4. *Calibration*—The loading device shall be one that shall provide an accuracy of ±2 percent at the specified test loads. A calibration curve shall be used. The machines used for performing the three-edge-bearing tests shall be verified in accordance with ASTM E 4.

4.5. *Procedure*:

4.5.1. Place the specimen on the two lower bearing strips in such a manner that the pipe or tile rests firmly and with uniform bearing on each strip.

4.5.2. Mark the two ends of the specimen at a point midway between the lower bearing strips and then establish the diametrically opposite point on each end. Place the upper bearing so that it is aligned with these marks.

4.5.3. For reinforced concrete pipe any rate of load application up to a maximum of 110 kN/linear meter [7500 lbf/linear foot] of pipe per minute shall be used up to 75 percent of the specified design strength, at which time the rate of loading shall be reduced to a maximum uniform rate of one-third of the specified design strength of the pipe per minute. This rate of loading shall be continuous until the specified acceptance design strength is reached. If both the design strength and the ultimate strength are being determined, a specified rate of loading need not be maintained after the acceptance design strength has been reached. For non-reinforced concrete pipe any rate of load application up to a maximum of 110 kN/linear meter [7500 lbf/linear foot] of pipe per minute may be used up to 75 percent of the specified ultimate strength at which time the rate of loading shall be reduced to the maximum uniform rate of 44 kN/linear meter [3000 lbf/linear foot] of pipe per minute. At the manufacturer's option, the rates of loading in this paragraph shall be any rates that do not exceed the specified maximums.

4.5.4. As defined in M 262, the design strength is the maximum load, expressed as a D-load, supported by the pipe before a crack having a width of 0.3 mm [0.01 in.] occurs throughout a continuous length of 300 mm [1 ft] or more measured parallel to the longitudinal axis of the pipe barrel. The crack is 0.3 mm [0.01 in.] in width when the point of the measuring gauge will, without forcing, penetrate 1.5 mm [$^1/_{16}$ in.] at close intervals throughout the specified distance of 300 mm [1 ft]. Measure the width of the crack by means of a gauge made from a leaf 0.3 mm [0.01 in.] in thickness (as in a set of standard machinist gauges), ground to a point of 1.5 mm [$^1/_{16}$ in.] in width with corners rounded and with a taper of 0.25 mm/mm [$^1/_4$ in./in.] as shown in Figure 6.

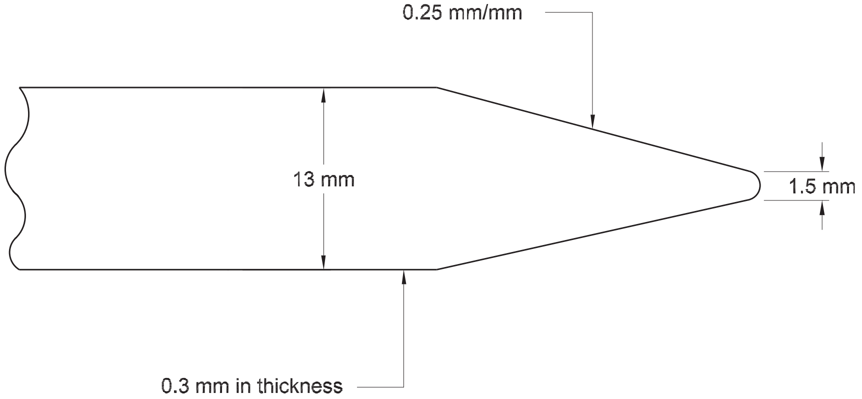


Figure 6—Gauge Leaf for Measuring Cracks

Note 2—As used in this specification, the 0.3-mm [0.01-in.] crack is a test criterion for pipe under load in three-edge-bearing test and is not intended as an indication of overstressed or failed pipe under installed conditions.

4.5.5. As defined in M 262, the ultimate strength is the maximum load supported by the pipe.

Note 3—Ultimate strength of concrete pipe in the buried condition is dependent on varying soil bedding factors and varying failure modes and shall have no relationship to the ultimate strength as defined under three-edge-bearing conditions.

4.6. *Conditioning*—The moisture requirements of Section 1.3 are not required, at the option of the manufacturer.

4.7. *Calculations*:

4.7.1. Strength test results shall be calculated in terms of newtons per linear meter [pounds per linear foot]. The laying length used in calculating the strength values shall be that indicated by *L* in Figures 1, 2, 3, and 4. For plain end pipe, no bell or spigot, the length *L* shall be the overall length. For pipe having a bell or spigot on one end with the opposite end being plain, *L* shall be the distance from the plain end to the center of the joint, where *L* equals the overall length minus one-half of the depth of the bell, or the overall length minus one-half the length of the spigot.

4.7.2. The ultimate strength in kilonewtons per linear meter [pounds per linear foot] shall be calculated by dividing the maximum test load applied to the pipe by the laying length *L*.

4.7.3. The D-load strength in kilonewtons per linear meter per meter [pounds per linear foot per foot] of inside diameter or horizontal span shall be either the 0.3-mm [0.01-in.] crack D-load strength or the ultimate D-load strength. The 0.3-mm [0.01-in.] crack D-load shall be calculated by dividing the test load required to produce the 0.3-mm [0.01-in.] crack by the laying length *L* and by the pipe inside diameter or horizontal span.

4.8. *Precision and Bias*—The user of this test method is advised that the true value for the strength of a concrete pipe cannot be determined because the specimen is tested to destruction and an exact duplicate specimen cannot be obtained. Therefore, no calculations of precision and bias are presently possible. Specifications that include this test method for the various types of concrete pipe should include a provision for additional tests of one or more specimens.

5. TEST METHOD FOR FLAT SLAB TOPS

5.1. *Summary of Test Method*—A load is applied to the flat slab top and the supporting capacity of the flat slab top is measured.

5.2. *Significance and Use*—The test method is a proof of design test performed to prove the adequacy of the design.

5.3. *Conditioning*—The moisture requirements of Section 1.3 are not required, at the option of the manufacturer.

5.4. *Procedure*—Place the section that has been designated to receive the flat slab top on a firm, even surface. Assemble the flat slab top to this section. If a frame or riser has been designed to be fitted to the access portion of the flat slab top, assemble it to the slab top. Apply the test load to the riser or frame as assembled to the flat slab top. If no access opening has been provided to the flat slab top, apply the test load to the center of the flat slab top by means of a 300 by 300 by 100 mm [12 by 12 by 4 in.] wood bearing block. (See Figure 7.) Calculate the test load as follows:

$$P_u = 1.3D + 2.17L + (1 + I) \tag{1}$$

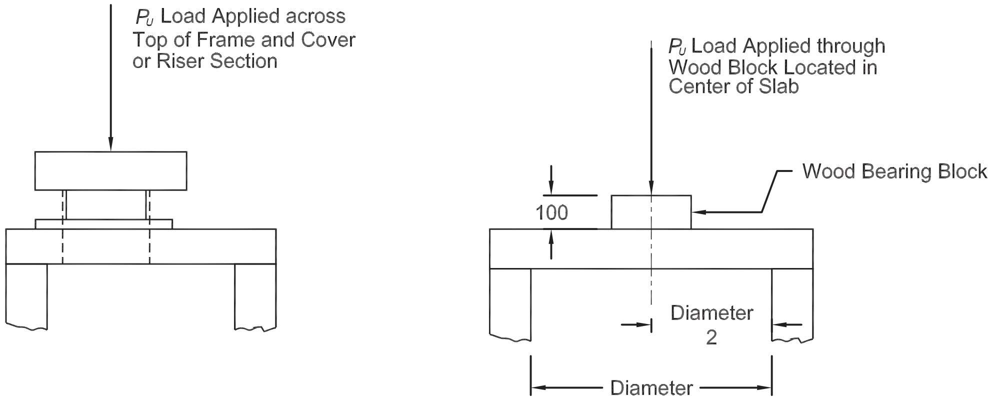
where:

P_u = applied minimum ultimate proof-of-design test load, N [lb];

D = total calculated field dead load on the slab, N [lb];

L = calculated live load on the flat slab top; and

I = impact factor, 30-percent minimum.



Flat Slab Top with Access Opening   Flat Slab Top without Access Opening

Figure 7—Flat Slab Top Test

6. CORE STRENGTH TEST METHOD

6.1. *Summary of Test Method*—The compressive strength of the concrete in the pipe is determined by making crushing tests of cores from the pipe.

6.2. *Significance and Use*—The core strength test is a quality-control test performed to establish the fact that the finished, shippable precast concrete product had sufficient concrete strength to meet the strengths stated in the specifications.

6.3. *Apparatus*—A core drill shall be used for securing cylindrical core specimens from the wall of the pipe; a shot drill or a diamond drill shall be used.

6.4. *Test Specimens*:

6.4.1. A core specimen for the determination of compressive strength shall have a diameter at least three times the maximum size of the coarse aggregate used in the concrete. If cores are cut from the wall of the pipe and tested, the length to diameter ratio shall lie between one and two after the curved surfaces have been removed from the cut core.

6.4.2. *Moisture Conditioning*—Unless the agency for which the testing is being done directs otherwise, the core test specimens shall be submerged in lime-saturated water in accordance with the provisions of T 24.

6.5. *Procedure*:

6.5.1. *End Preparation and Capping*—Core specimens to be tested in compression shall have ends that are essentially smooth and perpendicular to the axis and of the same diameter as the body of the specimen. Before making the compression test, cap the ends of the specimen in order to meet the requirements of T 231.

6.5.2. *Measurement*—Prior to testing, measure the length of the capped specimen to the nearest 2.5 mm [0.1 in.] and determine its average diameter to the nearest 2.5 mm [0.1 in.] from two measurements taken at right angles near the center of the length.

6.5.3. Test specimens as prescribed in the applicable sections of T 22.

6.6. *Calculation and Report*—Calculate the compressive strength of each specimen in pascals [pounds-force per square inch] based on the average diameter of the specimen. If the ratio of length to diameter is less than two, make allowance for the ratio of length to diameter by multiplying the compressive strength by the applicable correction factor given in the following table (determine values not given in the table by interpolation):

Ratio Length of Cylinder to Diameter, *l/d*	Strength Correction Factor
1.75	0.98
1.50	0.96
1.25	0.94
1.10	0.90
1.00	0.85

6.7. *Precision and Bias*—The user of this test method is advised that this method for testing concrete pipe for strength is considered satisfactory for acceptance testing of commercial shipments since the test method has been used extensively for acceptance testing. In cases of disagreement arising from differences in values reported by the owner and the manufacturer when using this test method for acceptance testing, the statistical bias, if any, between the laboratory of the owner and the laboratory of the manufacturer should be determined with each comparison being based on testing specimens randomly drawn from one pipe of the type being evaluated.

7. ABSORPTION TEST METHOD

7.1. *Summary of Test Method*—This test method covers the testing of a specimen that is a sample or core from the wall of the pipe. The test specimen is first subjected to drying, then to immersion to determine the specimen's absorption of water when tested by the described procedures.

7.2. *Significance and Use*—The test method is a quality-control test performed to establish the fact that the finished, shippable pipe meets the absorption limits stated in the specifications.

7.3. *Test Specimens*—Absorption test specimens shall be in accordance with the requirements of the applicable pipe specification.

7.4. *Procedure for Boiling Absorption Test*:

7.4.1. *Drying Specimens*—Dry specimens in a ventilated mechanical convection oven at a temperature of 105 to 115ºC [221 to 239ºF], until two successive weighings at intervals of not less than 6 hours show an increment of loss not greater than 0.10 percent of the last oven-dry mass of the specimen. Dry specimens with a wall thickness of 38 mm [1.5 in.] or less for a minimum of 24 hours; dry specimens with a wall thickness of 38 to 75 mm [1.5 to 3 in.] for a minimum of 48 hours; dry specimens with a wall thickness exceeding 75 mm [3 in.] for a minimum of 72 hours. Use the last 6 hours of the minimum drying time to determine whether or not the sample has obtained the proper dried mass.

7.4.2. *Weighing Dried Specimens*—Determine the mass of the oven-dried specimens immediately upon removal from the oven.

7.4.3. *Immersion and Boiling*—Within 24 hours, carefully place the dried specimen whose mass has been determined in a suitable receptacle that contains clean water at a temperature of 10 to 24ºC

[50 to 75ºF]. Use distilled water, rain water, or tap water that is known to have no effect on test results. Heat the water to boiling in not less than 1 hour and not more than 2 hours. Do not apply live steam to the water to shorten the pre-boil period until 1 hour of heating by gas or electricity has been completed. Continue the boiling for 5 hours. At the end of the 5-hour boiling period, turn off the heat, and allow the specimen to cool in water to room temperature by natural loss of heat for not less than 14 hours nor more than 24 hours.

7.4.4. *Reweighing Wet Specimens*—Remove the water-cooled specimens from the water, place on an open drain rack, and allow to drain for 60 seconds. Remove the remaining superficial water by quickly blotting the specimen with a dry absorbent cloth or paper. Determine the mass of the specimen immediately following blotting.

7.4.5. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

7.5. *Calculation and Report*—Take the increase in mass of the boiled specimen over its dry mass as the absorption of the specimen, and express it as a percentage of the dry mass. Report the results separately for each specimen.

7.6. *Precision and Bias*—The user of this test method is advised of the following:

7.6.1. *Single-Operator Precision*—The single operator standard deviation has been found to be 0.143 percent. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.40 percent.

Note 4—The numbers in Section 7.6.1 represent, respectively, the (1s) and (d2s) limits described in ASTM C 670.

7.6.2. *Multilaboratory Precision*—Multilaboratory Precision has not been determined, but is being investigated. Statements will be included when the proper data have been obtained and analyzed.

7.6.3. *Bias*—Bias cannot be determined since the true value of absorption is not known and cannot be determined except by application of tests for which the bias is not known.

8. HYDROSTATIC TEST METHOD

8.1. *Summary of Test Method*—The section of pipe or manhole is subjected to hydrostatic pressure and observed for leakage at the joint or on the surface of the wall. The joint is defined as a connection between the concrete section of the pipe or manhole that provides alignment and the flexible watertight seal using either rubber gaskets, sealing bands, or preformed flexible joint sealant.

8.2. *Significance and Use*—The test method is a quality-control test performed to establish the fact that the finished, shippable pipe or manhole meets the hydrostatic requirements stated in the specifications for the installed wall or joint, or both.

8.3. *Procedure*:

8.3.1. The equipment for making the test shall be such that, when the specimen under test is filled with water to the exclusion of air and subjected to the required hydrostatic pressure, there shall not be enough leakage of water from the ends of the pipe to interfere with the test. The specimen under test shall be free of all visible moisture prior to the initiation of the test.

8.3.2. Do not test when the temperature of the specimen, the air around the specimen, or the water within the specimen is below 1ºC [33ºF].

8.3.3. If the joint seal or flexible connector is being tested, it shall be the sole element providing joint watertightness. No mortar for concrete coatings, fillings, or packing shall be used prior to the test.

8.3.4. Connect a standardized pressure gauge to the specimen. If being tested in a vertical position, the gauge shall be placed at or as close to as is practical above the joint or section being tested. If being tested in a horizontal position, the gauge shall be placed to measure pressure at or as close to as practical above the horizontal axis. Raise the pressure of the water in approximately 1 minute to the required level and hold for the specified time. There shall be no visible leakage. Moisture appearing in the form of patches or beads adhering to the surface shall not be considered leakage. If leakage occurs, the manufacturer is not prohibited from extending the soak time to 24 hours.

8.4. *Precision and Bias*—No justifiable statement is presently possible either on precision or on the bias of this method of testing for leakage under hydrostatic pressure since the test result merely states whether there is conformance to the criteria for success specified.

9. PERMEABILITY TEST METHOD

9.1. *Summary of Test Method*—A section of pipe is kept filled with water for a specified time and the outer surface is tested for moisture.

9.2. *Significance and Use*—The test method is a quality-control test performed to establish the fact that the finished, shippable pipe meets the leakage limits stated in the specifications.

9.3. *Procedure*—The pipe specimen under test shall be free of all visible moisture prior to the initiation of the test. Perform tests by placing the specimen to be tested with the spigot end down on a soft rubber mat or its equivalent, weighted if necessary, and kept filled with water to a level of the base of the socket during the test period. Make the initial inspection approximately 15 minutes after the test has begun. If the pipe shows moist or damp spots on the outer surface of the pipe at that time, continue the tests for a period not to exceed 24 hours at the option of the manufacturer. Examine the pipe during the extended period for existence of moist or damp spots.

9.4. *Precision and Bias*—No justifiable statement is presently possible either on precision or on the bias of this method of testing for leakage since the test result merely states whether there is conformance to the criteria for success specified.

10. MANHOLE STEP TEST METHODS

10.1. *Summary of Test Method*—This test method determines the ability of an installed step to withstand a specified horizontal pull at right angles to the wall of a manhole riser or cone section, and then a vertical load parallel to the wall of the section.

10.2. *Significance and Use*—The manhole step tests are intended to be used for production control, lot acceptance, or adequacy of design. These tests are performed to establish whether or not the installed step has sufficient strength to withstand the specified loads.

10.3. *Apparatus*—In making the tests, any mechanical or hand-powered devices that have calibrated load indicators attached shall be used. The attachments from the heads of each testing device to the rung of the step are to be sufficiently sturdy to preclude any bending of the attachment and rung over the length of the attachment. The attachments to the rung are to be 90 mm [$3^1/_2$ in.] in length.

10.4. *Conditioning*—The moisture requirements of Section 1.3 are not required, at the option of the manufacturer.

10.5. *Procedure*—It is not prohibited that the tests be made with the section to be tested placed on its side for easier access to the step to be tested. The first load shall be applied to the plane of the step by means of a pullout device centered on the step rung and shall be applied at a uniform rate until the specified load is reached. The pullout device is then removed and the test attachment is centered at the same location on the rung, and a second load is applied perpendicular to the plane of the first load application. The second load is applied at a uniform rate until the specified load is reached.

10.5.1. *Maximum Loads*—The first load as defined in Section 10.4 shall be 1800 N [400 lb]. The second load as defined in Section 10.5 shall be 3600 N [800 lb].

10.6. *Precision and Bias*—No justifiable statement is presently possible either on precision or bias of these methods of testing for pull-out strength since the test results merely state whether there is conformance to the criteria for success specified.

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11. CYLINDER STRENGTH TEST METHOD

11.1. *Summary of Test Method*—The concrete compressive strength of a concrete pipe, box section, or manhole is determined by making crushing tests of concrete cylinders.

11.2. *Significance and Use*—The concrete cylinder strength test is a quality-control test performed to establish the fact that the finished, shippable precast concrete product had sufficient concrete compressive strength to meet the strengths stated in the specifications.

11.3. *Test Specimens*:

11.3.1. Cylinders shall be made, cured, and tested in accordance with T 23 and T 22 or by methods comparable to those used to consolidate and cure the concrete in the manufactured concrete product. Cylinder specimens of sizes other than 150 by 300 mm [6 by 12 in.] are not prohibited provided all other requirements of T 23 are met.

11.3.2. If the concrete consistency is too stiff for compaction by rodding or internal vibrations, the following alternative method shall be used:

11.3.2.1. Attach a cylinder mold to the top of a vibrating table or to the actual concrete pipe form being used to produce the concrete product.

11.3.2.2. Place concrete in the cylinder mold in three equal lifts.

11.3.2.3. Place a cylindrical hammer on the surface of each lift with the hammer to be 6 mm [$^1/_4$ in.] less in diameter than the inside diameter of the mold and of a weight to create a pressure of 2.4 kPa [0.353 psi] on the surface of the concrete.

11.3.2.4. External vibration shall be applied on each lift with a frequency of at least 800 vibrations per minute, and continue the vibration until cement paste begins to ooze up around the bottom edge of the hammer.

11.4. *Procedure*:

11.4.1. *End Preparation and Capping*—Cylinder specimens to be tested in compression shall have ends that are essentially smooth and perpendicular to the axis and of the same diameter as the body of the specimen. Before making the compression test, cap the ends of the specimen to meet the requirements of T 231 or ASTM C 1231.

11.4.2. *Testing*—Test specimens as prescribed in T 22.

11.5. *Calculation and Report*—Calculate the compressive strength of each specimen in kilopascal [pounds force per square inch] based on the average diameter of the specimen.

11.6. *Precision and Bias*—The user of this specification is advised that this method of testing concrete products for concrete compressive strength is considered satisfactory for acceptance testing of commercial shipments since the test method has been used extensively for acceptance testing. In cases of disagreement arising from differences in values reported by the owner and the manufacturer when using this method for acceptance testing, the statistical bias, if any, between the laboratory of the owner and the laboratory of the manufacturer should be determined with each comparison being based on testing specimens randomly selected from the specimens available for the type of concrete product being evaluated.

12. GASKET LUBRICANT TESTS

12.1. The lubricant manufacturer shall be responsible for all testing.

12.2. *Durometer and Volume Change Tests*:

12.2.1. The concrete pipe manufacturer or the gasket manufacturer shall supply the lubricant manufacturer with a minimum of three samples of each gasket material used by the pipe manufacturer.

12.2.2. Measure 50-mm [2-in.] samples from each gasket type for volume. The durometer shall be checked in accordance with ASTM D 2240. The samples shall be immersed in lubricant in a closed container.

12.2.3. The immersed samples shall be held at 21ºC [7ºF] for a period of 3 days.

12.2.4. At the end of the 3-day period, the volume of the samples shall be remeasured and the durometer of the samples rechecked in accordance with ASTM D 2440.

12.3. *Wash Test for Subaqueous Lubricants*:

12.3.1. A clean piece of concrete from the pipe shall be thoroughly wetted and then coated with a 3-mm [$^1/_8$-in.] layer of lubricant covering an area of 100 mm by 100 mm [4 by 4 in.].

12.3.2. The prepared specimen shall then be washed for 5 minutes with a soft stream 250 mL/min [0.07 gal/min] of tap water 21ºC [70ºF] from a height of 600 mm [2 ft] using equipment as shown in Figure 8.

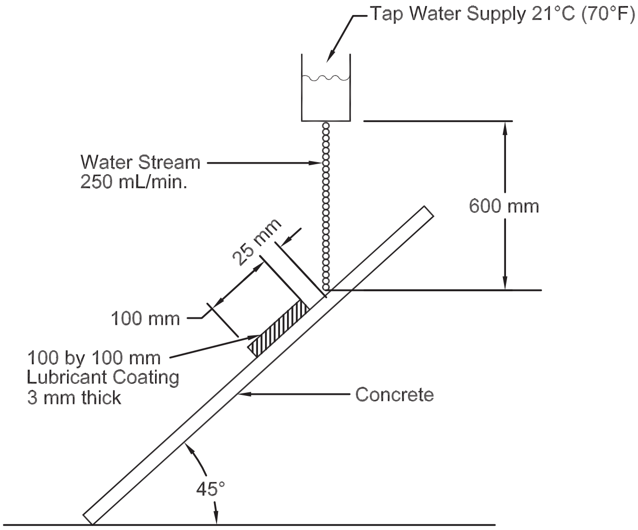


Figure 8—Lubricant Wash Test

12.3.3. After air drying, the washed-off area shall be divided by the original coated area and multiplied by one hundred; the result is the percentage washed away.

12.4. *Certification*:

12.4.1. The lubricant manufacturer shall supply the purchaser written certification that the gasket lubricant has met all test requirements specified for the gasket samples supplied.

12.4.2. Tests shall be performed each year on a gasket lubricant for certification, which shall be valid for one year, provided there are no changes in the materials or process used in the manufacture of either the gaskets or the lubricant.

12.4.3. No gasket lubricant shall be used on concrete pipe joints meeting this specification without valid certification provided to the concrete pipe manufacturer.

12.5. *Marking*:

12.5.1. The following information shall be clearly marked on each container of lubricant supplied to the pipe manufacturer.

12.5.1.1. Name of lubricant manufacturer.

12.5.1.2. Usable temperature range.

12.5.1.3. Shelf life.

12.5.1.4. Lot or batch number.

13. JOINT SHEAR TEST

13.1. *Summary of Test Method*—A shear force, normal to the longitudinal axis of the pipes, is applied across the assembled joint between two concrete pipes.

13.2. *Significance and Use*—This is a proof-of-design test that evaluates the structural capability of the pipe joint when subjected to a differential load.

13.3. *Apparatus*:

13.3.1. The testing machine shall be of any type that has sufficient capacity to apply the required test load or a suitable dead load shall be applied. The applied force shall not be less than the required force by more than two percent.

13.3.2. Supporting timber cradle blocks, with one face curved to match the outer diameter of the pipe barrel, shall be used to transmit the shear force from the test apparatus to the test pipe joint. The curved face shall be lined with a 25-mm [1-in.] thick hard rubber strip. Additional timber blocks or similar supports are necessary to elevate the test pipes. At the manufacturer's option, it is permissible to use flat timbers in lieu of cradle blocks.

13.4. *Procedure*:

13.4.1. To perform the test, two test pipes shall be assembled with one pipe fully supported and the spigot or tongue end of the second pipe installed in the bell or groove end of the first pipe as illustrated in Figure 9. Both pipes shall be supported so a uniform invert elevation is maintained. The user of this specification is advised that for safety reasons the pipe supports shall be constructed as shown in Figure 9. (**Warning**—Block or restrain the test pipe assembly horizontally to prevent any inadvertent pipe movements. The blocking or restraints shall be designed to avoid beneficial effects on the test.)

13.4.2. The joint shear test shall be run without water in the pipe or bulkheads installed on the pipe. A vertical test load (*F*) shall be applied to the suspended portion of the test joint until the total differential load, including the weight of a pipe, is 58.33 kN/m [4000 lb/ft] of pipe diameter.

Note 5—The manufacturer shall have the option to conduct concurrently a hydrostatic test and this structural test. If proven watertight under these combined conditions, hairline cracks that do not leak shall not be cause for rejection.

13.4.3. The test load shall be applied to the unsupported spigot of the test joint until the force reaches 58.33 kN/m [4000 lb/ft] for no less than 1 minute or the joint reaches the limit of its shear strength. The shear strength limit shall be noted by a sudden reduction in the applied load or shearing of the concrete.

Note 6—This is also a quality control test result for the lowest concrete strength and lowest class of pipe produced.

13.4.4. Cracks that occur during the test load are not considered failure, provided those cracks close to a width of less than 0.3 mm [0.01 in.] on release of the load.

13.4.5. *Calculations*:

13.4.6. The shear force resisted by the test joint shall be calculated by the resolution of applied and gravity forces on the pipe section. The total shear force on the joint is the sum of the resultants of the pipe weight and the applied force. (See Figures 9 and 10.)

13.5. *Precision and Bias*—The differential shear test provides an objective value of the structural strength of a concrete pipe joint. There is no widely accepted method of analysis for differential shear through the joints in buried concrete pipes. All current methods of concrete pipe design assume that the installed pipes are uniformly bedded along the length of the pipeline. Stronger joints will resist greater flaws in subgrade design or installation.

14. ALKALINITY OF CONCRETE MIXTURE

14.1. *Summary of Test Method*—This test method compares the ability of a sample of powdered, hardened concrete and pure calcium carbonate to neutralize acid. The concrete alkalinity is the ratio of the mass of acid neutralized by powdered concrete divided by the mass of acid neutralized by a similar sample of pure calcium carbonate.

14.2. *Significance and Use*—The user of this specification is advised that this is a proof-of-design test that evaluates the ability of the concrete mixture used in concrete pipes to resist the attack of acids that at times can form in sanitary sewers. The alkalinity rating of the concrete mixture is one of the design criteria used to predict the service life of concrete pipelines where hydrogen sulfide may be generated.

14.3. *Apparatus*:

14.3.1. One method of extracting powdered concrete samples is by use of a rotary drill with a twist bit.

14.3.2. A buret is required to complete the titration process on the concrete and calcium carbonate samples.

14.4. *Procedure*:

14.4.1. Samples of concrete from a pipe are obtained by drilling two 25-mm [1-in.] diameter cores from the interior pipe wall to the depth of the reinforcement. Each core sample is then placed in a separate container and dried in an oven for 1 to 2 hours at a temperature between 100 and 110°C [212 and 230°F]. The samples are then pulverized to obtain 100 percent passing a 150-µm [100-mesh] sieve.

14.4.2. Place approximately one gram of a sample into a beaker and add 10 milliliters of water. Next, slowly add 40 milliliters of standard 1-Normal hydrochloric acid, HCl, to the sample and water. When the effervescence has subsided, heat the mixture to boiling. Continue to boil for 30 seconds, and then cool.

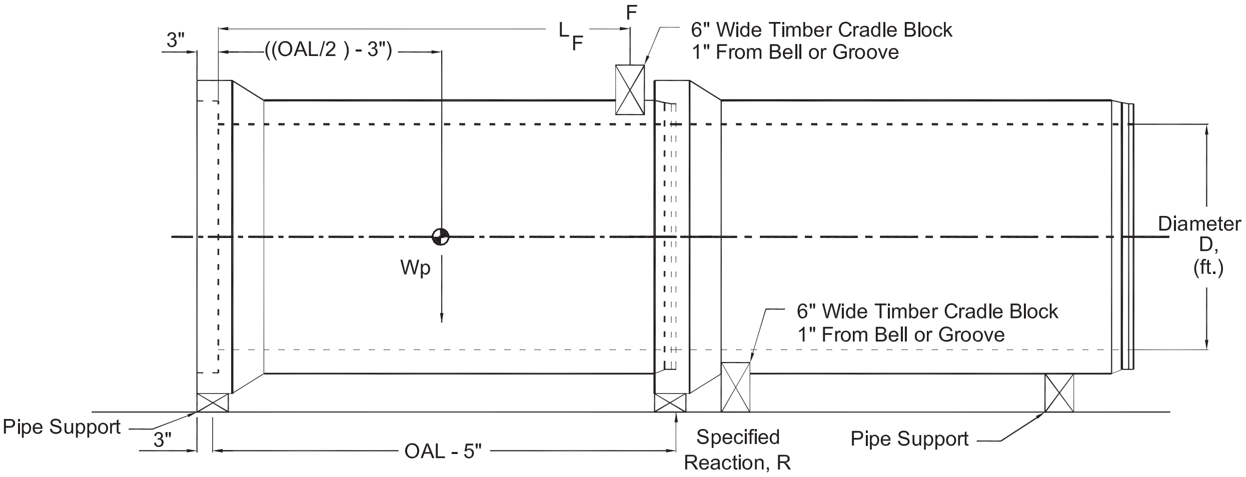
14.4.3. Add 50 to 100 milliliters of water to the cooled mixture and titrate with a carbonate free standard 1-Normal sodium hydroxide, NaOH, solution. Titrate the mixture until the pH stays above 6.8 for 2 minutes. The final pH shall be between 6.8 and 7.8. Run two tests on each core sample.

14.5. *Calculations*:

14.5.1. The alkalinity of the material is the average of all samples.

14.5.2. The net calcium carbonate equivalent of the sample is:

$$\text{CaCO}_3\ \text{Equivalent} = \frac{5[(\text{ml of HCl}) - (\text{ml of NaOH})]}{(\text{sample mass in grams})} \qquad (2)$$



R = Test Requirement
Wp = Nominal Weight of Test Pipe
F = Additional Test Force

R = 4000 lbs x Internal Diameter in Feet

$$F = \frac{((OAL) - 5^*)\,R - ((OAL/2) - 3")\,Wp}{L_F}\ (\text{lbs})$$

Figure 9—Joint Shear Test

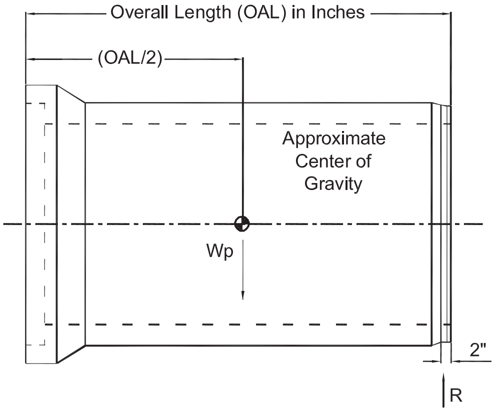
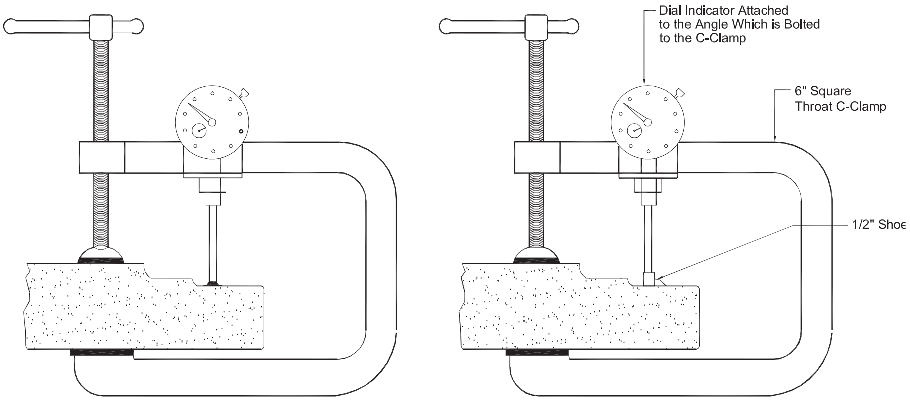
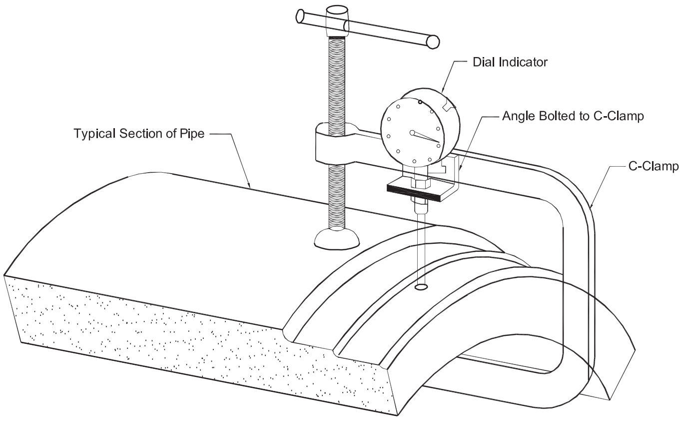


Figure 10—Simplified Center of Gravity of Pipe



Measuring Joint Depth
Without Gasket

Measuring Joint Depth
With Gasket



Isometric View
Gasket Removed for Clarity

Figure 11—Dial Indicator

15. MEASUREMENT OF RUBBER GASKET VOLUME AND DIMENSIONS

Note 7—These are measurements performed by the pipe manufacturer for quality control checks.

15.1. *Volume*—This method is used to determine the volume of a solid, circular cross section pipe gasket. Measure the mass of the gasket to the nearest gram. Next, immerse the gasket completely in water and measure the mass of the gasket while totally submerged. A surfactant shall be added to the water to minimize air bubbles from clinging to the gasket material. The difference in the dry mass and the immersed mass of the gasket, measured in grams, is the volume of the gasket in cubic centimeters.

15.1.1. As an alternate to the above, the gasket shall be placed in a water tank and the displaced water shall be collected. The volume of water is then measured directly in cubic centimeters or by pouring into a calibrated tube or the water displaced shall be weighed. One gram of water equals 1 cm^3.

15.2. *Unstretched Length*—This method is used to determine the unstretched length of a pipe gasket. Construct a flat, straight calibrated measuring scale such as a measuring tape attached to a table or the floor. Make an index mark on the gasket cross-section with the flat side down (or out). Place the gasket index mark at the zero point on the measuring scale and carefully roll the uncut gasket loop without sliding or stretching. The gasket length is the distance measured at the point where the index mark retouches the scale.

15.3. *Height of Profile Gasket*—These methods are used to determine the profile gasket height, while stretched to the design strain of the proposed joint geometry for which the gasket is to be utilized.

15.3.1. *Method 1*—This method requires a precise measuring device mounted on a rigid fixture attached to the pipe joint (see Figure 11).

15.3.1.1. Install the test gasket at the location on the joint that is designated by the joint data sheet. Equalize the gasket stretch according to the gasket manufacturer's recommendations.

15.3.1.2. Carefully measure the distance to the highest sealing surface of the gasket. For self-lubricating gaskets, the tube containing the lubricant must be rolled over the gasket body and held under slight pressure as the measurement is taken. Without disturbing the measuring device, slide the gasket out of the joint recess. Measure the point on the joint gasket bearing surface immediately under the point where the gasket measurement was taken. The difference in measurements is the stretched gasket height.

15.3.2. *Method 2*—Position the gasket or a segment of a gasket in the same orientation that the cross-section is to be installed on the pipe joint. Make two index marks 300 mm [12 in.] apart on a straightened, but nonstretched segment of gasket. With an axial force, elongate the gasket until the distance between the marks is equal 300[(100% + % design stretch)/100] [12[(100% + % design stretch)/100]]. Hold or clamp the gasket segment in the stretched position. Measure the distance between the two sealing surfaces of the gasket with a vernier, micrometer, or dial gauge.

16. OFF-CENTER HYDROSTATIC JOINT TEST

16.1. *Summary of Test Method*—An assembled concrete pipe joint sealed with a gasket shall be hydrostatically tested while the bell and spigot of the test joint assembly are placed in the maximum off-center position.

16.2. *Significance and Use*—This is a proof-of-design test that evaluates the performance of a gasketed joint between concrete pipes to remain sealed under hydrostatic pressure with both minimum and maximum gasket compression.

16.3. *Apparatus*:

16.3.1. Hydrostatic pressure tests on joints shall be made on an assembly of two sections of pipe, properly connected in accordance with the joint design. The hydrostatic pressure shall be measured with a gauge or manometer accurate to 65 percent of the test pressure.

16.3.2. The testing machine shall be of any type that has sufficient capacity to apply the required test load that is in addition to the weight of the pipe filled with water, or a suitable dead load shall be applied. The applied force shall not be less than the required force by more than 5 percent.

16.3.3. Timber blocks shall be used to support the pipes. An additional block shall be used to transmit the force from the test machine to the test pipe joint.

16.3.4. It is not prohibited to fill the assembled pipes with water under a pressure of 90 kPa [13 psi] or less for a maximum of 24 hours prior to the test.

16.4. *Procedure*:

16.4.1. Two test pipes shall be assembled with one pipe fully supported and the spigot or tongue end of the second pipe installed in the bell or groove end of the first pipe as illustrated in Figure 11. The bell or groove end of the second pipe shall be supported by a block. The supports for the pipes shall maintain a uniform invert elevation for both pipes.

16.4.2. A vertical test load (F) shall be applied to the suspended portion of the test pipe section until the total differential load on the joint, including the weight of the pipe filled with water, shall be either a minimum of 26.25 kN/m [1800 lb/ft] of pipe diameter or until there is concrete-to-concrete contact within the joint.

Note 8—26.25 kN/m (26.25 N/mm) [1800 lb/ft (150 lb/in.)] is approximately the load required to compress to 50 percent an unconfined 40 durometer rubber gasket with a 17 mm [$^{21}/_{32}$ in.] diameter circular cross-section.

16.4.3. The joint assembly shall be subjected to the required hydrostatic pressure of 90 kPa [13 lb/in.^{2}] for 20 minutes without leakage. Moisture or beads of water appearing on the surface of the joint shall not be considered as leakage. If leakage of the joint initially occurs, the manufacturer is not prohibited from extending the test period up to a maximum of 24 hours.

16.5. *Calculations*:

16.5.1. The additional force required to cause the maximum off-center position in the test joint shall be calculated by the resolution of applied and gravity forces on the joint. The total force on the joint is the sum of the resultants of the pipe weight, the water weight, and the force applied by the test machine (see Figures 12 and 13).

16.5.2. *Precision and Bias*—This test provides a subjective evaluation of the seal formed between the bell and spigot of a concrete pipe joint under conditions causing minimum and maximum gasket compression. The performance of a gasketed pipe joint is affected by its geometric design, manufacturing tolerances, and variability in subgrade support of an installed pipe. Tighter joints will resist greater flaws in subgrade design or installation.

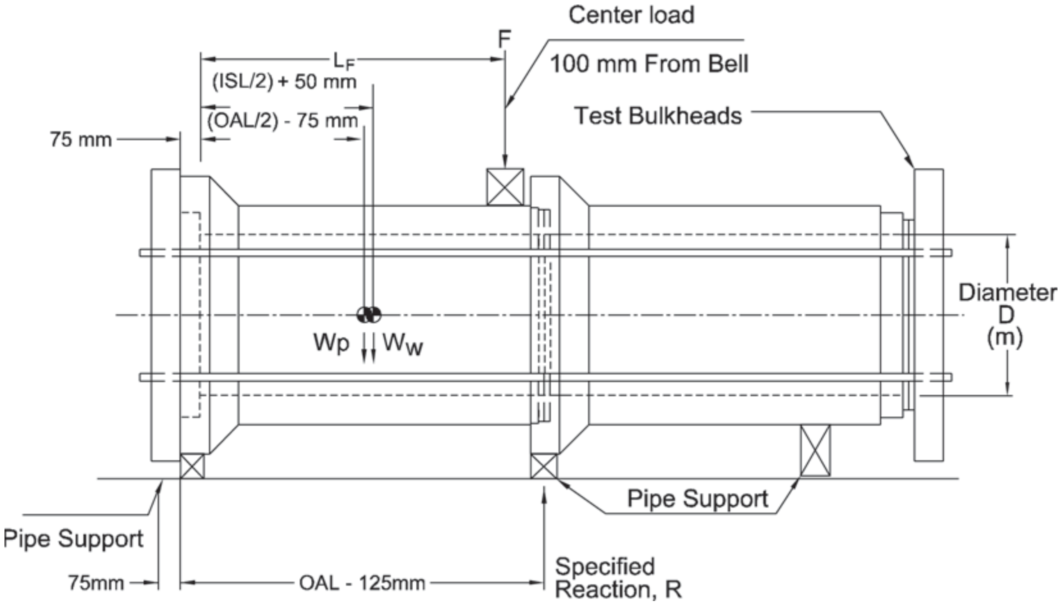


Figure 12—Off-Center Hydrostatic Joint Test

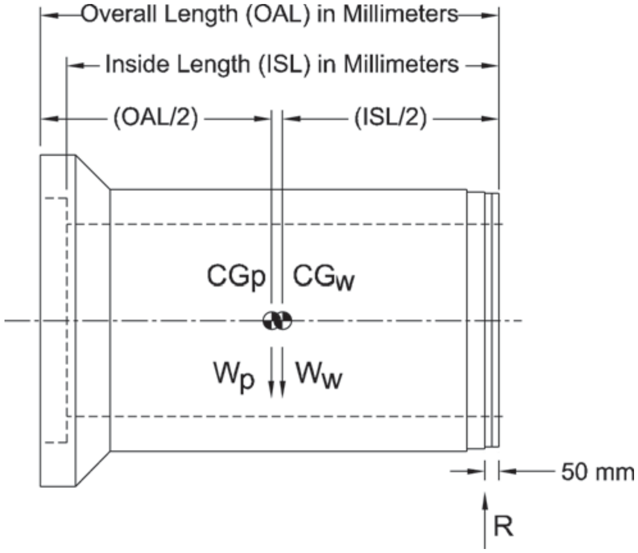


Figure 13—Center of Gravity of Pipe Filled with Water

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[1] This method agrees with ASTM C 497-05 except that the 5-hour boil absorption is the only absorption method, and for reference to weighing apparatus.

Standard Method of Test for

Vitrified Clay Pipe

AASHTO Designation: T 281-06[1]
ASTM Designation: C 301-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Vitrified Clay Pipe

AASHTO Designation: T 281-06[1]

ASTM Designation: C 301-04

1. SCOPE

1.1. These test methods cover the equipment for, and the techniques of, testing vitrified clay pipe prior to installation. Tests using whole pipe determine the resistance to crushing and hydrostatic forces. Tests using pipe fragments measure the amount of water absorption of the pipe body and the quantity of acid-soluble material that may be extracted from it.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 1—The following standards also apply to clay pipe and can be referenced for further information: ASTM C 12, C 425, C 700, and C 828.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 231, Weighing Devices Used in the Testing of Materials

2.2. *ASTM Standards*:

- C 12, Standard Practice for Installing Vitrified Clay Pipe Lines
- C 425, Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings
- C 700, Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated
- C 828, Standard Test Method for Low-Pressure Air Test of Vitrified Clay Pipe Lines
- C 896, Standard Terminology Relating to Clay Products
- E 6, Standard Terminology Relating to Methods of Mechanical Testing

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. For definitions of terms used in these test methods, refer to ASTM E 6 and C 896.

4. SIGNIFICANCE AND USE

4.1. *Meaning and Suitability*—The tests called for herein, from their results, indicate the suitability and acceptability of vitrified clay pipe for specifications acceptance, design purposes, regulatory statutes, manufacturing control, and research.

5. BEARING STRENGTH

5.1. *Test Specimens*:

5.1.1. The test specimens shall be sound, full-size pipe and shall be selected by the purchaser, or purchaser's representative, at points designated by the purchaser when placing the order.

5.1.2. The number of specimens to be tested shall not exceed 0.5 percent of the number of pipe of each size furnished, except that no less than two specimens shall be tested.

5.2. *Measurement and Inspection of Specimens*:

5.2.1. The specimens shall be free of all visible moisture and frost. These specimens shall be inspected and measured for conformance with the applicable specifications. The results of these observations shall be recorded.

5.2.2. Specimens that are observed to have defects in excess of the limits permitted in the applicable specifications shall be discarded and replaced with additional specimens from the lot to be tested.

5.3. *Loading Apparatus*—See Figure 1.

5.3.1. *Testing Machine*:

5.3.1.1. The loading apparatus shall consist of a testing machine capable of applying loads, with upper and lower bearings capable of transmitting these loads to the pipe. The bearings shall be bearing beams and contact edges.

5.3.1.2. Any motor-driven testing machine, capable of applying a load at a uniform rate of 29.2 ± 7.3 kilonewtons per minute per linear meter [2000 ± 500 pounds-force per minute per linear foot] of pipe length, may be used for making the test.

5.3.1.3. The load may be applied at a rapid rate until 50 percent of the required bearing strength is reached. Subsequently, the load shall be applied to the pipe at the rate of 29.2 ± 7.3 kilonewtons per minute per linear meter [2000 ± 500 pounds-force per minute per linear foot] of pipe length without vibration or shock.

5.3.1.4. The testing machine shall be sufficiently rigid so that the load distribution will not be appreciably affected by the deformation or yielding of any part. The machine and bearings shall be constructed to transmit the load in a vertical plane through the longitudinal axes of the bearings and pipe. The bearings shall be attached to the machine so as to receive and uniformly transmit the loads required in the tests, without vibration or shock. The upper bearing shall be free to rotate in a vertical plane through the longitudinal axis of the bearing and the pipe.

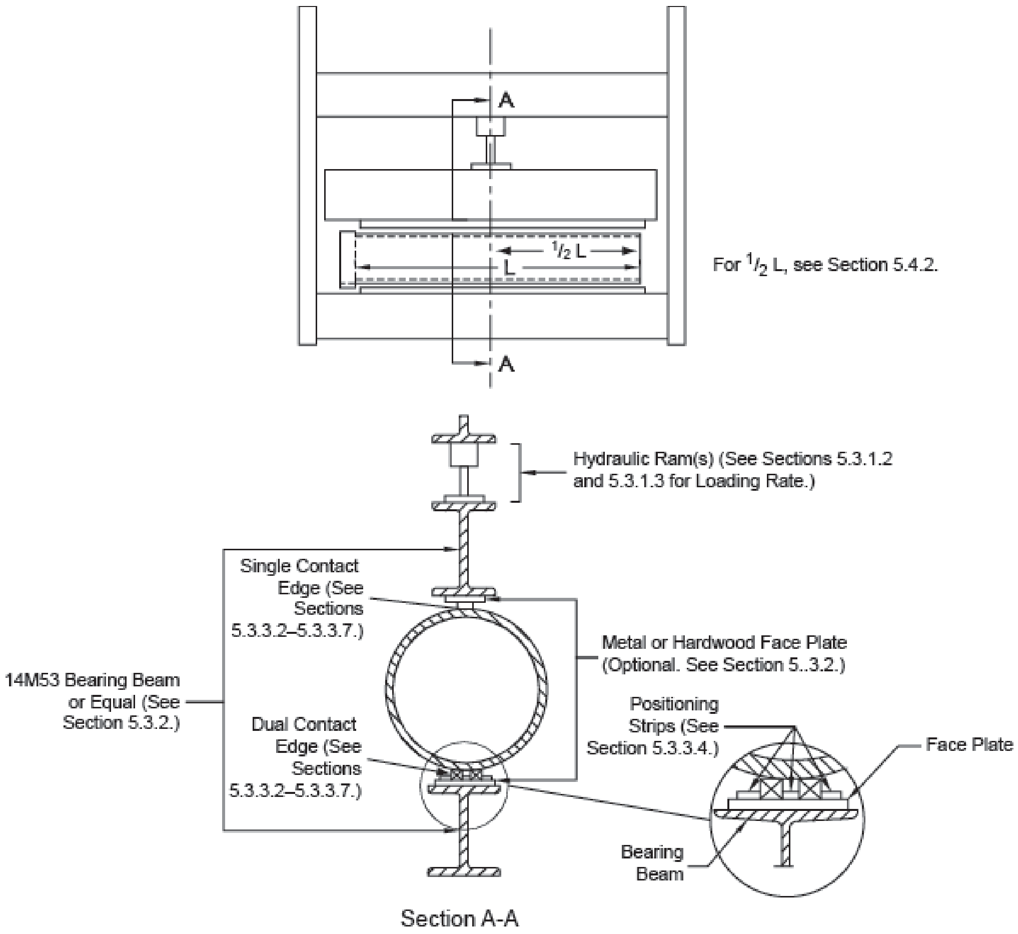

Figure 1—Three-Edge-Bearing Testing (Section 5.3.4 Segmented Testing)

5.3.2. *Bearing Beams*—Bearing beams shall not deflect more than a 355 by 205 mm [14 by 8 in.], 73 kg/linear m [53 lb/linear ft], wide flange beam as specified by the American Institute of Steel Construction. Under no circumstances shall the deflection in millimeters [inches] under maximum load exceed that given by the ratio $^{L}/_{720}$ in which L is the beam length in millimeters [inches]. The length of the bearing beams shall be no less than the full length of the outside barrel of the pipe. Built-up bearing beams may be used, provided their deflection does not exceed that specified. In order for the bell or socket of the pipe to clear the bearing beams, it is recommended that the bearing beams be faced with a metal or hardwood member for affixing the contact edges.

5.3.3. *Three-Edge-Bearings*:

5.3.3.1. Three-edge-bearings shall consist of an upper member, comprised of a bearing beam on which one contact edge is located so that it lies in the vertical plane passing through the longitudinal axis of the pipe, and a lower member comprised of a bearing beam on which two contact edges are symmetrically located parallel to that vertical plane.

5.3.3.2. The contact edges shall consist of rubber strips alone, or hardwood strips with plaster of paris fillets. Contact edges shall uniformly contact the outside barrel of the pipe.

5.3.3.3. The two contact edges on the lower member shall be spaced apart approximately 83 mm/m [1 in./ft] of pipe diameter, but in no case less than 25 mm [1 in.].

5.3.3.4. Positioning strips may be used to align the upper contact edge and to align and space the lower contact edges. In the case of rubber contact edges, positioning strips shall not exceed one-half of the thickness of the contact edge and may remain in place.

5.3.3.5. If rubber strips are used as contact edges, they shall be cut or formed from material having a Shore A, instantaneous, durometer hardness between 45 and 60. The strips shall be of rectangular cross section, having a 51-mm [2-in.] width, and a thickness not less than 25 mm [1 in.] nor more than 38 mm [$1^1/_2$ in.]. The contact edges shall be used with the 51-mm [2-in.] dimension in contact with the bearing beam. Rubber contact edges may be attached to the bearing beam by an adhesive, provided the contact edge remains firmly fixed in position.

5.3.3.6. If hardwood strips with plaster of paris fillets are used as contact edges, the strips shall be straight, and have a cross section not less than 25 mm [1 in.] in either direction. The bottom contact edges shall have vertical sides, with the interior top corners having a radius of approximately 13 mm [$^1/_2$ in.]. The contact edges shall be securely fastened to the beams.

5.3.3.7. Plaster of paris fillets shall be cast on hardwood contact edges to provide uniform bearing contact on the pipe barrel. Fillets shall be cast on the two lower contact edges and on the upper contact edge, along the pipe crown. Sufficient excess plaster shall be removed from between the two lower contact edges to eliminate the possibility of a single continuous lower contact. The pipe and contact edges shall be joined while the plaster of paris is still workable. Testing shall be performed only after the fillets have set.

5.3.4. *Segmented Bearings (Alternative to Three-Edge-Bearing)*—This apparatus shall consist of segmented upper and lower bearing members with the segments of each member connected to a common hydraulic manifold to provide uniform load along the length of the barrel. The segmented bearings shall be of uniform length with the number of segments equal to the nominal length of the test pipe measured in meters [feet]. They shall be adjustable to accommodate the length variation allowed in the pipe specification. In no instance shall the length of the segmented bearing be greater than the external length of the barrel of the pipe. Rubber contact edges conforming to Section 5.3.3.5 shall be attached to the bearing segments.

5.4. *Bearing Tests*—See Figure 1.

5.4.1. Test pipe for bearing strength in accordance with the three-edge-bearing or segmented method. Use either of the specified bearing methods on retests as provided in the applicable specifications.

5.4.2. For tests using rigid bearing beams, multiple loading rams may be used. Each ram must be the same load range, connected by a common hydraulic system, and spaced above the top bearing beam to deliver a uniformly distributed load. In testing pipe that is not straight, place it between the bearings in the position that most nearly gives uniform loading on the pipe.

5.4.3. The loading of the pipe shall be a continuous operation. Do not allow the pipe to stand under load longer than is required to apply the load and record the observations.

5.4.4. The loading shall be stopped after the required strength has been met.

5.4.5. For further evaluation or quality assurance, the loading may be continued to the point of pipe failure.

5.4.6. Record the maximum load sustained by the specimen.

5.5. *Calculation and Report*:

5.5.1. Calculate the crushing strength by dividing the applied load by the inside length of the barrel. The length shall be the average of two measurements taken at points 180 degrees [3.1 rad] apart. Report the individual results of the tests of pipe of each size or lot.

6. ABSORPTION

6.1. *Test Specimens*:

6.1.1. Absorption specimens shall be sound pieces of the full thickness of the barrel of the pipe, with all edges broken. Each specimen shall be as nearly square as possible, with the area on one barrel surface not less than 12 times the wall thickness, expressed as square units. They shall be free of observable cracks or shattered edges and shall not contain laminations and fissures more than is typical of the pipe from which the specimens were taken.

6.1.2. Each specimen shall be marked so that it may be identified with the lot of pipe from which it was taken. The markings shall be applied so that the pigment used shall cover not more than 1 percent of the area of the specimen.

6.1.3. Test at least one specimen from each size of pipe.

6.2. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

6.3. *Procedure*:

6.3.1. Dry the specimen at least 8 hours in a ventilated oven at a temperature between 110 and 120ºC [230 and 248ºF], and make successive mass determinations at intervals of not less than 3 hours until the loss at any mass determination is not greater than 0.1 percent of the original mass of the specimen.

6.3.2. Suspend the dried specimens in distilled, rain, or tap water that is known to have no effect on test results; heat to boiling; boil for 5 hours, and then cool in the water to ambient temperature. Take care that no fragments are broken from the specimens by physical disturbance during the test. When cool, remove the specimens from the water, and drain for not more than 60 seconds. Then remove the superficial moisture with a damp cloth and determine the mass of the specimens immediately.

6.4. *Calculation and Report*:

6.4.1. Calculate the absorption of each specimen as a percentage of the initial dry mass as follows:

$$\text{Absorption, } \% = \left[\left(SW - DW\right)/DW\right] \times 100 \qquad (1)$$

where:

SW = mass of specimen after boiling 5 hours, and

DW = initial dry mass of specimen.

6.4.2. Report the result for each specimen, together with the averages for the pipe of each size and shipment.

7. HYDROSTATIC PRESSURE TEST

7.1. When the pipe is subjected to an internal hydrostatic pressure of 69 kPa [10 psi] for the elapsed time shown in the following table, there shall be no leakage on the exterior of the pipe. At the option of the manufacturer, water within approximately 3ºC [5ºF] of the ambient air temperature may be introduced into the pipe for control of condensation. Moisture appearing on the surface of the pipe in the form of beads adhering to the surface shall not be considered leakage. However, moisture that starts to run on the pipe shall be construed as leakage regardless of quantity.

Testing Time for Pipes

Thickness of Barrel, mm [in.]	Test Time, min
Up to and including 25 [1]	7
Over 25 [1] and including 38 [$1^1/_2$]	9
Over 38 [$1^1/_2$] and including 51 [2]	12
Over 51 [2] and including 64 [$2^1/_2$]	15
Over 64 [$2^1/_2$] and including 76 [3]	18
Over 76 [3]	21

8. ACID RESISTANCE

8.1. Determine the acid resistance of clay pipe by the extraction of acid-soluble matter.

8.2. *Reagent*—When testing with sulfuric (H_2SO_4), hydrochloric (HCl), nitric (HNO_3), or acetic acid (CH_3COOH), as specified by the purchaser, a 1-normal acid solution shall be used.

Note 2—These 1-normal solutions should contain 40, 36.5, 63, and 60 g of the acid per liter of solution, respectively. For the purpose of these tests the solutions can be prepared by taking the following volumes of acid and diluting to 1 liter: H_2SO_4 (sp gr 1.84), 28.5 mL; HCl (sp gr 1.19), 88.9 mL; HNO_3 (sp gr 1.42), 65 mL; and glacial acetic acid (sp gr 1.05), 57.7 mL.

8.3. *Test Specimens*:

8.3.1. The specimens for acid resistance tests shall be about 51 mm [2 in.] square, and weigh not more than 200 g. They shall be sound pieces with all edges freshly broken, free of cracks or shattered edges, and shall be thoroughly cleaned.

8.3.2. Test at least one specimen from each size of pipe.

8.4. *Balances*—The balance for determining the mass of the specimens shall conform to the requirements for Class C balances in M 231.

8.5. *Procedure*:

8.5.1. Dry the specimens to constant mass at a temperature not less than 110ºC [230ºF].

8.5.2. Suspend the dried specimens in the acid at a temperature between 21 and 32ºC [70 and 90ºF] for a period of 48 hours, then remove them from the solution and thoroughly wash with hot water, allowing the washings to run into the solution in which the specimen was immersed. Filter the solution and wash the filter with hot water, adding the washings to the filtrate. Add 5 mL of H_2SO_4 (sp gr 1.84) to the filtrate. Then evaporate the solution (avoid loss by spattering) to about 5 mL, transfer to a porcelain crucible (previously ignited to constant mass), and heat cautiously to dryness. Then ignite the residue to constant weight.

8.6. *Calculation and Report*:

8.6.1. Calculate the percentage of acid-soluble matter as follows:

$$\text{Acid-soluble matter, \%} = (R/W) \times 100 \qquad (2)$$

where:

R = mass of residue, and

W = initial mass of the specimen.

8.6.2. Report the results for each specimen.

9. VISUAL INSPECTION

9.1. The specification for vitrified clay pipe requires visual inspection; reference should be made to ASTM C 700.

10. PRECISION AND BIAS

10.1. No statements are made on the precision or bias of these test methods for measuring (1) bearing strength, (2) absorption, (3) acid resistance, or (4) moisture transmitted through the pipe wall in the hydrostatic pressure test, since conformance to specific criteria is the only measure for success specified in these test methods.

11. KEYWORDS

11.1. Absorption; acid resistance; bearing strength; clay pipe; corrosion; corrosion resistance; hydrostatic; inspection; loading; pipe; segmented bearing; testing procedure; tests; three-edge-bearing; vitrified clay pipe.

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[1] This method agrees with ASTM C 301-04 except for reference to weighing apparatus.

Standard Method of Test for

Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading

AASHTO Designation: T 341-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading

AASHTO Designation: T 341-10

1. SCOPE

1.1 This test method covers determination of compression capacity of profile wall plastic pipe in the stub compression test.

1.2 This test method covers thermoplastic resin pipe.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- D 695, Standard Test Method for Compressive Properties of Rigid Plastics
- D 1600, Standard Terminology for Abbreviated Terms Relating to Plastics
- E 177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods
- F 412, Standard Terminology Relating to Plastic Piping Systems

3. TERMINOLOGY

3.1 Definitions are in accordance with ASTM F 412, and abbreviations are in accordance with ASTM D 1600, unless otherwise specified.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *local buckling*—local wrinkling resulting from compressive load in one or more elements of the wall section visible to the eye. When advanced, it may result in failure of the entire profile.

3.2.2 *period*—the length of a single repetition of the corrugation or rib pattern, defined as the distance from the centerline of a valley or liner element to the centerline of the adjacent valley or liner element (see Figure 1).

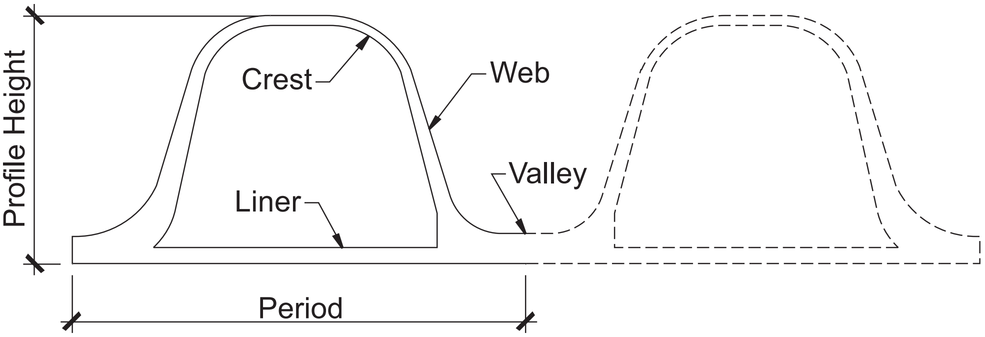

Figure 1—Typical Lined Profile Wall

3.2.3 *profile height*—the distance from the surface of the inside wall of the pipe (inner surface of the valley or liner element) to the surface of the outside wall of the pipe (outer surface of the crest or rib element in Figure 1). May also be determined as (OD – ID)/2.

3.2.4 *profile wall*—thin-walled pipe with corrugated or ribbed geometry.

4. SUMMARY OF TEST METHOD

4.1 A small sample of pipe wall is compressed between two rigid plates at a controlled rate. Both plates are fixed with respect to rotation. The sample has a longitudinal length of three periods and a chord (circumferential) length of 1.5 times the profile height. Load, displacement (of the load plates), and time data are obtained. The test ends when the ultimate load is exceeded and the level of load begins to decrease. The ultimate load, crosshead displacement at ultimate load, and test time at ultimate load are recorded.

5. SIGNIFICANCE AND USE

5.1 *The maximum load achieved in this test may be used for the following*:

5.1.1 To evaluate compression load capacity of profile wall thermoplastic pipe.

5.1.2 To evaluate the manufactured consistency of pipe wall cross-section thickness distribution.

6. APPARATUS

6.1 *Testing Machine*—A properly calibrated compression testing machine of the constant-rate-of-crosshead-movement type meeting the requirements of ASTM D 695 shall be used to conduct the test. The rate of head approach shall be 0.05 ± 0.01 in./min (1.27 ± 0.25 mm/min). The testing machine shall be capable of compressing the sample to its capacity. The testing machine shall monitor the applied load to accuracy of ±25 lb (110 N).

6.2 *Loading Plates*—The load shall be applied to the specimen through two parallel steel bearing plates. The plates shall be flat, smooth, and clean. The thickness of the plates shall be sufficient so that no bending or deformation occurs during the test, but shall not be less than 0.25 in. (6.0 mm). The plate length shall equal or exceed the specimen longitudinal length, and the plate width shall not be less than the profile height plus 6.0 in. (150 mm).

6.3 *Deflection Indicator*—The crosshead displacement shall be measured with a suitable instrument meeting the requirements of ASTM D 695, except that the instrument shall be accurate to 0.001 in. (0.025 mm).

Note 1—Monitoring crosshead motion of the test machine is an acceptable method of recording deflection; however, the test machine flexibility may result in apparent deflection in addition to the specimen deflection. This must be accounted for if the deflection data are used to evaluate strain at maximum load.

7. SAMPLING, TEST SPECIMENS, AND TEST UNITS

7.1 The test specimen shall be a wall section cut from a finished pipe product.

7.2 The specimen longitudinal length shall be three periods.

7.3 The specimen chord (circumferential) length shall be 1.5 times the profile height with tolerance of $^1/_4$ in.

7.4 Specimen ends shall be cut flat and parallel to each other and to the radial line through the center of the sample. The cut ends are not radial.

Note 2—The most important aspect of specimen preparation is cutting the ends to planar parallel surfaces. This is complicated by the thin flexible elements of many profile wall pipe. Guidance for specimen preparation is provided in Annex A.

8. CONDITIONING

8.1 Condition pipe for at least 4 hours in air, at a temperature of 73.4 ± 3.6ºF (23 ± 2ºC), and conduct the test in a room maintained at the same temperature.

9. PROCEDURE

9.1 Record the pipe nominal diameter, pipe model/classification, profile type, manufacturer, conditioning temperature, and date of test.

9.2 *Make and record the following measurements for each specimen*:

9.2.1 Determine the longitudinal length of each specimen to the nearest $^1/_{16}$ in. (1.5 mm) by making and averaging three measurements equally spaced over the chord length.

9.2.2 Determine the chord length of each specimen to the nearest $^1/_{16}$ in. (1.5 mm) by making and averaging three measurements equally spaced along the longitudinal length.

9.2.3 Determine the profile height of each specimen to the nearest $^1/_{16}$ in. (1.5 mm) by making and averaging three measurements equally spaced along the longitudinal length.

9.3 Place the specimen on the lower plate, centering the specimen under the testing machine crosshead vertical axis, as illustrated in Figure 2.

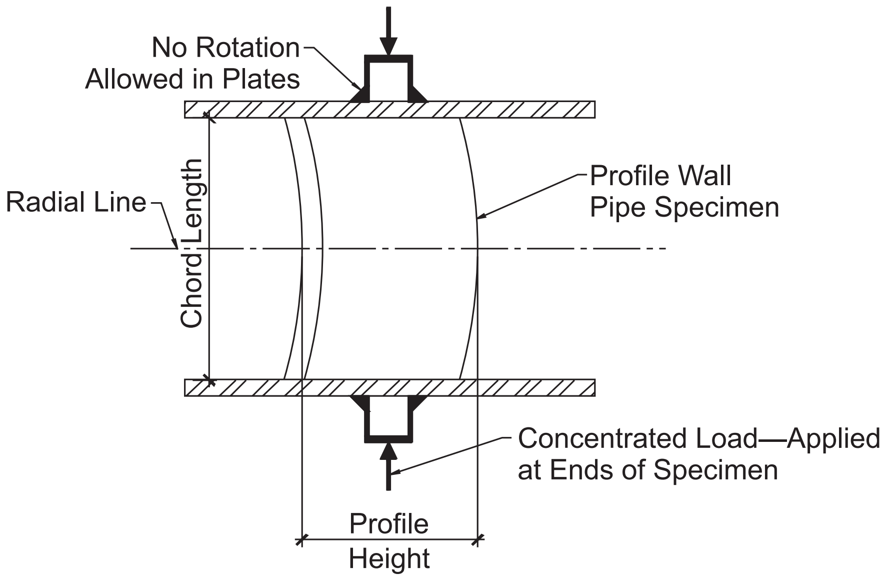

Figure 2—Stub Compression Test Setup

9.4 With the displacement indicator in place, bring the upper plate into contact with the specimen with no more than 50-lb (220-N) seating force.

9.5 Compress the sample at a constant rate of 0.05 ± 0.01 in./min (1.27 ± 0.25 mm/min).

9.6 Record the load, displacement, and time measurements continuously or intermittently with reference to the relative movement of the bearing plates. If measurements are made intermittently, make and record such measurements at increments of not more than 1 percent of the original specimen chord length.

9.7 Note the ultimate load carried by the sample.

9.8 Discontinue the test when the load on the specimen fails to increase with increasing deflection.

10. CALCULATION OR INTERPRETATION OF RESULTS

10.1 Calculate the ultimate compressive load capacity per unit length of pipe wall as the ultimate load (lb) divided by the average longitudinal length (in.).

11. REPORT

11.1 *Report the following information*:

11.1.1 Agency conducting test.

11.1.2 Date of test.

11.1.3 Complete identification of the material tested, including type, source, manufacturer's code, previous history (if any), product identification by standard number, and pipe nominal diameter.

11.1.4 Specimen dimensions, including longitudinal length, chord length, and profile height.

11.1.5 Conditioning temperature, time, and environment.

11.1.6 The ultimate load carried by the specimen.

11.1.7 The ultimate compressive load capacity of the pipe wall.

11.1.8 The average load rate throughout the test duration.

12. PRECISION AND BIAS

12.1 *Precision*—An interlaboratory study of stub-compression-test ultimate loads was conducted with six laboratories participating. The pipe samples were 24A = 24-in. high density polyethylene (HDPE) corrugated pipe, 24C = 24-in. HDPE corrugated pipe, 24D = 24-in. polyvinylchloride (PVC) ribbed pipe, 42B = 42-in. HDPE corrugated pipe, and 42C = 42-in. HDPE corrugated pipe. Information regarding the precision is found in Table 1.

Table 1—Stub Compression Test—Precision Statistics[a]

Material	Sample	Average	s_{mean}	s_r[b]	s_R[c]	r	R	Standard Deviation of Averages[d]	Repeat-ability Standard Deviation[d]	Reproduci-bility Standard Deviation[d]	Repeat-ability Limit (95%)[d]	Reproduci-bility Limit (95%)[d]
HDPE	24A	726	59.1	56.6	49.1	111	96	8.1	7.8	6.8	15.3	13.3
HDPE	24C	891	76.1	70.8	60.9	139	119	8.5	7.9	6.8	15.6	13.4
PVC	24D	1991	118.6	84.9	122.5	166	240	6.0	4.3	6.2	8.4	12.1
HDPE	42B	952	68.8	55.5	59.4	109	116	7.2	5.8	6.2	11.4	12.2
HDPE	42C	998	80.5	65.1	60.9	128	119	8.1	6.5	6.1	12.8	12.0

[a] Terms are as specified in ASTM E 177.

[b] s_r = standard deviation of repeatability (variation of replicate samples by the same laboratory).

[c] s_R = standard deviation of reproducibility (variation between laboratories).

[d] Precision statistics as percent of average.

13. KEYWORDS

13.1 Compression; local buckle; stub compression; thermoplastic pipe.

ANNEX

(Mandatory Information)

A1. SPECIMEN PREPARATION

A1.1. This annex provides a detailed procedure for preparing specimens for the stub compression test. Test specimens must be carefully prepared and have square, parallel faces equidistant from the radial line at the center of the specimen. Specimens are composed of thin elements and are very flexible; therefore, clamping and care are required to produce parallel ends for loading between the parallel plates. Suggested tools are those found to work best during the research to develop this standard. Other labs may use different procedures or equipment. Precise specimen preparation is critical to obtaining repeatable and reproducible test results.

A1.2. *A suggested specimen cutting procedure follows*:

A1.2.1. Rough cut specimens from the pipe to a chord length approximately 2 in. longer than the final chord length of 1.5 times the corrugation depth using a reciprocating saw or circular saw (Figure A1.1).

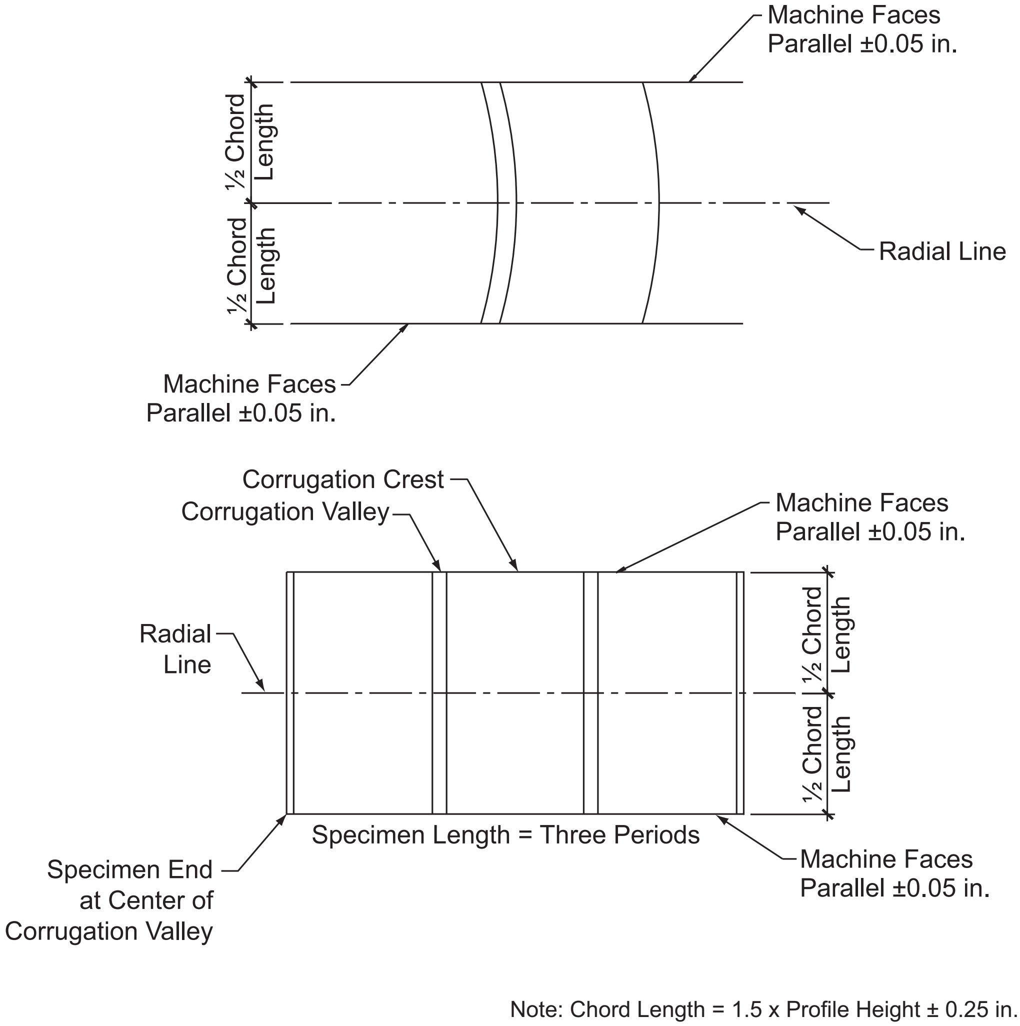

Figure A1.1—Specimen Dimensions

A1.2.2. Square the longitudinal ends to be parallel to the circumference of the pipe. Use a milling machine or belt sander to ensure the ends are square, and evaluate with a carpenter's square (Figure A1.2).

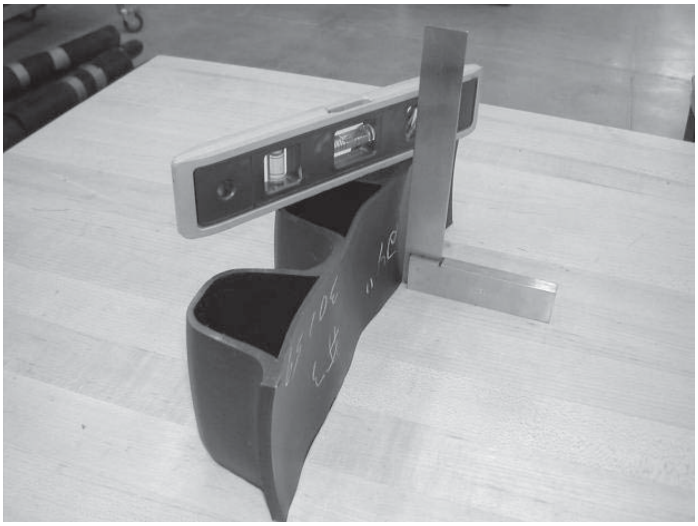

Figure A1.2—Evaluate the Ends of Milled Specimen with a Carpenter's Square

A1.2.3. Cut the circumferential ends of each specimen square and parallel with a milling machine. Clamp the test specimen to the table of the milling machine, supporting it at the center of the entire chord length. The sample must be clamped down firmly enough that it does not move during the milling process, but not so firmly that its shape is warped from the clamping pressure.

A1.2.4. To ensure a square cut, alternate milling each side of the specimen until the chord length is within the specified tolerance of 1.5 times the profile height, and the longitudinal faces are parallel to and equidistant from a radial passing through the center of the pipe and the midheight of the specimen.

A1.2.5. Place the specimen on a flat, level surface to check that the ends are plane, parallel, and square. Place a 6-in. level on the specimen in several locations to check that ends are plane along the specimen length and across the corrugation depth. Use a carpenter's square to check that the specimen center is parallel with a radial line from the center of the pipe from which the specimen was removed. Flip the specimen so that the opposing end is flat against the table, and repeat these checks.

A1.2.6. If necessary, make small adjustments to the ends of the sample using a belt sander. Following any adjustments, repeat checks for plane, parallel, and square ends described in the previous step.

Standard Method of Test for

Sampling and Testing Brick

AASHTO Designation: T 32-10
ASTM Designation: C 67-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling and Testing Brick

AASHTO Designation: T 32-10
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AASHTO T 32-10 is based on ASTM C 67-09, but contains only such portions of C 67 as are required for testing brick for conformance to AASHTO M 91 and M 114. Sections of C 67 that do not pertain to testing brick have not been adopted by AASHTO. All references to ASTM C 150 shall be replaced with AASHTO M 85.

Standard Method of Test for

Compressive Strength of Cylindrical Concrete Specimens

AASHTO Designation: T 22-10[1]
ASTM Designation: C 39/C 39M-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Compressive Strength of Cylindrical Concrete Specimens

AASHTO Designation: T 22-10[1]
ASTM Designation: C 39/C 39M-05

1. SCOPE

1.1 This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 800 kg/m^3 (50 lb/ft^3).

1.2 The values stated in SI units are the preferred standard.

1.3 *This standard may involve hazardous materials, operations, or equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Means should be provided to contain concrete fragments during sudden rupture of specimens. Tendency for sudden rupture increases with increasing concrete strength (Note 1).

Note 1—The safety precautions given in the *Manual of Aggregate and Concrete Testing*, located in the Related Materials section of Volume 04.02 of the *Annual Book of ASTM Standards*, are recommended.

1.4 The text of this standard references notes that provide explanatory material. These notes shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 231, Capping Cylindrical Concrete Specimens

2.2 *ASTM Standards*:

- C 31/C 31M, Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 42/C 42M, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- C 192/C 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C 617, Standard Practice for Capping Cylindrical Concrete Specimens

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 873, Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
- C 1077, Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
- C 1231/C 1231M, Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders
- E 4, Standard Practices for Force Verification of Testing Machines
- E 74, Standard Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
- *Manual of Aggregate and Concrete Testing*, *Annual Book of ASTM Standards*, Vol. 04.02

3. SUMMARY OF TEST METHOD

3.1 This test method consists of applying a compressive axial load to molded cylinders or cores at a rate that is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

4. SIGNIFICANCE AND USE

4.1 Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method because strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication, and the age, temperature, and moisture conditions during curing.

4.2 This test method may be used to determine compressive strength of cylindrical specimens prepared and cured in accordance with R 39, T 23, T 24M/T 24, T 231, and ASTM C 873.

4.3 The results of this test method may be used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specification; and control for evaluating effectiveness of admixtures and similar uses.

5. APPARATUS

5.1 *Testing Machine*—The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading prescribed in Section 7.5.

5.1.1 Verify calibration of the testing machines in accordance with ASTM E 4, except that the verified loading range shall be as required in Section 5.3. Verification is required under the following conditions:

5.1.1.1 At least annually, but not to exceed 13 months;

5.1.1.2 On original installation or immediately after relocation;

5.1.1.3 Immediately after making repairs or adjustments that affect the operation of the force applying system or the values displayed on the load indicating system, except for zero adjustments that compensate for the mass (weight) of tooling, or specimen, or both; or

5.1.1.4 Whenever there is reason to suspect the accuracy of the indicated loads.

5.1.2 *Design*—The design of the machine must include the following features:

5.1.2.1 The machine must be power-operated and must apply the load continuously rather than intermittently, and without shock. If it has only one loading rate (meeting the requirements of Section 7.5), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand-operated.

5.1.2.2 The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device that is of sufficient capacity to cover the potential loading range of the testing machine and that complies with the requirement of ASTM E 74.

Note 2—The types of elastic calibration devices most generally available and most commonly used for this purpose are the circular proving rings or load cells.

5.1.3 *Accuracy*—The accuracy of the testing machine shall be in accordance with the following provisions:

5.1.3.1 The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0 percent of the indicated load.

5.1.3.2 The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one-third of the difference between the maximum and minimum test loads.

5.1.3.3 The test load as indicated by the testing machine and the applied load computed from the readings of the verification device shall be recorded at each test point. Calculate the error, E, and the percentage of error, E_p, for each point from these data as follows:

$$E = A - B \tag{1}$$

$$E_p = 100\,(A - B)/B \tag{2}$$

where:

A = load, kN (or lbf) indicated by the machine being verified; and

B = applied load, kN (or lbf) as determined by the calibrating device.

5.1.3.4 The report on the verification of a testing machine shall state within what loading range it was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall the loading range be stated as including loads below the value that is 100 times the smallest change of load that can be estimated on the load-indicating mechanism of the testing machine or loads within that portion of the range below 10 percent of the maximum range capacity.

5.1.3.5 In no case shall the loading range be stated as including loads outside the range of loads applied during the verification test.

5.1.3.6 The indicated load of a testing machine shall not be corrected either by calculation or by the use of a calibration diagram to obtain values within the required permissible variation.

5.2 The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note 3), one of which is a spherically-seated block that will bear on the upper surface of the specimen, and the other a solid block on which the specimen shall rest. Bearing faces of the blocks shall have a minimum dimension at least 3 percent greater than the diameter of the specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.02 mm (0.001 in.) in any 150 mm (6 in.) of blocks 150 mm (6 in.) in diameter or larger, or by more than 0.02 mm (0.001 in.) in the diameter of any smaller block; and new blocks shall be manufactured within one-half of this tolerance. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than 13 mm (0.5 in.), concentric circles not more than 0.8 mm (0.03 in.) deep and not more than 1 mm (0.04 in.) wide shall be inscribed to facilitate proper centering.

Note 3—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than 55 HRC.

5.2.1 Bottom bearing blocks shall conform to the following requirements:

5.2.1.1 The bottom bearing block is specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions (Note 4). The top and bottom surfaces shall be parallel to each other. Its least horizontal dimension shall be at least 3 percent greater than the diameter of the specimen to be tested. Concentric circles as described in Section 5.2 are optional on the bottom block.

Note 4—The block may be fastened to the platen of the testing machine.

5.2.1.2 Final centering must be made with reference to the upper spherical block when the lower bearing block is used to assist in centering the specimen. The center of the concentric rings, when provided, or the center of the block itself must be directly below the center of the spherical head. Provision shall be made on the platen of the machine to assure such a position.

5.2.1.3 The bottom bearing block shall be at least 25 mm (1 in.) thick when new and at least 22.5 mm (0.9 in.) thick after resurfacing operations.

Note 5—If the testing machine is so designed that the platen itself can be readily maintained in the specified surface condition, a bottom block is not required.

5.2.2 The spherically seated bearing block shall conform to the following requirements:

5.2.2.1 The maximum diameter of the bearing face of the suspended spherically seated block shall not exceed the values given below:

Table 1—Maximum Diameter of Bearing Face

Diameter of Test Specimens, mm (in.)	Max Diameter of Bearing Face, mm (in.)
50 (2)	105 (4)
75 (3)	130 (5)
100 (4)	165 (6.5)
150 (6)	255 (10)
200 (8)	280 (11)

Note 6—Square bearing faces are permissible, provided the diameter of the largest possible inscribed circle does not exceed the above diameter.

5.2.2.2 The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 percent of the radius of the sphere. The diameter of the sphere shall be at least 75 percent of the diameter of the specimen to be tested.

5.2.2.3 The ball and the socket shall be designed so that the steel in the contact area does not permanently deform when loaded to the capacity of the test machine.

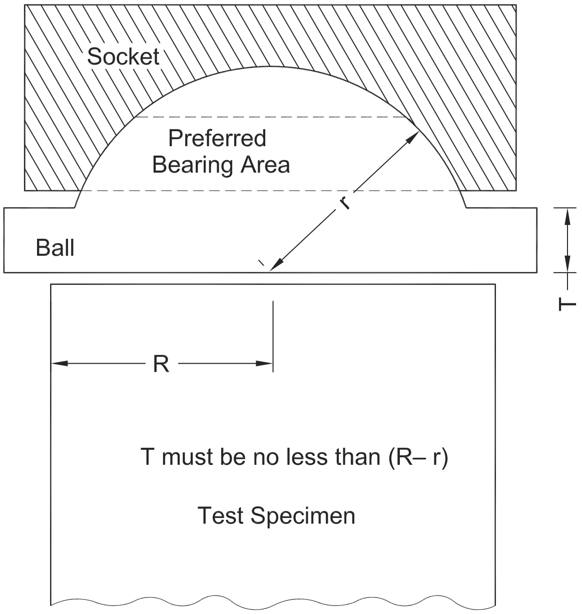
Note 7—The preferred contact area is in the form of a ring (described as "preferred bearing area") as shown in Figure 1.

5.2.2.4 The curved surfaces of the socket and the spherical portion shall be kept clean and shall be lubricated with a petroleum-type oil such as conventional motor oil, not with a pressure-type grease. After contacting the specimen and application of a small initial load, further tilting of the spherically seated block is not intended and is undesirable.

5.2.2.5 If the radius of the sphere is smaller than the radius of the largest specimen to be tested, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen. The least dimension of the bearing face shall be at least as great as the diameter of the sphere. (See Figure 1.)

5.2.2.6 The movable portion of the bearing block shall be held closely in the spherical seal, but the design shall be such that the bearing face can be rotated freely and tilted at least 4 degrees in any direction.

5.2.2.7 If the ball portion of the upper bearing block is a two-piece design composed of a spherical portion and a bearing plate, a mechanical means shall be provided to ensure that the spherical portion is fixed and centered on the bearing plate.



Note: Provision shall be made for holding the ball in the socket and for holding the entire unit in the testing machine.

Figure 1—Schematic Sketch of a Typical Spherical Bearing Block

5.3 *Load Indication*:

5.3.1 If the load of a compression machine used in concrete tests is registered on a dial, the dial shall be provided with a graduated scale that can be read to at least the nearest 0.1 percent of the full scale load (Note 8). The dial shall be readable within 1 percent of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment located outside the dial case and easily accessible from the front of the machine while observing the zero mark and dial pointer. Each dial shall be equipped with a suitable device that at all times, until reset, will indicate to within 1 percent accuracy the maximum load applied to the specimen.

Note 8—As close as can reasonably be read is considered to be 0.5 mm (0.02 in.) along the arc described by the end of the pointer. Also, one-half of the scale interval is about as close as can reasonably be read when the spacing on the load-indicating mechanism is between 1 mm (0.04 in.) and 2 mm (0.06 in.). When the spacing is between 2 mm and 3 mm (0.06 in. and 0.12 in.), one-third of a scale interval can be read with reasonable certainty. When the spacing is 3 mm (0.12 in.) or more, one-fourth of a scale interval can be read with reasonable certainty.

5.3.2 If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 percent of the full-scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 percent for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1.0 percent system accuracy the maximum load applied to the specimen.

5.4 Provide a means for containing fragments in the event of explosive rupture of the cylinders during testing.

6. SPECIMENS

6.1 Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 percent (Note 9).

Note 9—This may occur when single-use molds are damaged or deformed during shipment, when flexible single-use molds are deformed during molding, or when a core drill deflects or shifts during drilling.

6.2 Neither end of compressive test specimens when tested shall depart from perpendicularity to the axis by more than 0.5 degrees (approximately equivalent to 3 mm in 300 mm (0.12 in. in 12 in.)). The ends of compression test specimens that are not plane within 0.050 mm (0.002 in.) shall be sawed or ground to meet that tolerance or capped in accordance with either T 231 or, when permitted, ASTM C 1231. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.25 mm (0.01 in.) by averaging two diameters measured at right angles to each other at about mid-height of the specimen.

6.3 The number of individual cylinders measured for determination of average diameter may be reduced to one for each ten specimens or three specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reusable or single-use molds which consistently produce specimens with average diameters within a range of 0.5 mm (0.02 in.). When the average diameters do not fall within the range 0.5 mm (0.02 in.) or when the cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculation of the unit compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

6.4 If the purchaser of the testing services requests measurement of density of the test specimen, determine the mass of the specimen before capping. Remove any surface moisture with a towel and measure the mass of the specimen using a balance or scale that is accurate to within 0.3 percent of the mass being measured. Measure the length of the specimen to the nearest 1 mm (0.05 in.) at three locations spaced evenly around the circumference. Compute the average length and record to the nearest 1 mm (0.05 in.). Alternatively, determine the cylinder density by weighing the cylinder in air and then submerged under water at 23.0 ± 2.0°C (73.5 ± 3.5°F), and computing the volume according to Section 8.3.1.

6.5 When density determination is not required and the length to diameter ratio is less than 1.8 or more than 2.2, measure the length of the specimen to the nearest 0.05 *D*.

7. PROCEDURE

7.1 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from moist storage.

7.2 Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

7.3 All test specimens for a given test age shall be broken within the permissible time tolerances prescribed as follows:

Table 2—Permissible Time Tolerances

Test Age	Permissible Tolerance
12 h	±0.25 h or 2.1 percent
24 h	±0.5 h or 2.1 percent
3 days	2 h or 2.8 percent
7 days	6 h or 3.6 percent
28 days	20 h or 3.0 percent
56 days	40 h or 3.0 percent
90 days	2 days or 2.2 percent

7.4 *Placing the Specimen*—Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically-seated (upper) bearing block. Wipe clean the bearing faces of the upper- and lower-bearing blocks and of the test specimen and place the test specimen on the lower bearing block.

7.4.1 *Zero Verification and Block Seating*—Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator (Note 10). As the spherically-seated block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

Note 10—The technique used to verify and adjust the load indicator to zero will vary depending on the machine manufacturer. Consult your owner's manual or compression machine calibrator for the proper technique.

7.5 *Rate of Loading*—Apply the load continuously and without shock, except as permitted by ASTM C 1231/C 1231M.

7.5.1 The load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a stress rate on the specimen of 0.25 ± 0.05 MPa/s (35 ± 7 psi/s) (Note 11). The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase.

Note 11—For a screw driven or displacement-controlled testing machine, preliminary testing will be necessary to establish the required rate of movement to achieve the specified stress rate. The required rate of movement will depend on the size of the test specimen, the elastic modulus of the concrete, and the stiffness of the testing machine.

7.5.2 During application of the first half of the anticipated loading phase, a higher rate of loading shall be permitted. Apply the higher loading rate in a controlled manner so the specimen is not subjected to shock loading.

7.5.3 Do not adjust the rate of movement (platen to crosshead) as the ultimate load is being approached and the stress rate decreases due to cracking in the specimen.

7.6 Apply the compressive load until the load indicator shows that the load is decreasing steadily and the specimen displays a well-defined fracture pattern (Figure 2). For a testing machine equipped with a specimen break detector, automatic shut-off of the testing machine is prohibited until the load has dropped to a value that is less than 95 percent of the peak load. When testing with unbonded caps, a corner fracture may occur before the ultimate capacity of the specimen has been attained. Continue compressing the specimen until the user is certain that the ultimate capacity has been attained. Record the maximum load carried by the specimen during the test, and note the type of fracture pattern according to Figure 2. If the fracture pattern is not one of the typical patterns shown in Figure 2, sketch and describe briefly the fracture pattern. If the measured strength is lower than expected, examine the fractured concrete and note the presence of large air voids, evidence of segregation, whether fractures pass predominantly around or through the coarse aggregate particles, and verify end preparations were in accordance with T 231 or ASTM C 1231/C 1231M.

8. CALCULATION

8.1 Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Section 6 and express the result to the nearest 0.1 MPa (10 psi).

8.2 If the specimen length-to-diameter (*L*/*D*) ratio is 1.75 or less, correct the result obtained in Section 8.1 by multiplying the appropriate correction factor shown in the following table (Note 12):

L/*D* ratio:	1.75	1.50	1.25	1.00
Factor:	0.98	0.96	0.93	0.87

Use interpolation to determine correction factors for *L*/*D* values between those given in the table.

Note 12—Correction factors depend on various conditions such as moisture condition, strength level, and elastic modulus. Average values are given in the table. These correction factors apply to lightweight concrete weighing between 1,600 and 1,920 kg/m^3 (100 and 120 lb/ft^3) and to normal weight concrete. They are applicable to concrete dry or soaked at the time of loading and for nominal concrete strengths from 15 to 45 MPa (2000 to 6000 psi). For strengths higher than 45 MPa (6000 psi) correction factors may be larger than the values listed above.[2]

8.3 When required, calculate the density of the specimen to the nearest 10 kg/m^3 (1 lb/ft^3) as follows:

$$Density = \frac{W}{V} \qquad (3)$$

where:

W = mass of specimen, kg (lb); and

V = volume of specimen computed from the average diameter and average length or from weighing the cylinder in air and submerged, m^3 (ft^3)

8.3.1 When the volume is determined from submerged weighing, calculate the volume as follows:

$$V = \frac{W - W_s}{\gamma_w} \qquad (4)$$

where:

W_s = apparent mass of submerged specimen, kg (lb); and

γ_w = density of water at 23°C (73.5°F) = 997.5 kg/m^3 (62.27 lb/ft^3).

9. REPORT

9.1 *The report shall include the following*:

9.1.1 Identification number;

9.1.2 Diameter (and length, if outside the range of 1.8D to 2.2D), in inches or millimeters;

9.1.3 Cross-sectional area, in square inches or square centimeters;

9.1.4 Maximum load, in pounds-force or kilonewtons;

9.1.5 Compressive strength calculated to the nearest 0.1 MPa (10 psi);

9.1.6 Type of fracture, if other than the usual cone (see Figure 2);

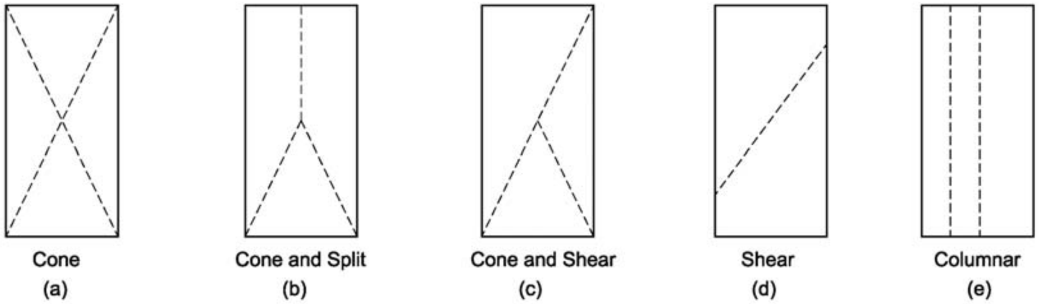


Figure 2—Sketches of Types of Fracture

9.1.7 Defects in either specimen or caps; and

9.1.8 Age of specimen.

9.1.9 When determined, record the density to the nearest 10 kg/m^3 (1 lb/ft^3).

10. PRECISION AND BIAS

10.1 *Precision*:

10.1.1 *Within-Test Precision*—The following table provides the within-test precision of tests of 150 by 300 mm (6 by 12 in.) and 100 by 200 mm (4 by 8 in.) cylinders made from a well-mixed sample of concrete under laboratory conditions and under field conditions (see Section 10.1.2):

	Coefficient of Variation[a]	Acceptable Range[a] of Individual Cylinder Strengths	
150 × 300 mm (6 × 12 in.)		2 cylinders	3 cylinders
Laboratory conditions	2.4 %	6.6 %	7.8 %
Field conditions	2.9 %	8.0 %	9.5 %
100 × 200 mm (4 × 8 in.)			
Laboratory conditions	3.2%	9.0%	10.6%

[a] These numbers represent respectively the (1s) and (d2s) limits as described in ASTM C 670.

10.1.2 The within-test coefficient of variation represents the expected variation of measured strength of companion cylinders prepared from the same sample of concrete and tested by one laboratory at the same age. The values given for the within-test coefficient of variation of 150 by 300 mm (6 by 12 in.) cylinders are applicable for compressive strengths between 15 to 55 MPa (2000 and 8000 psi) and those for 100 by 200 mm (4 by 8 in.) cylinders are applicable for compressive strengths between 17 to 32 MPa (2500 and 4700 psi.) The within-test coefficients of variation for 150 by 300 mm (6 by 12 in.) cylinders are derived from CCRL concrete proficiency sample data for laboratory conditions and a collection of 1265 test reports from 225 commercial testing laboratories in 1978 (ASTM Research Report RR: C09-1006).[3] The within-test coefficient of variation of 100 by 200 mm (4 by 8 in.) cylinders are derived from CCRL concrete proficiency sample data for laboratory conditions (ASTM Research Report RR C09-1027).[4]

10.1.3 *Multilaboratory Precision*—The multilaboratory coefficient of variation for compressive strength test results of 150 by 300 mm (6 by 12 in.) cylinders has been found to be 5.0 percent; therefore, the results of properly conducted tests by two laboratories on specimens prepared from the same sample of concrete are not expected to differ by more than 14 percent of the average (see Note 13). A strength test result is the average of two cylinders tested at the same age.

Note 13—The multilaboratory precision does not include variations associated with different operators preparing test specimens from split or independent samples of concrete. These variations are expected to increase the multilaboratory coefficient of variation.

10.1.4 The multilaboratory data were obtained from six separate organized strength testing round-robin programs where 150 by 300 mm (6 by 12 in.) cylindrical specimens were prepared at a single location and tested by different laboratories. The range of average strength from these programs was 17.0 to 90 MPa (2500 to 13000 psi).

Note 14—ASTM Subcommittee C09.61 will continue to examine recent concrete proficiency sample data and field test data and make revisions to precision statements when data indicate that they can be extended to cover a wider range of strengths and specimen sizes.

10.2 *Bias*—Since there is no accepted reference material, no statement on bias is being made.

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[1] This method agrees technically with C 39/C 39M-05 except for the use of SI units, and C 39 provides qualification restrictions for concrete laboratory technicians performing acceptance tests.

[2] Barlett, F. M. and J. G. MacGregor. "Effect of Core Length-to-Diameter Ratio on Concrete Core Strength." *ACI Materials Journal*, Vol. 91, No. 4, July–August, 1994, *pp*. 339–348.

[3] Supporting data may be obtained by requesting Research Report RR: C09-1006 from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

[4] Supporting data may be obtained by requesting Research Report RR: C09-1027 from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

Standard Method of Test for

Making and Curing Concrete Test Specimens in the Field

AASHTO Designation: T 23-08[1]
ASTM Designation: C 31-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Making and Curing Concrete Test Specimens in the Field

AASHTO Designation: T 23-08[1]
ASTM Designation: C 31-06

1. SCOPE

1.1. This method covers procedures for making and curing cylinder and beam specimens from representative samples of fresh concrete for a construction project.

1.2. The concrete used to make the molded specimens shall be sampled after all on-site adjustments have been made to the mixture proportions, including the addition of mix water and admixtures. This practice is not satisfactory for making specimens from concrete not having measurable slump or requiring other sizes or shapes of specimens.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to exposed skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 195, Lightweight Aggregates for Structural Concrete
- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 205M/M 205, Molds for Forming Concrete Test Cylinders Vertically
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
- T 197M/T 197, Time of Setting of Concrete Mixtures by Penetration Resistance
- T 231, Capping Cylindrical Concrete Specimens
- T 309M/T 309, Temperature of Freshly Mixed Hydraulic-Cement Concrete

2.2. *ASTM Standard*:

- C 125, Terminology Related to Concrete and Concrete Aggregates

2.3. *ACI Standard*:

- ACI 309R, *Guide for Consolidation of Concrete*

3. TERMINOLOGY

3.1. For definitions of terms used in this practice, refer to ASTM C 125.

4. SIGNIFICANCE AND USE

4.1. This method provides standardized requirements for making, curing, protecting, and transporting concrete test specimens under field conditions.

4.2. If the specimens are made and standard cured, as stipulated herein, the resulting strength test data where the specimens are tested are able to be used for the following purposes:

4.2.1. Acceptance testing for specified strength,

4.2.2. Checking the adequacy of mixture proportions for strength,

4.2.3. Quality control.

4.3. If the specimens are made and field cured, as stipulated herein, the resulting strength test data when the specimens are tested are able to be used for the following purposes:

4.3.1. Determination of whether a structure is capable of being put in service,

4.3.2. Comparison with test results of standard cured specimens or with test results from various in-place test methods,

4.3.3. Adequacy of curing and protection of concrete in the structure, or,

4.3.4. Form or shoring removal time requirements.

5. APPARATUS

5.1. *Molds, General*—Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall hold their dimensions and shape under conditions of use. Molds shall be watertight during use as judged by their ability to hold water poured into them. Provisions for tests of watertightness are given in M 205M/M 205. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive form release material before use.

5.2. *Cylinder*—Molds for casting concrete test specimens shall conform to the requirements of M 205M/M 205.

5.3. *Beam Molds*—Beam molds shall be of the shape and dimensions required to produce the specimens stipulated in Section 6.2. The inside surfaces of the molds shall be smooth. The sides, bottom, and ends shall be at right angles to each other and shall be straight and true and free of warpage. Maximum variation from the nominal cross section shall not exceed 3.2 mm ($^1/_8$ in.) for molds with depth or breadth of 152 mm (6 in.) or more. Molds shall produce specimens not more than 1.6 mm ($^1/_{16}$ in.) shorter than the required length in accordance with Section 5.2, but may exceed it by more than that amount.

5.4. *Tamping Rods*—Two sizes are specified as indicated in Table 1. Each shall be a round, straight steel rod with at least the tamping end rounded to a hemispherical tip of the same diameter as the rod. Both ends may be rounded if preferred.

Table 1—Tamping Rod Requirements

	Rod Dimensions[a]	
Diameter of Cylinder or Width of Beam, mm (in.)	Diameter, mm (in.)	Length of Rod, mm (in.)
<150 (6)	10 ($^3/_8$)	300 (12)
150 (6)	16 ($^5/_8$)	500 (20)
225 (9)	16 ($^5/_8$)	650 (26)

[a] Rod tolerances length ±100 mm (4 in.) and diameter ±2 mm ($^1/_{16}$ in.).

5.5. *Vibrators*—Internal vibrators shall be used. The vibrator frequency shall be at least 7000 vibrations per minute (150 Hz) while the vibrator is operating in the concrete. The diameter of a round vibrator shall be no more than one-fourth the diameter of the cylinder mold or one-fourth the width of the beam mold. Other shaped vibrators shall have a perimeter equivalent to the circumference of an appropriate round vibrator. The combined length of the vibrator shaft and vibrating element shall exceed the depth of the section being vibrated by at least 75 mm (3 in.). The vibrator frequency shall be checked periodically.

Note 1—For information on size and frequency of various vibrators and a method to periodically check vibrator frequency, see ACI 309R.

5.6. *Mallet*—A mallet with a rubber or rawhide head weighing 0.57 ± 0.23 kg (1.25 ± 0.50 lb) shall be used.

5.7. *Small Tools*—Tools and items that may be required are shovels, pails, trowels, wood float, metal float, blunted trowels, straightedge, feeler gauge, scoops, and rules.

5.8. *Slump Apparatus*—The apparatus for measurement of slump shall conform to the requirements of T 119M/T 119.

5.9. *Sampling and Mixing Receptacle*—The receptacle shall be a suitable heavy gauge metal pan, wheelbarrow, or flat, clean, nonabsorbent mixing board of sufficient capacity to allow easy remixing of the entire sample with a shovel or trowel.

5.10. *Air Content Apparatus*—The apparatus for measuring air content shall conform to the requirements of T 196M/T 196 or T 152.

5.11. *Temperature Measuring Devices*—The temperature measuring devices shall conform to the applicable requirements of T 309M/T 309.

6. TEST SPECIMENS

6.1. *Compressive Strength Specimens*—Compressive strength specimens shall be cylinders cast and allowed to set in an upright position. The length shall be twice the diameter. The cylinder diameter shall be at least three times the nominal maximum size of the coarse aggregate. When the nominal maximum size of the coarse aggregate exceeds 50 mm (2 in.), the concrete sample shall be treated by wet sieving through a 50-mm (2-in.) sieve as described in T 141. When the nominal maximum size of the coarse aggregate does not exceed 25.0 mm (1 in.), the specimens may be 100 by 200 mm (4 by 8 in.) cylinders.

Note 2—When molds in SI units are required and not available, equivalent inch–pound unit size molds should be permitted.

6.2. *Flexural Strength Specimens*—Flexural strength specimens shall be beams of concrete cast and hardened with long axes horizontal. The length shall be at least 50 mm (2 in.) greater than three times the depth as tested. The ratio of width to depth as molded shall not exceed 1.5. The standard beam shall be 152 by 152 mm (6 by 6 in.) in cross section, and shall be used for concrete with maximum size coarse aggregate up to 50 mm (2 in.) When the nominal maximum size of the coarse aggregate exceeds (50 mm) 2 in., the smaller cross-sectional dimension of the beam shall be at least three times the nominal maximum size of the coarse aggregate. Unless required by project specifications, beams made in the field shall not have a width or depth of less than 6 in.

7. SAMPLING CONCRETE

7.1. The samples used to fabricate test specimens under this standard shall be obtained in accordance with T 141 unless an alternative procedure has been approved.

7.2. Record the identification of the sample with respect to the location of the concrete represented and the time of casting.

8. SLUMP, AIR CONTENT, AND TEMPERATURE

8.1. *Slump*—Measure and record the slump of each batch of concrete, from which specimens are made, immediately after remixing in the receptacle as required in T 119.

8.2. *Air Content*—Determine and record the air content in accordance with either T 152 or T 196M/T 196. The concrete used in performing the air content test shall not be used in fabricating test specimens.

8.3. *Temperature*—Determine and record the temperature in accordance with T 309M/T 309.

Note 3—Some specifications may require the measurement of the unit weight of concrete. The volume of concrete produced per batch may be desired on some projects. Also, additional information on the air content measurements may be desired. Test Method T 121M/T 121 is used to measure the unit weight, yield, and gravimetric air content of freshly mixed concrete.

9. MOLDING SPECIMENS

9.1. *Place of Molding*—Mold specimens promptly on a level, rigid, horizontal surface, free from vibration and other disturbances, at a place as near as practicable to the location where they are to be stored.

9.2. *Casting the Concrete*—Place the concrete in the molds using a scoop, blunted trowel, or shovel. Select each scoopful, trowelful, or shovelful of concrete from the mixing pan to ensure that it is representative of the batch. Remix the concrete in the mixing pan with a shovel or trowel to prevent segregation during the molding of specimens. Move the scoop, trowel, or shovel around the perimeter of the mold opening when adding concrete so the concrete is uniformly distributed within each layer with a minimum of segregation. In placing the final layer, the operator shall attempt to add an amount of concrete that will exactly fill the mold after compaction. Underfilled molds shall be adjusted with representative concrete during consolidation of the top layer. Overfilled molds shall have excess concrete removed.

9.2.1. *Number of Layers*—Make specimens in layers as indicated in Tables 2 or 3.

Table 2—Molding Requirements by Rodding

Specimen Type and Size	Number of Layers of Approximately Equal Depth	Number of Roddings per Layer
Cylinders:		
Diameter, mm (in.)		
100 (4)	2	25
150 (6)	3	25
225 (9)	4	50
Beams:		
Width, mm (in.)		
150 (6) to 200 (8)	2	See Section 9.3.2
Over 200 (8)	3 or more equal depths, each not to exceed 150 mm (6 in.)	See Section 9.3.2

Table 3—Molding Requirements by Vibration

Specimen Type and Size	Number of Layers	Number of Vibrator Insertions per Layer	Approximate Depth of Layer, mm (in.)
Cylinders:			
Diameter, mm (in.)			
100 (4)	2	1	one-half depth of specimen
150 (6)	2	2	one-half depth of specimen
225 (9)	2	4	one-half depth of specimen
Beams:			
Width, mm (in.)			
150 (6) to 200 (8)	1	See Section 9.3.3.2	depth of specimen 200 (8) as near as practicable
over 200 (8)	2 or more	See Section 9.3.3.2	depth of specimen 200 (8) as near as practicable

9.2.2. Select the proper tamping rod from Section 5.4 and Table 1 or the proper vibrator from Section 5.5. If the method of consolidation is rodding, determine molding requirements from Table 2. If the method of consolidation is vibration, determine molding requirements from Table 3.

9.3. *Consolidation*:

9.3.1. *Methods of Consolidation*—Preparation of satisfactory specimens requires different methods of consolidation. The methods of consolidation are rodding and vibration. Base the selection of the method of consolidation on the slump, unless the method is stated in the specifications under which the work is being performed. Rod or vibrate concretes with slump greater than 25 mm (1 in.). Vibrate concretes with slump of less than or equal to 25 mm (1 in.). Concretes of such low water content that they cannot be properly consolidated by the methods described herein, or requiring other sizes and shapes of specimens to represent the product or structure, are not covered by this method. Specimens for such concretes shall be made in accordance with the requirements of R 39 with regard to specimen size and shape and method of consolidation.

9.3.2. *Rodding*—Place the concrete in the mold, in the required number of layers of approximately equal volume. Rod each layer with the rounded end of the rod using the number of roddings specified in Table 2. The number of roddings per layer required for beams is one for each 13 cm^2 (2 in.^2) top surface area of the specimen. Rod the bottom layer throughout its depth. Distribute the strokes uniformly over the cross section of the mold. For each layer, allow the rod to penetrate through the layer being rodded and into the layer below approximately 25 mm (1 in.). After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet, to close any holes left by rodding and to release any large air bubbles that may have been trapped. Use an open hand to tap light-gauge single-use molds that are susceptible to damage if tapped with a mallet. After tapping, spade each layer of the concrete along the sides and ends of beam molds with a trowel or other suitable tool.

9.3.3. *Vibration*—Maintain a uniform time period for duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually, sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth and large air bubbles cease to break through the top surface. Continue vibration only long enough to achieve proper consolidation of the concrete. (See Note 4.) Fill the molds and vibrate in the required number of approximately equal layers. Place all the concrete for each layer in the mold before starting vibration of that layer. Compacting the specimen, insert the vibrator slowly and do not allow it to rest on the bottom or sides of the mold. Slowly withdraw the vibrator so that no large air pockets are left in the specimen. When placing the final layer, avoid overfilling by more than 6 mm ($^1/_4$ in.).

Note 4—Generally, no more than 5 s of vibration should be required for each insertion to adequately consolidate concrete with a slump greater than 75 mm (3 in.). Longer times may be required for lower slump concrete, but the vibration time should rarely have to exceed 10 s per insertion.

9.3.3.1. *Cylinders*—The number of insertions of a vibrator per layer is given in Table 3. When more than one insertion per layer is required, distribute the insertion uniformly within each layer. Allow the vibration to penetrate through the layer being vibrated, and into the layer below, approximately 25 mm (1 in.). After each layer is vibrated, tap the outsides of the mold at least 10 times with the mallet, to close holes left by vibrating and to release entrapped air voids. Use an open hand to tap cardboard and single-use metal molds that are susceptible to damage if tapped with a mallet.

9.3.3.2. *Beam*—Insert the vibrator at intervals not exceeding 150 mm (6 in.) along the center line of the long dimension of the specimen. For specimens wider than 6 in., use alternating insertions along two lines. Allow the shaft of the vibrator to penetrate into the bottom layer approximately 25 mm (1 in.). After each layer is vibrated, tap the outsides of the mold sharply at least 10 times with the mallet, to close any holes left by vibrating and to release entrapped air voids.

9.4. *Finishing*—After consolidation, strike off excess concrete from the surface and float or trowel it as required. Perform all finishing with the minimum manipulation necessary to produce a flat even surface that is level with the rim or edge of the mold and that has no depressions or projections larger than 3.2 mm ($^1/_8$ in.).

9.4.1. *Cylinders*—After consolidation, finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits or with a wood float or trowel. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste that is permitted to harden and cure with the specimen. See section on Capping Materials of T 231.

9.4.2. *Beams*—After consolidation of the concrete, strike off the top surface to the required tolerance to produce a flat even surface. A wood float may be used.

9.5. *Initial Storage*—Immediately after being struck off, the specimens shall be moved to the storage place where they will remain undisturbed for the initial curing period. If specimens made in single-use mold are moved, lift and support the specimens from the bottom of the molds with a large trowel or similar device.

10. CURING

10.1. *Standard Curing*—Standard curing is the curing method used when the specimens are made and cured for the purposes stated in Section 4.2.

10.1.1. *Storage*—If specimens cannot be molded at the place where they will receive initial curing, immediately after finishing, move the specimens to an initial curing place for storage. The supporting surface on which specimens are stored shall be level to within 20 mm/m ($^1/_4$ in./ft). If cylinders in the single-use molds are moved, lift and support the cylinders from the bottom of the molds with a large trowel or similar device. If the top surface is marred during movement to place of initial storage, immediately refinish.

10.1.2. *Initial Curing*—Immediately after molding and finishing, the specimens shall be stored for a period up to 48 h in a temperature range from 16 to 27ºC (60 to 80ºF), and in an environment preventing moisture loss from the specimens. For concrete mixtures with a specified strength of 40 MPa (6000 psi) or greater, the initial curing temperature shall be between 20 and 26ºC (68 and 78ºF). Various procedures are capable of being used during the initial curing period to maintain the specified moisture and temperature conditions. An appropriate procedure or combination of procedures shall be used (Note 5). Shield all specimens from direct sunlight and, if used, radiant heating devices. The storage temperature shall be controlled by the use of heating and cooling devices, as necessary. Record the temperature using a maximum-minimum thermometer. If cardboard molds are used, protect the outside surface of the molds from contact with wet burlap or other sources of water.

Note 5—A satisfactory moisture environment can be created during the initial curing of the specimens by one or more of the following procedures: (1) immediately immerse molded specimens with plastic lids in water saturated with calcium hydroxide, (2) store in properly constructed wood boxes or structures, (3) place in damp sand pits, (4) cover with removable plastic lids, (5) place inside plastic bags, or (6) cover with plastic sheets or nonabsorbent plates if provisions are made to avoid drying and damp burlap is used inside the enclosure, but the burlap is prevented from contacting the concrete surfaces. A satisfactory temperature environment can be controlled during the initial curing of the specimens by one or more of the following procedures: (1) use of ventilation, (2) use of ice, (3) use of thermostatically controlled heating or cooling devices, or (4) use of heating methods such as stoves or light bulbs. Other suitable methods may be used if the requirements limiting specimen storage temperature and moisture loss are met. For concrete mixtures with a specified strength of 40 MPa (6000 psi) or greater, heat generated during the early ages may raise the temperature above the required storage temperature. When specimens are to be immersed in water saturated with calcium hydroxide, specimens in cardboard molds or other molds that expand when immersed in water should not be used. Early-age strength test results may be lower when stored at 16ºC (60ºF) and higher when stored at 27ºC (80ºF). On the other hand, at later ages, test results may be lower for higher initial storage temperatures.

10.1.3. *Final Curing*:

10.1.3.1. *Cylinders*—Upon completion of initial curing and within 30 minutes after removing the molds, cure specimens with free water maintained on their surfaces at all times at a temperature of 23 ± 2ºC (73 ± 3ºF) using water storage tanks or moist rooms complying with the requirements of Specification M 201, except when capping with sulfur mortar capping compound and immediately before testing. When capping with sulfur mortar capping compounds, the ends of the cylinder shall be dry enough to preclude the formation of steam or foam pockets under or in cap larger than 6 mm ($^1/_4$ in.) as described in T 231. For a period not to exceed 3 h immediately prior to test, standard curing temperature is not required provided free moisture is maintained on the cylinders and ambient temperature is between 20 to 30°C (68 to 80°F).

10.1.3.2. *Beams*—Beams are to be cured the same as cylinders (see Section 10.1.3.1), except that they shall be stored in water saturated with calcium hydroxide at 23 ± 2ºC (73 ± 3ºF) at least 20 hours prior to testing. Drying of the surfaces of the beam shall be prevented between removal from water storage and completion of testing (Note 6).

Note 6—Relatively small amounts of surface drying of flexural specimens can induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

10.2. *Field Curing*—Field curing is the curing method used for the specimens made for the purposes stated in Section 4.3.

10.2.1. *Cylinders*—Store cylinders in or on the structure as near to the point of deposit of the concrete represented as possible. Protect all surfaces of the cylinders from the elements in as near as possible the same way as the formed work. Provide the cylinders with the same temperature and moisture environment as the structural work. Test the specimens in the moisture condition resulting from the specified curing treatment. To meet these conditions, specimens made for the purpose of determining when a structure is capable of being put in service shall be removed from the molds at the time of removal of form work.

10.2.2. *Beams*—As nearly as practicable, cure beams in the same manner as the concrete in the structure. At the end of 48 ± 4 h after molding, take the molded specimens to the storage location and remove from the molds. Store specimens representing pavements of slabs on grade by placing them on the ground as molded, with their top surfaces up. Bank the sides and ends of the specimens with earth or sand that shall be kept damp, leaving the top surfaces exposed to the specified curing treatment. Store specimens representing structure concrete as near the point in the structure they represent as possible, and afford them the same temperature protection and moisture environment as the structure. At the end of the curing period, leave the specimens in place exposed to the weather in the same manner as the structure. Remove all beam specimens from field storage and store in water saturated with calcium hydroxide at 23 ± 2ºC (73 ± 3ºF) for 24 ± 4 h immediately before time of testing to ensure uniform moisture condition from specimen to specimen. Observe the precautions given in Section 10.1.3.2 to guard against drying between time of removal from curing to testing.

10.3. *Structural Lightweight Concrete Curing*—Cure structural lightweight concrete cylinders in accordance with M 195.

11. TRANSPORTATION OF SPECIMENS TO LABORATORY

11.1. Prior to transporting, cure and protect specimens as required in Section 10. Specimens shall not be transported until at least 8 hours after final set. (See Note 7.) During transporting, protect the specimen with suitable cushioning material to prevent damage from jarring. During cold weather, protect the specimens from freezing with suitable insulation material. Prevent moisture loss during transportation by wrapping the specimens in plastic, wet burlap, by surrounding them with wet sand or tight-fitting plastic caps on plastic molds. Transportation time shall not exceed 4 hours.

Note 7—Setting time may be measured by T 197M/T 197.

12. REPORT

12.1. *Report the following information to the laboratory that will test the specimens*:

12.1.1. Identification number;

12.1.2. Location of concrete represented by the samples;

12.1.3. Date, time, and name of individual molding specimens;

12.1.4. Slump, air content, and concrete temperature, test results and results of any other tests on the fresh concrete and any deviations from referenced standard test methods; and

12.1.5. *Curing Method*—For standard curing method, report the initial curing method with maximum and minimum temperatures and final curing method. For field curing method, report the location where stored, manner of protection from the elements, temperature, and moisture environment, and time of removal from molds.

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[1] T 23 conforms to ASTM C 31-06 except C 31 includes requirements for certification of field technicians.

Standard Method of Test for

Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

AASHTO Designation: T 24M/T 24-07
ASTM Designation: C 42/C 42M-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

AASHTO Designation: T 24M/T 24-07
ASTM Designation: C 42/C 42M-04

1. SCOPE

1.1. This method covers obtaining, preparing, and testing (1) cores drilled from concrete for length or compressive or splitting tensile strength determinations; and (2) beams sawed from concrete for flexural strength determinations.

1.2. The values stated in SI units or inch-pound units are to be regarded separately as the standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3. *This standard does not purport to address safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 97, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- T 140, Compressive Strength of Concrete Using Portions of Beams Broken in Flexure
- T 148, Measuring Length of Drilled Concrete Cores
- T 198, Splitting Tensile Strength of Cylindrical Concrete Specimens
- T 231, Capping Cylindrical Concrete Specimens

2.2. *ASTM Standard*:
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 823, Standard Practice for Examination and Sampling of Hardened Concrete in Constructions

2.3. *ACI Standard*:
- ACI 318, Building Code Requirements for Structural Concrete

3. SIGNIFICANCE AND USE

3.1. This test method provides standardized procedures for obtaining and testing specimens to determine the compressive, tensile, and flexural strength of in-place concrete. Sampling and sample preparation requirements are given to ensure that dimensional requirements are met and that the specimens are made of intact, sound concrete, and are as free of flaws as the particular structure will allow.

3.2. Generally, test specimens are obtained when doubt exists about the in-place concrete quality due to either too low strength test results during construction or signs of distress in the structure. Additionally, this method is used to provide strength information on older structures.

3.3. Concrete strength is affected by the location of the concrete in a structural element, with the concrete at the bottom tending to be stronger than the concrete at the top. Core strength is also affected by core orientation relative to the horizontal plane of the concrete as placed, with strength tending to be lower when measured parallel to the horizontal plane.[1] These factors shall be considered in planning the locations for obtaining concrete samples and in comparing strength test results.

3.4. The strength of concrete measured by tests of cores and beams is affected by the amount and distribution of moisture in the specimen at the time of test. There is no standard procedure to condition a specimen that will ensure that, at the time of test, it will be in the identical moisture condition as concrete in the structure. The moisture conditioning procedures in this test method are intended to provide reproducible moisture conditions that minimize within-laboratory and between-laboratory variations and to reduce the effects of moisture introduced during specimen preparation.

3.5. There is no universal relationship between the compressive strength of a core and the corresponding compressive strength of standard-cured molded cylinders. The relationship is affected by many factors, such as the strength level of the concrete, the in-place temperature and moisture history, and the strength gain characteristics of the concrete. Historically, it has been assumed that core strengths are generally 85 percent of the corresponding standard-cured cylinder strengths, but this is not applicable to all situations. The acceptance criteria for core strength is to be established by the specifying authority.

4. APPARATUS

4.1. *Core Drill*—For obtaining cylindrical core specimens, a diamond drill shall be used.

4.2. *Saw*—For cutting beam specimens to size for flexural strength tests and to trim ends of cores. The saw shall have a diamond or silicon-carbide cutting edge and shall be capable of cutting specimens, which conform to the prescribed dimensions, without excessive heating or shock.

5. SAMPLING

5.1. *General*:

5.1.1. Samples of hardened concrete for use in the preparation of strength test specimens shall not be taken until the concrete has become hard enough to permit sample removal without disturbing the bond between the mortar and the coarse aggregate (see Note 1 and Note 2). When preparing strength test specimens from samples of hardened concrete, samples that show abnormal defects or samples that have been damaged in the process of removal shall not be used unless the area with defects or damaged portions are removed and resulting test specimen is of suitable length.

Note 1—ASTM C 823 provides guidance on the development of a sampling plan for concrete in constructions.

Note 2—It is not possible to specify a minimum age when concrete is strong enough to withstand damage during removal, because the strength at any age depends on the curing history and strength grade of the concrete. If time permits, the concrete should not be removed before it is 14 days old. If this is not practical, removal of concrete can proceed if the cut surfaces do not display erosion of the mortar and the exposed coarse aggregate particles are embedded firmly in the mortar. In-place test methods may be used to estimate the level of strength development prior to attempting removal of concrete samples.

5.1.2. Specimens containing embedded reinforcement shall not be used for determining compressive, splitting tensile strength or flexural strength.

5.2. *Core Drilling*—A core specimen taken perpendicular to a horizontal surface shall be located, when possible, so that its axis is perpendicular to the bed of the concrete as originally placed and not near formed joints or obvious edges of a unit of deposit. A specimen taken perpendicular to a vertical surface, or perpendicular to a surface with a batter, shall be taken from near the middle of a unit of deposit when possible and not near formed joints or obvious edges of a unit of deposit.

5.3. *Slab Removal*—Remove a slab sufficiently large to secure the desired test specimens without the inclusion of any concrete that has been cracked, spalled, undercut, or otherwise damaged.

DRILLED CORES

6. LENGTH OF DRILLED CORE SPECIMENS

6.1. *Minimum Diameter*—A core specimen for the determination of length shall have a diameter of at least 95 mm [3.75 in.] or as specified by the specifying authority.

6.2. Measure the length of cores for determining the thickness of pavements, slabs, walls, or other structural elements in accordance with the provisions of T 148.

6.3. For cores that are not intended for determining structural dimensions, measure the longest and shortest lengths on the cut surface along lines parallel to the core axis. Record the average length to the nearest 5 mm [$^1/_4$ in.].

7. CORES FOR COMPRESSIVE STRENGTH

7.1. *Test Specimens*—The nominal diameter of core specimens for the determination of compressive strength shall be at least 95 mm [3.75 in.]. Core diameters less than 95 mm [3.75 in.] are permitted when it is impossible to obtain cores with length-to-diameter (L/D) ratio ≥ 1 for compressive strength evaluations in cases other than load bearing situations. For concrete with nominal maximum aggregate size greater than 37.5 mm [$1^1/_2$ in.], the nominal diameter should preferably be at least three times the nominal maximum size of the coarse aggregate and must be at least twice the nominal maximum size of the coarse aggregate. The preferred length of the capped or ground specimen is between 1.9 and 2.1 times the diameter. If the ratio of the length to the diameter of the core exceeds 2.1, reduce the length of the specimen so that the ratio is between 2.1 and 1.9. Core specimens with length-to-diameter ratios less than 1.75 require corrections to the measured compressive strength (see Section 7.7.1). A core having a maximum length of less than 95 percent of its diameter before capping or a length less than its diameter after capping shall not be tested.

Note 3—The compressive strengths of nominal 50 mm [2-in.] diameter cores are known to be somewhat lower and more variable than those of nominal 100 mm [4-in.] diameter cores. In addition, small diameter cores appear to be more sensitive to the effect of the length-to-diameter ratio.[2]

7.2. *End Preparation*—The ends of core specimens to be tested in compression shall be essentially smooth, perpendicular to the longitudinal axis, and of the same diameter as the body of the specimen in accordance with T 22. If necessary, saw or tool the ends of the specimens prior to capping until the following requirements are met:

7.2.1. Projections, if any, shall not extend more than 5 mm [0.2 in.] above the end surfaces.

7.2.2. The end surfaces shall not depart from perpendicularity to the longitudinal axis by a slope of more than 1: 0.3d or [1: 8d] where d is the average core diameter in mm or [inches].

7.2.3. The diameter of the ends shall not depart more than 2 mm [0.1 in.] from the mean diameter of the specimen.

7.3. *Moisture Conditioning*—Test cores after moisture conditioning as specified in this test method or as directed by the specifying authority. The moisture conditioning procedures specified in this test method are intended to preserve the moisture of the drilled core and to provide a reproducible moisture condition that minimizes the effects of moisture gradients introduced by wetting during drilling and specimen preparation.

7.3.1. After cores have been drilled, wipe off surface drill water and allow remaining surface moisture to evaporate. When surfaces appear dry, but not later than 1 h after drilling, place cores in separate plastic bags or nonabsorbent containers and seal to prevent moisture loss. Maintain cores at ambient temperature, and protect cores from exposure to direct sunlight. Transport the cores to the testing laboratory as soon as practicable. Keep cores in the sealed plastic bags or nonabsorbent containers at all times except during end preparation and for a maximum time of 2 hours to permit capping before testing.

7.3.2. If water is used during sawing or grinding of core ends, complete these operations as soon as practicable, but no later than 2 days after drilling of cores unless stipulated otherwise by the specifier of tests. After completing end preparation, wipe off surface moisture, allow the surfaces to dry, and place the cores in sealed plastic bags or nonabsorbent containers. Minimize the duration of exposure to water during end preparation.

7.3.3. Allow the cores to remain in the sealed plastic bags or nonabsorbent containers for at least 5 days after last being wetted before testing, unless stipulated otherwise by the specifier of tests.

Note 4—The waiting period of at least 5 days is intended to reduce moisture gradients introduced when the core is drilled or wetted during sawing or grinding.

7.3.4. When direction is given to test cores in a moisture condition other than achieved by conditioning according to Sections 7.3.1, 7.3.2, and 7.3.3, report the alternative procedure.

7.4. *Capping*—Before making the compression test, saw or grind the ends of the specimens in accordance with the tolerance requirements of T 22 or cap the ends of the specimens in conformance with the procedure prescribed in the applicable section of T 231. The capped surfaces of the specimens shall conform to the planeness requirements of T 231.

Note 5—Prior to capping, the density of a core may be determined by weighing it and dividing it by the volume calculated from the average diameter and length, or by any other standard method for determining density.

7.5. *Measurement*—Prior to testing, measure the length of the capped or ground specimen to the nearest 2 mm [0.1 in.] and use this length to compute the length-diameter ratio. Determine the average diameter by averaging two measurements taken at right angles to each other about the mid-height of the specimen. Measure core diameters to the nearest 0.2 mm [0.01 in.] when the difference in core diameters does not exceed 2 percent of their average, otherwise measure to the nearest 2 mm [0.1 in.]. Do not test cores if differences between the largest and smallest diameter exceed 5 percent of their average.

7.6. *Testing*—Test the specimens in accordance with the applicable provision of T 22. Test the specimens within 7 days after coring, unless specified otherwise.

7.7. *Calculations*—Calculate the compressive strength of each specimen using the computed cross-sectional area based on the average diameter of the specimen.

7.7.1. If the ratio of the length to diameter of the specimen is 1.75 or less, correct the result obtained in Section 7.7 by multiplying by the appropriate correction factor shown in the following table (see Note 6):

Ratio of Length of Cylinder to Diameter, 1/*D*	Strength Correction Factor
1.75	0.98
1.50	0.96
1.25	0.93
1.00	0.87

Use interpolation to determine correction factors for *L*/*D* values not given in the table.

Note 6—Correction factors depend on various conditions, such as moisture condition, strength level, and elastic modulus. Average values are given in Table 1. These correction factors apply to lightweight concrete weighing between 1600 and 1920 kg/m^3 [100 and 120 lb/ft^3] and normal weight concrete. They are applicable to both dry and wet concrete for strengths between 14 to 42 MPa [2000 and 6000 psi]. For strengths above 70 MPa [10000 psi], test data on cores show that the correction factors may be larger than the values listed above. Thus, these factors should be applied to high-strength concrete with caution.

7.8. *Report the results as required by T 22 with the addition of the following information*:

7.8.1. Length of core as drilled to the nearest 5 mm [0.2 in.];

7.8.2. Length of test specimen before and after capping or end grinding to the nearest 2 mm [0.1 in.], and average diameter of core to the nearest 0.2 mm [0. 01 in.] or 2 mm [0.1 in];

7.8.3. Compressive strength to the nearest 0.1MPa [10 psi] when the diameter is measured to the nearest 0.2 mm [0.01 in.], and to the nearest 0.5 MPa [50 psi] when the diameter is measured to the nearest 2 mm [0.1 in.], after correction for length-diameter ratio when required;

7.8.4. Direction of application of the load on the specimen with respect to the horizontal plane of the concrete as placed;

7.8.5. The moisture conditioning history:

7.8.5.1. The date and the time core was obtained and first placed in sealed bag or nonabsorbent container;

7.8.5.2. If water was used during end preparation, the date and time end preparation was completed and the core placed in sealed bag or nonabsorbent container;

7.8.6. The date and time when tested;

7.8.7. If determined, the density;

7.8.8. If applicable, description of defects in cores that could not be tested; and

7.8.9. If any deviation from this test method was required, describe the deviation and explain why it was necessary.

7.9. *Precision*:

7.9.1. The single-operator coefficient of variation on cores has been found to be 3.2 percent[3] for a range of compressive strength between 32.0 MPa [4500 psi] and 48.3 MPa [7000 psi]. Therefore, results of two properly conducted tests of single cores by the same operator on the same sample of material should not differ from each other by more than 9 percent[3] of their average.

7.9.2. The multilaboratory coefficient of variation on cores has been found to be 4.7 percent[3] for range of compressive strength between 32.0 MPa [4500 psi] and 48.3 MPa [7000 psi]. Therefore results on two properly conducted tests on cores sampled from the same hardened concrete (where a single test is defined as the average of two observations (cores), each made on separate adjacent drilled 100-mm [4-in.] diameter cores), and tested by two different laboratories should not differ from each other by more than 13 percent[3] of their average.

7.10. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

8. SPLITTING TENSILE STRENGTH

8.1. *Test Specimens*—The specimens shall conform to the dimensional requirements in Sections 7.1, 7.2.1, and 7.2.2. Ends are not to be capped.

8.2. *Moisture Conditioning*—Prior to testing, the specimens shall be conditioned as described in Section 7.3.

8.3. *Bearing Surfaces*—The line of contact between the specimen and each bearing strip shall be straight and free of any projections or depressions higher or deeper than 0.2 mm [0.01 in.]. When the line of contact is not straight or contains projections or depressions having heights or depths greater than 0.2 mm [0.01 in.], grind or cap the specimen so as to produce bearing lines meeting these requirements. Do not use specimens with projections or depressions greater than 2 mm [0.1 in.]. When capping is employed, the caps shall be as thin as practicable and shall be formed of high-strength gypsum plaster.

Note 7—Figure 1 illustrates a device suitable for applying caps to the bearing surfaces of core specimens.

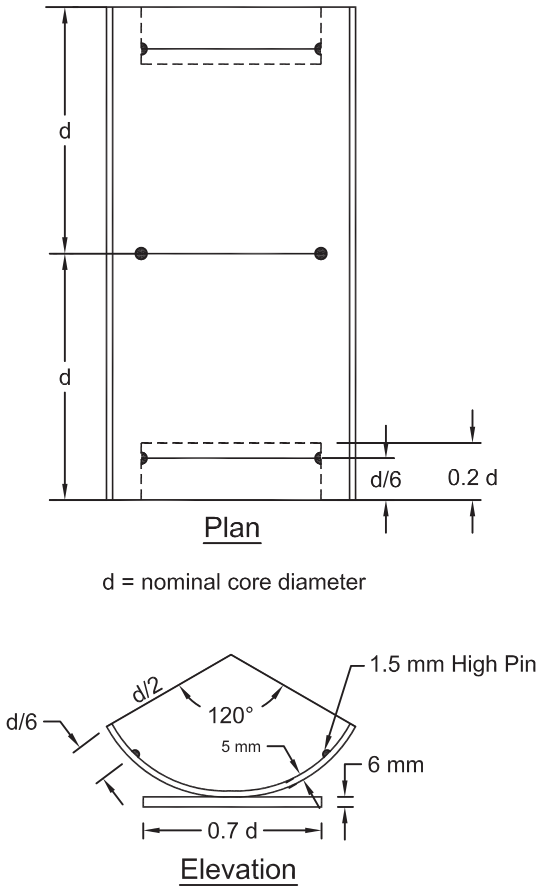

Figure 1—Suitable Capping Device for Splitting Tensile Strength Test

8.4. *Testing*—Test specimens in accordance with the applicable provisions of T 198.

8.5. *Calculation and Report*—Calculate the splitting tensile strength and report the results as required in T 198. When grinding or capping of the bearing surfaces is required, the diameter shall be measured between the finished surfaces. Indicate that the specimen was a core and state its moisture condition at the time of testing.

8.6. *Precision*:

8.6.1. The within laboratory single operator coefficient of variation for splitting tensile strength between 3.6 MPa [520 psi] and 4.1 MPa [590 psi] of cores has been found to be 5.3 percent. Therefore, results of two properly conducted tests by the same operator in the same laboratory on the same sample of material should not differ by more than 14.9 percent of their average.

8.6.2. The multilaboratory coefficient of variation for splitting tensile strength between 3.6 MPa [520 psi] and 4.1 MPa [590 psi] of cores has been found to be 15 percent. Therefore, results of two properly conducted tests on the same sample of material of hardened concrete and tested by two different laboratories should not differ from each other by more than 42.3 percent of their average.

8.7. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

SAWED BEAMS

9. FLEXURAL STRENGTH

9.1. *Test Specimens*—A beam specimen for the determination of flexural strength shall in general have a cross section of 150 × 150 mm [6 × 6 in.] (see Note 8). The specimen shall be at least 530 mm [21 in.] in length, but when two tests for flexural strength are to be made on one beam specimen, it shall be at least 840 mm [33 in.] in length. Perform the sawing operation so that the concrete will not be weakened by shock or by heating. The sawed surfaces shall be smooth, plane, parallel, and free from steps, ridges, and grooves. Take care in handling sawed beam specimens to avoid chipping or cracking.

Note 8—In many cases, particularly with prisms cut from pavement slabs, the width will be governed by the size of the coarse aggregate and the depth by the thickness of the slab.

9.2. *Moisture Conditioning*—Protect the surfaces of sawed specimens from evaporation by covering them with wet burlap and plastic sheeting during transportation and storage. Test the specimens within 7 days of sawing. Submerge the test specimens in lime-saturated water at 23.0 ± 2.0ºC [73.5 ± 3.5ºF] for at least 40 hours immediately prior to the flexure test. Test the specimens promptly after removal from water storage. During the period between removal from water storage and testing, keep the specimens moist by covering with a wet blanket of burlap or other suitable absorbent fabric.

9.2.1. When the specifying authority for the project so directs, beams shall be tested in a moisture condition other than that achieved by conditioning in accordance with Section 9.2. Relatively small amounts of drying of the surface of flexural specimens induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9.3. *Testing*—Test the specimens in accordance with the applicable provisions of T 97.

Note 9—The compressive strengths of portions of beams broken in flexure may be determined by testing such portions as modified cubes in accordance with T 140 (Modified Cube Method).

Note 10—Sawing may greatly reduce the indicated flexural strength; beams shall, therefore, be tested with a molded surface in tension whenever possible. The location of the tension face with respect to the position of the concrete as placed and the position of the sawed surfaces should be reported.

9.4. *Report*—Report the results in accordance with the applicable provisions of T 97 and the requirements of this method, including the moisture condition at the time of testing. Identify orientation of the specimen's finished, sawed, and tension faces with respect to their positions in the test apparatus.

10. PRECISION AND BIAS

10.1. *Precision*—Data are not available for preparing a statement on the precision of flexural strength measured on sawed beams.

Note 11—Users of this method who have replicate test data that may be appropriate for a statement on repeatability are encouraged to contact the chairman of the technical section.

10.2. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

11. KEYWORDS

11.1. Compressive strength; concrete; concrete coring; concrete sawing; flexural strength; splitting tensile strength.

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[1] Neville, A. Core Tests: Easy to Perform, Not Easy to Interpret. *Concrete International*, Vol. 23, No. 11, November 2001, *pp*. 59–68.

[2] Bartlett, F. M. and J. G. MacGregor. Effect of Core Diameter on Concrete Strengths. *ACI Journal*, Vol. 91, No. 5, September–October 1994, *pp*. 460–470.

[3] These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670.

Standard Method of Test for

Quality of Water to Be Used in Concrete

AASHTO Designation: T 26-79 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Quality of Water to Be Used in Concrete

AASHTO Designation: T 26-79 (2008)

1. SCOPE

1.1 This specification covers determination of the acidity or alkalinity in water to be used in concrete.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 107, Autoclave Expansion of Hydraulic Cement
- T 131, Time of Setting of Hydraulic Cement by Vicat Needle
- T 154, Time of Setting of Hydraulic Cement by Gillmore Needles

2.2 *ASTM Standards*:

- D 512, Chloride Ion in Water
- D 516, Sulfate Ion in Water

2.3 *Other Documents*:

- *Industrial and Engineering Chemistry*, Vol. V, No. 5, p. 336
- *Scott's Standard Methods of Chemical Analysis, Sixth Edition* (1963), Vol. II, p. 2388

3. ACIDITY AND ALKALINITY

3.1 The acidity or alkalinity shall be determined by one of the following methods, A or B. If extreme accuracy is desired, the method under "B" should be used.

3.1.1 *Method A*: The acidity or alkalinity shall be determined with standard solutions of one-tenth normal alkali or acid, respectively, using not less than 200 mL of the water under examination. Phenolphthalein or methyl orange should be used as an indicator. Excessive acidity or alkalinity indicates the necessity for further tests.

3.1.2 *Method B*:

3.1.2.1 The hydrogen ion concentration shall be determined either by electrometric or colorimetric method in conjunction with the necessary indicator, and shall be expressed in pH units ($\text{pH} = \log {}^{1}/_{H}+$). When the pH of the water is less than pH 4.5 or more than pH 8.5, further tests should be made. (The pH value of the solution is the logarithm of the reciprocal of the hydrogen ion concentration (H^+) in moles per liter. For example, a solution of 4.5 pH has a hydrogen ion concentration of $10^{-4.5}$).

3.1.2.2 The procedure for securing pH values shall be regulated entirely by the method used; that is, either by electrometric or colorimetric methods. The procedure to be followed in making the determinations shall be based on the type of apparatus used and in accordance with the methods and instruction furnished by the manufacturer for the particular type of apparatus in use. The apparatus used, either colorimetric or electrometric, shall have a working range suitable for the test being performed.

3.2 *Chloride Ion Concentration*—The chloride ion concentration shall be determined by ASTM D 512.

4. REFEREE METHOD B

4.1 *Sulfate Ion Concentration*—The sulfate ion concentration shall be determined by ASTM D 516, Referee method (gravimetric).

5. TOTAL SOLIDS AND INORGANIC MATTER

5.1 Evaporate 500 mL of the water to dryness in a dish. For this purpose a platinum dish of 100 to 200 mL capacity is found most convenient. The dish shall be nearly filled with water and placed on a water bath, additional portions of the sample of water being added from time-to-time until 500 mL have been used. The contents of the dish shall be evaporated to dryness, then placed in an oven at 132ºC (270ºF) and baked for one hour. The dish and contents shall then be cooled in a desiccator and the mass determined. The mass of the residue in grams divided by five is the percentage of total solids in the water.

5.2 The total solids obtained as described may consist of organic matter, or inorganic matter, or of combinations of organic and inorganic matter. The platinum dish shall be ignited at low red heat, and the darkening of the residue during the early stage of the ignition usually indicates the presence of organic matter. The percentage loss on ignition at low red heat will usually be an indicator of the amount of organic matter, but it should be noted that some mineral salts tend to volatilize or partly decompose on heating.

5.3 The determination of the composition of the mineral matter in the water requires a complete chemical analysis and is not generally undertaken except when the percentage of total solids is large, or the water appears to give abnormal tests in other respects. When the mineral analysis is desired, the procedure starting on page 2388 of *Scott's Standard Methods of Chemical Analysis* should be used. The results should be reported as the separate constituents in parts per million. If the hypothetical combination into salts is desired, the method given by Scott, or the method given on page 336 of *Industrial and Engineering Chemistry* should be used.

5.4 A comparison of the given water with distilled water can be obtained in accordance with T 107, T 131, or T 154 and T 106M/T 106 tests, using the same cement of standard quality with each water. (Suggested limits for the last named tests are as follows: Any indication of unsoundness, marked change in time-of-setting, or a reduction of more than 10 percent in strength from results obtained with mixtures containing the water of satisfactory quality shall be sufficient cause for rejection of the water under test).

Standard Method of Test for

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

AASHTO Designation: T 97-10
ASTM Designation: C 78-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

AASHTO Designation: T 97-10
ASTM Designation: C 78-08

1. SCOPE

1.1 This test method covers determination of the flexural strength of concrete by the use of a simple beam with third-point loading.

1.2 The values stated in SI units are to be regarded as the standard.

Note 1—For methods of molding concrete specimens, see T 23 and R 39.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 231, Capping Cylindrical Concrete Specimens

2.2 *ASTM Standards*:

- C 31/C 31M, Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 42/C 42M, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- C 192/C 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C 617, Standard Practice for Capping Cylindrical Concrete Specimens
- C 1077, Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
- E 4, Standard Practices for Force Verification of Testing Machines

3. SIGNIFICANCE AND USE

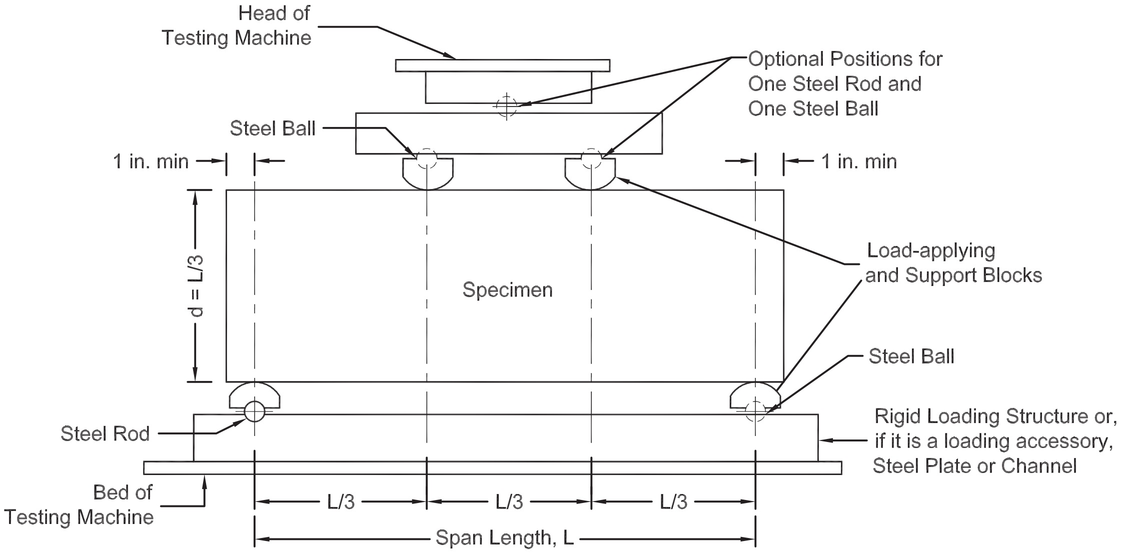
3.1 This test method is used to determine the flexural strength of specimens prepared and cured in accordance with T 23, T 24M/T 24, or R 39. Results are calculated and reported as the modulus of rupture. The strength determined will vary where there are differences in specimen size, preparation, moisture condition, curing, or where the beam has been molded or sawed to size.

3.2 The result of this test method may be used to determine compliance with specifications or as a basis for proportioning, mixing, and placement operations. It is used in testing concrete for construction of slabs and pavements.

4. APPARATUS

4.1 The testing machine shall conform to the requirements of sections on Basis of Verifications, Corrections, and Time Interval Between Verification of ASTM E 4. Hand-operated testing machines having pumps that do not provide a continuous loading in one stroke are not permitted. Motorized pumps or hand-operated positive displacement pumps having sufficient volume in one continuous stroke to complete a test without requiring replenishment are permitted and shall be capable of applying loads at a uniform rate without shock or interruption.

4.2 *Loading Apparatus*—The third-point loading method shall be used in making flexure tests of concrete employing bearing blocks, which will ensure that forces applied to the beam will be perpendicular to the face of the specimen and applied without eccentricity. A diagram of an apparatus that accomplishes this purpose is shown in Figure 1.



Notes: 1. in. = 25.4 mm

2. This apparatus may be used inverted. If the Testing Machine applies force through a spherically seated head, the center pivot may be omitted, provided one-load applying block pivots on a rod and the other on a ball.

Figure 1—Diagrammatic View of a Suitable Apparatus for Flexure Test of Concrete by Third-Point Loading Method

4.2.1 All apparatus for making flexure tests of concrete should be capable of maintaining the specified span length and distances between load-applying blocks and support blocks constant within ±1.3 mm (±0.05 in.).

4.2.2 The ratio of the horizontal distance between the point of application of the load and the point of application of the nearest reaction to the depth of the beam shall be 1.0 ±0.03.

4.2.3 If an apparatus similar to that illustrated in Figure 1 is used:

(a) The load-applying and support blocks should not be more than 64 mm ($2^1/_2$ in.) high, measured from the center or the axis of pivot, and should extend entirely across or beyond the full width of the specimen. Each case-hardened bearing surface in contact with the specimen shall not depart from a plane by more than 0.05 mm (0.002 in.) and should be a portion of a cylinder, the axis of which is coincidental with either the axis of the rod or center of the ball, whichever the block is pivoted upon. The angle subtended by the curved surface of each block should be at least 45 degrees (0.79 rad).

(b) The load-applying and support blocks should be maintained in a vertical position and in contact with the rod or ball by means of spring-loaded screws that hold them in contact with the pivot rod or ball.

(c) The uppermost bearing plate and centerpoint ball in Figure 1 may be omitted when a spherically seated bearing block is used, provided one rod and one ball are used as pivots for the upper load-applying blocks.

5. TESTING

5.1 The test specimen shall conform to all requirements of T 23, T 24M/T 24, and R 39. The specimen shall have a test span within 2 percent of being three times its depth as tested. The sides of the specimen shall be at right angles with the top and bottom. All surfaces shall be smooth and free of scars, indentations, holes, or inscribed identification marks.

6. PROCEDURE

6.1 Flexural tests of moist-cured specimens shall be made as soon as practical after removal from moist storage. Surface drying of the specimen results in a reduction in the measured flexural strength.

6.2 When using molded specimens, turn the test specimen on its side with respect to its position as molded and center it on the support blocks. When using sawed specimens, position the specimen so the tension face corresponds to the top or bottom of the specimen as cut from the parent material. Center the loading system in relation to the applied force. Bring the load-applying blocks in contact with the surface of the specimen at the third points and apply a load of between 3 and 6 percent of the estimated ultimate load. Using 0.10-mm (0.004-in.) and 0.38-mm (0.015-in.) leaf-type feeler gauges, determine whether any gap between the specimen and the load-applying or support blocks is greater or lesser than each of the gauges over a length of 25 mm (1 in.) or more. Grind, cap, or use leather shims on the specimen contact surface to eliminate any gap in excess of 0.10 mm (0.004 in.) in width. Leather shims shall be of uniform 6.4 mm (0.25 in.) thickness, 25 to 50 mm (1 to 2 in.) width, and shall extend across the full width of the specimen. Gaps in excess of 0.38 mm (0.015 in.) shall be eliminated only by capping or grinding. Grinding of lateral surfaces should be minimized in as much as grinding may change the physical characteristics of the specimens. Capping shall be in accordance with T 231.

6.3 Load the specimen continuously and without shock. The load shall be applied at a constant rate to the breaking point. Apply a load at a rate that constantly increases the maximum stress on the tension face between 0.9 and 1.2 MPa/min (125 and 175 psi), until rupture occurs. The loading rate is calculated using the following equation:

$$r = Sbd^2/L \qquad (1)$$

where:

r = loading rate, MN/min (lb/min);

S = rate of increase in extreme fiber stress, MPa/min (psi/min);

b = average width of specimen mm (in.);

d = average depth of specimen mm (in.); and

L = span length, mm (in.).

7. MEASUREMENT OF SPECIMENS AFTER TEST

7.1 To determine the dimensions of the specimen cross section for use in calculating modulus of rupture, take measurements across one of the fractured faces after testing. The width and depth are measured with the specimen as oriented for testing. For each dimension, take one measurement at each edge and one at the center of the cross section. Use the three measurements for each direction to determine the average width and the average depth. Take all measurements to the nearest 1.3 mm (0.05 in.). If the fracture occurs at a capped section, include the cap thickness in the measurement.

8. CALCULATIONS

8.1 If the fracture initiates in the tension surface within the middle third of the span length, calculate the modulus of rupture as follows:

$$R = Pl/bd^2 \tag{2}$$

where:

R = modulus of rupture, kPa (psi);

P = maximum applied load indicated by the testing machine, N (lbf);

l = span length, mm (in.);

b = average width of specimen mm (in.); and

d = average depth of specimen mm (in.).

Note 2—The weight of the beam is not included in the above calculation.

8.2 If the fracture occurs in the tension surface outside of the middle third of the span length by not more than 5 percent of the span length, calculate the modulus of rupture as follows:

$$R = 3Pa/bd^2 \tag{3}$$

where:

a = average distance between line of fracture and the nearest support measured on the tension surface of the beam, mm (in.).

See Note 2.

8.3 If the fracture occurs in the tension surface outside of the middle third of the span length by more than 5 percent of the span length, discard the results of the test.

9. REPORT

9.1 *The report shall include the following*:

9.1.1 Identification number;

9.1.2 Average width to the nearest 1 mm (0.05 in.);

9.1.3 Average depth to the nearest 1 mm (0.05 in.);

9.1.4 Span length in millimeters (inches);

9.1.5 Maximum applied load in newtons (pounds-force);

9.1.6 Modulus of rupture calculated to the nearest 0.05 MPa (5 psi);

9.1.7 Curing history and apparent moisture condition of the specimens at the time of test;

9.1.8 If specimens were capped, ground, or if leather shims were used;

9.1.9 If specimens were sawed or molded and any defects in the specimens; and

9.1.10 Age of specimens.

10. PRECISION AND BIAS

10.1 *Precision*—The coefficient of variation of test results has been observed to be dependent on the strength level of the beams. The single operator coefficient of variation has been found to be 5.7 percent. Therefore, results of two properly conducted tests by the same operator on beams made from the same batch sample should not differ from each other by more than 16 percent. The multilaboratory coefficient of variation has been found to be 7.0 percent. Therefore, results of two different laboratories on beams made from the same batch sample should not differ from each other by more than 19 percent.

10.2 *Bias*—Since there is no accepted standard for determining bias in this test method, no statement on bias is made.

Standard Method of Test for

Slump of Hydraulic Cement Concrete

AASHTO Designation: T 119M/T 119-10
ASTM Designation: C 143/C 143M-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Slump of Hydraulic Cement Concrete

AASHTO Designation: T 119M/T 119-10
ASTM Designation: C 143-03/C 143M-08

1. SCOPE

1.1. This test method covers determination of slump of concrete, both in the laboratory and in the field.

1.2. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3. The text of the standard reference notes and footnotes provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.4. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*
Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 141, Sampling Freshly Mixed Concrete

3. SUMMARY OF TEST METHOD

3.1. A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete.

4. SIGNIFICANCE AND USE

4.1. This test method is intended to provide the user with a procedure to determine the slump of plastic hydraulic cement concretes.

Note 1—This test method was originally developed to provide a technique to monitor the consistency of unhardened concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is not clearly and consistently shown. Care should therefore be taken in relating slump results obtained under field conditions to strength.

4.2. This test method is considered applicable to plastic concrete having coarse aggregate up to 37.5 mm [1.5 in.]. If the coarse aggregate is larger than 37.5 mm [1.5 in.] in size, the test method is applicable when it is performed on the fraction of concrete passing a 37.5-mm [1.5-in.] sieve, with the larger aggregate being removed in accordance with the section titled "Additional Procedures for Large Maximum Size Aggregate Concrete" in T 141.

4.3. This test method is not considered applicable to non-plastic and non-cohesive concrete.

Note 2—Concretes having slumps less than 15 mm [0.5 in.], may not be adequately plastic and concretes having slumps greater than about 230 mm [9 in.] may not be adequately cohesive for this test to have significance. Caution should be exercised in interpreting such results.

5. APPARATUS

5.1. *Mold*—The test specimen shall be formed in a mold made of metal not readily attacked by the cement paste. The metal shall not be thinner than 1.5 mm [0.060 in.] and if formed by the spinning process, there shall be no point on the mold at which the thickness is less than 1.15 mm [0.045 in.]. The mold shall be in the form of the lateral surface of the frustum of a cone with the base 203 mm [8 in.] in diameter, the top 102 mm [4 in.] in diameter, and the height 305 mm [12 in.]. Individual diameters and heights shall be within ±3.2 mm [0.125 in.] of the prescribed dimensions. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles similar to those shown in Figure 1. The mold shall be constructed without a seam. The interior of the mold shall be relatively smooth and free from projections. The mold shall be free from projections. A mold that clamps to a nonabsorbent base plate is acceptable instead of the one illustrated, provided the clamping arrangement is such that it can be fully released without movement of the mold and the base is large enough to contain all of the slumped concrete in an acceptable test.

5.1.1. Check and record conformance to the mold's specified dimensions when it is purchased or first placed in service and at least annually thereafter.

5.1.2. *Mold with Alternative Materials*:

5.1.2.1. Molds other than metal are permitted if the following requirements are met: The mold shall meet the shape, height, and internal dimensional requirements of Section 5.1. The mold shall be sufficiently rigid to maintain the specified dimensions and tolerances during use, resistant to impact forces, and shall be nonabsorbent. The mold shall be demonstrated to provide test results comparable to those obtained when using a metal mold meeting the requirements of Section 5.1. Comparability shall be demonstrated on behalf of the manufacturer by an independent testing laboratory. Test for comparability shall consist of not less than 10 consecutive pairs of comparisons performed at each of three different slumps ranging from 50 to 200 mm [2 to 8 in.]. No individual test results shall vary by more than 15 mm [0.50 in.] from that obtained using the metal mold. The average test results of each slump range obtained using the mold constructed of alternative material shall not vary by more than 6 mm [0.25 in.] from the average of test results obtained using the metal mold. Manufacturer comparability test data shall be available to users and laboratory inspection authorities (see Note 4). If any changes in material or method of manufacture are made, tests for comparability shall be repeated.

Note 3—The phrase "consecutive pairs of comparisons" does not mean without interruption or all in 1 day. At a schedule selected by the testing entity, the pairs of tests leading to 10 consecutive pairs may be accomplished in small groups. The word consecutive prevents ignoring pairs of tests that may not meet criteria.

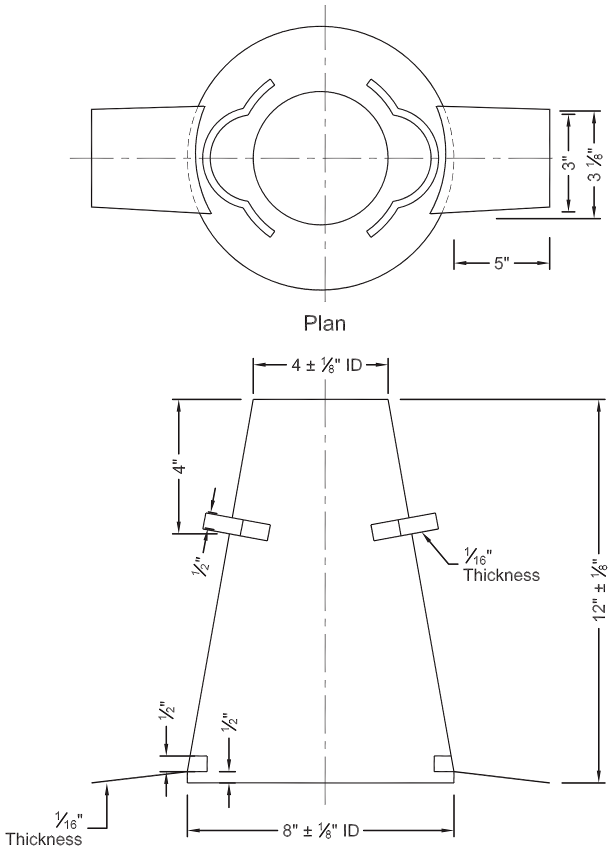
Note 4—Because the slump of concrete decreases with time and higher temperatures, it will be advantageous for the comparability tests to be performed by alternating the use of metal cones and alternative material cones, to utilize several technicians, and to minimize the time between test procedures.

5.1.2.2. If the condition of any individual mold is suspected of being out of tolerance from the as manufactured condition, a single comparative test shall be performed. If the test results differ by more than 15 mm [0.50 in.] from that obtained using the metal mold, the mold shall be removed from service.

5.2. *Tamping Rod*—The tamping rod shall be a round, straight steel rod 16 mm [0.625 in.] in diameter and approximately 600 mm [24 in.] in length, having the tamping end or both ends rounded to a hemispherical tip the diameter of which is 16 mm [0.625 in.].

5.3. *Measuring Device*—A ruler, metal roll-up measuring tape, or similar rigid or semi-rigid length measuring instrument marked in increments of 5 mm [0.25 in.] or smaller. The instrument length shall be at least 300 mm [12 in.].

5.4. *Scoop*—A scoop of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the mold.



Dimensional Units

mm	2	3	15	25	75	80	100	200	300
in.	[0.0625]	[0.125]	[0.5]	[1]	[3]	[3.128]	[4]	[8]	[12]

Figure 1—Mold for Slump Test

6. SAMPLE

6.1. The sample of concrete from which test specimens are made shall be representative of the entire batch. It shall be obtained in accordance with T 141.

7. PROCEDURE

7.1. Dampen the mold and place it on a flat, level, moist, nonabsorbent (rigid) surface such as a premoistened concrete floor or a base plate. It shall be held firmly in place during filling and perimeter cleaning by the operator standing on the two foot pieces, or by clamping arrangements to a base plate as described in Section 5.1. From the sample of concrete obtained in accordance with Section 6, immediately fill the mold in three layers, each approximately one-third the volume of the mold. Place the concrete in the mold using the scoop described in Section 5.4. Move the scoop around the perimeter of the mold opening to ensure an even distribution of the concrete with minimal segregation.

Note 5—One-third of the volume of the slump mold fills it to a depth of 67 mm [2.625 in.]; two-thirds of the volume fills it to a depth of 155 mm [6.125 in.].

7.2. Rod each layer with 25 strokes of the tamping rod. Uniformly distribute the strokes over the cross section of each layer. For the bottom layer this will necessitate inclining the rod slightly and making approximately half of the strokes near the perimeter, and then progressing with vertical strokes spirally toward the center. Rod the bottom layer throughout its depth. Rod the second layer and the top layer each throughout its depth, so that the strokes just penetrate into the underlying layer.

7.3. In filling and rodding the top layer, heap the concrete above the mold before rodding is started. If the rodding operation results in subsidence of the concrete below the top edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all times. After the top layer has been rodded, strike off the surface of the concrete by means of a screeding and rolling motion of the tamping rod. Continue to hold the mold down firmly and remove concrete from the area surrounding the base of the mold to preclude interface with the movement of slumping concrete. Remove the mold immediately from the concrete by raising it carefully in a vertical direction. Raise the mold a distance of 300 mm [12 in.] in 5 ± 2 seconds by a steady upward lift with no lateral or torsional motion. Complete the entire test from the start of the filling through removal of the mold without interruption and complete it within an elapsed time of 2.5 minutes.

7.4. Immediately measure the slump by determining the vertical difference between the top of the mold and the displaced original center of the top surface of the specimen. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs (Note 6), disregard the test and make a new test on another portion of the sample.

Note 6—If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, the concrete probably lacks necessary plasticity and cohesiveness for the slump test to be applicable.

8. REPORT

8.1. Record the slump in terms of inches [millimeters] to the nearest 5 mm [0.25 in.] of subsidence of the specimen during the test.

9. PRECISION AND BIAS

9.1. *Precision*—The estimates of precision for this test method are based upon results from tests conducted in Fayetteville, Arkansas by 15 technicians from 14 laboratories representing three states. All tests at three different slump ranges, from 25 mm [1.0 in.] to 160 mm [6.5 in.], were performed using one load of truck-mixed concrete. The concrete was delivered and tested at a low slump, with water then being added and mixed into the remaining concrete to independently produce moderate and finally high-slump concrete. The concrete mixture that used a No. 67 crushed limestone aggregate and a washed river sand, contained 297 kg of cementitious material per cubic meter [500 lb of cementitious materials per cubic yard]. The 227 kg [500 lb] were equally divided between a C 150, Type I/II cement and a Class C fly ash. A double dosage of a chemical retarder was used in an attempt to minimize slump losses and maintain workability of the concrete. Concrete temperatures ranged from 30 to 34°C [86 to 93°F]. Slump losses averaged 17 mm [0.68 in.] during the 20 minutes required to perform a series of six tests at one slump range. Testing was performed alternately using metal and plastic molds, which were determined to produce comparable results. Precision data thus applies to both metal and plastic molds. A total of 270 slump tests were performed.

9.1.1. *SI [Inch-Pound]*—The data used to develop the precision statement were obtained using metric units (millimeters). The precision values shown in inch-pound units are conversions from the millimeter measurements, which were recorded to the nearest 1 mm.

9.1.2. *Measure of Variability*—The standard deviation was determined to be the most consistent measure of variability and was found to vary with the slump value.

9.1.3. *Single-Operator Precision*—The single-operator standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by the same operator performing successive tests, one immediately following the other. Acceptable results of two properly conducted tests by the same operator on the same material (Note 7) will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and single-operator precision.

Table 1—Precison

Slump and Type Index	Standard Deviation (1s)[a]		Acceptable Range of Two Results (d2s)[a]	
	mm	[in.]	mm	[in.]
Single-Operator Precision:				
Slump 30 mm [1.2 in.]	6	[0.23]	17	[0.65]
Slump 85 mm [3.4 in.]	9	[0.38]	25	[1.07]
Slump 160 mm [6.5 in.]	10	[0.39]	28	[1.10]
Multilaboratory Precision:				
Slump 30 mm [1.2 in.]	7	[0.29]	20	[0.82]
Slump 85 mm [3.4 in.]	10	[0.39]	28	[1.10]
Slump 160 mm [6.5 in.]	13	[0.53]	37	[1.50]

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670.

9.1.4. *Multilaboratory Precision*—The multilaboratory standard deviation represented by (1s) is shown in Table 1 by average slump values. The reported results for the replicate readings apply to tests conducted by different operators from different laboratories performing tests less than 4 minutes apart. Therefore, acceptable results of two properly conducted slump tests on the same material (Note 7) by two different laboratories will not differ from each other by more than the (d2s) value of the last column of Table 1 for the appropriate slump value and multilaboratory precision.

Note 7—"Same materials" is used to mean freshly mixed concrete from one batch.

9.2. *Bias*—This test method has no bias because slump is defined in terms of this test method.

10. KEYWORDS

10.1. Concrete; cone; consistency; plasticity; slump; workability.

Standard Method of Test for

Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

AASHTO Designation: T 121M/T 121-09
ASTM Designation: C 138/C 138M-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

AASHTO Designation: T 121M/T 121-09
ASTM Designation: C 138/C 138M-08

1. SCOPE

1.1 This method covers determination of the density (see Note 1) of freshly mixed concrete and gives formulas for calculating the yield, cement content, and the air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

1.2 The values stated in either SI or inch-pound units shall be regarded separately as standard. The inch-pound units are shown in brackets. The values stated might not be exact equivalents; therefore, each system must be used independently of the other.

Note 1—Unit weight was the previous terminology used to describe the property determined by this test method, which is mass per unit volume.

1.3 The text of this test method references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of this test method.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:
- M 85, Portland Cement
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 133, Density of Hydraulic Cement
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method

2.2 *ASTM Standard*:
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. DEFINITIONS

3.1 *Symbols*:

A = air content (percentage of voids) in the concrete;

C = Actual cement content, kg/m^3 [lb/yd^3];

C_b = mass of cement in the batch, kg [lb];

D = density (unit weight) of concrete, kg/m^3 [lb/ft^3];

M = total mass of all materials batched, kg [lb] (see Note 3);

M_c = mass of the measure filled with concrete, kg [lb];
M_m = mass of the measure, kg [lb];
R_y = relative yield;
T = theoretical mass of the concrete computed on an airfree basis, or kg/m^3 [lb/ft^3] (see Note 2);
V = total absolute volume of the component ingredients in the batch, m^3 [ft^3];
V_m = volume of the measure;
Y_d = volume of concrete which the batch was designed to produce, m^3 [yd^3];
Y = yield, volume of concrete produced per batch, m^3 or [yd^3].

Note 2—The theoretical density, customarily, a laboratory determination, the value for which is assumed to remain constant for all batches made using identical component ingredients and proportions. It is calculated from the equation:

$$T = M/V \qquad (1)$$

The absolute volume of each ingredient in cubic meters is equal to the quotient of the mass of the ingredient divided by the product of its specific gravity times 62.4. The absolute volume of each ingredient in cubic meters is equal to the mass of the ingredient in kilograms divided by 1000 times its specific gravity. For the aggregate components, the bulk specific gravity and mass should be based on the saturated, surface-dry condition. For cement, the actual specific gravity should be determined by T 133. A value of 3.15 may be used for cements manufactured to meet the requirements of M 85.

Note 3—The total mass of all materials batched is the sum of the masses of the cement, the fine aggregate in the condition used, the coarse aggregate in the condition used, the mixing water added to the batch and any other solid or liquid materials used.

4. APPARATUS

4.1 *Balance*—A balance or scale accurate to within 45 g [0.1 lb] or 0.3 percent of the test load, whichever is greater, at any point within the range of use. The range of use shall be considered to extend from the mass of the measure empty to the mass of the measure plus its contents at 2600 kg/m^3 [160 lb/ft^3].

4.2 *Tamping Rod*—A round, straight steel rod, 16 mm [$^5/_8$ in.] in diameter and approximately 60 mm [24 in.] in length, having the tamping end rounded to a hemispherical tip the diameter of which is 16 mm [$^5/_8$ in.].

4.3 *Internal Vibrator*—Internal vibrators may have rigid or flexible shafts, preferably powered by electric motors. The frequency of vibration shall be 117 Hz [7000 vibrations per minute] or greater while in use. The outside diameter or the side dimension of the vibrating element shall be at least 19 mm [0.75 in.] and not greater than 38 mm [1.50 in.]. The length of the shaft shall be at least 610 mm [24 in.].

4.4 *Measure*—A cylindrical container made of steel or other suitable metal (Note 3). The minimum capacity of the measure shall conform to the requirements of Table 1 based on the nominal size of aggregate in the concrete to be tested. All measures, except for measuring bowls of air meters, which are also used for T 121 tests, shall conform to the requirements of T 19M/T 19. When measuring bowls of air meters are used, they shall conform to the requirements of T 152 and shall be calibrated for volume as described in T 19M/T 19. The top rim of the air meter bowls shall be smooth and plane within 0.25 mm [0.01 in.].

Note 4—The metal should not be readily subject to attack by cement paste. However, reactive materials such as aluminum alloys may be used in instances where as a consequence of an initial reaction, a surface film is rapidly formed which protects the metal against further corrosion.

Note 5—The top rim is satisfactorily plane if a 0.25-mm [0.01-in.] feeler gauge cannot be inserted between the rim and a piece of 6 mm [1/4 in.] or thicker plate glass laid over the top of the measure.

4.5 *Strike-Off Plate*—A flat rectangular metal plate at least 6 mm [1/4 in.] thick or a glass or acrylic plate at least 13 mm [1/2 in.] thick with a length and width at least 50 mm [2 in.] greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance of 1.6 mm [1/16 in.].

4.6 *Mallet*—A mallet (with a rubber or rawhide head) having a mass of 600 ± 200 g [1.25 ± 0.50 lb] for use with measures 14 L [0.5 ft^3] or smaller, and a mallet having a mass of 1000 ± 200 g [2.25 ± 0.50 lb] for use with measures larger than 0.014 m^3 [0.5 ft^3].

Table 1—Capacity of Measures

Nominal Maximum Size of Coarse Aggregate[a]		Capacity of Measure[a]	
mm	in.	L	ft^3
25.0	1	6	0.2
37.5	1 1/2	11	0.4
50	2	14	0.5
75	3	28	1.0
112	4 1/2	70	2.5
150	6	100	3.5

[a] The indicated size of measure shall be used to test concrete containing aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 percent of the nominal volume listed.

4.7 *Scoop*—A scoop of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the measure.

5. SAMPLE

5.1 Obtain the sample of freshly mixed concrete in accordance with T 141.

6. PROCEDURE

6.1 The methods of consolidation are rodding and internal vibration. Rod concretes with a slump greater than 75 mm [3 in.]. Rod or vibrate concrete with a slump of 25 to 75 mm [1 to 3 in.]. Consolidate concretes with a slump less than 25 mm [1 in.] by vibration.

Note 6—The nonplastic concrete, such as is commonly used in the manufacture of pipe and unit masonry, is not covered by this test method.

6.2 *Rodding*—Place the concrete in the measure in three layers of approximately equal volume using scoop described in 4.7. Rod each layer with 25 strokes of the tamping rod when the 0.014 m^3 [0.5 ft^3] or smaller measures are used and 50 strokes when the 0.028 m^3 [1 ft^3] measure is used. Rod the bottom layer throughout its depth but the rod shall not forcibly strike the bottom of the measure. Distribute the strokes uniformly over the cross section of the measure and for the top two layers, penetrate about 25 mm [1 in.] into the underlying layer. After each layer is rodded, tap the sides of the measure smartly 10 to 15 times with the appropriate mallet (Section 4.6) using such force so as to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Add the final layer so as to avoid overfilling.

6.3 *Internal Vibration*—Fill and vibrate the measure in two approximately equal layers. Place all of the concrete for each layer in the measure before starting vibration of that layer. Insert the vibrator at three different points of each layer. In compacting the bottom layer, do not allow the vibrator to rest on or touch the bottom or sides of the measure. In compacting the final layer, the vibrator shall penetrate into the underlying layer approximately 25 mm [1 in.]. Take care that the vibrator is withdrawn in such a manner that no air pockets are left in the specimen. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator (Note 7). Continue vibration only long enough to achieve proper consolidation of the concrete (Note 8). Observe a constant duration of vibration for the particular kind of concrete, vibrator, and measure involved.

Note 7—Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth.

Note 8—Overvibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

6.4 On completion of consolidation, the measure must not contain a substantial excess or deficiency of concrete. An excess of concrete protruding approximately 3 mm [$^1/_8$ in.] above the top of the mold is optimum. A small quantity of concrete may be added to correct a deficiency. If the measure contains a great excess of concrete at completion of consolidation, remove a representative portion of the excess concrete with a trowel or scoop immediately following completion of consolidation and before the measure is struck-off.

6.5 *Strike-Off*—After consolidation, strike-off the top surface of the concrete and finish it smoothly with the flat strike-off plate using great care to leave the measure just level full. The strike-off is best accomplished by pressing the strike-off plate on the top surface of the measure to cover about two-thirds of the surface and withdrawing the plate with a sawing motion to finish only the area originally covered. Then place the plate on the top of the measure to cover the original two-thirds of the surface and advance it with a vertical pressure and a sawing motion to cover the whole surface of the measure. Several final strokes with the inclined edge of the plate will produce a smooth finished surface.

6.6 *Mass Determination*—After strike-off, clean all excess concrete from the exterior of the measure and determine the net mass of the concrete in the measure to an accuracy consistent with the requirements of Section 4.1.

7. CALCULATIONS

7.1 *Density (Unit Mass)*—Calculate the net mass of the concrete in kilograms (pounds) by subtracting the mass of the measure from the gross mass. Calculate the unit mass, M_m, from the mass of the measure filled with concrete M_c. Calculate the density, D, by dividing the net mass of the concrete by the volume of the measure V_m as follows:

$$D = (M_c - M_m)/V_m \qquad (2)$$

7.2 *Yield*—Calculate the yield as follows:

$$Y(\mathrm{yd}^3) = M / (D \times 27) \qquad (3)$$

or,

$$Y(m^3 \text{ or } ft^3) = M/D \qquad (4)$$

7.3 *Relative Yield*—Relative yield is the ratio of the actual volume of concrete obtained to the volume as designed for the batch (see Note 9) calculated as follows:

$$R_y = Y/Y_d \qquad (5)$$

Note 9—A value for R_y greater than 1.00 indicates an excess of concrete being produced whereas a value less than this indicates the batch to be "short" of its designed volume. In practice, a ratio of yield in cubic feet per cubic yard of design concrete mixture is frequently used, for example, 27.3 ft^3/yd^3.

7.4 *Cement Content*—Calculate the actual cement content as follows:

$$C = C_b / Y \tag{6}$$

7.5 *Air Content*—Calculate the air content as follows:

$$A = \left[\left(T - D \right) / T \right] \times 100 \tag{7}$$

or,

$$A = \left[\left(Y - V \right) / Y \right] \times 100 \left(\text{SI units} \right) \tag{8}$$

or,

$$A = \left[(Y_f - V) / Y_f \right] \times 100 \left(\text{Inch-pound unit} \right) \tag{9}$$

8. REPORT

8.1 Report on the following information:

8.1.1 Identification of concrete represented by the sample.

8.1.2 Date of Test.

8.1.3 Volume of Density measure to the nearest .001 ft^3 (0.01 L).

8.1.4 Density (Unit Weight) to the nearest 0.1 lb/ft^3 (1.0 kg/m^3).

8.1.5 Yield, when requested, to the nearest 0.1 yd^3 (0.1m^3).

8.1.6 Relative Yield, when requested, to the nearest 0.01.

8.1.7 Cement Content, when requested, to the nearest 1.0 lb (0.5 kg).

8.1.8 Air Content, when requested, to the nearest 0.1 percent.

9. PRECISION AND BIAS

9.1 The following estimates of precision for this test method are based on a collection of data from various locations by the National Ready Mixed Concrete Association. The data represent concrete mixtures with slump ranging from 75 to 150 mm [3 to 6 in.] and density ranging from 1842 to 2483 kg/m^3 [115 to 155 lb/ft^3] and included air-entrained and non air-entrained concrete. The study was conducted using 7-L [0.25 ft^3] and 14-L [0.5 ft^3] measures.

9.1.1 *Single-Operator Precision*—The single operator standard deviation of density of freshly mixed concrete has been found to be 10.4 kg/m^3 [0.65 lb/ft^3] (1s). Therefore, results of two properly conducted by the same operator on the same sample of concrete should not differ by more than 29.6 kg/m^3 [1.85 lb/ft^3] (d2s).

9.1.2 *Multi-Operator Precision*—The multi-operator standard deviation of density of freshly mixed concrete has been found to be 13.1 kg/m^3 [0.82 lb/ft^3] (1s). Therefore, results of two properly conducted tests by the two operators on the same sample of concrete should not differ by more than 37.0 kg/m^3 [2.31 lb/ft^3] (d2s).

9.2 *Bias*—This test method has no bias since the density is defined only in terms of this test method.

10. KEYWORDS

10.1 Air content; cement content; concrete; relative yield; unit weight; yield.

Standard Method of Test for

Compressive Strength of Concrete Using Portions of Beams Broken in Flexure

AASHTO Designation: T 140-97 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Compressive Strength of Concrete Using Portions of Beams Broken in Flexure

AASHTO Designation: T 140-97 (2009)

1. SCOPE

1.1. This method covers the determination of compressive strength of concrete, using portions of beams broken in flexure for test specimens.

Note 1—This method was originally developed to cover testing portions of beams having a square cross section as "modified cubes" and former versions of this procedure were subtitled "Modified Cube Method." This terminology no longer applies because beams of rectangular cross section may be tested as provided under Section 6.1.

Note 2—For methods of making flexural test specimens from which the specimens for this test method may be obtained, refer to R 39, T 23, and T 24M/T 24.

Note 3—For methods of making the flexural strength test, refer to T 97 and T 177.

1.2. The values stated in inch-pound units are to be regarded as the standard.

1.3. *This standard does not purport to address the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 97, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- T 177, Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
- T 231, Capping Cylindrical Concrete Specimens

2.2. *ASTM Standard*:

- E 4, Standard Practices for Force Verification of Testing Machines

3. SIGNIFICANCE AND USE

3.1. This test method is intended for use in the laboratory and as a research tool for determining relative compressive strength values for various concrete mixtures. It is not intended as an alternative for T 22, and the test values obtained by these two test methods are not interchangeable and not necessarily comparable.

4. APPARATUS

4.1. The testing machine may be of any type of sufficient capacity that will provide the rate of loading prescribed in Section 6.3. It shall conform to the requirements of the sections on Basis of Verification, Corrections, and Time Interval between Verifications of ASTM E 4. The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note 4), one of which is a spherically seated block that will bear on the top bearing plate described in Section 4.2, and the other a plain rigid block that will support the bottom bearing plate described in Section 4.2. The diameter of the spherical bearing block shall be at least 75 percent of the width (B in Figure 1) of the specimen. The bearing faces shall not depart from a plane by more than 0.001 in. (0.025 mm) in any 6 in. (152 mm) for a block 6 in. (152 mm) in diameter or larger, or by more than 0.001 in. (0.025 mm) in the diameter of any smaller block; new blocks shall be manufactured within one-half of this tolerance.

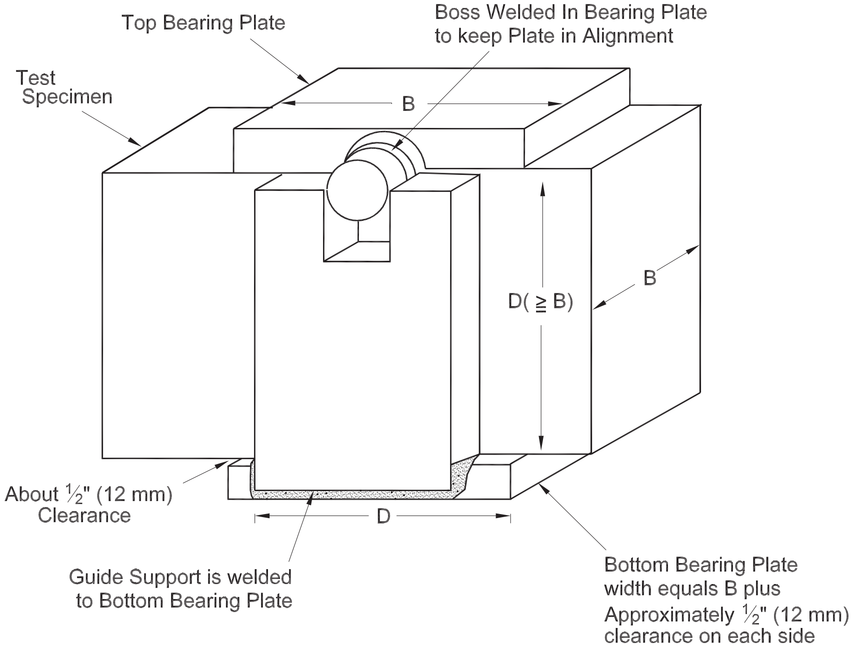


Figure 1—Device Suitable for Aligning Bearing Plates

Note 4—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than HRC 60.

4.2. Machined or ground metal bearing plates not less than $^3/_4$ in. (19 mm) in thickness, that meet the planeness requirements for the bearing faces of specimens specified in Section 5.2.1 and the hardness requirements for bearing blocks specified in Section 4.1, shall be mounted on the bearing surfaces of the specimen. The bearing plates shall be of such dimensions that the contact faces shall be substantially square and shall have the same dimensions as the nominal width of the beam tested. The upper bearing plate shall be placed directly over the lower plate. A drawing of a satisfactory device designed to ensure the proper location of the upper plate with reference to the lower plate is shown in Figure 1. The bearing faces shall not depart from a plane by more than 0.001 in. (0.025 mm) in 6 in. (152 mm), and new bearing plates shall be manufactured within one-half of this tolerance.

5. TEST SPECIMENS

5.1. The length of broken portions of beams selected for the compression test shall be at least 2 in. (50 mm) greater than the width. The selected compression test section shall be free from cracks, chipped surfaces and other obvious defects.

5.2. *Preparation of Test Specimens*:

5.2.1. The bearing faces of the specimen shall not depart from a plane by more than 0.002 in. (0.05 mm); bearing faces that are not plane shall be ground or capped to meet the 0.002 in. (0.05 mm) tolerance. Capping procedures shall follow the applicable provisions of T 231. Caps shall cover the full width of the beam and shall be of such length as to permit the adjustment of the bearing plates for the test so that the upper bearing plate may be aligned directly above the lower plate (Figure 1).

5.2.2. During the interval between testing of specimens in flexure, or after capping and testing the broken portions in compression, the specimens shall be kept in the same condition as prescribed under the method for making and curing flexural test specimens from which the specimens for this test were obtained.

6. PROCEDURE

6.1. Orientation of the specimen shall be such that the width (B in Figure 1) shall be equal to or less than the height (D in Figure 1). If the beam has a square cross section the bearing surfaces may be the sides of the beam as originally cast.

6.2. Center the bearing plates in the testing machine so that the thrust of the spherically seated block of the test machine is aligned with the center of the bearing plates. Apply the load to the bearing plates by means of an adjustable head.

6.3. *Rate of Loading*—Apply the load continuously and without shock. The moving head of the screw type of testing machine shall travel at the rate of approximately 0.05 in./minute (1.3 mm/min) when the machine is running idle. In hydraulic machines, adjust the loading to a constant rate within the limits of 35 ± 15 psi/second (241 ± 103 kPa/second).

6.4. Test specimens to failure. Record the total load indicated by the testing machine at failure of the test specimen.

7. CALCULATION

7.1. Calculate the unit compressive strength calculated to the nearest 10 psi (69 kPa). The cross-sectional area of the specimen shall be taken as the average of at least two measurements of the "B" dimensions (Figure 1) of both the top and bottom bearing plates multiplied by the average of at least two measurements of the "B" dimension of both the top and bottom bearing surfaces of the specimen determined to the nearest 0.01 in. (0.25 mm).

8. REPORT

8.1. *Report the following information*:

8.1.1. That the determination was made using this test method,

8.1.2. Specimen identification number,

8.1.3. "B" and "D" dimensions in inches (or millimeters),

8.1.4. Cross-sectional area, in square inches (or square millimeters),

8.1.5. Maximum load, in pound-force (newtons),

8.1.6. Compressive strength calculated to the nearest 10 psi (69 kPa),

8.1.7. Method of obtaining specimen,

8.1.8. Age of specimen and details of curing,

8.1.9. Orientation of specimen with respect to the top of the beam as cast,

8.1.10. Type of failure and appearance of concrete, and

8.1.11. Conditions of curing the specimens and moisture condition at time of test.

9. PRECISION AND BIAS

9.1. The precision of this test has not been determined, but data are being collected and a precision statement will be included when it is developed.

9.2. No statement concerning bias is being made at this time.

10. KEYWORDS

10.1. Compressive strength; concrete; flexural beams; strength testing.

Standard Method of Test for

Sampling Freshly Mixed Concrete

AASHTO Designation: T 141-05 (2009)
ASTM Designation: C 172-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling Freshly Mixed Concrete

AASHTO Designation: T 141-05 (2009)

ASTM Designation: C 172-04

1. SCOPE

1.1. This method covers the procedures for obtaining representative samples of fresh concrete as delivered to the project site and on which tests are to be performed to determine compliance with quality requirements of the specifications under which the concrete is furnished (Note 1). The method includes sampling from stationary, paving, and truck mixers, and from agitating and nonagitating equipment used to transport central mixed concrete.

1.2. The values stated in SI units are to be regarded as the standard. The inch-pound equivalents of metric units may be approximate.

Note 1—Composite samples are required by this method, unless specifically excepted by procedures governing the tests to be performed, such as tests to determine uniformity of consistency and mixer efficiency. Procedures used to select the specific test batches are not described in this method, but it is recommended that random sampling be used to determine overall specification compliance.

1.3. This practice also covers the procedures to be used for preparing a sample of concrete for further testing where it is desirable or necessary to remove the aggregate larger than a designated size. This removal of larger aggregate particles is preferably accomplished by wet-sieving.

1.4. The text of this standard references notes and footnotes that provide explanatory material and shall not be considered as requirements of the practice.

1.5. *This standard does not purport to address of all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 92, Wire-Cloth Sieves for Testing Purposes

3. SIGNIFICANCE AND USE

3.1. This practice is intended to provide standard requirements and procedures for sampling freshly mixed concrete from different containers used in the production or transportation of concrete. The detailed requirements as to materials, mixtures, air content, temperature, number of specimens, slump, interpretation of results, and precision and bias are in specific test methods.

4. SAMPLING

4.1. The elapsed time shall not exceed 15 minutes between obtaining the first and final portions of the composite sample.

4.1.1. Transport the individual samples to the place where fresh concrete tests are to be performed or where test specimens are to be molded. They shall then be combined and remixed with a shovel the minimum amount necessary to ensure uniformity and compliance with the minimum time limits specified in Section 4.1.2.

4.1.2. Start tests for slump, temperatures, and air content, within 5 minutes after obtaining the final portion of the composite sample. Complete these tests quickly. Start molding specimens for strength tests within 15 minutes after fabricating the composite sample. Quickly obtain and use the sample and protect the sample from the sun, wind, and other sources of rapid evaporation, and from contamination.

5. PROCEDURE

5.1. *Size of Sample*—Make the samples to be used for strength tests a minimum of 28 L (1 ft^3). Smaller samples are not prohibited for routine air content and slump tests and the size shall be dictated by the maximum aggregate size.

5.2. The procedures used in sampling shall include the use of every precaution that will assist in obtaining samples that are truly representative of the nature and condition of concrete sampled as follows:

Note 2—Sampling should normally be performed as the concrete is delivered from the mixer to the conveying vehicle used to transport the concrete to the forms; however, specifications may require other points of sampling, such as at the discharge of a concrete pump.

Note 3—As routine air content and slump tests are not readily adaptable to sampling the concrete at two or more regularly spaced intervals during discharge of the middle portion of the batch as specified in this method, the sample for air content, slump, and temperature may be taken after at least one-quarter cubic yard of concrete has been discharged.

5.2.1. *Sampling from Stationary Mixers, Except Paving Mixers*—Sample the concrete by collecting two or more portions taken at regularly spaced intervals during discharge of the middle of the batch. Obtain these portions within the time limit specified in Section 4. Composite the portions into one sample for testing purposes. Do not obtain portions of the composite sample from the very first or last part of the batch discharge (Note 4).

Perform sampling by passing a receptacle completely through the discharge stream, or by completely diverting the discharge into a sample container. If discharge of the concrete is too rapid to divert the complete discharge stream, discharge the concrete into a container or transportation unit sufficiently large to accommodate the entire batch and then accomplish the sampling in the same manner as given above. Take care not to restrict the flow of concrete from the mixer, container, or transportation unit so as to cause segregation. These requirements apply to both tilting and nontilting mixers.

Note 4—No sample should be taken before 10 percent or after 90 percent of the batch has been discharged. Due to the difficulty of determining the actual quantity of concrete discharged, the intent is to provide samples that are representative of widely separated portions, but not the beginning and end of the load.

5.2.2. *Sampling from Paving Mixers*—Sample the concrete after the contents of the paving mixer have been discharged. Obtain samples from at least five different portions of the pile and then composite into one sample for test purposes. Avoid contamination with subgrade material or prolonged contact with an absorptive subgrade. To preclude contamination or absorption by the subgrade, sample the concrete by placing three shallow containers on the subgrade and discharging the concrete across the containers. Composite the samples so obtained into one sample for test purposes. The containers shall be of a size sufficient to provide a composite sample size that is in agreement with the maximum aggregate size.

Note 5—In some instances, the containers may have to be supported above the subgrade to prevent displacement during discharge.

5.2.3. *Sampling from Revolving Drum Truck Mixers or Agitators*—Sample the concrete by collecting two or more portions taken at regularly spaced intervals during discharge of the middle portion of the batch. Take the samples so obtained within the time limit specified in Section 4 and composite them into one sample for test purposes. In any case do not obtain samples until after all of the water has been added to the mixer; also do not obtain samples from the very first or last portions of the batch discharge (Note 4). Sample by repeatedly passing a receptacle through the entire discharge stream or by completely diverting the discharge into a sample container. Regulate the rate of discharge of the batch by the rate of revolution of the drum and not by the size of the gate opening.

5.2.4. *Sampling from Open-Top Truck Mixers, Agitators, Nonagitating Equipment, or Other Types of Top Containers*—Take samples by whichever of the procedures described in Sections 5.2.1, 5.2.2, or 5.2.3 is most applicable under the given conditions.

6. ADDITIONAL PROCEDURE FOR LARGE, MAXIMUM SIZE AGGREGATE CONCRETE

6.1. When the concrete contains aggregate larger than that appropriate for the size of the molds or equipment to be used, wet-sieve the sample as described below except perform density (unit weight) tests for use in yield computations on the full mix.

Note 6—The effect of wet-sieving on the test results should be considered. For example, wet-sieving concrete causes the loss of a small amount of air due to additional handling. The air content of the wet-sieved fraction of concrete is greater than that of the total concrete because the larger size aggregate that is removed does not contain air. The apparent strength of wet-sieved concrete in smaller specimens is usually greater than that of the total concrete in larger appropriate size specimens. The effect of these differences may need to be considered or determined by supplementary testing for quality control or test result evaluation purposes.

6.2. *Definition*:

6.2.1. *Wet-Sieving Concrete*—the process of removing aggregate larger than a designated size from the fresh concrete by sieving it on a sieve of the designated size.

6.3. *Apparatus*:

6.3.1. Sieves, as designated, conforming to M 92.

6.3.2. *Wet-Sieving Equipment*—Equipment for wet-sieving concrete shall be a sieve as noted in Section 6.3.1 of suitable size and conveniently arranged and supported so that one can shake it rapidly by either hand or mechanical means. Generally, a horizontal back and forth motion is preferred. The equipment shall be capable of rapidly and effectively removing the designated size of aggregate.

6.3.3. *Hand Tools*—Shovels, hand scoops, plastering trowels, and rubber gloves as required.

6.4. *Procedure*:

6.4.1. *Wet-Sieving*—After sampling the concrete, pass the concrete over the designated sieve and remove and discard the aggregate retained. This shall be done before remixing. Shake or vibrate the sieve by hand or mechanical means until no undersize material remains on the sieve. Mortar adhering to the aggregate retained on the sieve shall not be wiped from it before it is discarded. Place only enough concrete on the sieve at any one time so that after sieving, the thickness of the layer of retained aggregate is not more than one particle thick. The concrete that passes the sieve shall fall into a batch pan of suitable size that has been dampened before use or onto a clean, moist, nonabsorbent surface. Scrape any mortar adhering to the sides of the wet-sieving equipment into the batch. After removing the larger aggregate particles by wet-sieving, remix the batch with a shovel the minimum amount necessary to ensure uniformity and proceed testing immediately.

7. KEYWORDS

7.1. Air content; batch; composite sample; concrete; slump; temperature; wet-sieving.

Standard Method of Test for

Measuring Length of Drilled Concrete Cores

AASHTO Designation: T 148-07[1]
ASTM Designation: C 174/C 174M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Measuring Length of Drilled Concrete Cores

AASHTO Designation: T 148-07[1]
ASTM Designation: C 174/C 174M-06

1. SCOPE

1.1. This test method covers determination of the length of a core drilled from a concrete pavement or structural element by measuring the length of a core drilled from a concrete structure.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. SIGNIFICANCE AND USE

2.1. This method is used to determine the compliance of concrete construction with design specifications. It is especially important in determining the thickness of pavements and other slab construction.

3. APPARATUS

3.1. The apparatus shall consist of a 3-point calipering device that will measure the length of axial elements of the core. While the details of the mechanical design are not prescribed, the apparatus shall conform to the requirements of Sections 3.2 to 3.6.

3.2. The apparatus shall be so designed that the specimen will be held with its axis in a vertical position by three symmetrically placed supports bearing against the lower end. These supports shall be short posts or studs of hardened steel, and the ends that bear against the surface of the specimen shall be rounded to a radius of not less than 6 mm ($^1/_4$ in.) and not more than 13 mm ($^1/_2$ in.).

3.3. The apparatus shall provide for the accommodation of specimens of different nominal lengths over a range of at least 100 to 250 mm (4 to 10 in.).

3.4. The calipering device shall be so designed that it will be possible to make a length measurement at the center of the upper end of the specimen, and at eight additional points spaced at equal intervals along the circumference of a circle whose center points coincides with that of the end area of the specimen and whose radius is not less than one-half nor more than three-fourths of the radius of the specimen.

3.5. The measuring rod or other device that makes contact with the end surface of the specimen for measurement shall be rounded to a radius of 3 mm ($^1/_8$ in.). The scale on which the length readings are made shall be marked with clear, definite, accurately spaced graduations. The spacing of the graduations shall be 1.0 mm (0.10 in.) during all normal measuring operations.

3.6. The apparatus shall be stable and sufficiently rigid to maintain its shape and alignment without a distortion or deflection of more than 0.25 mm (0.01 in.) during all normal measuring operations.

4. TEST SPECIMENS

4.1. Cores used as specimens for length measurement shall be in every way representative of the concrete in the structure from which they are removed. The specimen shall be drilled with the axis normal to the surface of the structure, and the ends shall be free from all conditions not typical of the surfaces of the structure. Cores that show abnormal defects or that have been damaged appreciably in the drilling operation shall not be used. If a core drilled from a pavement or structure placed on dense-graded base course aggregates includes particles of the aggregate bonded to the bottom surface of the concrete, the bonded particles shall be removed by wedging or by chisel and hammer applied so as to expose the lower surface of the concrete. If the concrete is placed on an open-graded aggregate base course, the mortar in the concrete may penetrate into the base and surround some particles. Use sufficient force with a wedge or chisel and hammer to remove bonded particles, but not such force as to fracture particles substantially surrounded by mortar. If during the removal of bonded aggregate the concrete is broken so that the instructions of Section 5.4 cannot be followed, the core shall not be used for length measurement.

5. PROCEDURE

5.1. Before any measurements of the core length are made, calibrate the apparatus with suitable gages so that errors caused by mechanical imperfections in the apparatus are known. When these errors exceed 0.25 mm (0.01 in.), apply suitable corrections to the core length measurements.

5.2. Place the specimen in the measuring apparatus with the smooth end of the core, that is, the end that represents the upper surface of the pavement slab or a formed surface in the case of other structures, placed down so as to bear against the three hardened-steel supports. So place the specimen on the supports that the central measuring position of the measuring apparatus is directly over the midpoint of the upper end of the specimen.

5.3. Make nine measurements of the length on each specimen, one at the central position and one each at eight additional positions spaced at equal intervals along the circumference of the circle of measurement. Read each of these nine measurements directly to the nearest 1.0 mm (0.05 in.).

5.4. If, in the course of the measuring operation, it is discovered that at one or more of the measuring points the surface of the specimen is not representative of the general plane of the core end because of a small projection or depression, the specimen shall be rotated slightly about its axis and a complete set of nine measurements made with the specimen in the new position. With cores from pavements placed over open-graded aggregate bases, the foregoing provisions frequently cannot be met because of the great number of projections or voids on the bottom surface.

6. REPORT

6.1. The individual observations shall be recorded to the nearest 1.0 mm (0.05 in.), and the average of the nine measurements expressed to the nearest 1.0 mm (0.1 in.) shall be reported as the length of the concrete core.

7. PRECISION AND BIAS

7.1. *Precision*:

7.1.1. *3-Point Caliper*—No statement is made about the precision of this Test Method, however, a precision statement may be drafted in the future.

7.2. *Bias*—Because there are not acceptable reference cores suitable for determining the bias of these procedures, no statement on bias is being made.

8. KEYWORDS

8.1. 3-point caliper; concrete; cores; length measurement; thickness measurement.

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[1] This method is the same as ASTM C 174/C 174M-06 except for the following: Section 1.2 of C 174 allows either the SI units or inch-pound units to be regarded as standard. Figure 1 of C 174 is not included.

Standard Method of Test for

Air Content of Freshly Mixed Concrete by the Pressure Method

AASHTO Designation: T 152-10
ASTM Designation: C 231-08c

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Air Content of Freshly Mixed Concrete by the Pressure Method

AASHTO Designation: T 152-10
ASTM Designation: C 231-08c

1. SCOPE

1.1 This method covers determination of the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure.

1.2 This method is intended for use with concretes and mortars made with relatively dense aggregates for which the aggregate correction factor can be satisfactorily determined by the technique described in Section 5. It is not applicable to concretes made with light-weight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. In these cases, T 196M/T 196 should be used. This test method is also not applicable to nonplastic concrete such as is commonly used in the manufacture of pipe and concrete masonry units.

1.3 The text of this standard references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements for this standard.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See Note A1.7 for a specific caution statement.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

2.2 *ASTM Standards*:

- C 138/C 138M, Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- C 172, Standard Practice for Sampling Freshly Mixed Concrete

- C 173/C 173M, Standard Test Method for Air Content of Freshly Mixed Concrete by Volumetric Method
- C 192/C 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods [1]

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3. SIGNIFICANCE AND USE

3.1 This test method covers the determination of the air content of freshly mixed concrete. The test determines the air content of freshly mixed concrete exclusive of any air that exists inside voids within aggregate particles. For this reason, it is applicable to concrete made with relatively dense aggregate particles and requires determination of the aggregate correction factor. (See Sections 6.1 and 9.1.)

3.2 This test method and T 121M/T 121 and T 196M/T 196 provide pressure, gravimetric, and volumetric procedures, respectively, for determining the air content of freshly mixed concrete. The pressure procedure of this test method gives substantially the same air content as the other two test methods for concrete made with dense aggregates.

3.3 The air content of hardened concrete may be either higher or lower than that determined by this test method. This depends upon the methods and amount of consolidation effort applied to the concrete from which the hardened concrete specimen is taken; uniformity and stability of the air bubbles in the fresh and hardened concrete; accuracy of the microscopic examination, if used; time of comparison; environmental exposure; stage in the delivery, placement, and consolidation processes at which the air determined, that is, before or after the concrete goes through a pump; and other factors.

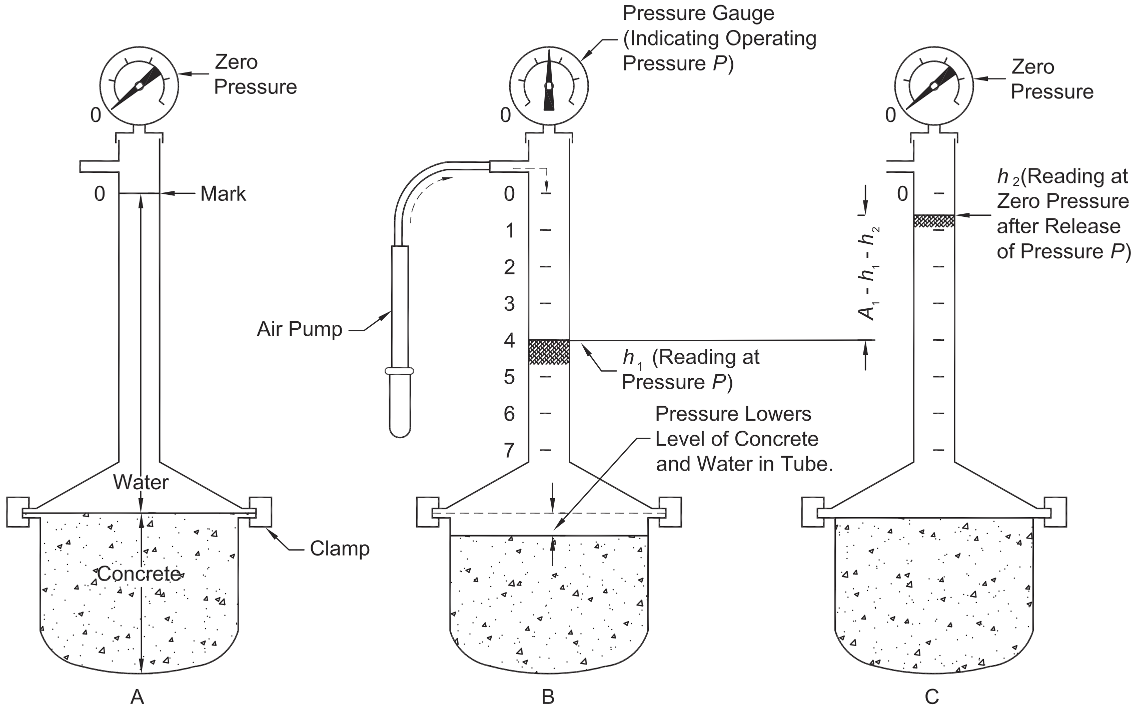
4. APPARATUS

4.1 *Air Meters*—There are available satisfactory apparatus of two basic operational designs employing the principle of Boyle's Law. For purposes of reference herein these are designated Meter Type A and Meter Type B.

4.1.1 *Meter Type A*—An air meter consisting of a measuring bowl and cover assembly (Figure 1) conforming to the requirements of Sections 4.2 and 4.3. The operational principle of this meter consists of introducing water to a predetermined height above a sample of concrete of known volume, and the application of a predetermined air pressure over the water. The determination consists of the reduction in volume of the air in the concrete sample by observing the amount the water level is lowered under the applied pressure, the latter amount being calibrated in terms of percent of air in the concrete sample.

4.1.2 *Meter Type B*—An air meter consisting of a measuring bowl and cover assembly (Figure 2) conforming to the requirements of Sections 4.2 and 4.3. The operational principle of this meter consists of equalizing a known volume of air at a known pressure in a sealed air chamber with the unknown volume of air in the concrete sample, the dial on the pressure gauge being calibrated in terms of percent air for the observed pressure at which equalization takes place. Working pressures of 7.5 to 30.0 psi (51 to 207 kPa) have been used satisfactorily.

4.2 *Measuring Bowl*—The measuring bowl shall be essentially cylindrical in shape, made of steel, hard metal, or other hard material not readily attacked by the cement paste, having a minimum diameter equal to 0.75 to 1.25 times the height, and a capacity of at least 0.20 ft^3 (5.7 L). It shall be flanged or otherwise constructed to provide for a pressure-tight fit between bowl and cover assembly. The interior surfaces of the bowl and surfaces of rims, flanges, and other component fitted parts shall be machined smooth. The measuring bowl and cover assembly shall be sufficiently rigid to limit the expansion factor, *D*, of the apparatus assembly (Annex A1.5) to not more than 0.1 percent of air content on the indicator scale when under normal operating pressure.



Note: $A_1 = h_1 - h_2$ when bowl contains concrete as shown in this figure; when bowl contains only aggregate and water, $h_1 - h_2 = G$ (aggregate correction factor). $A_1 - G = A$ (entrained air content of concrete).

Figure 1—Illustration of the Pressure Method for Air Content: Type A Meter

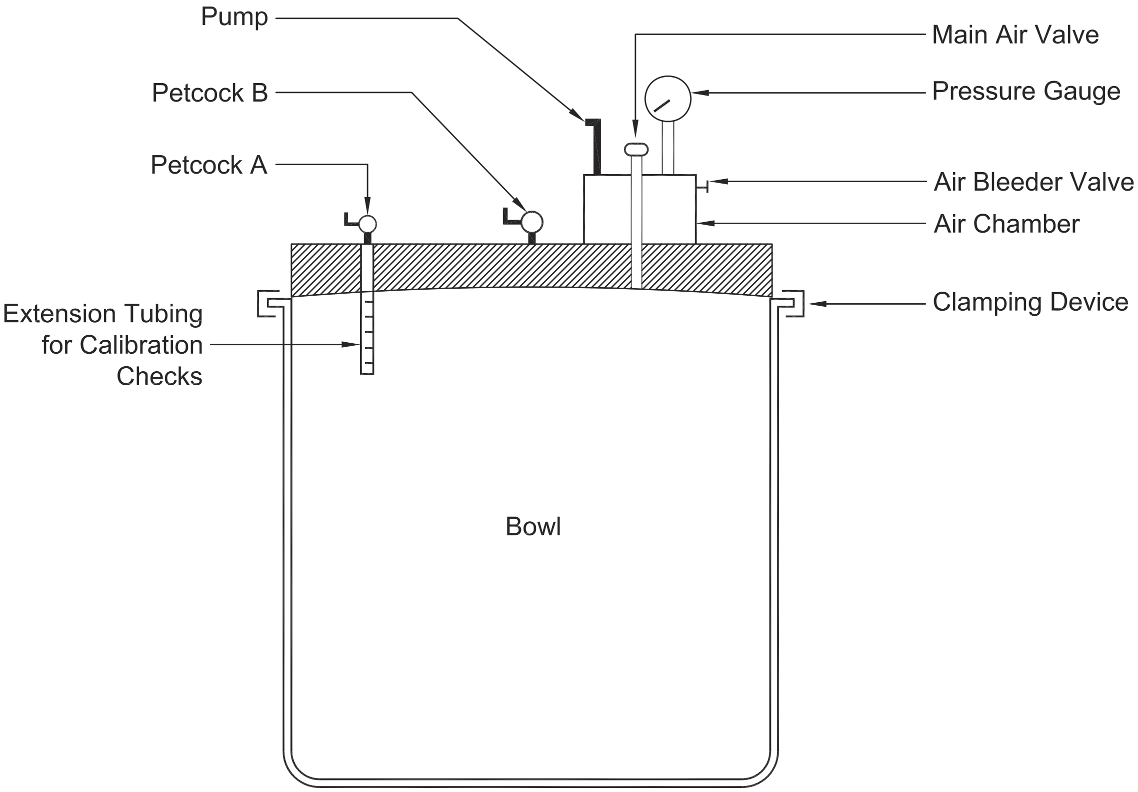


Figure 2—Schematic Diagram: Type B Meter

4.3 *Cover Assembly*:

4.3.1 The cover assembly shall be made of steel, hard metal, or other hard material not readily attacked by the cement paste. It shall be flanged or otherwise constructed to provide for a pressure-tight fit between bowl and cover assembly and shall have machined-smooth interior surfaces contoured to provide an air space above the level of the top of the measuring bowl. The cover shall be sufficiently rigid to limit the expansion factor of the apparatus assembly as prescribed in Section 4.2.

4.3.2 The cover assembly shall be fitted with a means of direct reading of the air content. The cover for the Type A meter shall be fitted with a standpipe, which may be a transparent graduated tube or may be a metal tube of uniform bore with a glass water gauge attached. In the Type B meter, the dial of the pressure gauge shall be calibrated to indicate the percent of air. Graduations shall be provided for a range in air content of at least 8 percent easily readable to 0.1 percent as determined by the proper air pressure calibration test.

4.3.3 The cover assembly shall be fitted with air valves, air bleeder valves, and petcocks for bleeding off or through which water may be introduced as necessary for the particular meter design. Suitable means for clamping the cover to the bowl shall be provided to make a pressure-tight seal without entrapping air at the joint between the flanges of the cover and bowl. A suitable hand pump shall be provided with the cover either as an attachment or as an accessory.

4.4 *Calibration Vessel*—A measure having an internal volume equal to a percent of the volume of the measuring bowl corresponding to the approximate percent of air in the concrete to be tested; or, if smaller, it shall be possible to check calibration of the meter indicator at the approximate percent of air in the concrete to be tested by repeated filling of the measure. When the design of the meter requires placing the calibration vessel within the measuring bowl to check calibration, the measure shall be cylindrical in shape and of an inside depth $^1/_2$ in. (13 mm) less than that of the bowl.

Note 1—A satisfactory calibration vessel to place within the measure bowl may be machined for No. 16 gauge brass tubing, of a diameter to provide the volume desired, to which a brass disk $^1/_2$ in. thick is soldered to form an end. When design of the meter requires withdrawing of water from the water-filled bowl and cover assembly to check calibration, the measure may be an integral part of the cover assembly or may be a separate cylindrical measure similar to the above described cylinder.

4.5 The designs of various available types of airmeters are such that they differ in operating techniques and therefore, all of the items described in Sections 4.6 through 4.16 may not be required. The items required shall be those necessary for use with the particular design of apparatus used to satisfactorily determine air content in accordance with the procedures prescribed herein.

4.6 *Coil Spring or Other Device for Holding Calibration Cylinder in Place*:

4.7 *Spray Tube*—A brass tube of appropriate diameter, which may be an integral part of the cover assembly or which may be provided separately. It shall be so constructed that when water is added to the container, it is sprayed to the walls of the cover in such a manner as to flow down the sides causing a minimum of disturbance to the concrete.

4.8 *Trowel*—A standard brick mason's trowel.

4.9 *Tamping Rod*—The tamping rod shall be a round straight steel rod $^5/_8$ in. (16 mm) in diameter and not less than approximately 16 in. (400 mm) in length, having the tamping end rounded to hemispherical tip the diameter of which is $^5/_8$ in. (16 mm).

4.10 *Mallet*—A mallet (with a rubber or rawhide head) weighing approximately 1.25 ± 0.50 lb (0.57 ± 0.23 kg) for use with measures of 0.5 ft^3 (14 L) or smaller, and a mallet weighing approximately 2.25 ± 0.50 lb (1.02 ± 0.23 kg) for use with measures larger than 0.5 ft^3 (14 L).

4.11 *Strike-Off Bar*—A flat straight bar of steel or other suitable metal at least $^1/_8$ in. (3 mm) thick and $^3/_4$ in. (20 mm) wide by 12 in. (300 mm) long.

4.12 *Strike-Off Plate*—A flat rectangular metal plate at least $^1/_4$ in. (6 mm) thick or a glass or acrylic plate at least $^1/_2$ in. (12 mm) thick with a length and width at least 2 in. (50 mm) greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance of $^1/_{16}$ in. (1.5 mm).

4.13 *Funnel*—with the spout fitting into spray tube.

4.14 *Measure for Water*—having the necessary capacity to fill the indicator with water from the top of the concrete to the zero mark.

4.15 *Vibrator*—as described in R 39.

4.16 *Sieves*—$1^1/_2$ in. (37.5 mm) with not less than 2 ft^2 (0.19 m^2) of sieving area.

4.17 *Scoop*—of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the measuring bowl.

5. CALIBRATION OF APPARATUS

5.1 Make calibration tests in accordance with procedures prescribed in the annex. Rough handling will affect the calibration of both Types A and B meters. Changes in barometric pressure will affect the calibration of the Type A meter but not the Type B meter. The steps described in Sections A1.2 to A1.6, as applicable to the meter type under consideration, are prerequisites for the final calibration test to determine the operating pressure, *P*, on the pressure gauge of the Type A meter as described in Section A1.7, or to determine the accuracy of the graduations indicating air content on the dial face of the pressure gauge of the Type B meter. Normally, the steps in Sections A1.2 to A1.6 need be made only once (at the time of initial calibration), or only occasionally to check volume constancy of the calibration cylinder and measuring bowl. On the other hand, the calibration test described in Sections A1.7 and A1.9, as applicable to the meter type being checked, must be made as frequently as necessary to ensure that the proper gauge pressure, *P*, is being used for the Type A meter or that the correct air contents are being indicated on the pressure gauge air content scale for the Type B meter. A change in elevation of more than 600 ft (183 m) from the location at which a Type A meter was last calibrated will require recalibration in accordance with Section A1.7.

5.2 *Calibration Records*—Information to be maintained in the records shall include determination of expansion factor, size of the calibration vessel used, and the reading of the meter at the calibration test point(s).

6. DETERMINATION OF AGGREGATE CORRECTION FACTOR

6.1 *Procedure*—Determine the aggregate correction factor on a combined sample of fine and coarse aggregate as directed in Sections 6.2 to 6.4. It is determined independently by applying the calibrated pressure to a sample of inundated fine and coarse aggregate in approximately the same moisture condition, amount, and proportions occurring in the concrete sample under test.

6.2 *Aggregate Sample Size*—Calculate the weights of fine and coarse aggregate present in the sample of fresh concrete whose air content is to be determined, as follows:

$$F_s = (S/B) \times F_b \tag{1}$$

$$C_s = (S/B) \times C_b \tag{2}$$

where:

F_s = weight of fine aggregate in concrete sample under test, lb (kg);
S = volume of concrete sample (same as volume of measuring bowl), ft^3 (m^3);
B = volume of concrete produced per batch (Note 2), ft^3 (m^3);
F_b = total weight of fine aggregate in the moisture condition used in batch, lb (kg);
C_s = weight of coarse aggregate in concrete sample under test, lb (kg); and
C_b = total weight of coarse aggregate in the moisture condition used in batch, lb (kg).

Note 2—The volume of concrete produced per batch can be determined in accordance with applicable provisions of T 121M/T 121.

Note 3—The term “weight” is temporarily used in this standard because of established trade usage. The word is used to mean both “force” and “mass” and care must be taken to determine which is meant in each case (SI unit for force = newton and for mass = kilogram).

6.3 *Placement of Aggregate in Measuring Bowl*—Mix representative samples of fine aggregate F_s, and coarse aggregate C_s, and place in the measuring bowl filled one-third full with water. Place the mixed aggregate, a small amount at a time, into the measuring bowl; if necessary, add additional water so as to inundate all of the aggregate. Add each scoopful in a manner that will entrap as little air as possible and remove accumulations of foam promptly. Tap the sides of the bowl and lightly rod the upper 1 in. (25 mm) of the aggregate about 8-12 times. Stir after each addition of aggregate to eliminate entrapped air.

6.4 *Aggregate Correction Factor Determination*:

6.4.1 *Initial Procedure for Types A and B Meters*—When all of the aggregate has been placed in the measuring bowl, remove excess foam and keep the aggregate inundated for a period of time approximately equal to the time between introduction of the water into the mixer and the time of performing the test for air content before proceeding with the determination as directed in Section 6.4.2 or 6.4.3.

6.4.2 *Type A Meter*—Complete the test as described in Sections 8.2.1-8.2.3. The aggregate correction factor, G, is equal to $h_1 - h_2$. (See Figure 1, Note 4.)

6.4.3 *Type B Meter*—Perform the procedures as described in Section 8.3.1. Remove a volume of water from the assembled and filled apparatus approximately equivalent to the volume of air that would be contained in a typical concrete sample of a size equal to the volume of the bowl. Remove the water in the manner described in Section A1.9 of the Annex for the calibration tests. Complete the test as described in Section 8.3.2. The aggregate correction factor, G, is equal to the reading on the air-content scale minus the volume of water removed from the bowl expressed as a percent of the volume of the bowl. (See Figure 1.)

Note 4—The aggregate correction factor will vary with different aggregates. It can be determined only by test, because apparently it is not directly related to absorption of the particles. The test can be easily made and must not be ignored. Ordinarily the factor will remain reasonably constant for given aggregates, but an occasional check test is recommended.

7. PREPARATION OF CONCRETE TEST SAMPLE

7.1 Obtain the sample of freshly mixed concrete in accordance with applicable procedures of T 141. If the concrete contains coarse aggregate particles that would be retained on a 2-in. (50-mm) sieve, wet-sieve a sufficient amount of the representative sample over a $1^1/_2$-in. (37.5-mm) sieve, as described in T 141 to yield somewhat more than enough material to fill the measuring bowl of the size selected for use. Carry out the wet-sieving operation with the minimum practical disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on the sieve.

8. PROCEDURE FOR DETERMINING AIR CONTENT OF CONCRETE

8.1 *Placement and Consolidation of Sample*:

8.1.1 Dampen the interior of the measuring bowl and place it on a flat, level, firm surface. Using the scoop described in 4.17 place a representative sample of the concrete, prepared as described in Section 7, in the measuring bowl in equal layers. Consolidate each layer by the rodding procedure (Section 8.1.2) or by vibration (Section 8.1.3). Strike off the finally consolidated layer (Section 8.1.4). Rod concretes with a slump greater than 3 in. (75 mm). Rod or vibrate concrete with a slump of 1 to 3 in. (25 to 75 mm). Consolidate concretes with a slump of less than 1 in. (25 mm) by vibration.

8.1.2 *Rodding*—Place the concrete in the measuring bowl in three layers of approximately equal volume. Consolidate each layer of concrete by 25 strokes of the tamping rod evenly distributed over the cross section. After each layer is rodded, tap the sides of the measure smartly 10 to 15 times with the mallet to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Rod the bottom layer throughout its depth, but the rod shall not forcibly strike the bottom of the measure. In rodding the second and final layers, use only enough force to cause the rod to penetrate the surface of the previous layer about 1 in. (25 mm). Add the final layer of concrete in a manner to avoid excessive overfilling (Section 8.1.4).

8.1.3 *Vibration*—Place the concrete in the measuring bowl in two layers of approximately equal volume. Place all of the concrete for each layer before starting vibration of that layer. Consolidate each layer by three insertions of the vibrator evenly distributed over the cross section. Add the final layer in a manner to avoid excessive overfilling (Section 8.1.4). In consolidating each layer, do not allow the vibrator to rest on or touch the measuring bowl. Take care in withdrawing the vibrator to ensure that no air pockets are left in the specimen. Observe a standard duration of vibration for the particular kind of concrete, vibrator, and measuring bowl involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Continue vibration only long enough to achieve proper consolidation of the concrete. Overvibration may cause segregation and loss of intentionally entrained air. Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and has a glazed appearance. Never continue vibration long enough to cause escape of froth from the sample.

Note 5—Overvibration may cause segregation and loss of intentionally entrained air. Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and has a glazed appearance.

8.1.4 *Strike Off*—After consolidation of the concrete, strike off the top surface by sliding the strike-off bar across the top flange or rim of the measuring bowl with a sawing motion until the bowl is just level full. On completion of consolidation, the bowl must not contain an excess or deficiency of concrete. Removal of approximately $^1/_8$ in. (3 mm) during strike off is optimum. A small quantity of representative concrete may be added to correct a deficiency. If the measure contains a great excess, remove a representative portion of concrete with a trowel or scoop before the measure is struck off. When a strike-off plate is used, strike off concrete as prescribed in T 121M/T 121.

Note 6—A small quantity of representative concrete may be added to correct a deficiency. If the measure contains great excess, remove a representative portion of the concrete with a trowel or scoop before the measure is struck off.

Note 7—The use of the strike-off plate on cast aluminum or other relatively soft metal air meter bases may cause rapid wear of the rim and require frequent maintenance, calibration, and ultimately, replacement.

8.1.5 *Application of Test Method*—Any portion of the test method not specifically designated as pertaining to Type A or Type B meter shall apply to both types.

8.2 *Procedure—Type A Meter*:

8.2.1 *Preparation for Test*—Thoroughly clean the flanges or rims of the bowl and of the cover assembly so that when the cover is clamped in place a pressure-tight seal will be obtained. Assemble the apparatus and add water over the concrete by means of the tube until it rises to about the halfway mark in the standpipe. Incline the apparatus assembly about 30 degrees from vertical and, using the bottom of the bowl as a pivot, describe several complete circles with the upper end of the column, simultaneously tapping the cover lightly to remove any entrapped air bubbles above the concrete sample. Return the apparatus assembly to a vertical position and fill the water column slightly above the zero mark, while lightly tapping the sides of the bowl. Bring the water level to the zero mark of the graduated tube before closing the vent at the top of the water column. (See Figure 1A.)

Note 8—Some Type A meters have a calibrated starting fill mark above the zero mark. Generally, this starting mark should not be used since, as noted in Section 8.2.3, the apparent air content is the difference between the water level reading H, at pressure P and the water level h_2 at zero pressure after release of pressure P.

8.2.2 The internal surface of the cover assembly shall be kept clean and free from oil or grease; the surface shall be wet to prevent adherence of air bubbles that might be difficult to dislodge after assembly of the apparatus.

8.2.3 *Test Procedure*—Apply slightly more than the desired test pressure, P, (about 0.2 psi (1380 kPa) more) to the concrete by means of the small hand pump. To relieve local restraints, tap the sides of the measure sharply and, when the pressure gauge indicates the exact test pressure, P, as determined in accordance with Section A1.7, read the water level, h_1, and record to the nearest division or half-division on the graduated precision-bore tube or gauge glass of the standpipe. (See Figure 1B.) For extremely harsh mixes it may be necessary to tap the bowl vigorously until further tapping produces no change in the indicated air content. Gradually release the air pressure through the vent at the top of the water column and tap the sides of the bowl lightly for about one minute. Record the water level, h_2, to the nearest division or half-division. (See Figure 1C.) Calculate the apparent air content as follows:

$$A_1 = h_1 - h_2 \tag{3}$$

where:

A_1 = apparent air content;
h_1 = water level reading at pressure, P (Note 9); and
h_2 = water level reading at zero pressure after release of pressure, P.

8.2.4 *Check Test*—Repeat the steps described in Section 8.2.3 without adding water to reestablish the water level at the zero mark. The two consecutive determinations of apparent air content should check within 0.2 percent of air and shall be averaged to give the value A_1 to be used in calculating the air content, A_s, in accordance with Section 9.

8.2.5 In the event the air content exceeds the range of the meter when it is operated at the normal test pressure P, reduce the test pressure to the alternative test pressure P_1 and repeat the steps outlined in Sections 8.2.2 and 8.2.3.

Note 9—See Section A1.7 for exact calibration procedures. An approximate value of the alternative pressure, P_1, such that the apparent air content will equal twice the meter reading can be computed from the following relationship:

$$P_1 = P_a P / (2P_a + P) \tag{4}$$

where:

P_1 = alternative test pressure, psi (kPa);
P_a = atmospheric pressure, psi (kPa) (approximately 14.7 psi (101 kPa) but will vary with altitude and weather conditions); and
P = normal test or operating gauge pressure, psi (kPa).

8.3 *Procedure—Type B Meter.*

8.3.1 *Preparation for Test*—Thoroughly clean the flanges or rims, of the bowl and the cover assembly so that when the cover is clamped in place a pressure-tight seal will be obtained. Assemble the apparatus. Close the air valve between the air chamber and the measuring bowl and open both petcocks on the holes through the cover. Using a rubber syringe, inject water through one petcock until water emerges from the opposite petcock. Jar the meter gently until all air is expelled from this same petcock.

8.3.2 *Test Procedure*—Close the airbleeder valve on the air chamber and pump air into the air chamber until the gauge hand is on the initial pressure line. Allow a few seconds for the compressed air to cool to normal temperature. Stabilize the gauge hand at the initial pressure line by pumping or bleeding off air as necessary, tapping the gauge lightly by hand. Close both petcocks on the holes through the cover. Open the air valve between the air chamber and the measuring bowl. Tap the sides of the measuring bowl smartly with the mallet to relieve local restraints. Lightly tap the pressure gauge by hand to stabilize the gauge hand and read the percentage of air on the dial of the pressure gauge. Failure to close the main air valve before releasing the pressure from either the container or the air chamber will result in water being drawn into the air chamber, thus introducing error in subsequent measurements. In the event water enters the air chamber, it must be bled from the air chamber through the bleeder valve followed by several strokes of the pump to blow out the last traces of water. Release the pressure by opening both petcocks (Figure 2) before removing the cover.

9. CALCULATION

9.1 *Air Content of Sample Tested*—Calculate the air content of the concrete in the measuring bowl as follows:

$$A_s = A_1 - G \qquad (5)$$

where:

A_s = air content of sample tested, percent;

A_1 = apparent air content of the sample tested, percent (Sections 8.2.3 and 8.3.2); and

G = aggregate correction factor, percent (Section 6).

9.2 *Air Content of Full Mixture*—When the sample tested represents that portion of the mixture that is obtained by wet-sieving to remove aggregate particles larger than a $1^1/_2$-in. (37.5-mm) sieve, the air content of the full mixture may be calculated as follows:

$$A_t = 100 A_s V_c / (100\, V_t - A_s V_a) \qquad (6)$$

where (see Note 10):

A_t = air content of the full mixture, percent;

V_c = absolute volume of the ingredients of the mixture passing a $1^1/_2$-in. (37.5-mm) sieve, airfree, as determined from the original batch weights, ft^3 (m^3);

V_t = absolute volume of all ingredients of the mixture, airfree, ft^3 (m^3); and

V_a = absolute volume of the aggregate in the mixture coarser than a $1^1/_2$-in. (37.5-mm) sieve, as determined from original batch weights, ft^3 (m^3).

9.3 *Air Content of the Mortar Fraction*—When it is desired to know the air content of the mortar fraction of the mixture, calculate it as follows:

$$A_m = 100 A_s V_c \Big/ \left[100 V_m + A_s \left(V_c - V_m \right) \right] \qquad (7)$$

where (see Note 10):

A_m = air content of the mortar fraction, percent; and

V_m = absolute volume of the ingredients of the mortar fraction of the mixture, airfree, ft^3 (m^3).

Note 10—The values for use in Equations 6 and 7 are most conveniently obtained from data on the concrete mixture tabulated as follows for a batch of any size:

	Absolute Volume, ft^3 (m^3)	
Cement		
Water	____	
Fine aggregate	____	$V_m \} V_c$
Coarse aggregate No. 4 (4.75-mm) to $1^1/_2$ in. (37.5-mm)	____ ____	
Coarse aggregate $1^1/_2$-in. (37.5-mm)	____	V_a
Total	____	V_t

10. REPORT

10.1 *Report the following information*:

10.1.1 The air content of the concrete sample to the nearest 0.1 percent after subtracting the aggregate correction factor, unless the gauge reading of the meter exceeds 8 percent, in which case the corrected reading shall be reported to the nearest 1⁄2 scale division on the dial.

10.1.2 The date and time of the test.

10.1.3 When requested, and when the absolute volume of the ingredients of the mortar fraction of the mixture can be determined, the air content of the mortar fraction of the mixture to the nearest 0.25 percent.

11. PRECISION AND BIAS

11.1 *Precision*:

11.1.1 *Single-Operator Precision*—The single operator standard deviation cannot be established because the sample requirements for this test, as established in T 141, do not allow a single operator time to conduct more than one test on a sample.

11.1.2 *Multilaboratory Precision*—The multilaboratory standard deviation has not been established.

11.1.3 *Multi-Operator Precision*—The multi-operator standard deviation of a single test has been found to be 0.28 percent air by volume of concrete for Type A air meter as long as the air content does not exceed 7 percent. Therefore, results of the two tests properly conducted by different operators but on the same materials should not differ by more than 0.8 percent air by volume of concrete. (See ASTM E 177, Notes 11 and 12).

Note 11—These numbers represent, respectively the (1s) and (d2s) limits as described in ASTM C 670. The precision statements are based on the variation in tests on three different concretes, each tested by eleven different operators.

Note 12—The precision of this test method using Type B air meters has not been determined.

11.2 *Bias*—This test method has no bias because the air content of freshly mixed concrete can only be defined in terms of the test methods.

12. KEYWORDS

12.1 Air content; calibration; concrete; correction factor; measuring bowl; meter; pressure; pump; unit weight.

ANNEX

(Mandatory Information)

A1. CALIBRATION OF APPARATUS

A1.1. Calibration tests shall be performed in accordance with the following procedures as applicable to the meter type being employed.

A1.2. *Calibration of the Calibration Vessel*—Determine accurately the weight of water required to fill the calibration vessel, w, using a scale accurate to 0.1 percent of the weight of the vessel filled with water. This step shall be performed for Type A and B Meters.

A1.3. *Calibration of the Measuring Bowl*—Determine the weight of water required to fill the measuring bowl, W, using a scale accurate to 0.1 percent of the weight of the bowl filled with water. Slide a glass plate carefully over the flange of the bowl in a manner to ensure that the bowl is completely filled with water. A thin film of cup grease smeared on the flange of the bowl will make a watertight joint between the glass plate and the top of the bowl. This step shall be performed for Types A and B meters.

A1.4. *Effective Volume of the Calibration Vessel, R*—The constant R represents the effective volume of the calibration vessel expressed as a percentage of the volume of the measuring bowl.

A1.4.1. For Type A meters, calculate R as follows (Note A1):

$$R = 0.98\, w/W \tag{A1.1}$$

where:

w = weight of water required to fill the calibration vessel, and

W = weight of water required to fill the measuring bowl.

Note A1—The factor 0.98 is used to correct for the reduction in the volume of air in the calibration vessel when it is compressed by a depth of water equal to the depth of the measuring bowl. This factor is approximately 0.98 for an 8-in. (203-mm) deep measuring bowl at sea level. Its value decreases to approximately 0.975 at 5000 ft (1524 m) above sea level and 0.970 at 13000 ft (3962 m) above sea level. The value of this constant will decrease by about 0.01 for each 4 in. (102 mm) increase in bowl depth. The depth of the measuring bowl and atmospheric pressure do not affect the effective volume of the calibration vessel for Type B meters.

A1.4.2. For Type B meters, calculate R as follows (Note A1):

$$R = w/W \tag{A1.2}$$

A1.5. *Determination of, or Check of, Allowance for Expansion Factor, D*:

A1.5.1. For meter assemblies of Type A, determine the expansion factor, *D* (Note A2) by filling the apparatus with water only (making certain that all entrapped air has been removed and the water level is exactly on the zero mark (Note A3) and applying an air pressure approximately equal to the operating pressure, *P*, determined by the calibration test described in Section A1.7. The amount the water column lowers will be the equivalent expansion factor, *D*, for that particular apparatus and pressure (Note A5).

Note A2—Although the bowl, cover, and clamping mechanism of the apparatus must of necessity be sturdily constructed so that it will be pressure-tight, the application of internal pressure will result in a small increase in volume. This expansion will not affect the test results because, with the procedure described in Sections 6 and 8, the amount of expansion is the same for the test for air in concrete as for the test for aggregate correction factor on combined fine and coarse aggregates, and is thereby automatically cancelled. However, it does enter into the calibration test to determine the air pressure to be used in testing fresh concrete.

Note A3—The water columns on some meters of Type A design are marked with an initial water level and a zero mark, the difference between the two marks being the allowance for the expansion factor. This allowance should be checked in the same manner as for meters not so marked and in such a case, the expansion factor should be omitted in computing the calibration readings in Section A1.7.

Note A4—It will be sufficiently accurate for this purpose to use an approximate value for *P* determined by making a preliminary calibration test as described in Section A1.7 except that an approximate value for the calibration factor, *K*, should be used. For this test $K = 0.98R$ which is the same as Equation A1.2 except that the expansion reading, *D*, as yet unknown, is assumed to be zero.

A1.5.2. For meters of Type B design, the allowance for the expansion factor, *D*, is included in the difference between the initial pressure indicated on the pressure gauge and the zero percent mark on the air-content scale on the pressure gauge. This allowance shall be checked by filling the apparatus with water (making certain that all entrapped air has been removed), pumping air into the air chamber until the gauge hand is stabilized at the indicated initial pressure line, and then releasing the air to the measuring bowl (Note A5). If the initial pressure line is correctly positioned, the gauge should read zero percent. The initial pressure line shall be adjusted if two or more determinations show the same variation from zero percent and the test repeated to check the adjusted initial pressure line.

Note A5—This procedure may be accomplished in connection with the calibration test described in Section A1.9.

A1.6. *Calibration Reading, K*—The calibration reading, *K*, is the final meter reading to be obtained when the meter is operated at the correct calibration pressure.

A1.6.1. For Type A meters, the calibration reading, K, is as follows:

$$K = R + D \tag{A1.3}$$

where:

R = effective volume of the calibration vessel (Section A1.4.1), and

D = expansion factor (Section A1.5.1, Note A6).

A1.6.2. For Type B meters, the calibration reading, *K*, equals the effective volume of the calibration vessel (Section A1.4.2) as follows:

$$K = R \tag{A1.4}$$

Note A6—If the water column indicator is graduated to include an initial water level and a zero mark, the difference between the two marks being equivalent to the expansion factor, the term *D* shall be omitted from Equation A1.4.

A1.7. *Calibration Test to Determine Operating Pressure, P, on Pressure Gauge, Type A Meter*—If the rim of the calibration cylinder contains no recesses or projections, fit it with three or more spacers equally spaced around the circumference. Invert the cylinder and place it at the center of the dry bottom of the measuring bowl. The spacers will provide an opening for flow of water into the calibration cylinder when pressure is applied. Secure the inverted cylinder against displacement and carefully lower the cover assembly. After the cover is clamped in place, carefully adjust the apparatus assembly to a vertical position and add water at air temperature, by means of the tube and funnel, until it rises above the zero mark on the standpipe. Close the vent and pump air into the apparatus to the approximate operating pressure. Incline the assembly about 30 degrees from vertical and, using the bottom of the bowl as a pivot, describe several complete circles with the upper end of the standpipe, simultaneously tapping the cover and sides of the bowl lightly to remove any entrapped air adhering to the inner surfaces of the apparatus. Return the apparatus to a vertical position, gradually release the pressure (to avoid loss of air from the calibration vessel) and open the vent. Bring the water level exactly to the zero mark by bleeding water through the petcock in the top of the conical cover. After closing the vent, apply pressure until the water level has dropped an amount equivalent to about 0.1 to 0.2 percent of air more than the value of the calibration reading, *K*, determined as described in Section A1.6. To relieve local restraints, lightly tap the sides of the bowl and when the water level is exactly at the value of the calibration reading, *K*, read the pressure, *P*, indicated by the gauge and record to the nearest 0.1 psi (690 kPa). Gradually release the pressure and open the vent to determine whether the water level returns to the zero mark when the sides of the bowl are tapped lightly (failure to do so indicates loss of air from the calibration vessel or loss of water due to a leak in the assembly). If the water level fails to return to within 0.05 percent air of the zero mark and no leakage beyond a few drops of water is found, some air probably was lost from the calibration cylinder. In this case, repeat the calibration procedure step-by-step from the beginning of this paragraph. If the leakage is more than a few drops of water, tighten the leaking joint before repeating the calibration procedure. Check the indicated pressure reading promptly by bringing the water level exactly to the zero mark, closing the vent, and applying pressure, *P*, just determined. Tap the gauge lightly with a finger. When the gauge indicates the exact pressure, *P*, the water column should read the value of the calibration factor, *K*, used in the first pressure application within about 0.05 percent of air.

Note A7—**Caution**: The apparatus assembly must not be moved from the vertical position until pressure has been applied which will force water about one-third of the way up into the calibration cylinder. Any loss of air from this cylinder will nullify the calibration.

A1.8. *Calibration Test to Determine Alternative Operating Pressure P_1—Type A Meter*—The range of air contents which can be measured with a given meter can be doubled by determining an alternative operating pressure P_1 such that the meter reads half of the calibration reading, *K*, (Equation A1.3). Exact calibration will require determination of the expansion factor at the reduced pressure in Section A1.5. For most purposes the change in expansion factor can be disregarded and the alternative operating pressure determined during the determination of the regular operating pressure in Section A1.7.

A1.9. *Calibration Test to Check the Air Content Graduations on the Pressure Gauge, Type B Meter*—Fill the measuring bowl with water as described in Section A1.3. Screw the short piece of tubing or pipe furnished with the apparatus into the threaded petcock hole on the underside of the cover assembly. Assemble the apparatus. Close the air valve between the air chamber and the measuring bowl and open the two petcocks on holes through the cover assembly. Add water through the petcock on the cover assembly having the extension below until all air is expelled from the second petcock. Pump air into the air chamber until the pressure reaches the indicated initial pressure line. Allow a few seconds for the compressed air to cool to normal temperature. Stabilize the gauge hand at the initial pressure line by pumping or bleeding off air as necessary, tapping the gauge lightly. Close the petcock not provided with the tube or pipe extension on the under side of the cover. Remove water from the assembly to the calibrating vessel controlling the flow, depending on the particular meter design, by opening the petcock provided with the tube or pipe extension and cracking the air valve between the air chamber and the measuring bowl, or by opening the air valve and using the petcock to control flow. Perform the calibration at an air content that is within the normal range of use. If the calibration vessel (Section A1.2) has a capacity within the normal range of use, remove exactly that amount of water. With some meters the calibrating vessel is quite small and it will be necessary to remove several times that volume to obtain an air content within the normal range of use. In this instance, carefully collect the water in an auxiliary container and determine the amount removed by weighing to the nearest 0.1 percent. Calculate the correct air content, R, by using Equation A1.2. Release the air from the apparatus at the petcock not used for filling the calibration vessel and if the apparatus employs an auxiliary tube for filling the calibration container, open the petcock to which the tube is connected to drain the tube back into the measuring bowl (Note A7). At this point of procedure the measuring bowl contains the percentage of air determined by the calibration test of the calibrating vessel. Pump air into the air chamber until the pressure reaches the initial pressure line marked on the pressure gauge, close both petcocks in the cover assembly, and then open the valve between the air chamber and the measuring bowl. The indicated air content on the pressure gauge dial should correspond to the percentage of air determined to be in the measuring bowl. If two or more determinations show the same variation from the correct air content, the dial hand shall be reset to the correct air content and the test repeated until the gauge reading corresponds to the calibrated air content within 0.1 percent. If the dial hand was reset to obtain the correct air content, recheck the initial pressure mark as in Section A1.5.2. If a new initial pressure reading is required, repeat the calibration to check the accuracy of the graduation on the pressure gauge described earlier in this section. If difficulty is encountered in obtaining consistent readings, check for leaks, for the presence of water inside the air chamber (Figure 2), or the presence of air bubbles clinging to the inside surfaces of the meter from the use of cool, aerated water. In this latter instance, use deaerated water, which can be obtained by cooling hot water to room temperature.

Note A8—If the calibrating vessel is an integral part of the cover assembly, the petcock used in filling the vessel should be closed immediately after filling the calibration vessel and not opened until the test is complete.

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[1] *Annual Book of ASTM Standards,* Vol. 14.02.

Standard Method of Test for

Water Retention by Liquid Membrane-Forming Curing Compounds for Concrete

AASHTO Designation: T 155-08
ASTM Designation: C 156-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Water Retention by Liquid Membrane-Forming Curing Compounds for Concrete

AASHTO Designation: T 155-08
ASTM Designation: C 156-05

1. SCOPE

1.1. This test method covers laboratory determination of the efficiency of liquid membrane-forming compounds for curing concrete, as measured by their ability to reduce moisture loss during the early hardening period.

1.2. The values stated in SI units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 85, Portland Cement
- T 71, Effect of Organic Impurities in Fine Aggregate on Strength of Mortar

2.2. *ASTM Standards*:
- C 230/C 230M, Standard Specification for Flow Table for Use in Tests of Hydraulic Cement
- C 305, Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
- C 778, Standard Specification for Standard Sand
- D 1475, Standard Test Method For Density of Liquid Coatings, Inks, and Related Products
- D 1644, Standard Test Methods for Nonvolatile Content of Varnishes
- D 1653, Standard Test Methods for Water Vapor Transmission of Organic Coating Films
- D 2369, Standard Test Method for Volatile Content of Coatings
- E 178, Standard Practice for Dealing With Outlying Observations

3. SIGNIFICANCE AND USE

3.1. The moisture retaining ability of a product as determined by this test method is used to assess the suitability of materials for contributing to an appropriate curing environment for concrete. The laboratory test method is used both in formulating and in specifying or qualifying curing products. This test method gives the user a measure of the ability of tested curing materials to impede the escape of moisture from a hydraulic cement mortar. Since it is desirable to retain moisture in fresh concrete to promote the hydration process, failure of the product to minimize the escape of moisture may lead to loss of strength, cracking, shrinkage, or low abrasion resistance of the hardened concrete, or a combination thereof.

3.2. Many factors affect the laboratory test results. Test results obtained may be highly variable as indicated by the precision statement. Critical factors include the precision of the control of the temperature, humidity, and air circulation in the curing cabinet; preparation and sealing of the mortar specimens, the age and surface condition of the mortar specimen when the curing product is applied; and the uniformity and quantity of application of the curing membrane.

4. APPARATUS

4.1. *Mechanical Mortar Mixer*—as described in ASTM C 305, or a larger size mixer operating on the same principle.

4.2. *Molds*—Molds shall be made of metal, glass, hard rubber, or plastic, and shall be watertight and rigidly constructed to prevent distortion during molding of the specimens or handling the mold containing fresh mortar. They shall have a minimum surface area of 12000 mm^2 (18.6 in.), and a minimum depth of 19 mm ($^3/_4$ in.). The top surface shall be round, square, or rectangular with length not more than twice the width. The top of the mold shall have a rim to provide a firm level surface to support the wood float and to facilitate the grooving and sealing steps of the procedure. The rim shall be parallel with the bottom surface of the mold.

Note 1—Take care to avoid use of an excessive amount of oil, grease, or mold release compound on molds, particularly along the top rim where sealing compound will be applied. Use of masking tape on the top rim during application of release compound to prevent contamination has been found to be expedient.

4.3. *Gloves*—of rubber or plastic to be worn while molding the specimens.

4.4. *Tamper*—of a nonabsorptive, nonabrasive material such as medium-hard rubber or seasoned oak rendered non-absorptive by immersion for 15 minutes in paraffin at approximately 200ºC. The tamper shall be rectangular with a 25- by 50-mm (1- by 2-in.) cross section and it shall be a convenient length (150 to 300 mm (6 to 12 in.)).

4.5. *Wood Float*—approximately 75 by 280 by 20 mm thick (3 by 11 by $^3/_4$ in.).

Note 2—A commercial wood float equipped with a substantial handle can be readily reduced to these dimensions. The float shall be resurfaced or replaced when there is noticeable wear to the floating surface.

4.6. *Brush*—medium-soft bristle 50-mm (2-in.) paintbrush to brush the surface of the specimens prior to sealing.

4.7. *Curing Cabinet*—maintained at a temperature of 37.8 ± 1.1ºC (100 ± 2ºF) and a relative humidity of 32 ± 2 percent. The curing cabinet shall be of a design that allows movement of conditioned air such that the solvent from the curing compound will be readily evaporated and eliminated from the system. Air circulation shall be equivalent for all specimens.

4.8. *Balance*—having a capacity to determine the mass of a filled specimen mold to the nearest 0.1 g or less.

4.9. *Applicator*—For spray application, any apparatus that can be used to apply the curing compound uniformly and with minimum overspray is acceptable. For brush or roller application, use the equipment recommended by the curing compound manufacturer.

4.10. *Spoon*—A stainless steel serving spoon having a bowl 75 to 100 mm (3 to 4 in.) long and 50 to 75 mm (2 to 3 in.) wide for transferring the mortar from the mixing bowl to the mold.

5. MATERIALS

5.1. Portland cement conforming to the requirements for Type 1 of M 85.

5.2. Graded standard sand conforming to the requirements of ASTM C 778.

5.3. Sealing compound that will not be affected by the curing material and that effectively seals against moisture loss between the boundary of the specimen and the edge of the mold.

Note 3—Issue embedding wax, readily available from scientific supply houses, is a convenient and reliable sealant.

6. CONDITIONING

6.1. The temperature of the room and of all materials when used in this test shall be 23 ± 2ºC (73 ± 4ºF) unless otherwise specified, and the room humidity shall be 50 ± 10 percent.

7. NUMBER OF SPECIMENS

7.1. A set of three or more test specimens shall be made in order to constitute a test of a given curing material.

Note 4—When more than one set of specimens is to be prepared, each set should be handled as a group throughout the preparation to make the elapsed time between molding and application of the curing product as uniform as possible. This may require mixing the mortar for each set separately.

7.2. For determining the quantity of curing compound to be applied (MA), calculate the total top surface area of the specimen, including the seal and the rim of the mold, in square millimeters using appropriate geometric formulae.

Note 5—The area (A) used in calculating the mass loss per unit area (L) is calculated in Section 4.2 from the surface dimensions measured inside the seal of the specimen.

8. PROPORTIONING AND MIXING MORTAR

8.1. *Proportioning*—Determine the sand content of the mortar by adding dry sand to a cement paste having a water-cement ratio of 0.40 by weight, to produce a flow of 35 ± 5 in 10 drops. Determine the flow in accordance with T 71. Discard the mix used to determine the proportion of sand to cement.

Note 6—This mix is discarded because it is thought that the age and the mixing history of the mortar where the curing compound is applied, measured from the first addition of water, affects the final results and must be controlled.

8.2. *Mixing*—Combine the components of the mortar in a mortar-mixing machine to produce a homogeneous mortar not more than 6 minutes from the time the water and the cement are combined.

Note 7—A generally effective sequence is to add the cement to all of the water in the mixing bowl and allow it to stand for 30 seconds. Then, mix at low speed for 30 seconds and, without stopping the mixer, add the sand within 30 seconds and continue mixing for 1 minute. Stop the mixer for 1 minute. During the first 15 seconds, scrape down the sides of the bowl. Finish by mixing for an additional 1 minute, and promptly begin molding the specimens.

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9. PREPARING SPECIMENS

9.1. Thoroughly clean the molds before each use. Use of a mold release is acceptable provided that care is taken to avoid its application to the top rim of the mold to prevent interference with sealing of the edge.

9.2. Half fill the mold and spread the mortar with the back of the spoon to create a layer of approximately uniform thickness. Tamp over the entire surface with one stroke of the 25 by 50 mm (1 by 2 in.) face of the tamper per 1000 mm^2 of surface area rounded to the nearest integer. Place a second layer of mortar, sufficient in amount to slightly overfill the mold, and tamp in a similar manner. Using the 25-mm (1-in.) wide by 150- to 300-mm (6- to 12-in.) long edge of the tamper, fill the indentations made by the tamping and level the surface by pressing down firmly with a series of contacts across the entire surface. Strike off the specimen level with the top of the mold using a wood float with one pass only, in the direction of the long axis of the specimen for rectangular molds, using a sawing motion of the float. Keep the 75-mm (3-in.) face of the float firmly in contact with the mortar and edges of the mold so the float creates a uniformly dense surface free of voids and cracks.

9.3. Immediately after molding, wipe the outside surfaces of the molds clean and then place the specimens in the curing cabinet maintained at the conditions specified in Section 4.9. The specimens shall be level and not subject to vibration. The spacing between the individual specimens and between the specimens and the side walls of the cabinet shall be between 50 and 175 mm (2 to 7 in.). Within these limits, the spacing shall be the same for all specimens. Use dummy specimens to fill any empty spaces in the cabinet.

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10. SURFACE PREPARATION AND EDGE SEALING

10.1. Remove the specimens from the cabinet immediately upon disappearance of the surface water and lightly brush the surface using sufficient force to remove the laitance and glaze but not so as to scarify the mortar surface. If surface water appears upon brushing, return the specimen to the cabinet. When the water brought to the surface by the brushing operation disappears, immediately remove the specimen and then brush again. The mortar shall be free of surface water but shall not be dry below the surface. The proper surface condition will be attained when brushing does not bring free water to the surface or does not produce smearing when rubbing an area with the fingertip.

Note 8—The exposure time in the cabinet and the initial moisture loss that will result in the proper surface condition is characteristic of the curing cabinet used and other testing conditions related to the laboratory performing the test. Uniformity of test surface conditions may be maintained by setting an expected exposure time or initial moisture loss. When any test condition is changed (sand, cement, or the like), a new exposure time or initial moisture loss, or both, shall be determined.

10.2. Form a V-shaped groove approximately 3 mm ($^1/_8$ in.) deep and not more than 3 mm ($^1/_8$ in.) wide between the edge of the mortar specimen and the mold. Fill the groove with the sealing compound. The sealing compound shall not extend more than 6 mm ($^1/_4$ in.) from the edge of the mold onto the surface of the specimen.

Note 9—To cut out the groove for sealing, the tip of a pointed trowel, a pointed spatula, a pointed triangular can opener, or a "hawksbill point" ground on the end of a spatula or knife blade have all been reported to be effective.

11. APPLICATION OF CURING MATERIAL

11.1. *Liquid Membrane-Forming Compounds*:

11.1.1. Calculate the mass of the curing compound to be applied (*MA*) to the nearest 0.1 g based on the specified application rate, the total surface area calculated per Section 7.2, and the density of the curing compound determined in accordance with ASTM D 1475. If no rate is specified, apply the curing compound at the rate of 0.2 L/m^2 (gal/200 ft^2). The method of application shall be in accordance with the manufacturer's recommendations.

11.1.2. Immediately after sealing, weigh the specimen to the nearest 0.1 g (M_1), then uniformly apply the curing compound at the specified rate of application. Application shall be made expeditiously to only one specimen at a time.

Note 10—It is desirable to use a spray booth or a laboratory hood to control overspray and solvent fumes especially for curing compounds that are sprayed. However, the velocity of air movement in the vicinity of the specimen must be kept at a minimum so as to prevent, as much as possible, significant loss of volatiles during spraying and before the final weighing. Spraying shall be accomplished with the minimum pressure and flow rate of air with which an acceptable spray pattern can be attained.

11.1.3. Determine the proper coverage by comparing the initial mass of the specimen (M_1), before applying the curing compound to the mass after coating. The final mass shall equal the initial mass of the specimen plus the predetermined mass of the curing compound to be applied. This will necessitate frequent weighing of the specimen during application as full coverage is approached. In the case of brush application, proper coverage may be determined by weighing the container, brush, and curing compound before and after application of the compound to the specimen. Total time for application shall not exceed 2 minutes. Weigh to the nearest 0.1 g (M_2). If the final amount of curing compound applied differs from the calculated amount for the specified coverage by more than 10 percent, the sample shall be discarded.

Note 11—In previous versions of this test method, coverage was determined by weighing the application equipment and the curing compound before and after application to the specimen. Which method is more precise has not been established.

11.2. Return the specimens to the cabinet without delay.

Note 12—Unusual loss caused by a leaking mold or a faulty seal may be detected by weighing the specimens 3 to 4 hours after application of the curing material. If one specimen has lost considerably more than the others, this specimen is probably faulty. If only three specimens are being tested, consider the test invalid. (See Section 14.4.)

12. DETERMINATION OF NON-VOLATILE CONTENT OF CURING COMPOUNDS

12.1. Determine the proportion of non-volatile matter in the curing compound (*NV*) in accordance with ASTM D 1644.

Note 13—Previous versions of this test method required that non-volatile content be determined by coating a metal pan, or plate, of known mass having an area equal to that of the top of the test specimen with the same mass of curing compound as used on the specimen, placing the sample in the curing cabinet with the test specimens, and weighing at the conclusion of the test.

13. DURATION OF TEST

13.1. Specimens shall be stored in the test cabinet for 72 hours, then removed, and immediately weighed (M_3). Other test times may be specified by the purchaser.

14. CALCULATIONS

14.1. *Loss of Mass*:

14.1.1. Calculate the loss of mass from each specimen in grams as follows:

$$ML = M_1 + \left(NV \times MA\right) - M_3 \qquad (1)$$

where:

ML = mass loss of the sample, g;

M_1 = mass of the sealed sample, g;

NV = proportion of non-volatile matter in the curing compound, g;

MA = mass of the curing compound applied, $g = M_2 - M_1$;

M_2 = mass of the sample immediately after applying curing compound, g; and

M_3 = mass of sample at the conclusion of the test, g.

14.2. *Specimen Area*:

14.2.1. Calculate the area of the specimen (A) in square millimeters by measuring the dimensions of the surface from the inner edges of the seal to the nearest millimeter and applying the appropriate geometric formula.

14.3. For each specimen, calculate the mass loss per unit area (L) in kg/m^2 as:

$$L = 1000 \times ML/A \qquad (2)$$

14.4. *Rejection of Results*:

14.4.1. In a set of three or more specimens, if the difference in moisture loss between the specimen having the greatest loss and that with the least loss exceeds 0.15 kg/m^2, the test shall be repeated and the average taken as that of all specimens in the original and repeat tests. If, after the repeat test, it is determined that the result on a single specimen, whether from the original or repeat test, meets the criteria for rejection as an outlier as given in ASTM E 178, such value shall be disregarded and a new average calculated that does not include such outlying value.

15. REPORT

15.1. The report shall include the following information for the materials tested:

15.1.1. Manufacturer's name, address, and brand designation;

15.1.2. Type of curing material;

15.1.3. Manufacturer's batch number;

15.1.4. Quantity of material represented by the sample;

15.1.5. Date sampled; and

15.1.6. Source of the sample.

15.2. The report shall include the following information regarding the test:

15.2.1. Laboratory sample identification,

15.2.2. Brand of cement used,

15.2.3. Proportions of mortar by weight,

15.2.4. Method of application,

15.2.5. Duration of the test,

15.2.6. Rate of application (membrane-forming compounds), and

15.2.7. Average loss of water per unit area.

16. PRECISION AND BIAS

16.1. *Precision*—Efforts to establish a more meaningful measure of the precision of this test method continue. The previous version of this test method, containing some differences in testing technique, contained a precision statement.[1] The single-operator standard deviation was reported as 0.13 kg/m^2 and the multilaboratory standard deviation as 0.30 kg/m^2.

16.2. *Bias*—Since there is no accepted reference material suitable for determining the bias of this test method, no statement on bias is being made.

17. KEYWORDS

17.1. Concrete curing materials; liquid membrane-forming curing compounds; moisture retention by concrete curing materials.

ANNEX

(Mandatory Information)

A1. STANDARDIZATION OF EVAPORATION RATE IN TEST CABINETS

A1.1. This procedure provides a means for measuring the rate of evaporation of water from a standard surface in order to characterize a controlled set of environmental conditions (temperature, humidity, air circulation) by providing a system that will lose water at a nearly constant rate for a period of time long enough to establish a characteristic rate. Comparison of results from different positions in the same cabinet can establish whether or not conditions are uniform throughout the cabinet. Comparisons between labs may help to rationalize differing results.

A1.2. *Apparatus:*

A1.2.1. *Cup*—A permeability cup, conforming to the specifications of ASTM D 1653.

A1.2.2. *Filter Paper*—7-cm disks.

A1.2.3. *Absorbent Filler*—Absorbent cotton balls.

A1.2.4. *Mold Cover*—Stiff cardboard or sheet metal plate having the same dimensions as the top of the specimen mold and having a 63-mm ($2^1/_2$-in.) diameter hole in its center.

A1.2.5. *Balance*—Any balance having a capacity of 200 g or more and a sensitivity and accuracy of 0.01 g or less.

A1.3. *Procedure*:

A1.3.1. Fill the permeability cup with the absorbent filler using three cotton balls pulled together to make a uniform sponge. Fill the cup with distilled water, lay a disk of filter paper over the cup, and complete assembly of the cup. Place the mold cover on top of an empty specimen mold and fasten it in place with masking tape. Put the cup in the hole in the center of the mold. Place the mold and cup in the test cabinet in the position to be tested and allow 1 hour for it to reach temperature equilibrium. Determine the mass of the cup to the nearest 0.01 g and immediately return it to the cabinet. Reweigh at approximately 1 hour intervals for 5 to 7 hours. Record the mass and the total elapsed time to the nearest 2 minutes for each interval.

A1.4. *Calculation*:

A1.4.1. Calculate the total mass loss at each time interval as follows:

$$L = m_i - m_t \qquad (3)$$

where:

L = cumulative mass loss,

m_i = initial mass, and

m_t = mass at time t.

A1.4.2. Plot the cumulative mass loss (L) versus elapsed time (t) and determine the slope for the test period. Report calculated by a "least squares" method. (The rate of loss should be nearly constant throughout the test period.)

A1.5. *Precision and Bias*:

A1.5.1. *Precision*—Data for a precision statement are being collected.

A1.5.2. *Bias*—This test method has no bias because the evaporation rate is defined only in terms of this test method.

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[1] See Test Method C 156-80a, *1987 Annual Book of ASTM Standards*, Vol. 04.02,

Standard Method of Test for

Air-Entraining Admixtures for Concrete

AASHTO Designation: T 157-06
ASTM Designation: C 233-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Air-Entraining Admixtures for Concrete

AASHTO Designation: T 157-06
ASTM Designation: C 233-04

1. SCOPE

1.1. This method covers the testing of materials proposed for use as air-entraining admixtures in the field.

1.2. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information purposes only.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4. The text of this standard references notes and footnotes that provide explanatory materials. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 154, Air-Entraining Admixtures for Concrete
- M 240, Blended Hydraulic Cement
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 2, Sampling of Aggregates
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 97, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- T 105, Chemical Analysis of Hydraulic Cement
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 137, Air Content of Hydraulic Cement Mortar
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 158, Bleeding of Concrete
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete
- T 161, Resistance of Concrete to Rapid Freezing and Thawing

- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
- T 197M/T 197, Time of Setting of Concrete Mixtures by Penetration Resistance
- T 200, pH of Aqueous Solutions with the Glass Electrode

2.2. *ASTM Standards*:

- C 33, Standard Specification for Concrete Aggregates
- C 136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
- C 185, Standard Test Method for Air Content of Hydraulic Cement Mortar
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 1157, Standard Performance Specification for Hydraulic Cement
- D 75, Standard Practice for Sampling Aggregates
- D 1193, Standard Specification for Reagent Water
- D 1429, Standard Test Methods for Specific Gravity of Water and Brine
- E 100, Standard Specification for ASTM Hydrometers
- *Manual of Aggregate and Concrete Testing*

2.3. *ACI Standard*:

- ACI 211.1-91, Recommended Practice for Selecting Proportions for Normal, Heavy-Weight and Mass Concrete

3. SIGNIFICANCE AND USE

3.1. This test method is used to develop data for comparison with the requirements of M 154. These tests are based on arbitrary stipulations permitting highly standardized testing in the laboratory,and are not intended to simulate actual job conditions.

4. MATERIALS

4.1. *Cementitious Material*—The cementitious material used in any series of tests shall meet any of the following:

- The cementitious material proposed for specific work in accordance with Section 4.4, portland cement conforming to the specifications for either Type I, Type II, or Type III M 85 hydraulic cement, conforming to the specification of ASTM C 1157;
- Blended hydraulic cement conforming to the specification of M 240. If a blend of cements is used, it shall be a combination that produces an air content of less than 10 percent when tested in accordance with T 137 (Note 3).

4.2. *Aggregates*—Except when tests are made in accordance with Section 4.4, using the aggregates proposed for specific work, the fine and coarse aggregates used in any series of tests shall come from single lots of well-graded, sound materials that conform to the requirements of M 6 and M 80, except that the grading of the aggregates shall conform to the following requirements:

4.2.1. *Fine Aggregate Grading*—The fine aggregate shall meet the requirements for the fine aggregate in ASTM C 33.

Sieve	Percentage Passing
4.75 mm (No. 4)	100
1.18 mm (No. 16)	65 to 75
0.300 mm (No. 50)	15 to 20
0.150 mm (No. 100)	2 to 5

4.2.2. *Coarse Aggregate Grading*—The coarse aggregate shall meet the requirements for Size 57 of ASTM C 33.

Note 1—Take care in loading and delivery to avoid segregation.

4.2.3. The coarse aggregate used for each set of reference concrete and comparable test admixture-treated concrete shall be essentially the same. Therefore, a set of test concrete consists of one reference concrete and as many test admixture-containing concretes as are intended to be compared to that one reference. Thus, coarse aggregate for one set shall consist of enough material for one reference concrete, the test admixture-containing concrete to be compared with that reference, and the sample for grading analysis testing.

4.2.3.1 Prepare coarse aggregate for a set, comprising a sample large enough for concrete trials, as follows: fill tared containers, one each for a sample, a batch of reference concrete, and one or more test concretes to the required mass from the aggregate stockpile. Accomplish this by starting with a scoopful into the first container and repeat this procedure until all containers have the required mass. Repeat the process for each of the three or more sets needed. One or more spare sets may be needed. See the Appendix of ASTM D 75, Practice for Sampling Aggregates, and the *Manual of Aggregate and Concrete Testing* (See *Annual Book of ASTM Standards*, Vol. D 4.02.) for guidance for conditions and procedures.

4.2.4. Test coarse aggregate samples representing each set by ASTM C 136 requirements for the sieves shown below. Discard any set for which the sample does not comply with Size 57. Average test results for samples that comply with Size 57 for each sieve size. Discard any set for which the sample deviates from this average by more than the amount shown in Column 3. Continue the process of preparation, testing, and averaging until sufficient sets of aggregate within tolerance are obtained.

Sieve	Specification C 33, No. 57 Percent Passing	Maximum Variation from Average/Passing
37.5 mm	100	00
25.0 mm	95 to 100	1.0
12.5 mm	25 to 60	4.0
4.75 mm	0 to 10	4.0
2.36 mm	0 to 5	1.0

Note 2—All of the results required for demonstrating compliance under this specification are dependent on the uniformity of the aggregate samples prepared and used. Careful, skilled, and well-supervised work is essential.

4.3. *Reference Admixture*—For this method, unless otherwise requested by the purchaser, the reference admixture used in the concrete mixture specified in Section 5 shall be "neutralized Vinsol resin."[1]

4.4. *Materials for Tests for Specific Uses*—When it is desired to test an air-entraining admixture for use in specific work, the cementitious material and aggregates used should be representative of those proposed for use in the work, and the concrete mixtures should be designed to have the cementitious material content specified for use in the work (Note 3). If the maximum size of coarse aggregate is greater than 25.0 mm (1 in.), the freshly mixed concrete shall be screened over a 25.0-mm (1-in.) sieve prior to fabricating the test specimens in accordance with the wet sieving procedure described in T 141. When other admixtures are intended to be used in the production of concrete, they should be included in the trial batch.

4.5. *Preparation and Mass Determination*—All materials shall be prepared and all mass determinations shall be made as prescribed in R 39.

Note 3—It is recommended that whenever practicable, tests be made in accordance with Section 4.4 using the cementitious materials and chemical admixtures, if any, proposed for specific work.

5. CONCRETE MIXTURES

5.1. *Proportions*—Using ACI 211.1-91, all concrete shall be proportioned to conform to the following requirements:

5.1.1. The cement content shall be 307 ± 3 kg/m^3 (517 ± 5 lb/yd^3) except when tests are being made for specific uses (Section 4.4).

5.1.2. The first trial mixture shall contain the amount of coarse aggregate shown in Table 6.3.6 of ACI 211.1-91 for the maximum size of aggregate and for the fineness modulus of the sand being used.

Note 4—The volumes of coarse aggregate in Table 6.3.6 of ACI 211.1-91 are intended to assure workable mixtures with the least favorable combinations of aggregate likely to be used. It is suggested, therefore, that for a closer approximation of the proportions required for this test, the recommended values selected from Table 6.3.6 be increased by about 7 percent for the first trial mixture.

5.1.3. The air content used in the computation of proportions for all concrete shall be 5.5 percent except where the admixture under test is for use in specific work (Section 4.4). In this case the air content used in selecting proportions shall be the median of the range to be permitted in the work. If lightweight aggregates are to be used in specific work, the unit mass of concrete used in selecting proportions shall be the median of the range permitted in the work.

5.1.4. The water content and sand content shall be adjusted to obtain a slump of 89 ± 13 mm (3.5 ± 0.5 in.). The workability of the concrete mixture shall be suitable for consolidation by hand rodding and the concrete mixture shall have the minimum water content possible. These conditions shall be achieved by final adjustments in the proportion of fine aggregate to total aggregate, in the amount of total aggregate, or both, while maintaining the yield and slump in the required ranges.

5.2. *Conditions*—Concrete mixtures shall be prepared both with the air-entraining admixture under test and with the reference admixture. The admixtures shall be added in the amounts necessary to produce the air content selected in accordance with Section 5.1.3 within a tolerance of ±0.5 percent of the volume of concrete.

6. MIXING

6.1. Machine mix the concrete as prescribed in R 39.

7. TESTS AND PROPERTIES OF FRESHLY MIXED CONCRETE

7.1. Test samples of freshly mixed concrete from at least three separate batches for each condition of concrete in accordance with the following methods. The minimum number of tests shall be as prescribed in Table 1.

7.1.1. *Slump*—Refer to T 119M/T 119.

7.1.2. *Air Content*—Refer to T 152. When lightweight aggregates, air-cooled blast furnace slag, or aggregates are used under the provisions of Section 4.4, use T 196M/T 196.

7.1.3. *Bleeding*—Refer to T 158.

7.1.4. *Time of Setting*—Refer to T 197M/T 197, except that the temperature of each of the ingredients of the concrete mixtures, just prior to mixing, and the temperature at which the time of setting specimens are stored during the test period shall be 23.0 ± 1.7ºC (73.4 ± 3ºF).

Table 1—Types and Minimum Number of Specimens and Tests

Test	Number of Types of Specimens[a]	Number of Test Ages	Number of Conditions of Concrete[b]	Minimum Number of Specimens
Slump	1	1	2	[c]
Air content	1	1	2	[c]
Bleeding	1	1	2	6
Time of setting	1	[d]	2	6
Compressive strength	1	3	2	18
Flexural strength	1	3	2	18
Freezing and thawing	1	1	2	12[e]
Length change	1	1	2	6

[a] See Sections 7 and 9.2.

[b] See Section 4.2.

[c] Determined on each batch of concrete mixed.

[d] See Section 7.1.4.

[e] Specimens for duplicate tests from each batch.

8. PREPARATION OF TEST SPECIMENS

8.1. Specimens for tests of hardened concrete, representing each test and age of test and each condition of concrete being compared, shall be made from at least three separate batches, and the minimum number of specimens shall be as prescribed in Table 1. On a given day, at least one specimen shall be made for each test and age of test from each condition of concrete except that at least two specimens for the freezing and thawing test shall be made from each condition of concrete. The preparation of all specimens shall be completed in 3 days of mixing.

8.2. *Manifestly Faulty Specimens*—Each group of specimens representing a given test or a given age of test, including tests of freshly mixed concrete, shall be examined visually before or during the test, or both, whichever is appropriate. Discard any specimens found to be manifestly faulty by such examination without testing. Visually examine all specimens representing a given test at a given age after testing and should any specimen be found to be manifestly faulty, the test results thereof shall be disregarded. Should more than one specimen representing a given test at a given age be found manifestly faulty, either before or after testing, the entire test shall be disregarded and repeated. The test result reported shall be the average of the individual test results of the specimens tested or, in the event that one specimen or one result has been discarded, it shall be the average of the test results of the remaining specimens.

9. TEST SPECIMENS OF HARDENED CONCRETE

9.1. *Number of Specimens*—Make six or more test specimens for the freezing and thawing test and three or more test specimens for each other type of test and age of test specified in Table 1 for each condition of concrete to be compared.

9.2. *Types of Specimens*—Prepare specimens made from concrete with and without the air-entraining admixture under test in accordance with the following:

9.2.1. *Compressive Strength*—Make and cure test specimens in accordance with R 39.

9.2.2. *Flexural Strength*—Make and cure test specimens in accordance with R 39.

9.2.3. *Resistance to Freezing and Thawing*—Test specimens shall consist of prisms made and cured in accordance with the applicable requirement of R 39. Test specimen dimensions shall be as required by T 161. Make one set of specimens from the concrete mixture containing the air-entraining admixture under test and from the reference concrete mixture, the air content of each mixture being as specified in Section 5.2.

9.2.4. *Length Change*—Make and cure test specimens in accordance with T 160. The moist-curing period, including the period in the molds, shall be 14 days.

10. TESTS ON HARDENED CONCRETE

10.1. Test specimens of hardened concrete in accordance with the following methods:

10.1.1. *Compressive Strength*—Refer to T 22. Test specimens at ages 3, 7, 28, 56, and 180 days, and 1 year. Calculate the compressive strength of the concrete containing the admixture under test as a percentage of the compressive strength of the reference concrete as follows:

10.1.1.1 Divide the average compressive strength of the specimens made from the concrete containing the admixture under test at a given age of test by the average compressive strength of the specimens made from the reference concrete at the same age of test and then multiply the quotient by 100.

10.1.2. *Flexural Strength*—Refer to T 97. Test specimens at ages 3, 7, 28, 56, and 180 days, and 1 year. Calculate the flexural strength of the concrete containing the admixture under test as a percentage of the flexural strength of the reference concrete as follows:

10.1.2.1 Divide the average flexural strength of the specimens made from the concrete containing the admixture under test at a given age of test by the average flexural strength of the specimens made from the reference concrete at the same age of test and then multiply the quotient by 100.

10.1.3. *Resistance to Freezing and Thawing*—Procedure A of T 161. Place specimens under test at the age of 14 days.

10.1.4. *Length Change*—Refer to T 160. The drying period shall be 14 days.

10.1.5. The flexural strength and length change tests are applicable only when specifically required by the purchaser.

11. CHECK TESTS FOR UNIFORMITY

11.1. The check tests enumerated in M 154 in the section on Optional Uniformity Requirements shall be determined as follows:

11.1.1. *pH*—The pH of liquid air-entraining admixtures shall be determined in accordance with ASTM E 70. Non-liquid admixtures should be prepared in solution to determine pH. Unless there is reason to do otherwise, dissolve the material in water in the proportions specified for job use as shown on the package or in the manufacturer's instructions. The temperature of the check test sample shall be within ±1ºC (±2ºF) of that for the acceptance sample and preferably in the range of 21 to 27ºC (70 to 80ºF).

11.1.2. *Air Content of Mortar*—Using the same amounts of successive lots of air-entraining admixtures with the same cement, determine the air contents of mortars in accordance with T 137. The air-entraining admixture shall be combined with the mixing water prior to the start of the mixing procedure. The determinations for both the check test sample and acceptance sample should be made on the same day. Any changes in the air-entraining capacity of the acceptance sample as successive check tests are made should be noted.

12. PROCEDURE FOR RESIDUE BY OVEN DRYING

12.1. Determine the mass of an aluminum dish (about 57-mm diameter, 15-mm height, and about 1 g in mass) to the nearest 0.0001 g. Using a pipet, evenly distribute 1 mL of the liquid air-entraining admixture in the dish and determine the mass to the nearest 0.0001 g. Place the aluminum dish in a drying oven (Section 11.1.4.2); dry for 25 ± 2 minutes at 125 ± 1ºC (257 ± 2ºF). At the end of the drying period, transfer the aluminum dish to a desiccator, cool to room temperature, and determine its mass to the nearest 0.0001 g.

12.2. The drying oven shall be either a forced circulation type or one with provision for free access of air. There shall be precise control of temperature and time of drying so that the degree of volatilization of the material other than water from sample to sample will not vary.

12.3. *Calculation*:

12.3.1. Record the following masses:

M_1 = mass of aluminum dish and admixture prior to heating,

M_2 = mass of empty aluminum dish,

M_3 = $M_1 - M_2$ = mass of sample,

M_4 = mass of aluminum dish and dried residue, and

M_5 = $M_4 - M_2$ = mass of dried residue.

12.3.2. Calculate the residue by using the following equation:

$$\text{Residue by Oven Drying } (\%\text{ of mass}) = \left(M_5 \times 100\right) \Big/ M_3 \qquad (1)$$

13. REPORT

13.1. *Report the following information*:

13.1.1. Results of the tests specified in this method as compared with the requirements of M 154.

13.1.2. Brand name, manufacturer's name and lot number, character of the material, and quantity represented by the sample of the admixture under test.

13.1.3. Brand name, manufacturer's name, and other data on the reference admixture.

13.1.4. Brand name, manufacturer's name, type, and test data on the portland cement or cements used.

13.1.5. Description of and test data on the fine and coarse aggregate used.

13.1.6. Detailed data on the concrete mixtures used, including amounts and proportions of admixtures used, actual amounts of cementitious materials, water-cementitious material ratios, ratios of fine to total aggregate, consistency, and air content.

13.1.7. In reporting on check tests for uniformity, report both the initial and current air contents of mortar for the acceptance sample and the air content of the check test sample, all as determined by ASTM C 185.

14. PRECISION AND BIAS[2]

14.1. *Precision*:

14.1.1. The single-laboratory coefficient of variation of residue by oven drying has been found to be 0.79 percent. Therefore, the results of two properly conducted tests on the same material in the same laboratory should not differ by more than 2.24 percent of their average.[3]

Note 5—As an example, two tests conducted on the same material yield residues by oven drying of 6.14 percent and 6.04 percent, respectively. The average of these two measurements is 6.09 percent. The acceptable range of results is then 2.24 percent of 6.09 percent or ±0.136 percent. As the difference between 6.14 percent and 6.04 percent is 0.10 percent, the results are within the acceptable range.

14.1.2. The multilaboratory coefficient of variation of residue by oven drying has been found to be 2.35 percent. Therefore, the results of two properly conducted tests on the same material in different laboratories should not differ by more than 6.65 percent of their average.[3]

14.1.3. Other procedures referenced in this test method use results obtained from other AASHTO and ASTM test methods listed in the Referenced Documents section. Refer to these documents for their respective precision statements.

14.2. *Bias*—Since there is no accepted reference material suitable for determining the bias of this test method, no statement on bias is made.

15. KEYWORDS

15.1. Air content; air-entraining admixture; cement; concrete; pH; residue; specific gravity.

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[1] Vinsol resin is manufactured by Hercules, Inc., Wilmington, Delaware. Neutralization may be accomplished by treating 100 parts of the Vinsol with 9 to 15 parts of NaOH by mass. In an aqueous solution, the ratio of water to the resinate shall not exceed 12:1 by mass.

[2] A copy of the research report used to develop the precision statement is available by requesting Research Report RR: C09-1005 from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

[3] These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670.

Standard Method of Test for

Bleeding of Concrete

AASHTO Designation: T 158-09
ASTM Designation: C 232-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Bleeding of Concrete

AASHTO Designation: T 158-09
ASTM Designation: C 232-07

1. SCOPE

1.1. These test methods cover the determination of the relative quantity of mixing water that will bleed from a sample of freshly mixed concrete. Two test methods that differ primarily in the degree of vibration to which the concrete sample is subjected are included.

1.2. The two test methods are not expected to yield the same test results when samples of concrete from the same batch are tested by each method. When various concretes are to be compared, all the tests should be conducted using the same method, and the sample masses, if the batches are of similar unit weight, should not differ by more than 1 kg (2 lb).

1.3. The values stated in SI units are to be regarded as standard. The values in parentheses are provided for information purposes only.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SIGNIFICANCE AND USE

3.1. This test method provides procedures to be used for determining the effect of variables of composition, treatment, environment, or other factors in the bleeding of concrete. It may also be used to determine the conformance of a product or treatment with a requirement relating to its effect on bleeding of concrete.

3.2. *Method A*—For a sample consolidated by rodding only and tested without further disturbance, thus simulating conditions in which concrete, after placement, is not subjected to intermittent vibration.

3.3. *Method B*—For a sample consolidated by vibration and tested with further intermittent periods of vibration, thus simulating conditions in which concrete, after being placed is subjected to intermittent vibration.

METHOD A—SAMPLE CONSOLIDATED BY TAMPING

4. APPARATUS

4.1. *Container*—A cylindrical container of approximately 14 L (approximately $^1/_2$-ft^3) capacity, having an inside diameter of 255 ± 5 mm (10 ± $^1/_4$ in.) and an inside height of 280 ± 5 mm (11 ± $^1/_4$ in.). The container shall be made of metal having a thickness of 2.67 to 3.40 mm (0.105 to 0.134 in.) and shall be externally reinforced around the top with a 2.67 to 3.40 mm (0.105 to 0.134 in.) metal band, 40 mm (1$^1/_2$ in.) wide. The inside shall be smooth and free from corrosion, coatings, or lubricants.

4.2. *Scale*, of sufficient capacity to determine the mass of the load required with an accuracy of 0.5 percent. Balances or scales shall be calibrated at least annually or whenever there is a reason to question the accuracy of the equipment. Equipment not in operating condition or out of tolerance shall be marked as such and taken out of service until corrected.

4.3. *Pipet* or similar instrument, for drawing off free water from the surface of the test specimen.

4.4. *Glass Graduate*, of 100-mL capacity for collecting and measuring the quantity of water withdrawn.

4.5. *Tamping Rod*—A round, straight steel rod, 16 mm ($^5/_8$ in.) in diameter and approximately 610 mm (approximately 24 in.) in length, having the tamping end rounded to a hemispherical tip, the diameter of which is 16 mm ($^5/_8$ in.).

4.6. *Metal Beaker (Optional)*—A 1000-mL metal beaker for collecting the decanted supernatant water and sludge (Note 1).

4.7. *Balance (Optional)*—A balance sensitive to one gram for determining the mass of the decanted water and sludge (Note 1).

4.8. *Hot Plate (Optional)*—A small electric hot plate or other source of heat for evaporating decanted water (Note 1).

Note 1—The apparatus listed in Sections 4.6, 4.7, and 4.8 will be required if the procedure of measuring the amount of bleeding water recovered is one involving weighing, evaporation, and reweighing.

5. TEST SPECIMEN

5.1. For concrete made in the laboratory, prepare the concrete as described in R 39. For concrete made in the field, sample the concrete as described in T 141. The apparatus described in this method may be used with samples of concrete containing any size of aggregate graded up to and including a nominal maximum size of 50 mm (2 in.). Concrete containing aggregate larger than 50 mm (2 in.) in nominal maximum size shall be wet-sieved over a 37.5-mm ($1^1/_2$-in.) sieve and the test performed on a portion of the sample that passes through the sieve.

5.2. Fill the container with the concrete in accordance with T 121M/T 121, except that the container shall be filled to a height of 254 ± 3 mm (10 ± $^1/_8$ in.). Level the top surface of the concrete to a reasonably smooth surface by a minimum amount of troweling.

6. PROCEDURE

6.1. During the test, maintain the ambient temperature between 18 to 24ºC (65 and 75ºF). Immediately after troweling the surface of the specimen, record the time and determine the mass of the container and contents. Place the specimen and container on a level platform or floor free from noticeable vibration and cover the container to prevent evaporation of the bleed water. Keep the cover in place throughout the test, except when drawing off the water. Draw off (with pipet or similar instrument) the water that has accumulated on the surface, at 10-minute intervals during the first 40 minutes and at 30-minute intervals thereafter, until cessation of bleeding. To facilitate the collection of bleeding water, tilt the specimen carefully by placing a block approximately 50-mm (2-in.) thick under the one side of the container 2 minutes prior to each time the water is withdrawn. After the water is removed, return the container to a level position without jarring. After each withdrawal, transfer the water to a 100-mL graduate. Record the accumulated quantity of water after each transfer. When only the total volume of bleeding is desired to be determined, the periodic removal procedure may be omitted and the entire amount removed in a single operation. If it is desired to determine the mass of the bleeding water and to exclude the material present other than the water, carefully decant the contents of the cylinder into a metal beaker. Determine the mass and record the mass of the beaker and its contents. Dry the beaker and its contents to constant mass and record the final mass. The difference between the two masses, D, is equal to the mass of the bleeding water. The mass of the sludge may also be obtained, if desired, by initially determining the tare mass of the beaker.

7. CALCULATIONS

7.1. Calculate the volume of bleeding water per unit area of surface, V, as follows:

$$V = V_1/A \tag{1}$$

where:

V_1 = volume of bleeding water during the selected time interval, mL; and

A = area of exposed concrete, cm^2.

The comparative rate of bleeding can be determined as the test progresses by comparing the volume of bleeding water for each equal time interval.

7.2. Calculate the accumulated bleeding water, expressed as a percentage of the net mixing water contained within the test specimen, as follows:

$$C = (w/M) \times S \qquad (2)$$

$$\text{Bleeding, percent} = D/C \times 100 \qquad (3)$$

where:

C = mass of water in the test specimen, g;

M = total mass of batch, kg;

w = net mixing water (the total amount of water minus the water absorbed by the aggregates), kg;

S = mass of sample, g; and

D = mass of bleeding water, g, or total volume withdrawn from the test specimen in cubic centimeters multiplied by 1 g/mL^3.

METHOD B—SAMPLE CONSOLIDATED BY VIBRATION

8. APPARATUS

8.1. *Vibrating Platform*—A platform shall be provided upon which the filled container shall be mounted. The platform shall be equipped with a suitable device so that intermittent periods of vibration of reproducible duration, frequency, and amplitudes will be imparted to the specimen container as prescribed by Section 8. (See Figure 1.) Suitable vibration will be provided if there is bolted to the platform a 93-W ($^1/_8$-hp) electric motor, to the shaft of which a small eccentric whose mass is approximately 110 g is attached by means of a setscrew. The eccentric should be fabricated from cold-rolled stock in accordance with the details and dimensions shown in Figure 2. The hole through the eccentric is 13.5 mm ($^{17}/_{32}$ in.) or an appropriate size to accommodate the motor shaft. The platform should be supported on rubber supports resting on a concrete slab. The concrete slab should be separated from the floor by a layer of cork as shown in Figure 2.

8.2. *Timer*—A timing device, by means of which the periods of vibration provided to the platform and specimen in accordance with the provisions of Section 8 may be regulated.

8.3. *Container*—A steel container 290 mm (11$^1/_2$ in.) in diameter at the top, 279 mm (11 in.) in diameter at the bottom, and 280 mm (11$^1/_8$ in.) high shall be provided. A steel container cover shall also be provided. The container and cover shall conform with the details given in Figure 3.

8.3.1. The remainder of the apparatus is identical with that given for Method A.

9. VIBRATING CYCLE

9.1. The vibrating cycle shall be as follows: Power on for 3 seconds, power off 30 seconds. However, due to the coasting of the motor after the power is turned off, the period of perceptible vibration is approximately 7 seconds (Figure 1).

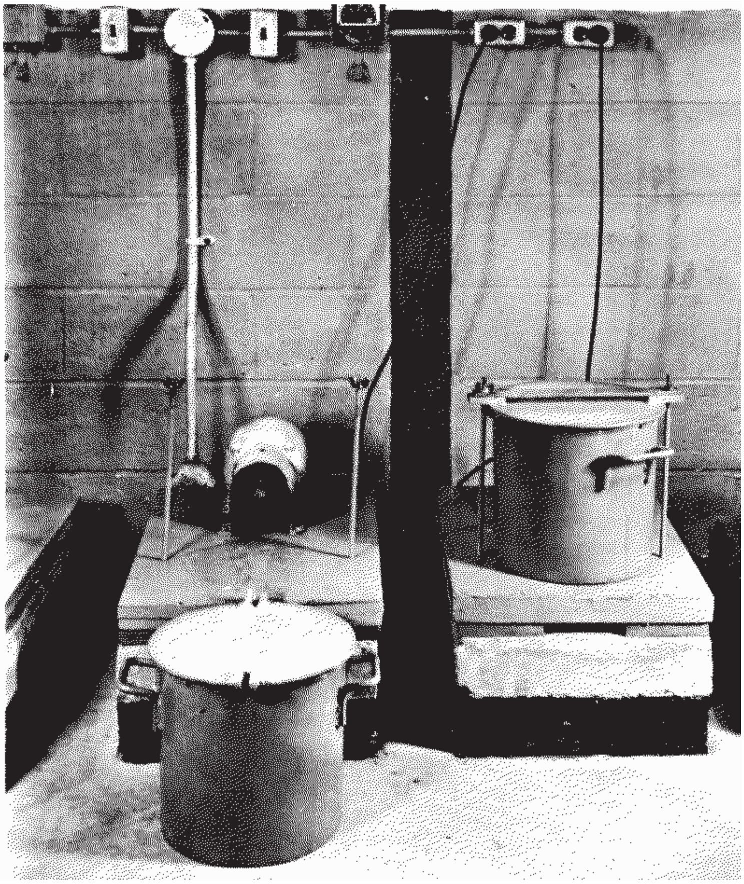


Figure 1—Vibrating Platform and Timer

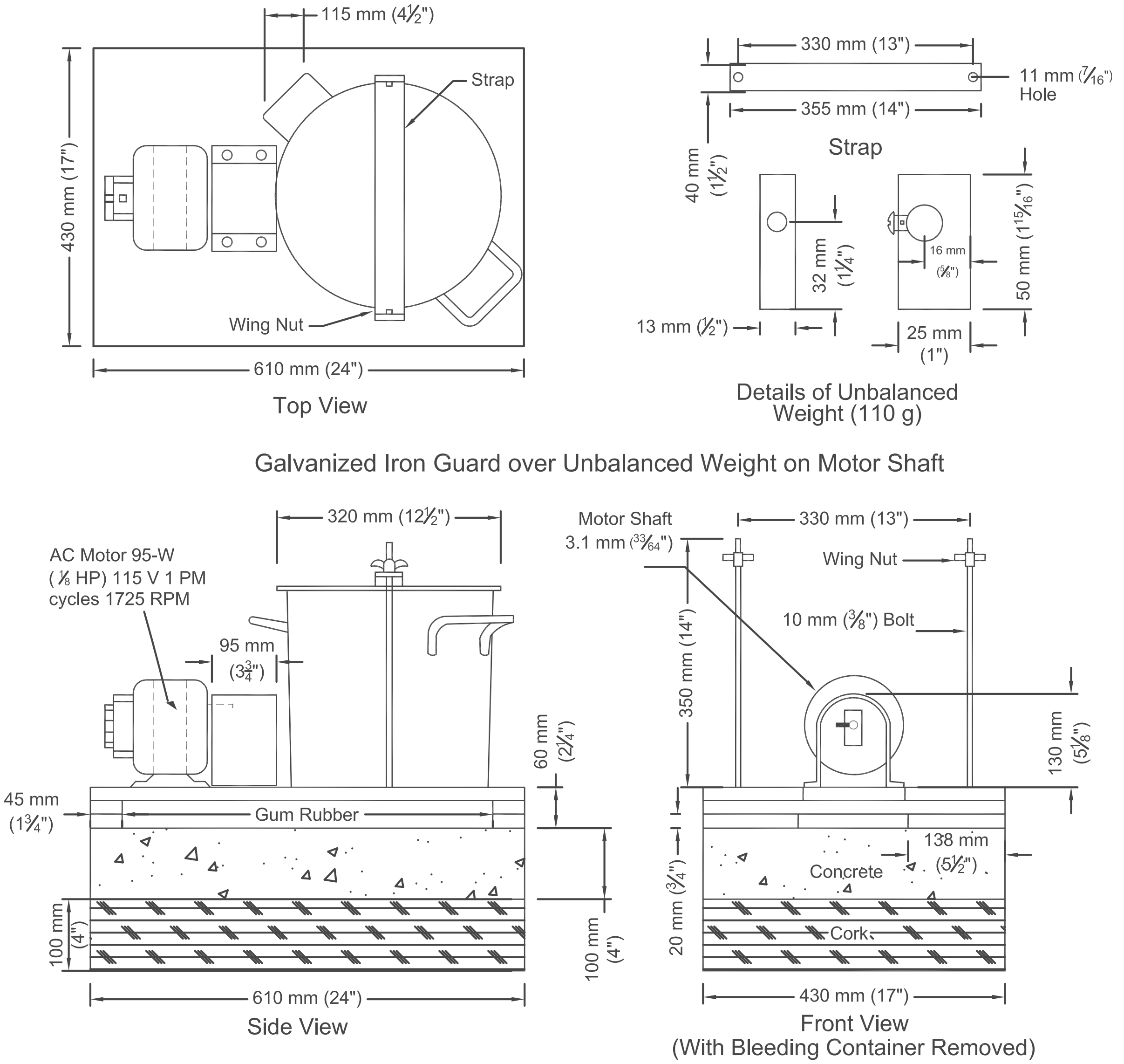
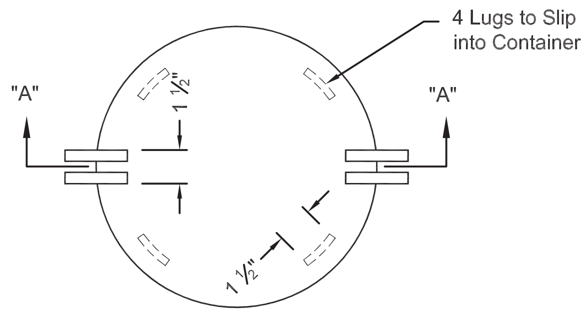
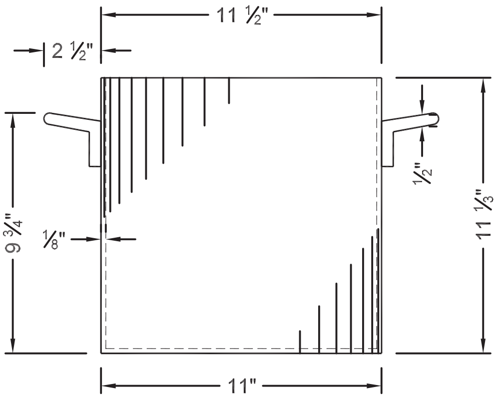


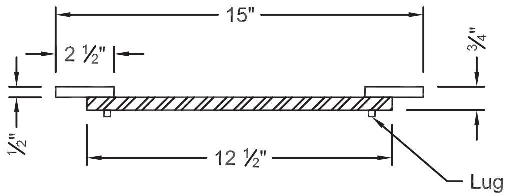
Figure 2—Detail of Vibrating Platform Apparatus



Top View of Cover



Bleeding Container



Section "A-A"

Figure 3—Container and Cover

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10. TEST SPECIMEN

10.1. The sample shall be prepared as described for Method A.

10.2. The sample shall be placed in the container to a depth equal to approximately one-half the average diameter of the container. The size of the test sample can best be regulated by mass; a sample weighing with a mass of 20 ± 0.5 kg (45 ± 1 lb) usually meets the requirements for the apparatus described herein (Figure 2).

11. PROCEDURE

11.1. *Consolidation of Test Specimen*—Consolidate the sample in the container by means of vibration of only that duration required to affect the desired degree of compaction. Sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth. Stop the consolidating procedure immediately upon the first appearance of free water segregating from the concrete, as indicated by the development of a water sheen on its surface. For some unusually wet or plastic mixtures, no consolidating effort will be needed beyond that supplied by placing the sample in the container and handling the container during the operations of determining the mass and placing it on the platform for test.

11.2. *Intermittent Vibration*—Place the cover on the container and the container on the vibrating platform. Clamp the container and cover down tightly. Note and record the time, and start the motor. Continue intermittent vibration for 1 hour.

11.3. *Determination of Bleeding Water*—The intermittent periods of vibrations do not permit the determination of bleeding water at a number of different time intervals. Determine the total volume of bleeding water as described for Method A.

12. CALCULATIONS

12.1. Calculate the percentage bleeding water as described for Method A.

13. PRECISION AND BIAS

13.1. *Precision*:

13.1.1. *Method A*—Data are not available to evaluate the precision of Method A directly. However, there is reason to believe that the precision for Method A is at least as good as that for Method B. The values given for Method B shall be used as maximum precision limits for Method A.

13.1.2. *Method B*—The single operator-day-multibatch standard deviation (1s) has been found to be 0.71 percent for a bleeding range from 200 to 10 percent, 1.06 percent for a bleeding range from 10 to 20 percent, and 1.77 percent for more than 20 percent. Therefore, results of two properly conducted tests by the same operator on the same day on different batches of the same mixture should not deviate by more than 2.0 percent (d2s) for a bleeding range from 200 to 10 percent, 3.0 percent for a range from 10 to 20 percent, and 5.0 percent for more than 20 percent. (See Note 2.)

Note 2—These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for preparing Precision and Bias Statements for Test Methods for Construction Materials.

13.2. *Bias*—The test methods have no bias because the values determined can be defined only in terms of the test methods.

14. KEYWORDS

14.1. Bleeding; concrete, bleeding of.

Standard Method of Test for

Length Change of Hardened Hydraulic Cement Mortar and Concrete

AASHTO Designation: T 160-09
ASTM Designation: C 157/C 157M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Length Change of Hardened Hydraulic Cement Mortar and Concrete

AASHTO Designation: T 160-09
ASTM Designation: C 157/C 157M-06

1. SCOPE

1.1. This test method covers determination of the length changes that are produced by causes other than externally applied forces and temperature changes in hardened hydraulic-cement mortar and concrete specimens made in the laboratory and exposed to controlled conditions of temperature and moisture.

1.2. The values stated in either inch-pound or SI units are to be regarded separately as standard. An exception is with regard to sieve sizes and nominal size of aggregate, in which the SI values are the standard, as stated in specification E 11. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 143/C 143M, Standard Test Method for Slump of Hydraulic-Cement Concrete
- C 172, Standard Practice for Sampling Freshly Mixed Concrete

- C 192/ 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C 305, Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
- C 490, Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- C 511, Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- C 596, Standard Test Method for Drying Shrinkage of Mortar Containing Hydraulic Cement
- C 1347, Standard Practice for Preparation and Dissolution of Uranium Materials for Analysis
- E 11, Standard Specification for Woven Wire Test Sieve Cloth Standard Test Sieves
- E 337, Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

3. TERMINOLOGY

3.1. *Definitions*—The terms used in this test method are defined in terminology C 125.

3.2. *Definition of Terms Specific to This Standard*:

3.2.1. *length change*—an increase or decrease in the length of a test specimen that has been caused to change by any factor other than externally applied forces and temperature changes.

4. SIGNIFICANCE AND USE

4.1. Measurement of length change permits assessment of the potential for volumetric expansion or contraction of mortar or concrete due to various causes other than applied force or temperature change. The method is particularly useful for comparative evaluation of this potential in different hydraulic-cement mortar or concrete mixtures.

4.2. This test method provides useful information for experimental purposes or for products that require testing under nonstandard mixing, placing, handling, or curing conditions, such as high product workability or different demolding times. Standard Conditions are described in Section 5.4.1.

4.3. If conditions for mixing, curing, sampling, and storage other than those specified in this method are required, they shall be reported but are not to be considered as standard conditions of this test method. Nonstandard conditions and the reasons for departure from standard conditions shall be reported clearly and prominently with comparator values.

5. APPARATUS

5.1. *Molds and Length Comparator*—The molds for casting test specimens and the length comparator for measuring length change shall conform to the requirements of M 210.

5.2. *Tamper*—The tamper shall be made of a nonabsorptive, nonabrasive material such as medium-hard rubber or seasoned oak wood rendered nonabsorptive by immersion for 15 minutes in paraffin at approximately 200ºC (392ºF), and shall have a cross section of 13 by 25 mm or $^1/_2$ by

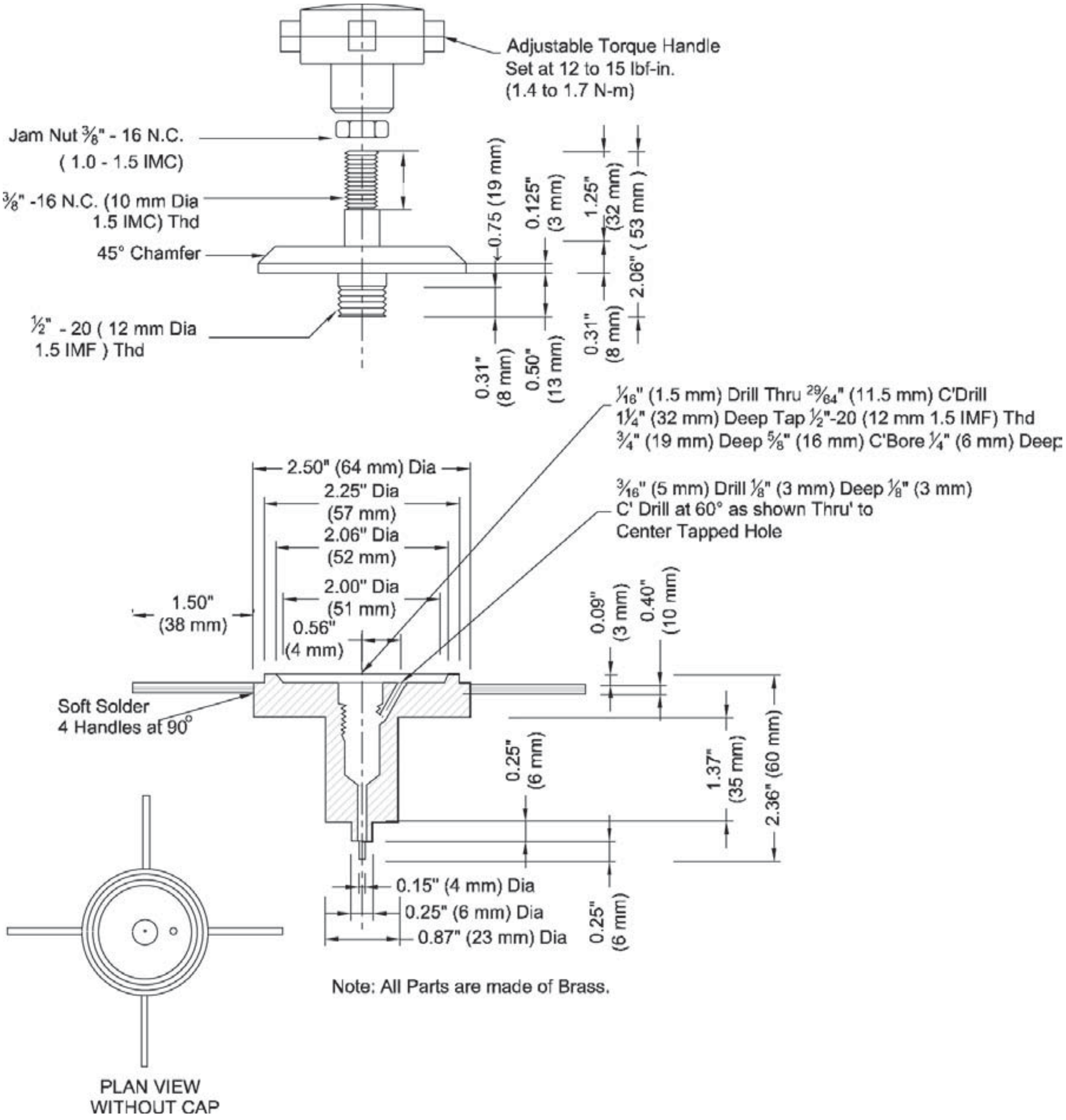
1 in. and a convenient length of about 150 mm or 6 in. The tamping face of the tamper shall be flat and at right angles to the length of the tamper.

5.3. *Tamping Rod*—The tamping rod shall be a straight steel rod 10 mm or $^3/_8$ in. in diameter and not less than 250 mm or 10 in. in length, having at least the tamping end rounded to a hemispherical tip of the same diameter.

5.4. *Drying Room and Controls*—A drying room with suitable racks shall be provided when storing specimens in air. The racks shall be designed for free circulation of air around specimens, except for necessary supports, and shall be so situated with respect to the nearest wall or other obstruction that air circulation is not restricted in the intervening space. The supports shall be horizontal and shall consist of two nonabsorptive members not deeper than 25 mm or 1 in. and having a bearing area of not more than 6 mm or $^1/_4$ in. in width. Conditioned air shall be circulated into and out of the room in a uniform manner so that the specified rate of evaporation is attained adjacent to all specimens.

5.4.1. The air in the room shall be maintained at a temperature of 23.0 ± 1.7ºC (73.4 ± 3.0ºF) and a relative humidity of 50 ± 4 percent. The air movement past all specimens shall be such that the rate of evaporation is 77 ± 30 mL/24 hours from an atmometer or 13 ± 15 mL/24 hours from a 400-mL Griffin low-form beaker filled to $^3/_4$ in. or 20 mm from the top. The temperature and relative humidity of the air in the room shall be measured with either a sling or Assmann psychrometer at least twice each working day. The psychrometer shall comply with ASTM E 337, except that thermometers having an overall length of 250 mm or 10 in. and marked in subdivisions of 0.25ºC (0.5ºF) are permitted. The room shall be equipped with a means of measuring and recording wet- and dry-bulb temperatures continuously. Correction factors as indicated by the sling or Assmann psychrometer shall be applied to the recorded data. The rate of evaporation within the room shall be determined daily by the use of the atmometer or by the loss of mass of water from a 400-mL Griffin low-form beaker filled initially to 20 mm or $^3/_4$ in. from the top.

5.5. *Atmometer*—The atmometer shall be constructed as shown in Figure 1.



Note: All parts are made of brass.

Figure 1—Atmometer

5.5.1. *Mounting*—Figure 2 shows a suggested arrangement for operating the atmometer. Punch a central hole 13 mm or $^1/_2$ in. in diameter in a filter paper, place it on the atmometer, and secure it in place while dry, by turning the torque handle only, until it just starts to slip. Mount the atmometer on a stand with the filter paper in a horizontal position. Mount a 100-mL glass graduate so that the 100-mL mark is from 25 to 75 mm or 1 to 3 in. below the level of the filter paper. Stopper the graduate so that entrance is provided for two short glass tubes not extending to the water level and one long tube extending to the bottom of the graduate. Connect the glass tubing leading from the bottom of the graduate to the inlet of the atmometer by means of clear plastic tubing.

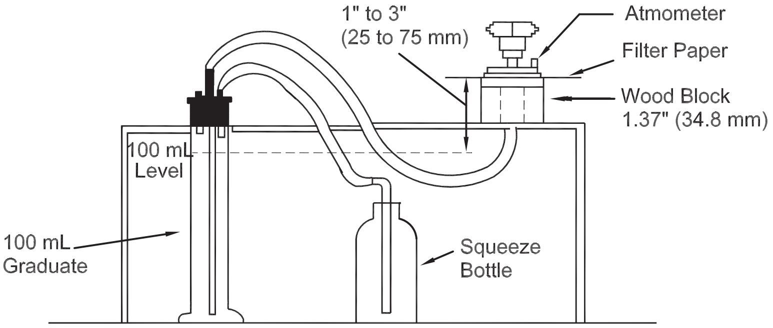


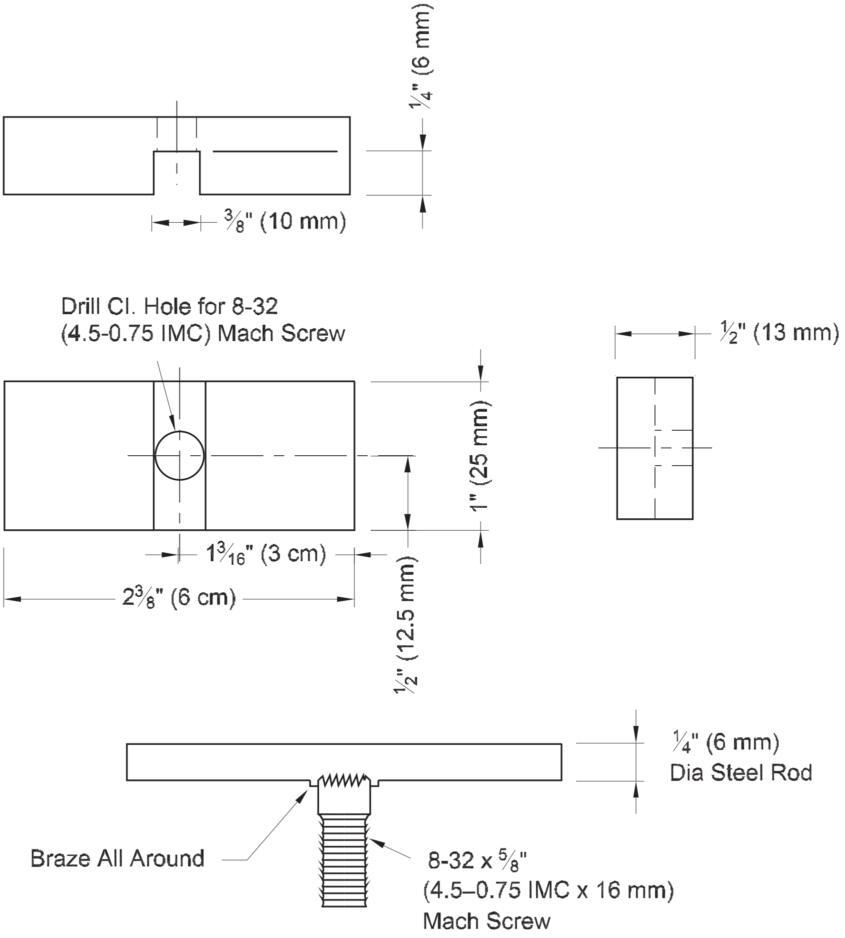
Figure 2—Suggested Arrangement for Operating the Atmometer

5.5.2. *Operation*—Use clear plastic tubing to connect a squeeze bottle containing distilled or deionized water to one of the short glass tubes into the graduate. Force water into the graduate until it is about half full and then close the remaining glass tube into the graduate. Continue to force water through the graduate into the atmometer until the filter paper is saturated and there are no air bubbles in the system. Open the glass tube into the graduate and release pressure on the squeeze bottle gradually to avoid trapping air in the tube leading to the atmometer. Adjust the level of water in the graduate to approximately the 100-mL mark. If the atmometer is to be used under variable temperature conditions, disconnect the squeeze bottle after filling the graduate to avoid the possibility of additional water being forced into the graduate. Permit evaporation of water from the filter paper for one hour before recording the time and initial reading of the graduate. It is not permitted to omit the waiting period during subsequent use of the atmometer provided the filter paper does not become dry. Change the filter paper whenever it shows signs of contamination but not less frequently than once every two weeks.

5.6. *Filter Paper*—The filter paper to be used with the atmometer shall be white with a smooth surface texture. It shall be 152 mm (6 in.) in diameter and 1.27 ± 0.08 mm (0.050 ± 0.003 in.) thick and shall have a cotton fiber content of not less than 75 weight. The density shall be between 0.400 and 0.425 g/cm^3. The Mullen bursting strength shall not be less than 345 kPa (50 psi).

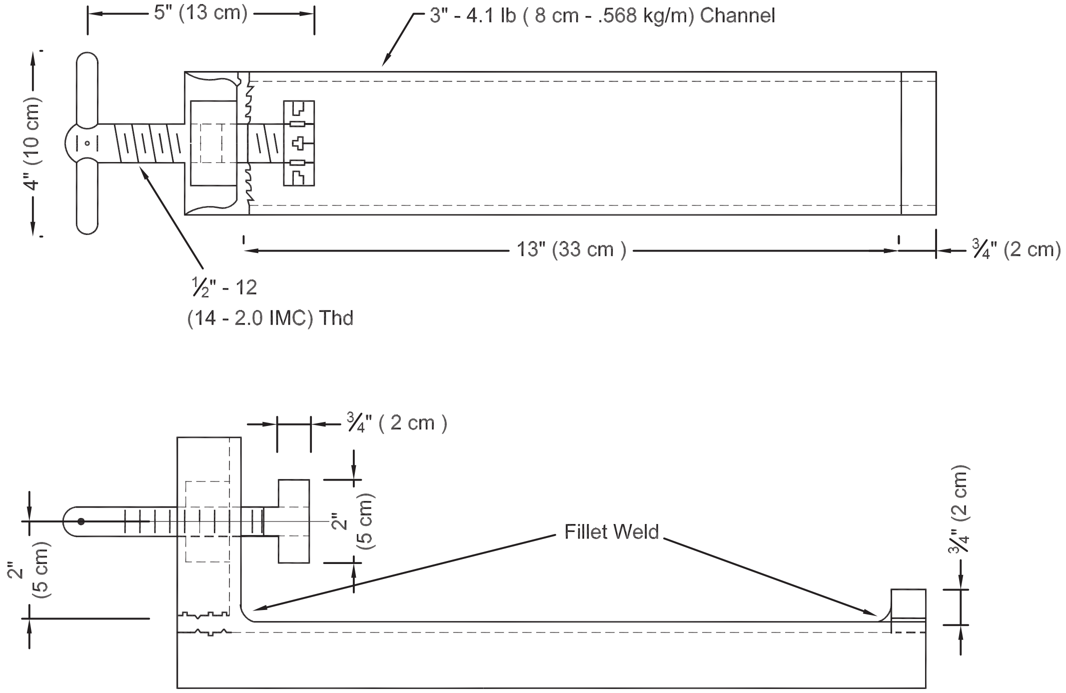
Note 1—E and D filter paper No. 625 has been found suitable.[1]

5.7. *Apparatus for Demolding Specimens*—It is useful to construct an apparatus for demolding specimens molded in double molds as detailed in Fig. 3 or to a different design that serves the same purpose. When this device is to be used, the center side plate of the double mold must be appropriately drilled and tapped to receive the 8-32 (4.5-0.75 IMC) machine screw of the demolding thumb screw. Figure 4 shows the details of a suitable apparatus for demolding specimens molded in single molds.



Instructions for Use: Remove end and outer side plates leaving base, center side plate, and gauge stud holders in place. Engage machine screw in drilled and tapped end of center side plate. Turn thumb screw to loose bars.

Figure 3—Device for Detaching 25-mm (1-in.) Square by 285-mm ($11^{1}/_{4}$- in.) Bars from Center Side Plate of Double Molds



Note: Dimensions shown are appropriate for one design of mold for 3 in. (8 cm) square specimens. Change dimensions are required for other molds.

Figure 4—Device for Demolding Specimens from Single Molds

6. SAMPLING

6.1. Take samples according to the applicable provisions of R 39 from batches of hydraulic-cement mortar or concrete made in the laboratory (Note 2).

Note 2—When collecting samples in nonstandard conditions, such as field concrete, it is suggested that T 141 be followed. Field cast specimens can show up to twice as much drying shrinkage as laboratory cast specimens from the same materials and proportions.

7. TEST SPECIMENS

7.1. *Mortar*—The test specimen for mortar shall be a prism of 25-mm or 1-in. square cross section and approximately 285 mm or $11^{1}/_{4}$ in. in length. Three specimens shall be prepared for each test condition.

7.2. *Concrete*—The test specimen for concrete, in which all of the aggregate passes a 50-mm (2-in.) sieve, shall be a prism of 100-mm or 4-in. square cross section and approximately 285 mm or $11^{1}/_{4}$ in. long. However, a prism of 75-mm or 3-in. square cross section may be used if all of the aggregate passes a 25.0-mm (1-in.) sieve. Three specimens shall be prepared for each test condition. Since length change is capable of being influenced by the size of the specimen, specimens to be compared shall have the same dimensions, and any specification limit based upon this method shall be applied to a specified size of specimen.

8. PROCEDURE FOR MIXING MORTARS AND CONCRETE

8.1. If the mortar or concrete to be tested is made in accordance with requirements other than those given in one of the following paragraphs, samples shall be taken and specimens molded as described in the sections on sampling and on molding specimens.

8.2. Bring all materials to a temperature between 18 and 24ºC (65 and 75ºF) before using to make mortar or concrete. Proportion solid materials by mass (that is, not by volume). It is permitted to batch water and liquid admixtures either by mass or by volume. For calculation of batch quantities, assume aggregates to be saturated and surface-dry; if they are not in this condition at the time of use, apply appropriate corrections, as necessary, to batch quantities to compensate for absorption or free moisture.

8.3. *Mortar*—Mix mortar in a mechanical mixer as described in T 162. The clearances between paddle and bowl specified in T 162 are suitable only for mortars made with fine aggregates that are finer than the 2.36 mm (No. 8) sieve. Mortars made with aggregates containing particles coarser than this sieve require special clearances or a different type of paddle to permit the mixer to operate freely and to avoid damage to the paddle and bowl. The sequence of mixing shall be in accordance with the applicable provisions of T 162. Determine the flow of the mortar in accordance with the applicable provisions of T 106, and use sufficient mixing water to produce a flow of 110 ± 5 percent.

8.4. *Concrete*—Mix concrete in a suitable laboratory mixer in accordance with the applicable provisions of R 39. Determine the slump of the concrete using T 119M/T 119 and use sufficient mixing water to produce a slump of 90 ± 15 mm or $3^1/_2 \pm {}^1/_2$ in.

9. PROCEDURE FOR MOLDING SPECIMENS

9.1. *Mortar Specimens*—Place the mortar in the mold in two approximately equal layers. Compact each layer with the tamper. Work the mortar into the corners, around the gauge studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, strike off the mortar flush with the top of the mold, and smooth the surface with a few strokes of a trowel. Immediately after completion of molding, loosen the device by holding the gauge studs in position at each end of the mold in order to prevent any restraint of the gauge studs during initial shrinkage of the specimen.

9.2. *Concrete Specimens*—Place the concrete in the mold in two approximately equal layers in accordance with the general instructions for placing concrete in specimens given in R 39. Consolidate each layer by rodding, except use external vibration if the slump is less than 75 mm or 3 in. in accordance with the instructions for consolidation of flexure test specimens given in R 39. The same method of consolidation is to be used for all specimens to be compared. In addition, as the top layer is being placed, work the concrete thoroughly around each gauge stud with the fingers. The top layer shall slightly overfill the mold. After consolidation is complete, strike off the excess material with a straightedge. Immediately after completion of molding, loosen the device by holding the gauge studs in position at each end of the mold in order to prevent any restraint of the gauge studs before the test specimens are demolded.

10. PROCEDURE FOR CURING OF SPECIMENS

10.1. Cure the test specimens in the molds in a moist cabinet or room in accordance with M 201. Protect specimens from dripping water.

10.2. Remove specimens from the molds at an age of 23$^1/_2$ hours ± $^1/_2$ hour after the addition of water to the cement during the mixing operation. In order to avoid damage during removal from the molds, it is not permitted, especially in the case of certain slow-hardening cements, to allow specimens to remain in the molds for more than 24 hours. When this is found necessary, the moist curing schedule shall be extended, but all specimens that are to be directly compared with each other shall be subjected to the same conditions of moist-curing and shall have their initial comparator reading made within ±$^1/_2$ hour of the same age. It is permitted to use the demolding device to remove specimens without striking or jarring and with particular care not to exert pressure directly against the gauge studs. The gauge stud holder shall remain attached to the stud during this operation. Marks placed on the specimens for identification or positioning are only to be made by graphite applied either by a soft pencil or as a liquid that deposits essentially graphite without binder, or made with waterproof indelible ink. Upon removal of the specimens from the molds, place them in lime-saturated water maintained at 23.0 ± 0.5ºC (73. ± 1ºF) for a minimum of 15 minutes in the case of 25-mm or 1-in. square cross-section specimens and for a minimum of 30 minutes in the case of 75-mm or 3-in. or 100-mm or 4-in. square cross-section specimens before being measured for length. This is to minimize variation in length due to variation in temperature. At an age of 24 hours ± $^1/_2$ hour after the addition of water to the cement during the mixing operation, remove the specimens from water storage one at a time, wipe with a damp cloth, and immediately take the initial comparator reading.

10.3. After the initial comparator reading, store the specimens in lime-saturated water at 23.0 ± 2ºC (73.4 ± 3.0ºF) until they have reached an age of 28 days, including the period in the molds At the end of the curing period, make a second comparator reading after the specimens have been brought to a more closely controlled temperature as was done prior to the earlier reading and in the manner described above.

11. PROCEDURE FOR STORAGE OF SPECIMENS

11.1. After measurement at the end of the curing period, store the specimens as described in either of the following:

11.1.1. *Water Storage*—Immerse the specimens in lime-saturated water storage in accordance with M 201. Take comparator readings of each specimen when it has reached an age, including the curing period of 8, 16, 32, and 64 weeks. Make these readings immediately after the specimens have been subjected to storage in water at 23.0 ± 0.5ºC (73. ± 1.0ºF) for at least 15 minutes in the case of 25-mm (or 1-in.) specimens or 30 minutes in the case of 75-mm (or 3-in.) or 100-mm (or 4-in.) specimens.

11.1.2. *Air Storage*—Store the specimens in the drying room, so that the specimens have a clearance of at least 1 in. or 25 mm on all sides. Take comparator readings of each specimen after periods of air storage after curing of 4, 7, 14, and 28 days, and after 8, 16, 32, and 64 weeks. Preferably, take these readings in a room maintained at a relative humidity of 50 ± 4 percent while the specimens are at a temperature of 23.0 ± 2ºC (73. ± 3.0ºF).

12. PROCEDURE FOR CALCULATING LENGTH CHANGE

12.1. *Comparator Reading*—Read the comparator dial with the test specimen in the comparator; then read the comparator dial with the reference bar in the comparator. Calculate the difference between the two readings as described in M 210.

12.2. *Length Change*—Calculate the length change of any specimen at any age after the initial comparator reading as follows:

$$\triangle L_x = \frac{CRD - \text{ initial } CRD}{G} \times 100 \qquad (1)$$

where:

ΔL_x = length change of specimen at any age, percent;

CRD = difference between the comparator reading of the specimen and the reference bar at any age; and

G = the gauge length (250 mm or 10 in.). (See Note 3.)

Note 3—In M 210, the comparator dial gauge specified for use with 10-gauge length specimens shall be graduated in fractions of an inch; the comparator dial gauge specified for use with 250-mm gauge length specimens shall be graduated in fractions of a millimeter.

13. REPORT

13.1. *Report the following information*:

13.1.1. Identification as mortar or concrete specimens, number of specimens for each condition, and date molded;

13.1.2. Source and identification of each material employed;

13.1.3. Type, maximum size, moisture condition, and grading of the aggregate;

13.1.4. Size of specimens;

13.1.5. Mortar or concrete mixture data at time of mixing, including flow or slump and temperature of mixture;

13.1.6. Description of consolidation of concrete, specifying whether rodding or external vibration was used;

13.1.7. Conditions and periods of moist-curing prior and subsequent to removal of molds, if different from those specified;

13.1.8. Description of storage condition, including temperature and humidity, either by indicating whether water or air storage was followed or by giving the details of any procedure not conforming to either of these conditions;

13.1.9. Total elapsed time of storage and total age of specimen, or total elapsed time of curing and storage if the same condition was used for both;

13.1.10. Length change data, reported as percent increase or decrease in linear dimension to the nearest 0.001 percent, of the gauge length based on the initial measurement made at the time of removal from the molds; and

13.1.11. Any other pertinent information.

14. PRECISION AND BIAS

14.1. *Precision*:

14.1.1. When this test method was used for the purpose of determining drying shrinkage of mortar as affected by the choice of portland cement used in making it, the precision was found to be as reported in ASTM C 596.

14.1.1.1. The following single-laboratory, multiple-operator precision applies to concrete specimens measured at 180 days.

14.1.1.2. For specimens stored in water, the standard deviation (1s) among specimens is 0.0045 percent. When three replicate specimens are tested, the maximum range among them is not expected to exceed 0.0266 percent in 95 percent of the sets tested. When a test result represents the mean of three specimens, the 1s is 0.0026 percent. The difference between two such means is not expected to exceed 0.0074 percent in 95 percent of such duplicate tests performed.

14.1.1.3. For specimens stored in air, the standard deviation (1s) among specimens is 0.0084 percent. When three replicate specimens are tested, the maximum range among them is not expected to exceed 0.0496 percent in 95 percent of the sets tested. When a test result represents the mean of three specimens, the 1s is 0.0048 percent. The difference between two such means is not expected to exceed 0.0137 percent in 95 percent of such duplicate tests performed.

Note 4—These precision values were calculated from data taken on specimens described on page 47 of STP 205,[2] representing 193 concrete mixtures; two specimens made from each of three batches made on separate days, one of each two specimens stored in water, the other stored at nominal 50 percent relative humidity.

14.2. *Bias*—No statement on bias is being made since there is no accepted reference material suitable for determining the bias of these procedures.

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[1] Manufactured by and available from Eaton-Dikeman Co., Mt. Holly Springs, PA 17065.

[2] Mather, Bryant, "The Partial Replacement of Portland Cement in Concrete," *Cement and Concrete*, ASTM STP 205, ASTM 1958.

Standard Method of Test for

Resistance of Concrete to Rapid Freezing and Thawing

AASHTO Designation: T 161-08
ASTM Designation: C 666/C 666M-03

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Resistance of Concrete to Rapid Freezing and Thawing

AASHTO Designation: T 161-08
ASTM Designation: C 666/C 666M-03

1. SCOPE

1.1. This method covers the determination of the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing in the laboratory by two different procedures: Procedure A, Rapid Freezing and Thawing in Water, and Procedure B, Rapid Freezing in Air and Thawing in Water. Both procedures are intended for use in determining the effects of variations in the properties of concrete on the resistance of the concrete to the freezing and thawing cycles specified in the particular procedure. Neither procedure is intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

1.2. The values stated in SI units are the preferred standard.

1.3. All material in this test method not specifically designated as belonging to Procedure A or Procedure B applies to either procedure.

1.4. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 194, Chemical Admixtures for Concrete
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 157, Air-Entraining Admixtures for Concrete
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete

2.2. *ASTM Standards*:
- C 215, Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens
- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- C 341, Standard Practice for Length Change of Cast, Drilled, or Sawed Specimens of Hydraulic-Cement Mortar and Concrete

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 823, Standard Practice for Examination and Sampling of Hardened Concrete in Constructions

3. SIGNIFICANCE AND USE

3.1. As noted in the scope, the two procedures described in this method are intended to determine the effects of variations in both properties and conditioning of concrete in the resistance to freezing and thawing cycles specified in the particular procedure. Specific applications include specified use in M 194, T 157, and ranking of coarse aggregates as to their effect on concrete freeze–thaw durability, especially where soundness of the aggregate is questionable.

3.2. It is assumed that the procedures will have no significantly damaging effects on frost-resistant concrete that may be defined as (1) any concrete not critically saturated with water (that is, not sufficiently saturated to be damaged by freezing) and (2) concrete made with frost-resistant aggregates and having an adequate air-void system that has achieved appropriate maturity and thus will prevent critical saturation by water under common conditions.

3.3. If, as a result of performance tests as described in this method, concrete is found to be relatively unaffected, it can be assumed that it was either not critically saturated, or was made with “sound” aggregates, a proper air-void system, and allowed to mature properly.

3.4. No relationship has been established between the resistance to cycles of freezing and thawing of specimens cut from hardened concrete and specimens prepared in the laboratory.

4. APPARATUS

4.1. *Freezing and Thawing Apparatus*:

4.1.1. The freezing and thawing apparatus shall consist of a suitable chamber or chambers in which the specimens may be subjected to the specified freezing and thawing cycle, together with the necessary refrigerating and heating equipment and controls to produce continuously and automatically, reproducible cycles within the specified temperature requirements. In the event that the equipment does not operate automatically, provision shall be made for either its continuous manual operation on a 24-hour a day basis or for the storage of all specimens in a frozen condition when the equipment is not in operation.

4.1.2. The apparatus shall be so arranged that, except for necessary supports, each specimen is: (1) for Procedure A, completely surrounded by not less than 1 mm ($^1/_{32}$ in.) nor more than 3 mm ($^1/_8$ in.) of water at all times while it is being subjected to freezing and thawing cycles, or (2) for Procedure B, completely surrounded by air during the freezing phase of the cycle and by water during the thawing phase. Rigid containers, which have the potential to damage specimens, are not permitted. Length change specimens in vertical containers shall be supported in a manner to avoid damage to the gauge studs.

Note 1—Experience has indicated that ice or water pressure, during freezing tests, particularly in equipment that uses air rather than a liquid as the heat transfer medium, can cause excessive damage to rigid metal containers, and possibly to the specimens therein. Results of tests during which bulging or other distortion of containers occurs should be interpreted with caution.

4.1.3. The temperature of the heat-exchanging medium shall be uniform within 3°C (6°F) throughout the specimen cabinet when measured at any given time, at any point on the surface of any specimen container for Procedure A or on the surface of any specimen for Procedure B, except during the transition between freezing and thawing and vice versa.

4.1.3.1. Support each specimen at the bottom of its container in such a way that the temperature of the heat-exchanging medium will not be transmitted directly through the bottom of the container to the full area of the bottom of the specimen, thereby subjecting it to conditions substantially different from the remainder of the specimen.

Note 2—A flat spiral of 3-mm ($^1/_8$-in.) wire placed in the bottom of the container has been found adequate for supporting specimens.

4.1.4. For Procedure B, it is not contemplated that the specimens will be kept in containers. The supports on which the specimens rest shall be such that they are not in contact with the full area of the supported side or end of the specimen, thereby subjecting this area to conditions substantially different from those imposed on the remainder of the specimen.

Note 3—The use of relatively open gratings, metal rods, or the edges of metal angles has been found adequate for supporting specimens, provided the heat-exchanging medium can circulate in the direction of the long axis of the rods or angles.

4.2. *Temperature-Measuring Equipment*—consisting of thermometers, resistance thermometers, or thermocouples, capable of measuring the temperature at various points within the specimen chamber and at the centers of control specimens to within 1°C (2°F).

4.3. *Dynamic Testing Apparatus*—conforming to the requirements of ASTM C 215.

4.4. *Optional Length Change Test Length, Change Comparator*—conforming to the requirements of M 210. When specimens are longer than the nominal 285-mm ($11^1/_4$-in.) length provided for in M 210 are used for freeze-thaw tests, use an appropriate length reference bar, which otherwise meets the M 210 requirements. Dial gauge micrometers for use on these longer length change comparators shall meet the gradation interval and accuracy requirements for M 210 for the millimeter (inch) calibration requirements. Prior to the start of measurements on any specimens, fix the comparator at an appropriate length to accommodate all of the specimens to be monitored for length change.

4.5. *Scales*—with a capacity approximately 50 percent greater than the weight of the specimens and accurate to at least 5 g (0.01 lb) within the range of ±10 percent of the specimen weight will be satisfactory.

4.6. *Tempering Tank*—with suitable provisions for maintaining the temperature of the test specimens in water, such that when removed from the tank and tested for fundamental transverse frequency and length change, the specimens will be maintained within –1° and +2°C (–2° and +4°F) of the target thaw temperature for specimens in the actual freezing and thawing cycle and equipment being used. The use of the specimen chamber in the freezing and thawing apparatus by stopping the apparatus at the end of the thawing cycle and holding the specimens in it shall be considered as meeting this requirement, provided the specimens are tested for fundamental transverse frequency within the above temperature range. It is required that the same target specimen thaw temperature be used throughout the testing of an individual specimen because a change in specimen temperature at the time of length measurement can affect the length of the specimen significantly.

5. FREEZING AND THAWING CYCLE

5.1. Base conformity with the requirements for the freezing and thawing cycle on temperature measurements of control specimens of similar concrete to the specimens under test in which suitable temperature-measuring devices have been imbedded. Change the position of these control specimens frequently in such a way as to indicate the extremes of temperature variation at different locations in the specimen cabinet.

5.2. The nominal freezing and thawing cycle for both procedures of this method shall consist of alternately lowering the temperature of the specimens from 4 to –18°C (40 to 0°F) and raising it from –18 to 4°C (0 to 40°F) in not less than 2 nor more than 5 hours. For Procedure A, not less than 25 percent of the time shall be used for thawing, and for Procedure B, not less than 20 percent of the time shall be used for thawing (Note 4). At the end of the cooling period the temperature at the centers of the specimens shall be –18 ± 2°C (0 ± 3°F), and at the end of the heating period the temperature shall be 4 ± 2°C (40 ± 3°F), with no specimen at any time reaching a temperature lower than –20°C (–3°F) nor higher than 6°C (43°F). The time required for the temperature at the center of any single specimen to be reduced from 3 to –16°C (37 to 3°F) shall be no less than one-half of the length of the cooling period, and the time required for the temperature at the center of any single specimen to be raised from –16 to 3°C (3 to 37°F) shall be not less than one-half of the length of the heating period. For specimens to be compared with each other, the time required to change the temperature at the centers of any specimens from 2 to –12°C (35 to 10°F) shall not differ by more than one-sixth of the length of the cooling period from the time required for any specimen and the time required to change the temperature at the centers of any specimens from –12 to 2°C (10 to 35°F) shall not differ by more than one-third of the length of the heating period from the time required for any specimen.

Note 4—In most cases, uniform temperature and time conditions can be controlled most conveniently by maintaining a capacity load of specimens in the equipment at all times. In the event that a capacity load of test specimens is not available, dummy specimens can be used to fill empty spaces. This procedure also assists greatly in maintaining uniform fluid level conditions in the specimen and solution tanks.

The testing of concrete specimens composed of widely varying materials or with widely varying thermal properties, in the same equipment at the same time, may not permit adherence to the time-temperature requirements for all specimens. It is advisable that such specimens be tested at different times and that appropriate adjustments be made to the equipment.

5.3. The difference between the temperature at the center of a specimen and the temperature at its surface shall at no time exceed 28°C (50°F).

5.4. The period of transition between the freezing and thawing phases of the cycle shall not exceed 10 minutes, except when specimens are being tested in accordance with Section 8.3.

6. SAMPLING

6.1. Constituent materials for concrete specimens made in the laboratory shall be sampled using applicable standard methods.

6.2. Samples cut from hardened concrete are to be obtained in accordance with ASTM C 823.

7. TEST SPECIMENS

7.1. The specimens for use in this test shall be prisms or cylinders made and cured in accordance with the applicable requirements of M 210 and R 39.

7.2. Specimens used shall not be less than 75 mm (3 in.) nor more than 125 mm (5 in.) in width, depth, or diameter, and not less than 275 mm (11 in.) nor more than 405 mm (16 in.) in length.

7.3. Test specimens may also be cores or prisms cut from hardened concrete. If so, the specimens should not be allowed to dry to a moisture condition below that of the structure from which they were taken. This may be accomplished by wrapping in plastic or by other suitable means. The specimens so obtained shall be furnished with gauge studs in accordance with ASTM C 341.

7.4. For this test the specimens shall be stored in saturated lime water from the time of their removal from the molds until the time freezing and thawing tests are started. All specimens to be compared with each other initially shall be of the same nominal dimensions.

8. PROCEDURE

8.1. Molded beam specimens shall be cured for 14 days prior to testing unless otherwise specified. Beam specimens sawed from hardened concrete shall be moisture-conditioned by immersing in saturated lime water at 23 ± 2°C (73 ± 3°F) for 48 hours prior to testing unless otherwise specified.

8.2. Immediately after the specified curing or conditioning period, bring the specimen to a temperature within –1° and +2°C (–2° and +4°F) of the target thaw temperature that will be used in the freeze-thaw cycle and test for fundamental transverse frequency, determine the mass, determine the average length and cross-section dimensions of the concrete specimen within the tolerance required in ASTM C 215, and determine the initial length comparator reading (optional) for the specimen with the length change comparator. Protect the specimens against loss of moisture between the time of removal from curing and the start of the freezing and thawing cycles.

8.3. Start freezing and thawing tests by placing the specimens in the thawing water at the beginning of the thawing phase of the cycle. Remove the specimens from the apparatus, in a thawed condition, at intervals not exceeding 36 cycles of exposure to the freezing and thawing cycles, test for fundamental transverse frequency and measure length change (optional) with the specimens within the temperature range specified for the tempering tank in Section 4.6, determine the mass of each specimen, and return them to the apparatus. To ensure that the specimens are completely thawed and at the specified temperature, place them in the tempering tank or hold them at the end of the thaw cycle in the freezing and thawing apparatus for a sufficient time for this condition to be attained throughout each specimen to be tested. Protect the specimens against loss of moisture while out of the apparatus and turn them end-for-end when returned. For Procedure A, rinse out the container and add clean water. Return the specimens either to random positions in the apparatus or to positions according to some predetermined rotation scheme that will ensure that each specimen that continues under test for any length of time is subjected to conditions in all parts of the freezing apparatus. Continue each specimen in the test until it has been subjected to 300 cycles or until its relative dynamic modulus of elasticity reaches 60 percent of the initial modulus, whichever occurs first, unless other limits are specified (Note 5). For the optional length change test, 0.10 percent expansion may be used as the end of test. Whenever a specimen is removed because of failure, replace it for the remainder of the test by a dummy specimen. Each time a specimen is tested for fundamental frequency (Note 6) and length change, make a note of its visual appearance and make special comment on any defects that develop (Note 7). When it is anticipated that specimens may deteriorate rapidly, they should be tested for fundamental transverse frequency and length change (optional) at intervals not exceeding 10 cycles when initially subjected to freezing and thawing.

Note 5—It is not recommended that specimens be continued in the test after their relative dynamic modulus of elasticity has fallen below 50 percent.

Note 6—It is recommended that the fundamental longitudinal frequency be determined initially and as a check whenever a question exists concerning the accuracy of determination of fundamental transverse frequency, and that the fundamental torsional frequency be determined initially and periodically as a check on the value of Poisson's ratio.

Note 7—In some applications, such as airfield pavements and other slabs, popouts may be defects that are a concern. A popout is characterized by the breaking away of a small portion of the concrete surface due to internal pressure, thereby leaving a shallow and typically conical spall in the surface of the concrete through the aggregate particle. Popouts may be observed as defects in the test specimens. Where popouts are a concern, the number and general description should be reported as a special comment. The aggregates causing the popout may be identified by petrographic examination as in ASTM C 295.

8.4. When the sequence of freezing and thawing cycles must be interrupted, store the specimens in a frozen condition.

Note 8—If, due to equipment breakdown or for other reasons, it becomes necessary to interrupt the cycles for a protracted period, store the specimens in a frozen condition in such a way as to prevent loss of moisture. For Procedure A, maintain the specimens in the containers and surround them by ice, if possible. If it is not possible to store the specimens in their containers, wrap and seal them, in as wet a condition as possible, in moisture-proof material to prevent dehydration and store in a refrigerator or cold room maintained at –18 ± 2°C (0 ± 3°F). Follow the latter procedure when Procedure B is being used. In general, for specimens to remain in a thawed condition for more than two cycles is undesirable, but a longer period may be permissible if this occurs only once or twice during a complete test.

9. CALCULATIONS

9.1. *Relative Dynamic Modulus of Elasticity*—Calculate the numerical values of relative dynamic modulus of elasticity as follows:

$$P_c = (n_1^2/n^2) \times 100 \qquad (1)$$

where:

P_c = relative dynamic modulus of elasticity, after c cycles of freezing and thawing, percent;

n = fundamental transverse frequency at 0 cycles of freezing and thawing; and

n_1 = fundamental transverse frequency after c cycles of freezing and thawing.

Note 9—This calculation of relative dynamic modulus of elasticity is based on the assumption that the mass and dimensions of the specimen remain constant throughout the test. This assumption is not true in many cases due to disintegration of the specimen. However, if the test is to be used to make comparisons between the relative dynamic moduli of different specimens or of different concrete formulations, P_c as defined is adequate for the purpose.

9.2. *Durability Factor*—Calculate the durability factor as follows:

$$DF = PN/M \qquad (2)$$

where:

DF = durability factor of the test specimen;

P = relative dynamic modulus of elasticity at N cycles, percent;

N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less; and

M = specified number of cycles at which the exposure is to be terminated.

9.3. *Length Change in Percent (Optional)*—Calculate the length change as follows:

$$L_c = \frac{(l_2 - l_1)}{L_s} \times 100 \qquad (3)$$

where:

L_c = length change of the test specimen after c cycles of freezing and thawing, percent;

I_1 = length comparator reading at 0 cycles;

I_2 = length comparator reading after c cycles; and

L_s = the effective gauge length between the innermost ends of the gauge studs as shown in the mold diagram in M 210.

10. REPORT

10.1. Report the following data such as are pertinent to the variables or combination of variables studied in the tests:

10.2. *Properties of Concrete Mixture*:

10.2.1. Type and proportions of cement, fine aggregate, and coarse aggregate, including maximum size and grading (or designated grading indices), and ratio of net water content to cement.

10.2.2. Kind and proportion of any addition or admixture used.

10.2.3. Air content of fresh concrete.

10.2.4. Unit mass of fresh concrete.

10.2.5. Consistency of fresh concrete.

10.2.6. Air content of the hardened concrete when available.

10.2.7. Indicate if the test specimens are cut from hardened concrete, and if so, state the size, shape, orientation of the specimens in the structure, and any other pertinent information available.

10.2.8. Curing period.

10.3. *Mixing, Molding, and Curing Procedures*—Report any departures from the standard procedures for mixing, molding, and curing as prescribed in Section 7.

10.4. *Procedure*—Report which of the two procedures was used.

10.5. *Characteristics of Test Specimens*:

10.5.1. Dimensions of specimens at zero cycles of freezing and thawing,

10.5.2. Mass of specimens at zero cycles of freezing and thawing,

10.5.3. Nominal gauge length between embedded ends of gauge studs, and

10.5.4. Any defects in each specimen present at zero cycles of freezing and thawing.

10.6. *Results*:

10.6.1. Values for the durability factor of each specimen, calculated to the nearest whole number, and for the average durability factor for each group of similar specimens, also calculated to the nearest whole number, and the specified values for minimum relative dynamic modulus and maximum number of cycles (Note 10);

10.6.2. Values for the percent length change of each specimen and for the average percent length change for each group of similar specimens (Note 10);

10.6.3. Values of loss or gain of mass for each specimen and average values for each group of similar specimens; and

10.6.4. Any defects in each specimen that develop during testing, and the number of cycles at which such defects were noted.

Note 10—It is recommended that the results of the test on each specimen, and the average of the results on each group of similar specimens, be plotted as curves showing the value of relative modulus of elasticity or percent length change against time expressed as the number of cycles of freezing and thawing.

11. PRECISION

11.1. *Dynamic Modulus*:

11.1.1. *Within-Laboratory Precision (Single Beams)*—Criteria for judging the acceptability of durability factor results obtained by the two procedures in the same laboratory on concrete specimens made from the same batch of concrete or from two batches made with the same materials are given in Table 1. Precision data for length change (optional) are not available at this time.

Table 1—Within-Laboratory Durability Factor Precision for Single Beams

Range of Average Durability Factor	Procedure A		Procedure B	
	Standard Deviation[a]	Acceptable Range of Two Results[a]	Standard Deviation[a]	Acceptable Range of Two Results[a]
0 to 5	0.8	2.2	1.1	3.0
5 to 10	1.5	4.4	4.0	11.4
10 to 20	5.9	16.7	8.1	22.9
20 to 30	8.4	23.6	10.5	29.8
30 to 50	12.7	35.9	15.4	43.5
50 to 70	15.3	43.2	20.1	56.9
70 to 80	11.6	32.7	17.1	48.3
80 to 90	5.7	16.0	8.8	24.9
90 to 95	2.1	6.0	3.9	11.0
Over 95	1.1	3.1	2.0	5.7

[a] These numbers represent the (1s) and (d2s) limits as described in ASTM C 670.

Note: The values given in Columns 2 and 4 are the standard deviations that have been found to be appropriate for Procedures A and B, respectively, for tests for which the average durability factor is in the corresponding range given in Column 1. The values given in Columns 3 and 5 are the corresponding limits that should not be exceeded by the difference between the results of two single test beams.

Note 11—The between-batch precision of durability factors has been found to be the same as the within-batch precision. Thus, the limits given in this precision statement apply to specimens from different batches made with the same materials and mix design and having the same air content as well as to specimens from the same batch.

Note 12—The precision of this method for both procedures has been found to depend primarily on the average durability factor and not on the maximum N or minimum P specified for terminating the test nor on the size of the beams within limits. The data on which these precision statements are based cover maximum N_s from 100 to 300 cycles, and minimum P_s from 50 to 70 percent of E_o. The indexes of precision are thus valid at least over these ranges.

11.1.1.1. The different specimen sizes represented by the data include the following: 75 by 75 by 405 mm; 75 by 75 by 420 mm; 75 by 100 by 405 mm; 90 by 115 by 405 mm; 75 by 75 by 280 mm; 90 by 100 by 405 mm; and 100 by 75 by 405 mm (3 by 3 by 16 in.; 3 by 3 by $16^1/_4$ in.; 3 by 4 by 16 in.; $3^1/_2$ by $4^1/_2$ by 16 in.; 3 by 3 by 11 in.; $3^1/_2$ by 4 by 16 in.; and 4 by 3 by 16 in.). The first dimension given represents the direction in which the specimens were vibrated in the test for fundamental transverse frequency. The most commonly used size was 75 by 100 by 405 mm (3 by 4 by 16 in.).

11.1.2. *Within-Laboratory Precision (Averages of Two or More Beams)*—Specifications sometimes call for comparisons between averages of two or more beams. Tables 2 and 3 give appropriate standard deviations and acceptable ranges for the two procedures for two averages of the number of test beams shown.

Table 2—Within-Laboratory Durability Factor Precision for Averages of Two or More Beams—Procedure A

Range of Average Durability Factor	Number of Beams Averaged									
	2		3		4		5		6	
	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]
0 to 5	0.6	1.6	0.5	1.3	0.4	1.1	0.4	1.0	0.3	0.9
5 to 10	1.1	3.1	0.9	2.5	0.8	2.2	0.7	2.0	0.6	1.8
10 to 20	4.2	11.8	3.4	9.7	3.0	8.4	2.7	7.5	2.4	6.8
20 to 30	5.9	16.7	4.8	13.7	4.2	11.8	3.7	10.6	3.4	9.7
30 to 50	9.0	25.4	7.4	20.8	6.4	18.0	5.7	16.1	5.2	14.7
50 to 70	10.8	30.6	8.8	25.0	7.6	21.6	6.8	19.3	6.2	17.6
70 to 80	8.2	23.1	6.7	18.9	5.8	16.4	5.2	14.6	4.7	13.4
80 to 90	4.0	11.3	3.3	9.2	2.8	8.0	2.5	7.2	2.3	6.5
90 to 95	1.5	4.2	1.2	3.5	1.1	3.0	0.9	2.7	0.9	2.4
Above 95	0.8	2.2	0.6	1.8	0.5	1.5	0.5	1.4	0.4	1.3

[a] These numbers represent the (1s) and (d2s) limits as described in ASTM C 670.

Table 3—Within-Laboratory Durability Factor Precision for Averages of Two or More Beams—Procedure B

Range of Average Durability Factor	Number of Beams Averaged									
	2		3		4		5		6	
	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]	Standard Deviation[a]	Acceptable Range[a]
0 to 5	0.8	2.1	0.6	1.8	0.5	1.5	0.5	1.4	0.4	1.2
5 to 10	2.9	8.1	2.3	6.6	2.0	5.7	1.8	5.1	1.7	4.7
10 to 20	5.7	16.2	4.7	13.2	4.1	11.5	3.6	10.3	3.3	7.4
20 to 30	7.4	21.0	6.1	17.2	5.3	14.9	4.7	13.3	4.3	12.2
30 to 50	10.9	30.8	8.9	25.1	7.7	21.8	6.9	19.5	6.3	17.8
50 to 70	14.2	40.2	11.6	32.9	10.1	28.5	9.0	25.5	8.2	23.2
70 to 80	12.1	34.2	9.9	27.9	8.5	24.2	7.6	11.6	7.0	19.7
80 to 90	6.2	17.6	5.0	14.4	4.4	12.5	3.9	11.1	3.6	10.2
90 to 95	2.8	7.8	2.3	6.4	2.0	5.5	1.7	4.9	1.6	4.5
Above 95	1.4	4.1	1.2	3.3	1.0	2.9	0.9	2.6	0.8	2.3

[a] These numbers represent the (1s) and (d2s) limits as described in ASTM C 670.

11.1.3. *Multilaboratory Precision*—No data are available for evaluation of multilaboratory precision. It is believed that a multilaboratory statement of precision is not appropriate because of the limited possibility that two or more laboratories will be performing freezing and thawing tests on the same concretes.

11.2. *Length Change*:

11.2.1. *Within-Laboratory Precision*—The single operator coefficient of variation has been determined to be 29.9 percent. Therefore results of two properly conducted tests by the same operator on samples from the same batch of concrete, using the same freeze-thaw apparatus and the same length comparator, should not differ from each other by more than 84.6 percent of the average.

11.2.2. *Multilaboratory Precision*—No data are available for multilaboratory precision. It is believed that a multilaboratory statement of precision is not appropriate because of the limited possibility that two or more laboratories will be performing freeze-and-thawing tests on the same concretes.

11.3. *Bias*—This test method has no bias because the values determined can be defined only in terms of this test method.

12. KEYWORDS

12.1. Accelerated testing; concrete-weathering tests; conditioning; freezing and thawing; resistance-frost.

Standard Method of Test for

Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

AASHTO Designation: T 177-10
ASTM Designation: C 293-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

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1. SCOPE

1.1. This method covers the determination of the flexural strength of concrete specimens by the use of a simple beam with center-point loading. It is not an alternative to T 97.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 97, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- T 231, Capping Cylindrical Concrete Specimens

2.2. *ASTM Standards*:
- C 31/C 31M, Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 78, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
- C 192/C 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C 617, Standard Practice for Capping Cylindrical Concrete Specimens
- C 1077, Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
- E 4, Standard Practices for Force Verification of Testing Machines

3. SIGNIFICANCE AND USE

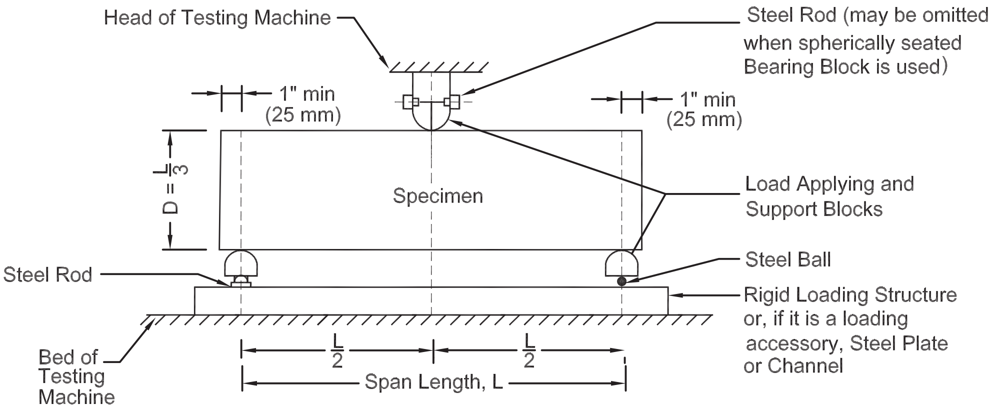
3.1. This test method is used to determine the modulus of rupture of specimens prepared and cured in accordance with R 39 or T 23. The strength determined will vary where there are differences in specimen size, preparation, moisture, condition, or curing.

3.2. The results of this test method may be used to determine compliance with specifications or as a basis for proportioning mixing and placement operations. This test method produces values of flexural strength significantly higher than T 97.

4. APPARATUS

4.1. *Testing Machine*—The testing machine shall conform to the requirements of the sections on Basis of Verification, Corrections, and Time Interval Between Verifications of ASTM E 4. Hand-operated testing machines having pumps that do not provide a continuous loading to failure in one stroke are not permitted. Motorized pumps or hand-operated positive displacement pumps having sufficient volume in one continuous stroke to complete a test without requiring replenishment are permitted and shall be capable of applying loads at a uniform rate without shock or interruption.

4.2. *Loading Apparatus*—The mechanism by which forces are applied to the specimen shall employ a load-applying block and two specimen support blocks. It shall ensure that all forces are applied perpendicular to the face of the specimen without eccentricity. A diagram of an apparatus that accomplishes this purpose is shown in Figure 1.



Note: Apparatus may be used inverted.

Figure 1—Diagrammatic View of a Suitable Apparatus for Flexure Test of Concrete by Center-Point Loading Method

4.2.1. All apparatus for making center-point loading flexural tests shall be similar to Figure 1 and maintain the span length and central position of the load-applying block with respect to the support blocks constant within ±1.3 mm (±0.05 in.).

4.2.2. Reactions shall be parallel to the direction of the applied load at all times during the test and the ratio of the horizontal distance between the point of load application and nearest reaction to the depth of the beam shall be 1.5 ± 2 percent.

4.2.3. The load-applying and support blocks shall not be more than 64 mm ($2^{1}/_{2}$ in.) high, measured from the center or the axis of pivot, and shall extend at least across the full width of the specimen. Each hardened bearing surface in contact with the specimen shall not depart from a plane by more than 0.051 mm (0.002 in.) and shall be a portion of a cylinder, the axis of which is coincidental with either the axis of the rod or center of the ball, whichever the block is pivoted upon. The angle subtended by the curved surface of each block shall be at least 0.79 rad (45 degrees). The load-applying and support blocks should be maintained in a vertical position and in contact with the rod or ball by means of spring-loaded screws that hold them in contact with the pivot rod or ball. The rod in the center load-applying block in Figure 1 may be omitted when a spherically seated bearing block is used.

5. TESTING

5.1. The test specimen shall conform to all requirements of R 39 or T 23 applicable to beam specimens and shall have a test span within 2 percent of being three times its depth as tested. The sides of the specimen shall be at right angles with the top and bottom. All surfaces shall be smooth and free of scars, indentations, holes, or inscribed identification marks.

5.2. The individual who tests concrete beams for acceptance testing shall meet the concrete laboratory requirements of ASTM C 1077 including Test T 177 as a relevant test.

6. PROCEDURE

6.1. Flexural tests of moist-cured specimens shall be made as soon as practical after removal from moist storage. Surface drying of the specimen results in a reduction in the measured modulus of rupture.

6.2. Turn the test specimen on its side with respect to its position as molded and center it on the support blocks. Center the loading system in relation to the applied force. Bring the load-applying block in contact with the surface of the specimen at the center and apply a load of between 3 and 6 percent of the estimated ultimate load. Using 0.10 mm (0.004 in.) and 0.38 mm (0.015 in.) leaf-type feeler gauges, determine whether any gap between the specimen and the load-applying or support blocks is greater or less than each of the gauges over a length of 25 mm (1 in.) or more. Grind, cap, or use leather shims on the specimen contact surface to eliminate any gap in excess of 0.10 mm (0.004 in.). Leather shims shall be of uniform 6.4 mm (0.25 in.) thickness, 25 to 50 mm (1 to 2 in.) in width, and shall extend across the full width of the specimen. Gaps in excess of 0.38 mm (0.015 in.) shall be eliminated only by capping or grinding. Grinding of lateral surfaces shall be minimized in as much as grinding may change the physical characteristics of the specimens. Capping shall be in accordance with T 231.

6.3. Load the specimen continuously and without shock. The load shall be applied at a constant rate for the duration of the test. Apply the load so the maximum stress on the tension face increases at a rate between 0.9 and 1.2 MPa/min (125 and 175 psi). The loading rate is computed using:

$$r = 2Sbd^2/3L \qquad (1)$$

where:

r = loading rate, mN/min (lb/min);

S = rate of increase in extreme fiber stress, MPa/min (psi/min);

b = average width of the specimen, mm (in.);

d = average depth of the specimen, mm (in.); and

L = span length, mm (in.).

7. MEASUREMENT OF SPECIMENS AFTER TEST

7.1. To determine the dimensions of the specimen section for use in calculating modulus of rupture, take measurements across one of the fractured faces after testing. The width and depth are measured with the specimen as oriented for testing. For each dimension, take one measurement at each end of the specimen and one at the center of the cross section. Use the three measurements for each direction to determine the average width and the average depth. Take all measurements to the nearest 1.3 mm (0.05 in.). If the fracture occurs at a capped section, include the cap thickness in the measurement.

8. CALCULATIONS

8.1. Calculate the modulus of rupture as follows:

$$R = \frac{3Pl}{2bd^2} \qquad (2)$$

where:

R = modulus of rupture, MPa (psi);

P = maximum applied load indicated by the testing machine, (N or lbf);

l = span length, mm (in.);

b = average width of specimen, at the point of fracture, mm (in.); and

d = average depth of specimen, at the point of fracture, mm (in.).

Note 1—The weight of the beam is not included in the above calculation.

9. REPORT

9.1. *Report the following information*:

9.1.1. Identification number;

9.1.2. Average width to the nearest 1.3 mm (0.05 in.), at the fracture;

9.1.3. Average depth to the nearest 1.3 mm (0.05 in.), at the fracture;

9.1.4. Span length in millimeters (or inches);

9.1.5. Maximum applied load in newtons (or pounds-force);

9.1.6. Modulus of rupture calculated to the nearest 0.05 MPa (5 psi);

9.1.7. Record of curing and apparent moisture condition of the specimens at the time of test;

9.1.8. If specimens were capped, ground, or if leather shims were used;

9.1.9. Defects in specimens; and

9.1.10. Age of specimens.

10. PRECISION AND BIAS

10.1. *Precision*—The coefficient of variation of test results has been observed to be dependent on the strength level of the beams. The single operator coefficient of variation has been found to be 4.4 percent. Therefore, results of two properly conducted tests by the same operator on beams made from the same batch sample should not differ from each other by more than 12 percent. The multilaboratory coefficient of variation has been found to be 5.3 percent. Therefore, results of two different laboratories on beams made from the same batch sample should not differ from each other by more than 15 percent.

10.2. *Bias*—Because there is no accepted standard for determining bias in this test method, no statement on bias is made.

Standard Test Method for

Portland-Cement Content of Hardened Hydraulic-Cement Concrete

AASHTO Designation: T 178-10
ASTM Designation: C 1084-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Portland-Cement Content of Hardened Hydraulic-Cement Concrete

AASHTO Designation: T 178-10
ASTM Designation: C 1084-02

1. SCOPE

1.1 This test method covers the determination of portland cement content of a sample of hardened hydraulic-cement concrete.

1.2 The values in SI units are to be regarded as the standard. The values given in parentheses are provided for information purposes only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Disposal of some or all of the chemicals used in this method may require adherence to EPA or other regulatory guidelines.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 105, Chemical Analysis of Hydraulic Cement
- T 248, Reducing Samples of Aggregate to Testing Size

2.2 *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 823, Standard Practice for Examination and Sampling of Hardened Concrete in Constructions
- C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- D 1193, Standard Specification for Reagent Water
- E 832, Standard Specification for Laboratory Filter Papers

3. SIGNIFICANCE AND USE

3.1 This test method consists of two independent procedures: an oxide-analysis procedure that consists of two sub-procedures and an extraction procedure. Each procedure requires a substantial degree of chemical skill and relatively elaborate chemical instrumentation. Except for the influence of known interference, determined cement contents are normally equal to, or slightly greater than, actual values except for the Maleic Acid procedure, where results can also be significantly lower when the paste is carbonated (Note 1).

Note 1—With certain limitations, the procedure is also applicable for eliminating the combined content of portland cement and pozzolan or slag in concretes made with blended hydraulic cement and blends of portland cement with pozzolans and slags. The results of this test method when applied to concrete made with blended cement or pozzolans depend on the composition of the pozzolan, the age of the concrete, the extent of the reaction of the pozzolan, and the fact that this test method may determine only the portland cement component of a blended cement. The test method should be applied to determine the blended cement content or the pozzolanic content only by use of calibration concrete samples or other information. Earlier versions of this test method can provide useful information as detailed by Hime[1] and Minnick.[2]

4. INTERFERENCES

4.1 Many constituents of concrete may interfere with the analysis of the concrete for portland cement content. The following limited lists of materials have been provided as a guide. The rocks, minerals, or mineral admixtures listed will interfere with the cement content determination to the extent of their solubility during the dissolution procedure used. The solubility of rocks, minerals, or mineral admixtures may depend on the fineness of the test sample, the water-cement ratio of the concrete, the extent of hydration, and the age of the concrete (extended exposure of the high pH of the concrete may affect the solubility of some minerals).

4.2 *Substances Affecting Calcium Oxide Sub-Procedure*:

4.2.1 The following are soluble in even the cold dilute hydrochloric acid of this procedure and will contribute a high bias to the cement content calculated from the soluble calcium oxide: limestone, marble, dolomitic limestone, calcareous sandstone, calcareous chert, and caliche-encrusted and calcite- or dolomite-coated rocks.

4.2.2 The following may be soluble depending on the age and pH of the concrete; whether the mineral present is glassy or crystalline, or weathered or strained; and the fineness of the minerals present, and, if soluble, will bias the cement content calculated from the soluble calcium oxide high depending on the calcium content of the minerals: weathered or altered plagioclase feldspar, caliche-encrusted rocks, altered volcanic rocks (with calcareous inclusions), and many other calcium containing rocks.

4.2.3 Every percent of soluble calcium oxide that is contributed by soluble aggregate or mineral admixtures will bias the cement content high by approximately 1.6 percent.

4.2.4 Silica fume may lower the acid solubility of the sample and hence bias the result low.

4.3 *Substances Affecting the Soluble Silica Sub-Procedure*:

4.3.1 The following may be soluble depending on the age and pH of the concrete; whether the aggregate is glassy or crystalline, or weathered or strained; and the fineness of the minerals: chert, opal, chalcedony, glassy volcanic rock, strained quartz (highly strained), quartzite, cataclastic rocks (mylonite, phyllonite), gneiss, schist, metagraywacke, and many other soluble silicon-containing rocks and minerals.

4.3.2 Every percent of soluble SiO_2 contributed by aggregate or mineral admixtures will bias the reported cement content high by approximately 4.7 percent.

4.3.3 Silica fume may lower the acid solubility of the sample and hence bias the result low. If the digestion time or temperature are sufficient to digest all of the portland cement, the silica fume will also be solubilized and bias the calculated cement content high.

4.4 *Substances Affecting the Maleic Acid Procedure*:

4.4.1 The same substances that are soluble in the soluble calcium or the soluble silica sub-procedures may be soluble in the maleic acid procedure. (See Sections 4.2.1, 4.2.2, and 4.3.1.)

4.4.2 Every 1 percent of the sample that is aggregate or mineral admixture dissolved by the maleic acid will bias the cement content high by 1 percent.

4.4.3 Carbonated cement paste may not be soluble in the maleic acid-methanol dissolution and thus may bias the cement content results low.

4.4.4 The unhydrated iron and aluminum phases of the portland cement may not be soluble in the maleic acid and, if not soluble, will bias the cement content low. This may be significant at early ages and less significant at later ages.

5. APPARATUS

5.1 Choose the apparatus from applicable items given in T 105 and from the following:

5.1.1 Chipmunk (jaw ore crusher).

5.1.2 Disk Pulverizer.

5.1.3 Rotary Mill (rotating puck).

5.1.4 Sieve, 300 um (No. 50), 1.18-mm (No.16), and 4.75-mm (No. 4).

5.1.5 Ice Bath or electric cooling apparatus.

5.1.6 Steam Bath.

5.1.7 Funnel, Buchner-type porcelain funnel.

5.1.8 Filter paper, Type II, Class F and Class G as described in ASTM Specification E 832.

5.1.9 Beakers, 1000 and 250 mL.

5.1.10 Magnetic Stirrer, variable speed, with a TFE-fluorocarbon-coated magnetic stirring rod, or an overhead stirrer with a propeller.

5.1.11 Volumetric flask, 1000 mL and 500 mL.

5.1.12 Filtering flask, 2000 mL.

5.1.13 Vacuum pump.

5.1.14 Watch glass, 125 mm.

6. REAGENT AND MATERIALS

6.1 *Soluble Silica Sub-Procedure*:

6.1.1 *Hydrochloric Acid,* reagent grade, density 1.19 Mg/m^3.

6.1.2 *Hydrochloric Acid (1:3)*—Mix 300 mL of hydrochloric acid into 900 mL of water.

6.1.3 *Hydrochloric Acid (1:9)*—Mix 100 mL of hydrochloric acid into 900 mL of water.

6.1.4 *Sodium Hydroxide (10 g/L)*—Dissolve 5 g of reagent grade sodium hydroxide in 200 mL of water and dilute to 500 mL.

6.1.5 *Hydrofluoric Acid,* 48 percent, reagent grade.

6.1.6 *Sulfuric Acid,* density 1.84 Mg/m^3, reagents grade.

6.2 *Calcium Oxide Sub-Procedure*—Use reagent as required in T 105.

6.3 *Maleic Acid Procedure*:

6.3.1 *Maleic Acid*, technical grade.

6.3.2 *Methanol,* technical grade, anhydrous.

6.3.3 *Maleic acid solution*—prepare a fresh solution of 15 percent maleic acid in methanol by dissolving and diluting 180 + 1 g of maleic acid with methanol to a final solution volume of 1200 mL. Prepare this solution fresh daily. Care must be taken to use methanol only in well ventilated areas, preferably under a hood, to avoid skin contact and breathing vapors. Disposal of the maleic acid/methanol solution shall be according to applicable regulations.

6.3.4 *Fuller's earth*—a clay-like material consisting of a porous colloidal aluminum silicate. Its high absorptivity has been found very beneficial for decolorizing and purifying materials.

6.4 *Water*—All references to water shall be understood to mean reagent water Type I through IV of ASTM D 1193.

7. SAMPLING

7.1 Choose the concrete sample in accordance with the purposes of the investigation (Note 2).

Note 2—A standard procedure for sampling hardened concrete is given in ASTM C 823 and a standard procedure for obtaining cores is given in T 24.

7.2 Both the sample for cement content and for density shall have a minimum length and diameter of four times the nominal maximum size of the aggregate (Note 3).

Note 3—A single concrete core taken through the entire depth of the concrete is ordinarily an appropriate sample. This sample may be sawed or split lengthwise to provide samples for cement content, density, and petrographic examination, provided that the length and thickness of the split samples for cement content and density meet the minimum size specified in Section 7.2. If the split sample would not meet the minimum size requirements, perform the density measurement first, and then crush the entire dry sample for cement content determination. The recommended mass of concrete for cement content determination is 4.5 kg (10 lb). This mass should be obtained from more than one core when the concrete depth is small and one core will not supply a mass of 4.5 kg (10 lb). If the concrete sample did not have a mass of 4.5 kg (10 lb), it should be so stated in the final report for the cement content result.

7.3 For cement content determination, crush the sample to pass a 4.75-mm (No. 4) sieve, mix thoroughly, and obtain a representative subsample for analysis by coning and quartering or by riffle splitting as described in T 248. The subsample should have a mass of 0.45 kg (1 lb).

8. CEMENT CONTENT PROCEDURE

8.1 *Oxide Analysis Procedure*:

8.1.1 Crush or grind the subsample prepared as described in Section 7.3 using a chipmunk (jaw ore crusher), a disk pulverizer, or a rotary mill (rotating-puck) device, so that all of the material passes a 300-μm (No. 50) sieve. To minimize production of very fine material, use several passes of the sample through the equipment, removing the portion passing the device before regrinding the remainder of the sample. Thoroughly mix by coning ten times from one paper to another.

8.1.2 Dry the crushed and ground materials in an oven at 105 to 115°C (220 to 240°F) for 3 h and retain the sample in a sealed container.

8.1.3 Sub-procedure to be used:

8.1.3.1 The soluble silica sub-procedure shall be performed in all cases except where a petrographic examination has indicated there are siliceous aggregates or mineral admixtures that will be soluble in cold hydrochloric acid.

8.1.3.2 The calcium oxide sub-procedure shall also be employed unless the aggregate contains a significant amount of calcareous components.

8.1.3.3 All analysis shall be done in triplicate and the average of the three values shall be used in calculating cement content.

8.1.4 *Soluble Silica Sub-Procedure*:

8.1.4.1 Introduce 100 mL of dilute hydrochloric acid (1:3) into each of three 250-mL beakers. Cool until within the range of 3 to 5°C (38 to 41°F) using an ice bath or electric cooling apparatus.

8.1.4.2 Weigh a 2-g sample to 0.001 g and slowly, over a 1-minute period, add it to the cold hydrochloric acid. Maintain the 3 to 5°C (38 to 41°F) temperature for a 5-minute period, and stir the mixture either continuously or at least several times during this period (Note 4).

Note 4—Observation of the solution during the introduction of the sample may provide useful information. Considerable effervescence indicates a substantial amount of calcite or carbonated paste. Delayed effervescence suggests a dolomitic aggregate. Lack of effervescence suggests the applicability of the calcium oxide sub-procedure.

8.1.4.3 Decant through a Buchner-type porcelain funnel fitted snugly with two disks of a quantitative filter paper for fine precipitate, Type II, Class G filter paper. Once the filtration has begun, take care so that the mat and accumulated residue do not dry completely until the filtration process is complete. Regulate the suction so as to maintain a rapid rate of dripping during the greater part of the filtration. Retain as much of the residue in the beaker as possible. Wash twice by decantation with hot water. Save the filtrate. Transfer the filter paper from the funnel to the beaker containing the balance of the residue, being careful that no residue is lost. Add 75 mL of hot sodium hydroxide solution (10 g/L) to the residue while stirring, macerate the filter paper, and digest, covered, on a steam bath for 15 minutes. During the digestion, occasionally stir the mixture. Filter all solids, and wash twice with hot water until the filtrate is neutral to litmus. Combine the filtrates.

8.1.4.4 The filtrate now contains the silica in the form of silicic acid, either in true solution or in suspension in the hydrochloric acid medium. To ensure analysis of only the soluble silicon, refilter any filtrate that is cloudy. (Allowing the filtrate to stand overnight will usually permit suspended silica to settle.) The soluble silica may be analyzed by either Section 8.1.4.4.1 or 8.1.4.4.2.

8.1.4.5 Analysis of soluble silica by conversion to silicon tetrafluoride with hydrofluoric acid—In the case where the aggregate of the original sample contains a substantial amount of material that yields calcium oxide (CaO) on acid treatment, add 10 mL of hydrochloric acid (density 1.19 Mg/m^3) to the solution from Section 8.1.4.4. Transfer to a suitable beaker, with several rinsings of the filter flask. Evaporate to dryness with great care to minimize spattering, bake at not over 120^{o}C (248^{o}F) for 1 h, moisten with hydrochloric acid (density 1.19 Mg/m^3), evaporate and bake again, and take up for filtration in 75 mL of hydrochloric acid (1:3). Heat to boiling, filter through an ashless filter paper, and wash the residue with 50 mL of hot hydrochloric acid (1:9) and hot water until the washings are free of chlorides. Determine the silica present in the sample by treatment with hydrofluoric acid and sulfuric acid in accordance T 105.

8.1.4.6 *Instrumental analysis of soluble silica*—Transfer the filtrate from Section 8.1.4.4 to a 500-mL volumetric flask with several rinsings of the filtration flask and bring the volume in the volumetric flask to 500 mL with water. Analyze the soluble silica by any instrumental method found acceptable for cement analysis in accordance with the performance requirement for rapid method of T 105, provided it can be applied to the filtrate. Suitable instrumental techniques may include atomic absorption or inductively coupled plasma spectroscopy.

8.1.4.7 *Calculation*—Calculate the cement percentage, C_s, by dividing the percentage of silica (SiO_2) in the concrete by the percentage of silica (SiO_2) in the cement and multiplying by 100. If the cement silica value is unknown, assume 21.0 percent.

8.1.5 *Calcium Oxide Sub-Procedure*—Calcium oxide may be determined by either of the following procedures. Omit the determination if it is known that the aggregate contains a substantial amount of calcareous components.

8.1.5.1 *Oxalate Precipitation of Calcium*—Using the filtrate from the removal of the silica (Section 8.1.4.4), separate the ammonium hydroxide group and then determine the calcium oxide, both in accordance with T 105 or proceed as described in Section 8.1.5.2.

8.1.5.2 *Instrumental analysis of calcium oxide*—Any calcium method found acceptable for cement analysis in accordance with the performance requirements for rapid methods of T 105 may be used, provided that the method may be applied to the filtrate. Further, the method must be acceptable for cement analysis in the same silica-present or silica-absent condition as is the case for the state of analysis of the concrete.

8.1.5.3 *Calculation*—Calculate the cement percentage, C_c, by dividing the percentage of calcium oxide in the concrete by the percentage of calcium oxide in the cement and multiplying by 100. If the cement calcium oxide value is unknown, assume 63.5 percent.

8.2 *Maleic Acid Extraction Procedure*:

8.2.1 Crush or grind and dry the sample as described in Sections 8.1.1 and 8.1.2, except that the materials shall pass a 1.18-mm (No. 16) sieve meeting M 92.

8.2.2 *Combined water*—Measure 10 g of the dried crushed sample to the nearest 0.001g into a tared pre-heated crucible and dry at 520 ± 5°C (970 ± 40°F) for 3 hours or to constant mass (Note 5). Cool in a desiccator and determine the mass.

Note 5—The temperature of 540°C (1005°F) should not be exceeded to avoid the decomposition of the calcite or dolomitic carbonates in certain aggregates.

8.2.2.1 Calculate the percentage of combined water as follows:

$$L_c, \% = \frac{(C - D) \times 100}{C} \qquad (1)$$

where:

L_c = percentage of combined water, dry basis,

C = mass of dried sample, g, and

D = mass after heating at 520°C (1005°F), g.

8.2.3 *Extraction—Determine* the mass of a 20-g sample of the ground dried concrete and a 2.5-g sample of Fuller's earth, dried at 105 to 115°C (220 to 240°F), to 0.001 g, and transfer both to a 1000-mL beaker or flask. Add 800-mL of maleic acid solution, and stir with a magnetic stirrer (or overhead stirrer equipped with a propeller) for 60 minutes. Allow the mixture to settle for 60 minutes. Filter the solution by carefully decanting through a Whatman 41 filter paper or equivalent of known mass fitted into a 100-mm Buchner funnel, using suction, and collect the filtrate in a 2000-mL vacuum filtering flask. Allow the residue to remain in the beaker.

8.2.3.1 Add 400-mL of maleic acid solution to the residue in the beaker and stir for 10 minutes. Allow the mixture to settle for 30 minutes and filter the entire contents of the beaker through the original filter paper. Rinse the beaker thoroughly with methanol to ensure complete transfer. Wash the residue contained on the filter paper 4 to 5 times with approximately 50 mL portions of methanol to remove any residual maleic acid. Also wash any iron filling that may be attached to the magnetic stir bar into the Buchner funnel. The filtrate should be clear.

8.2.3.2 Transfer the filter paper and residue onto a 125-mm watch glass and place in an oven at 105°C (220°F). Dry to a constant mass and determine the mass of the residue and filter paper to the nearest 0.001 g.

8.2.4 *Calculation*—Calculate the percentage of insoluble residue as follows:

$$R, \% = \frac{(F - G) \times 100}{E} \qquad (2)$$

where:

R = percentage of insoluble residue;

E = mass of sample used, g;

F = combined mass of residue, filter paper, and Fuller's earth, g; and

G = combined mass of filter paper and Fuller's earth, g.

8.2.5 *Calculation*—Calculate the percentage of cement content, C_m, by subtracting R and L_c from 100.

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9. UNIT WEIGHT AND LOSS OF FREE WATER

9.1 Determine the density of a separate sample of the concrete, of a minimum dimension four times the maximum size of the aggregate and a sample mass of at least 0.45 kg (1 lb), as follows:

9.1.1 *Saturated surface dry density*—For saturated surface-dry density, which will usually correlate well with the density of the concrete as placed, immerse the concrete in water and soak it for a minimum of 24 hours or to constant weight. (Constant weight may take 48 hours for $^1/_2$ of a 100-mm (4-in.) diameter core.) Determine the mass of the sample while immersed in the water to the nearest 0.1 g (0.001 lb). Remove from the water, surface dry, and determine the mass to the nearest 0.1 g (0.001 lb). Calculate the density, D_{SSD}, in kilograms per cubic meter (or alternately in pounds per cubic foot), as:

$$D_{SSD} = \frac{W_1 \times \rho}{W_1 - W_2} \qquad (3)$$

where:

D_{SSD} = saturated surface- dry unit weight, kg/m^3 (or, alternatively, lb/ft^3);

W_1 = saturated surface-dry (SSD) mass in air after the 48 hour soak, kg;

W_2 = SSD mass suspended and immersed in water, kg; and

ρ = density of water, 997 kg/m^3 (62.3 lb/ft^3)

9.1.2 *Dry unit weight and free water*—Dry the sample from Section 9.1.1 for a minimum of 24 hours or to constant weight at 105 to 115°C (220 to 240°F). Cool. Determine the mass to the nearest 0.1 g (0.001 lb). Calculate the density, D_{SSD}, in kilograms per cubic meter (pounds per cubic foot), and the free water, L_f, as:

$$D_{\mathrm{dry}} = \frac{D_{SSD} \times W_3}{W_1} \qquad (4)$$

$$L_f = \frac{(W_1 - W_3) \times \rho}{W_1 - W_2}$$

where:

D_{SSD} = saturated surface-dry unit weight, kg/m^3 (or, alternatively, lb/ft^3);

W_1 = saturated surface-dry (SSD) mass in air after the 48 hour soak, kg;

W_3 = dry mass, kg; and

L_f = free water, kg/m^3 (or, alternatively, lb/ft^3).

10. ADDITIONAL CALCULATIONS

10.1 *Cement content*—Calculate the cement content of the concrete from the data for each procedure used as follows:

$$\text{Cement content, kg/m}^3 = \frac{C \times D_1}{100} \quad (5)$$

$$\text{Cement content, lb/yd}^3 = \frac{C \times D_2 \times 27}{100} \quad (6)$$

where:

C = determine cement percentage, percentage by mass, either as C_s, C_c, or C_m;

D_1 = D_{dry}, kg/m^3; and

D_2 = D_{dry}, lb/ft^3.

11. REPORT

11.1 Report the cement percentage, and, if required, the cement content, to the nearest kg/m^3 (lb/yd^3) as follows:

11.1.1 If two or more procedures or sub-procedures have been performed, report the lowest result and report the procedure used.

12. PRECISION AND BIAS

12.1 *Precision*—The precision of the cement content test procedures is dependent upon the composition of the concrete.

12.1.1 The use of the soluble silica procedure may lead to erroneously high results for concrete that contains siliceous aggregates, pozzolans, or other cementitious components.

12.1.2 The use of the calcium oxide procedure will lead to erroneously high results if calcareous aggregates or other cementitious materials are present, and may do so with many pozzolanic materials.

12.1.3 The use of the maleic acid procedure may lead to erroneously low or high results, depending upon the solubility of the aggregates in the maleic acid solution, the amount of unhydrated aluminate and ferrite phases in the cement that are insoluble, and the carbonation of the paste.

12.1.4 For these reasons, precision data obtained on one concrete may not be useful in estimating that obtainable for another concrete.

12.1.5 The following sections on the soluble silica and calcium oxide procedures are based on results of cooperative analyses of a suite of three samples (Note 6), one having an aggregate providing a calcium interference, one an aggregate providing a silica interference, and one providing both interferences.

Note 6—These precision statements are based on tests of samples that were ground to pass a 600-µm (No. 30) sieve by a single laboratory. For this reason, interlaboratory tests did not include any variation in results that will occur because of sampling and sample preparation.

12.1.6 The section on maleic acid extraction is based on results of cooperative analyses from eleven laboratories on a suite of four concrete samples (Note 7), one with a limestone coarse aggregate, one with dolomite, and two with siliceous aggregates. One specimen contained fly ash. Total cementitious material contents ranged from 250 to 355 kg/m^3 (400 to 600 lb/yd^3).

Note 7—This precision statement is based on tests of samples that were ground to pass a 1.18 mm (No. 16) sieve by a single laboratory. For this reason, interlaboratory tests did not include any variation in results that will occur because of sampling and sampling preparation.

12.1.7 *Soluble silica procedure*—The single laboratory standard deviation has been found to be 15.6 kg/m^3 (26.3 lb/yd^3) (Note 8). Therefore, results of two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 71.4 kg/m^3 (120.3 lb/yd^3) (Note 8).

12.1.8 *Calcium oxide procedure*—Where applicable, the single laboratory standard deviation has been found to be 2.8 kg/m^3 (4.7 lb/yd^3). Therefore, results of two properly conducted tests in the same laboratory on the same material should not differ by more than 7.8 kg/m^3 (13.2 lb/yd^3) (Note 8).

12.1.8.1 The multilaboratory standard deviation has been found to be 10.0 kg/m^3 (16.9 lb/yd^3) (Note 8). Therefore, results of two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 28.4 kg/m^3 (47.9 lb/yd^3) (Note 8).

Note 8—These numbers represent, respectively, the 1s and d2s limits as described in ASTM C 670.

12.1.9 *Maleic Acid Procedure*—The single laboratory standard deviation has been found to be 14 kg/m^3 (24 lb/yd^3) (Note 8). Therefore, results of two properly conducted tests in the same laboratory on the same materials should not differ by more than 40 kg/m^3 (67 lb/yd^3) (Note 8).

12.1.9.1 The multilaboratory standard deviation has been found to be 22 kg/m^3 (37 lb/yd^3) (Note 8). Therefore, results of two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 62 kg/m^3 (104 lb/yd^3) (Note 8).

12.2 *Bias*—The bias of the test procedure is dependent upon the composition of the concrete for reasons described in Sections 12.1.1–12.1.3. For these reasons, bias data obtained on one concrete may be useless in estimating that obtainable for another concrete. Refer to Section 12.1.5 for a description of the test program on which the following is based.

12.2.1 *Soluble Silica Sub-Procedure*—For the soluble silica procedure, determined values may be expected to be from about 20 kg/m^3 (50 lb/yd^3) below the true value to 10 kg/m^3 (25 lb/yd^3) above for no silica interference, to 45 kg/m^3 (100 lb/yd^3) or more above for severe silica interferences (for example, for samples containing slag or volcanic aggregate, or a fly ash addition).

12.2.2 *Calcium Oxide Sub-Procedure*—Where the calcium procedure is applicable, determined values should be within 10 kg/m^3 (25 lb/yd^3) of the true value.

12.2.3 The use of either of the oxide determination procedures may lead to error to the extent that the oxide content used for calculations differs from the true value for the cement. Errors greater than 4 percent relative are unusual for this parameter.

12.2.4 Bias may be reduced by analysis of separate samples of calcareous aggregates representing those used in the concrete, employing the same procedures and applying corrections based on mix design data or estimates of aggregate proportion as based on petrographic studies. Where corrected values are 45 kg/m^3 (100 lb/yd^3) or more below uncorrected values, the method is probably inapplicable.

12.2.5 *Maleic Acid Procedure*—The bias of the maleic acid procedure is dependent upon the composition of the concrete for reasons stated in Section 12.1.3. Based on the mean values from the interlaboratory test program described under the precision, the values determined should be within –10 to +4 kg/m^3 (–17 to +6 lb/yd^3) of the actual values.

12.2.5.1 Approximately 40 percent of the fly ash in the interlaboratory test program was consumed in the extraction and contributed to the determined cement content of the concrete. Other sources have found that variable amounts of fly ash can be consumed in some cases. This demonstrates the need for caution and compensation for induced bias when testing concrete containing fly ash, slag, silica fumes, or natural pozzolan. Various sources of these materials will have highly variable effects on the results from this test.

12.2.5.2 Concrete samples that have deeply carbonated should be tested with caution as the maleic acid test results can be significantly affected, producing erroneously low cement content values.

12.2.6 Particular aggregate sources have been found to significantly affect the bias of this test method. Therefore, the separate testing of aggregate materials may be useful to indicate the solubility of the materials and possible significant contribution from the aggregates to the cement content results.

12.2.7 Petrographic studies such as those performed according to ASTM C 856 can be used in indicating potential interferences to each of the cement content procedures.

13. KEYWORDS

13.1 Cement content; concrete; hardened.

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[1] Hime, W. G., “Cement Content,” *Significance of Test and Properties of Concrete and Concrete-Making Materials,* ASTM STP 169B, ASTM, 1978, *pp*. 462–470, and “Analyses of Cement and Other Materials in Hardened Concrete,” Chapter 29, *Significance of Tests and Properties of Concrete and Concrete-Making Materials,* ASTM STP 169C, *pp*. 315–319.

[2] Minnick, L. J., “Cement-Content, Hardened Concrete,” *Significance of Tests and Properties of Concrete and Concrete-Making Materials,* ASTM STP 169A, ASTM, 1966, *pp*. 326–329.

Standard Method of Test for

Air Content of Freshly Mixed Concrete by the Volumetric Method

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AASHTO Designation: T 196M/T 196-09
ASTM Designation: C 173/C 173M-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Air Content of Freshly Mixed Concrete by the Volumetric Method

AASHTO Designation: T 196M/T 196-09
ASTM Designation: C 173/C 173M-08

1. SCOPE

1.1. This test method covers determination of the air content of freshly mixed concrete containing any type of aggregate, whether it be dense, cellular, or lightweight.

1.2. The values stated in either inch-pound or SI units shall be regarded separately as standard. The inch-pound units are shown in brackets. The values stated are not exact equivalents; therefore each system must be used independently of the other. Combining values from the two units may result in nonconformance.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SIGNIFICANCE AND USE

3.1. This test covers the determination of the air content of freshly mixed concrete. It measures the air contained in the mortar fraction of the concrete, but is not affected by air that may be present inside porous aggregate particles. Therefore, this is the appropriate test to determine the air content of concretes containing lightweight aggregates, air-cooled slag, and highly porous or vesicular natural aggregates.

3.2. This test method requires the addition of sufficient isopropyl alcohol, when the meter is initially being filled with water, so that after the first or subsequent rolling little or no foam collects in the neck of the top section of the meter. If more foam is present than that equivalent to 2 percent air above the water level, the test is declared invalid and must be repeated using a larger quantity of alcohol. Addition of alcohol to dispel foam any time after the initial filling of the meter to the zero mark is not permitted.

3.3. The air content of hardened concrete may be either higher or lower than that determined by this test method. This depends upon the methods and amounts of consolidation effort applied to the concrete from which the hardened concrete specimen is taken; uniformity and stability of the air bubbles in the fresh and hardened concrete; accuracy of the microscopic examination, if used; time of comparison; environmental exposure; stage in the delivery, placement, and consolidation processes at which the air content of the unhardened concrete is determined, that is, before or after the concrete goes through a pump; and other factors.

4. APPARATUS

4.1. *Air Meter*—An air meter consisting of a bowl and a top section (Figure 1) conforming to the following requirements:

4.1.1. The bowl and top sections shall be of sufficient thickness and rigidity to withstand rough field use. The material shall not be attacked by high pH cement paste, deform when stored at high temperatures in closed spaces, or become brittle or crack at low temperatures. A watertight seal must be obtained when the top section is attached to the bowl.

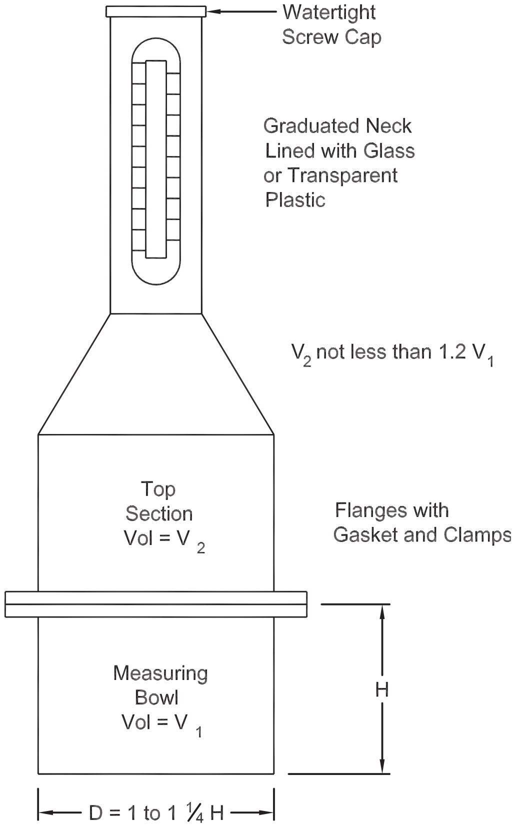


Figure 1—Apparatus for Measuring Air Content of Fresh Concrete by Volumetric Method

4.1.2. *Bowl*—The bowl shall have a diameter equal to 1 to 1.25 times the height and be constructed with a flange at or near the top surface. Bowls shall not have a capacity of less than 2.0 L [0.075 ft^3].

4.1.3. *Top Section*—The top section shall have a capacity at least 20 percent larger than the bowl and shall be equipped with a flexible gasket and a device to attach the top section to the bowl and make a watertight connection. The top section shall be equipped with a transparent scale, graduated in increments not greater than 0.5 percent from zero at the top, to 9 percent or more of the volume of the bowl. Graduations shall be accurate to ± 0.1 percent by volume of the bowl. The upper end of the neck shall have a watertight cap that will maintain a seal when the meter is inverted and rolled.

4.2. *Funnel*—A funnel with a spout of a size permitting it to be inserted through the neck of the top section and long enough to extend to a point just above the bottom of the top section. The discharge end of the spout shall be so constructed that when water is added to the container there will be a minimum disturbance of the concrete.

4.3. *Tamping Rod*—A round, smooth, straight 16 ± 2-mm [$^5/_8$ ± $^1/_{16}$-in.] diameter rod at least 300 mm [12 in.] long with both ends rounded to a hemispherical tip of the same diameter. The rod shall be made of steel, high-density polyethylene, or other plastic of equal or greater abrasion resistance.

4.4. *Strike-Off Bar*—A flat, straight steel bar at least 3 by 20 by 300 mm [0.125 by 0.75 by 12 in.], or a flat, straight, high-density polyurethane bar, or other plastic of equal or greater abrasion resistance, at least 6 by 20 by 300 mm [$^1/_4$ by $^3/_4$ by 12 in.].

4.5. *Calibrated Cup*—A metal or plastic cup either having a capacity of or being graduated in increments equal to 1.0 ± 0.04 percent of the volume of the bowl of the air meter. The calibrated cup is only to be used to add water when the concrete air content exceeds 9 percent or the calibrated range of the meter.

4.6. *Measuring Vessel for Isopropyl Alcohol*—A vessel with a minimum capacity of at least 500 mL [1 pt] with graduations not larger than 100 mL [4 oz] for measuring a quantity of isopropyl alcohol.

4.7. *Syringe*—A rubber syringe having a capacity of at least 50 mL [2 oz].

4.8. *Pouring Vessel for Water*—A container of approximately 1 L [1 qt] capacity.

4.9. *Scoop*—Of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the bowl.

4.10. *Isopropyl Alcohol*—Use 70 percent by volume isopropyl alcohol (approximately 65 percent by mass) (Note 1). Other foam-dispersing agents are permitted if tests demonstrate that the use of the agent does not change the indicated air content, in the amounts being used, by more than 0.1 percent or if correction factors are developed similar to those in Table 1. When other dispersing agents are used, a copy of the records documenting the testing or calculations shall be available in the laboratory.

Note 1—Seventy percent isopropyl alcohol is commonly available as rubbing alcohol. More concentrated grades can be diluted with water to the required concentration.

Table 1—Correction for the Effect of Isopropyl Alcohol on ASTM C 173/C 173M Air Meter Reading

70% Isopropyl Alcohol Used			Correction
pt	oz	L	(Subtract)[a]
0.5	8	0.2	0.0[b]
1.0	16	0.5	0.0[b]
1.5	24	0.7	0.0[b]
2.0	32	0.9	0.0[b]
3.0	48	1.4	0.3
4.0	64	1.9	0.6
5.0	80	2.4	0.9

[a] Subtract from final meter reading.

[b] Corrections less than 0.125 are not significant and are to be applied only when 1.2 L [2.5 pt] or more alcohol is used. The effect occurs when the meter is inverted after being filled with an alcohol-water solution which then becomes further diluted when it's mixed with the water in the concrete. The values given are for air meters that have a bowl volume of 2.1 L [0.075 ft^3] and a top section that is 1.2 times the volume of the bowl.

4.11. *Mallet*—A mallet (with a rubber or rawhide head) with a mass of approximately 600 ± 200 g [1.25 ± 0.5 lb].

5. CALIBRATION

5.1. Calibrate the meter and calibrated cup initially and at 3-year intervals or whenever there is reason to suspect damage or deformation of the meter or calibrated cup.

5.2. Determine the volume of the bowl, with an accuracy of at least 0.1 percent, by determining the mass of water required to fill it at room temperature and dividing this weight by the density of water at the same temperature. Follow the calibration procedure outlined in T 19M/T 19.

5.3. Determine the accuracy of the graduations on the neck of the top section of the air meter by filling the assembled measuring bowl and top section with water to a preselected air content graduation and then determining the quantity of 21.1ºC (70ºF) water required to fill the meter to the zero mark. The quantity of water added shall equal the preselected air content graduation within ± 0.1 volume percent of the measuring bowl. Repeat the procedure to check a minimum of three gradations within the expected range of use.

5.3.1. Add water in increments of 1.0 percent of the volume of the bowl to check accuracy throughout the graduated range of air content. The error at any point throughout the graduated range shall not exceed 0.1 percent of air.

5.4. Determine the volume of the calibrated cup using water at 21.1ºC (70ºF) by the method outlined in Section 5.2. A quick check can be made by adding one or more calibrated cups of water to the assembled apparatus and observing the increase in the height of the water column after filling to a given level.

6. SAMPLING

6.1. Obtain the sample of freshly mixed concrete in accordance with T 141. If the concrete contains coarse aggregate particles that would be retained on a 37.5-mm [$1^1/_2$-in.] sieve, wet-sieve a representative sample over a 25-mm [1-in.] sieve to yield somewhat more than enough material to fill the measuring bowl. The wet-sieving procedure is described in T 141. Carry out the wet-sieving operation with the minimum practicable disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on the sieve.

7. PROCEDURE

7.1. *Rodding and Tapping*—Wet the inside of the bowl and dry it to a damp, not shiny appearance. Using the scoop described in Section 4.9, fill the bowl with freshly mixed concrete in two layers of equal depth. Rod each layer 25 times with the tamping rod. Do not forcibly strike the bottom of the bowl when rodding the first layer. When rodding the second layer, penetrate the prior layer approximately 25 mm [1 in.]. After each layer is rodded, tap the sides of the measure 10 to 15 times with the mallet to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. After tapping the final layer, a slight excess of concrete, 3 mm [$^1/_8$ in.] or less, above the rim is acceptable. Add or remove a representative sample of concrete if necessary to obtain the required amount of concrete.

7.2. *Striking Off*—After rodding and tapping of the second layer, strike off the excess concrete with the strike-off bar until the surface is flush with the top of the bowl. Wipe the flange of the bowl clean.

7.3. *Adding Water*—Wet the inside of the top section of the meter, including the gasket. Attach the top section into position on the bowl, and then insert the funnel. Add at least 0.5 L [1 pt] of water followed by the selected amount (Note 2) of isopropyl alcohol. Record the amount of isopropyl alcohol added. Continue adding water until it appears in the graduated neck of the top section (Note 3). Remove the funnel. Adjust the liquid level until the bottom of the meniscus is level with the zero mark. A rubber syringe is useful for this purpose. Attach and tighten the watertight cap.

Note 2—The amount of isopropyl alcohol necessary to obtain a stable reading and a minimum of foam at the top of the water column will depend upon a number of factors. Many concretes made with less than 300 kg/m^3 [500 lb/yd^3] of cement and air contents less than 4 percent may require less than 200 mL [0.5 pt] of alcohol. Some high-cement mixes made with silica fume that have air contents of 6 percent or more may require more than 1400 mL [3 pt] of alcohol. The amount required will vary with the concrete air content, the amount and type of air-entraining admixture, the cement content and cement alkali content, and perhaps other factors. Generally, the amount of alcohol necessary can be established for given mixture proportions and should not change greatly during the course of a job.

Note 3—When, if ever, it is necessary to use more than 2.0 L [4 or 4.5 pt] of isopropyl alcohol, it may be necessary to restrict the amount of water added initially to avoid overfilling the meter. However, it is desirable to add at least some water initially to aid in mixing the alcohol and limit the contact of the concentrated alcohol with the top surface of the concrete.

7.4. Displace the volume of air in the concrete specimen using these procedures:

7.4.1. *Free the Concrete from the Base*—Quickly invert the meter, shake the base horizontally, and return the meter to the upright position. To prevent the aggregate from lodging in the neck of the unit, do not keep it inverted for more than 5 seconds at a time. Repeat the inversion and shaking process for a minimum of 45 seconds and until the concrete has broken free and the aggregate can be heard moving in the meter as it is inverted.

7.4.2. *Rolling*—Place one hand on the neck of the meter and the other on the flange. Using the hand on the neck, tilt the top of the meter approximately 45 degrees from the vertical position with the bottom edge of the base of the meter resting on the floor or on the work surface. Maintain this position through the procedures described in this section. Using the hand on the flange to rotate the meter, vigorously roll the meter $^1/_4$ to $^1/_2$ turn forward and back several times, quickly starting and stopping the roll. Turn the base of the meter about $^1/_3$ turn and repeat the rolling procedure as stated previously. Continue the turning and rolling procedures for approximately 1 minute. The aggregate must be heard sliding in the meter during this process.

7.4.2.1. If, at any time, during the inversion and rolling procedures liquid is found to be leaking from the meter, the test is invalid and a new test shall be started as in Section 6.1.

7.4.2.2. Set the unit upright and loosen the top to allow any pressure to stabilize. Allow the meter to stand while the air rises to the top and until the liquid level stabilizes. The liquid level is considered stable when it does not change more than 0.25 percent air within a 2-minute period.

7.4.2.3. If it takes more than 6 minutes for the liquid level to stabilize or if there is more foam than that equivalent to 2 full percent air content divisions on the meter scale over the liquid level, discard the trial and start a new test as in Section 6.1. Use a larger addition of alcohol than was used in the initial trial.

7.4.2.4. If the level is stable without excessive foam, read the bottom of the meniscus to the nearest 0.25 percent and record the *initial meter reading*.

7.4.2.5. If the air content is greater than the 9 percent range of the meter, add a sufficient number of calibrated cups of water to bring the liquid level within the graduate range. Read the bottom of the meniscus to the nearest 0.25 percent. Record the number of calibrated cups of water to be added to the final meter reading in Section 8.1.3.

7.5. *Confirmation of the Initial Meter Reading*:

7.5.1. When an initial meter reading is obtained as in Section 7.4.2.4, retighten the top and repeat the 1-minute rolling as in Sections 7.4.2, 7.4.2.2, and 7.4.2.3.

7.5.2. When the liquid level is stable as in Section 7.4.2.2 and the requirements of Section 7.4.2.3 are met, make a direct reading to the bottom of the meniscus and estimate to 0.25 percent air. If this reading has not changed more than 0.25 percent from the initial meter reading in Section 7.4.2.4, record it as the *final meter reading* of the sample tested.

7.5.2.1. If the reading has changed from the *initial meter reading* by more than 0.25 percent air, record this reading as a new "*initial reading*" and repeat the 1-minute rolling as in Section 7.4.2. Read the indicated air content. If this reading has not changed by more than 0.25 percent air from the "*newest initial reading*" record it as the *final meter reading*.

7.5.2.2. If the reading has changed by more than 0.25 percent, discard the test and start a new test on a new sample of concrete as in Section 6.1 using more alcohol.

7.6. Disassemble the apparatus and examine the contents to be sure that there are no portions of undisturbed, tightly packed concrete in the base. If portions of undisturbed concrete are found, the test is invalid.

8. CALCULATION

8.1. The final meter reading tends to be slightly higher than the actual air content of the sample when 1.2 L [2.5 pt] or more of isopropyl alcohol is used. (See Note 5.)

8.1.1. When less than 1.2 L [2.5 pt] of isopropyl alcohol is used, the final meter reading is the air content of the sample of concrete tested except as modified in Sections 8.1.3 or 8.2.

8.1.2. When 1.2 L [2.5 pt] or more isopropyl alcohol is used, subtract the correction from Table 1 from the final meter reading to obtain the air content of the concrete sample tested, except as modified in Sections 8.1.3 or 8.2.

Note 4—Use linear interpolation to obtain a correction factor if the quantity of isopropyl used falls between amounts listed in Table 1.

8.1.3. If it was necessary to add calibrated cups of water to obtain a reading as in Section 7.4.2.5, add the number of cups recorded to the air content found in Sections 8.1.1 or 8.1.2.

8.1.4. Report the air content to the nearest 0.25 percent air.

Note 5—When the top section is initially filled to the zero mark with water and isopropyl alcohol, that mixture has a defined volume; however, when that solution is further mixed with the water present in the concrete, the concentration of alcohol changes, and the new solution occupies a volume slightly smaller than it did when the meter was initially filled to the zero mark. For this reason, the meter tends to indicate a higher than actual air content when more than about 1.2 L [2.5 pt] of alcohol is used. Therefore, when large amounts of alcohol are used, the correction factors in Table 1 reduce the air content indicated by the meter.

8.2. When the sample tested represents that portion of the mixture obtained by wet-sieving over a 25-mm [1-in.] sieve, calculate the air content of the mortar or of the full mixture using the formulas given in T 152. Use appropriate quantities coarser or finer than the 25-mm [1-in.] sieve instead of the 37.5-mm [$1^1/_2$-in.] sieve specified in T 152.

9. PRECISION AND BIAS

9.1. The standard deviation is essentially proportional to the average for different levels of air content. The following precision statement is based on 979 tests made in six field experiments by the West Virginia DOT. The multi-operator coefficient of variation has been found to be 11 percent of the measured air content. Therefore, results of tests by two different operators on specimens taken from a single concrete sample should not differ from each other by more than 32 percent of their average air content (Note 6).

Note 6—These numbers represent, respectively, the 1s percent and d2s percent limits described in ASTM C 670. The data collected for the precision statement were obtained using procedures standard prior to the use of large amounts of isopropyl alcohol in ASTM C 173/C 173M.

9.2. This test method provides volumetric procedures for determining the air content of freshly mixed concrete. When conducted properly, this test method has no bias because the value of the air content can only be defined in terms of the test method.

10. KEYWORDS

10.1. Air content; calibration; concrete; correction factor; freshly mixed concrete; measuring bowl; meter; volumetric method.

APPENDIX

(Nonmandatory Information)

X1. CHECK LIST FOR PERFORMING THE VOLUMETRIC AIR CONTENT TEST METHOD

X1.1. The following outline (Figures X1.1a–X1.1c) does not include all steps and precautions required to perform this test method properly. It is provided to help new users follow the sequence of the procedures.

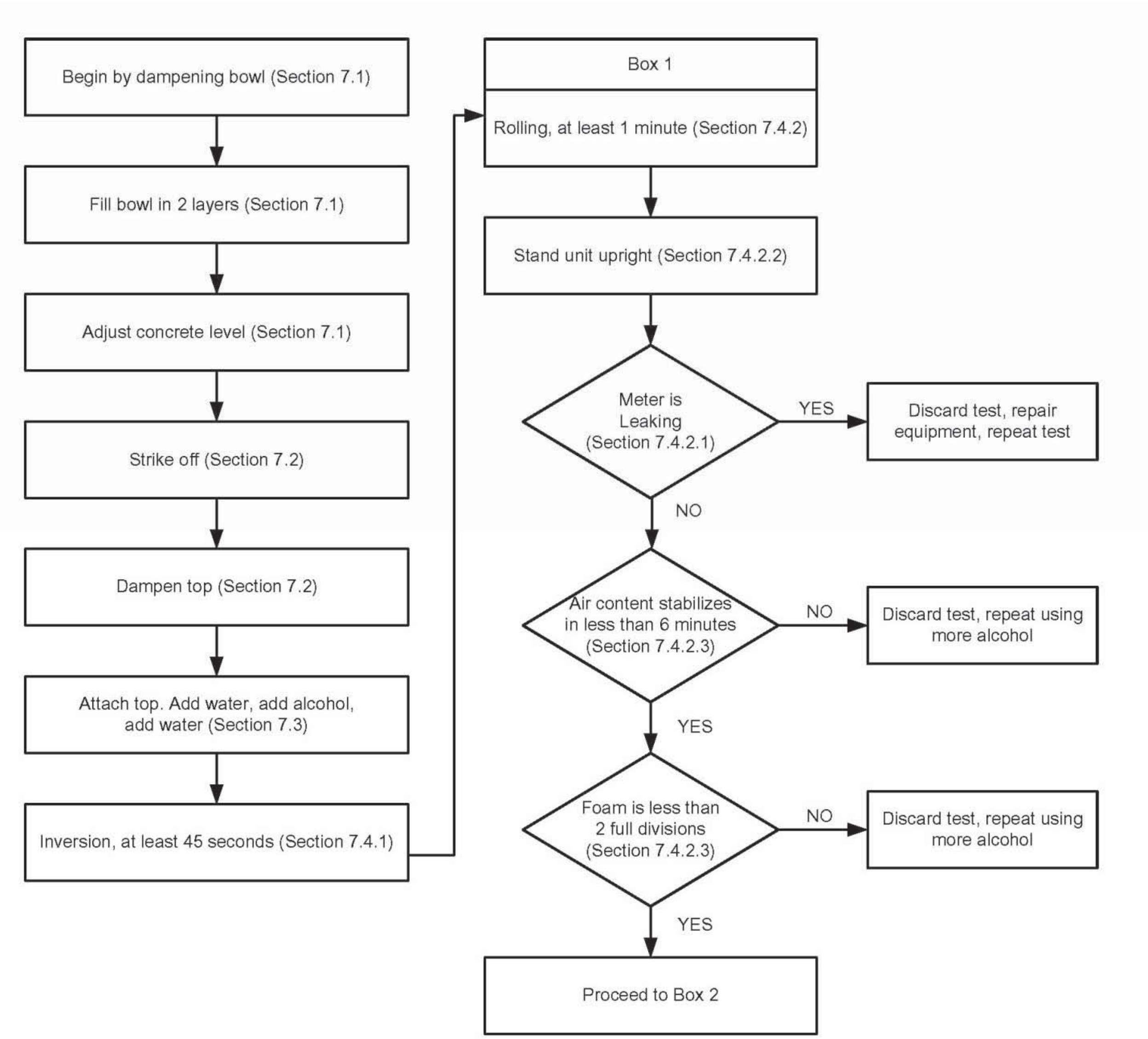


Figure X1.1a—Outline of Checklist for Performing the Volumetric Air Content Test Method

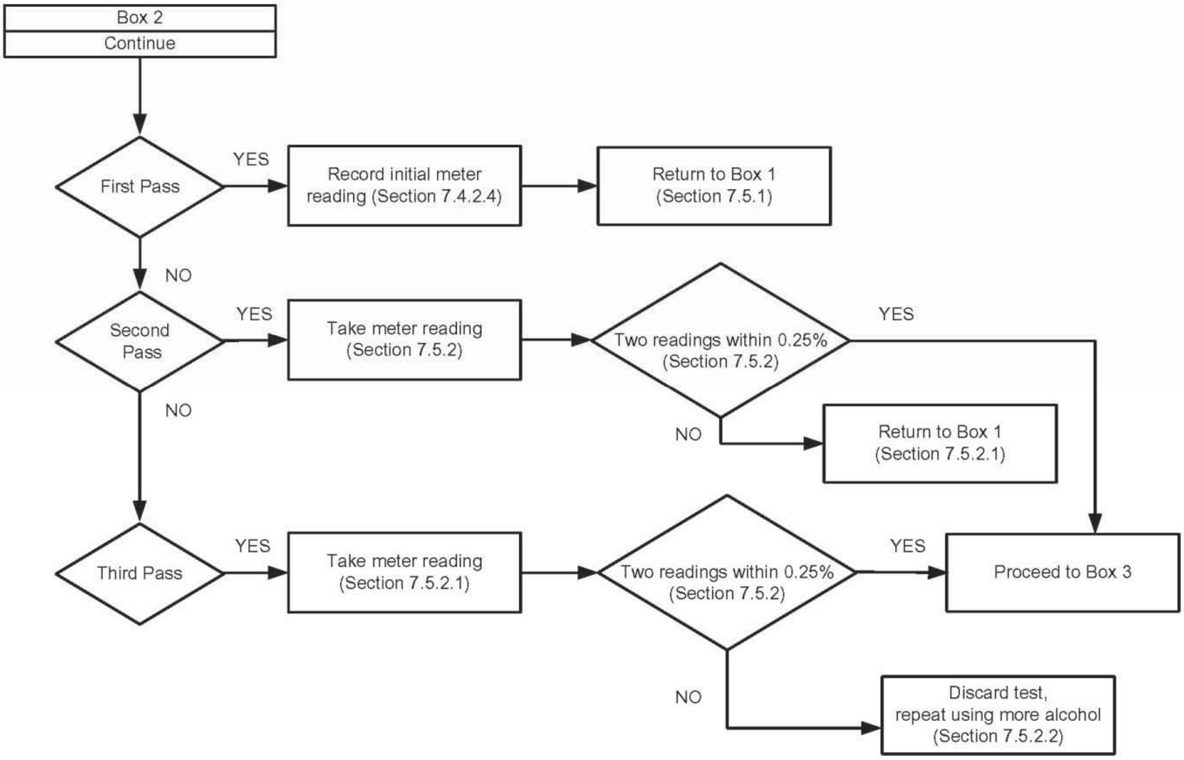


Figure X1.1b—Outline of Checklist for Performing the Volumetric Air Content Test Method (*Continued*)

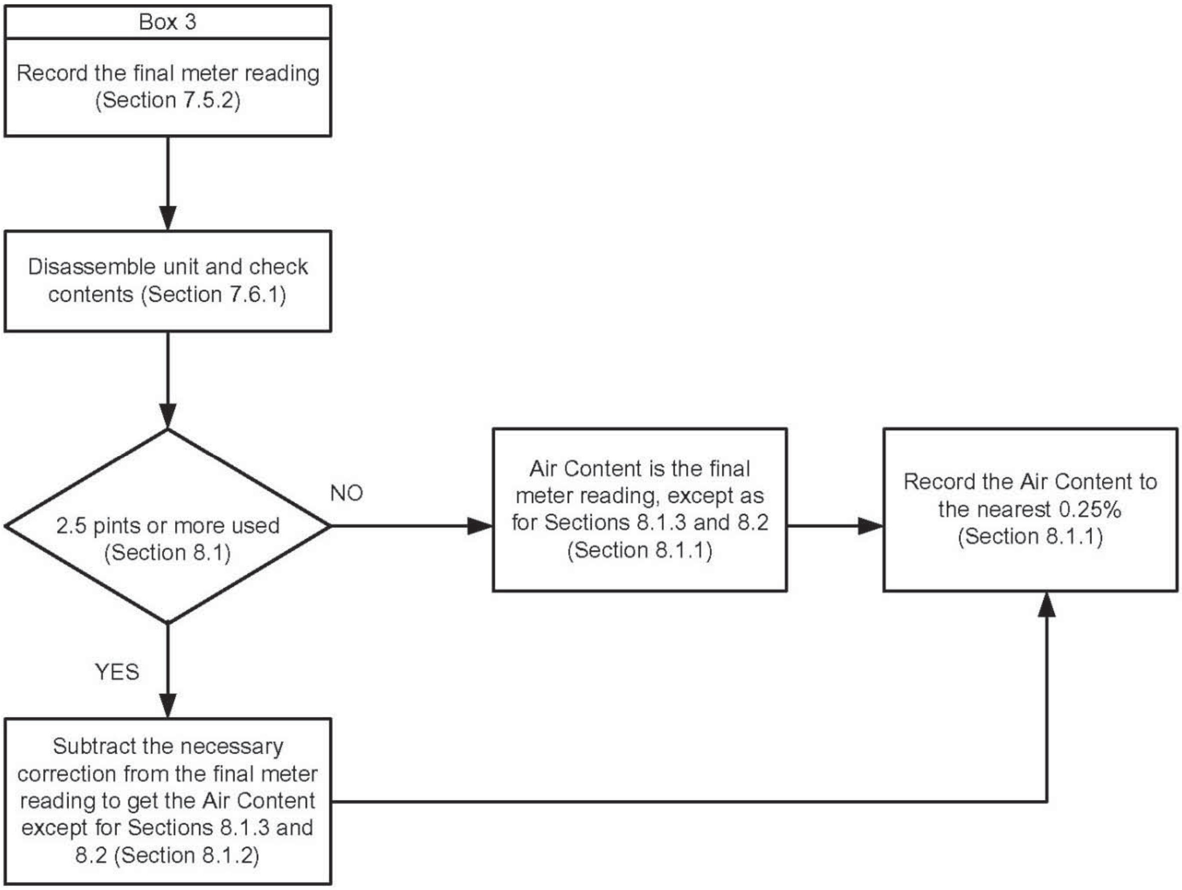


Figure X1.1c—Outline of Checklist for Performing the Volumetric Air Content Test Method (*Continued*)

Standard Method of Test for

Time of Setting of Concrete Mixtures by Penetration Resistance

AASHTO Designation: T 197M/T 197-08
ASTM Designation: C 403/C 403M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Time of Setting of Concrete Mixtures by Penetration Resistance

AASHTO Designation: T 197M/T 197-08
ASTM Designation: C 403/C 403M-06

1. SCOPE

1.1. This test method covers the determination of the time of setting of concrete, with slump greater than zero, by means of penetration resistance measurements on mortar sieved from the concrete mixture.

1.2. This test method is suitable for use only when tests of the mortar fraction will provide the information required.

1.3. This test method may also be applied to prepared mortars and grouts.

1.4. This test method is applicable under controlled laboratory conditions, as well as under field conditions.

1.5. The values stated in SI units are to be regarded as the standard.

1.6. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 143/C 143M, Standard Test Method for Slump of Hydraulic-Cement Concrete
- C 172, Standard Practice for Sampling Freshly Mixed Concrete
- C 173, Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

- C 192/C 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
- C 231, Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 1558, Standard Test Method for Moisture Content Penetration Resistance Relationships of Fine-Grained Soils
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 11, Standard Specification for Woven Wire Test Sieve Cloth Standard Test Sieves

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *time of initial setting*—the elapsed time, after initial contact of cement and water, required for the mortar sieved from the concrete to reach a penetration resistance of 3.5 MPa (500 psi).

3.1.2. *time of final setting*—the elapsed time, after initial contact of cement and water, required for the mortar sieved from the concrete to reach a penetration resistance of 27.6 MPa (4000 psi).

4. SUMMARY OF TEST METHOD

4.1. A mortar sample is obtained by sieving a representative sample of fresh concrete. The mortar is placed in a container and stored at a specified ambient temperature. At regular time intervals, the resistance of the mortar to penetration by standard needles is measured. From a plot of penetration resistance versus elapsed time, the times of initial and final setting are determined.

5. SIGNIFICANCE AND USE

5.1. Since the setting of concrete is a gradual process, any definition of time of setting must necessarily be arbitrary. In this test method, the times required for the mortar to reach specified values of resistance to penetration are used to define times of setting.

5.2. This test method can be used to determine the effects of variables, such as brand, type and content of cementitious material, water content, and admixtures, upon the time of setting of concrete. This test method may also be used to determine compliance with specified time of setting requirements.

5.3. This test method may also be applied to prepared mortars and grouts. However, when the setting time of concrete is desired, the test shall be performed on mortar sieved from the concrete mixture and not on a prepared mortar intended to simulate the mortar fraction of the concrete; it has been shown that the initial and final setting times may be increased when using the prepared mortar.

6. APPARATUS

6.1. *Containers for Mortar Specimens*—The containers shall be rigid, watertight, nonabsorptive, nonoiled, and either cylindrical or rectangular in cross section. Mortar surface area shall be provided for 10 undisturbed readings of penetration resistance in accordance with Section 9.2 for clear distance requirements. The minimum lateral dimension shall be 150 mm (6 in.) and the height at least 150 mm (6 in.).

6.2. *Penetration Needles*—Needles shall be provided which can be attached to the loading apparatus and which have the following bearing areas: 645, 323, 161, 65, 32, and 16 mm^2 (1, $^1/_2$, $^1/_4$, $^1/_{10}$, $^1/_{20}$, and $^1/_{40}$ in.^{2}). Each needle shank shall be scribed circumferentially at a distance 25 mm (1 in.) from the bearing area. The length of the 16-mm^2 ($^1/_{40}$-in.^{2}) needle shall not be more than 90 mm (3$^1/_2$ in.).

6.3. *Loading Apparatus*—A device shall be provided to measure the force required to cause penetration of the needles. The device shall be capable of measuring the penetration force with an accuracy of ±10 N (2 lbf) and shall have a capacity of at least 600 N (130 lbf).

Note 1—Suitable loading apparatus can be of the spring-reaction type as described in ASTM D 1558, or of other types with a calibrated force measuring device, such as an electronic load cell or a hydraulic pressure gauge.

6.4. *Tamping Rod*—The tamping rod shall be a round, straight, steel rod 16 mm ($^5/_8$ in.) in diameter and approximately 600 mm (24 in.) in length, having the tamping end or both ends rounded to a hemispherical tip, the diameter of which is 16 mm ($^5/_8$ in.).

6.5. *Pipet*—A pipet or other suitable instrument shall be used for drawing off bleeding water from the surface of the test specimen.

6.6. *Thermometer*—The thermometer shall be capable of measuring the temperature of the fresh mortar to ±0.5ºC (±1ºF). ASTM liquid-in-glass thermometers having a temperature range from –18 to 49ºC (0 to 120ºF), and conforming to the requirements of Thermometer 97ºC (97ºF), as prescribed in ASTM E 1 are satisfactory. Other thermometers of the required accuracy, including the metal immersion type, are acceptable.

7. SAMPLING, TEST SPECIMENS, AND TEST UNITS

7.1. For tests under field conditions, three specimens shall be prepared from each sample of concrete.

7.2. For tests under laboratory conditions, the requirements depend upon the purpose of the tests.

7.2.1. For testing to prove compliance of a material with performance requirements, make at least three separate concrete batches for each variable under investigation. One time of setting test shall be made on each batch. An equal number of batches for each condition shall be made on any given day. When it is impossible to make at least one test for each variable on a given day, the mixing of the entire series of batches shall be completed in as few days as possible and one of the mixtures shall be repeated each day as a standard of comparison.

7.2.2. For other tests, three test specimens shall be prepared from one batch of concrete for each test condition.

7.3. Record the time at which initial contact was made between cement and mixing water.

7.4. For tests under field conditions, obtain a representative sample of the fresh concrete in accordance with T 141. Determine and record the slump (T 119M/T 119) and air content (T 196M/T 196 or T 152) of the fresh concrete.

7.5. From the concrete mixture not used in the slump and air content tests, select a representative portion of concrete of sufficient volume to provide enough mortar to fill the test container, or containers, to a depth of at least 140 mm (5$^1/_2$ in.).

7.6. Using the procedure in Section 6.4.1 of T 141, obtain a mortar sample by wet-sieving the selected portion of concrete through a 4.75-mm (No. 4) sieve[1] onto a nonabsorptive surface.

7.7. Thoroughly remix the mortar by hand methods on the nonabsorptive surface. Measure and record the temperature of the mortar. Place the mortar in the container, or containers, using a single layer. Consolidate the mortar to eliminate air pockets in the specimen and level the top surface. This may be accomplished by rocking the container back and forth on a solid surface, by tapping the sides of the container with the tamping rod, by rodding the mortar or by placing the container on a vibrating table. (See Note 2.) If rodding is used, rod the mortar with the round end of the tamping rod. Rod the mortar once for each 645 mm2 (1 in.^{2}) of top surface area of the specimen and distribute the strokes uniformly over the cross section of the specimen. After completion of the rodding, tap the sides of the containers lightly with the tamping rod to close voids left by the tamping rod and to further level the surface of the specimen. Upon completion of specimen preparation, the mortar surface shall be at least 13 mm (0.5 in.) below the top edge of the container to provide space for the collection and removal of bleeding water and to avoid contact between the mortar surface and the protective covering specified in Section 8.

Note 2—Sieved mortar is generally of fluid consistency and air pockets are readily removed by the listed consolidation methods. The user is called upon to exercise judgment in the selection of the consolidation method. Rocking the container or tapping of the sides should be sufficient for fluid mortars. Rodding or using a vibrating table may be desirable for stiffer mortars. When using a vibrating table, use low-amplitude vibration so that portions of the sample are not ejected from the container.

8. CONDITIONING

8.1. For tests under laboratory conditions, the storage temperature for specimens shall be within the range 20 to 25ºC (68 to 77ºF), or as specified by the user.

8.2. For tests under field conditions, store the specimens under ambient conditions, or as specified by the user. Shield the specimens from direct sunlight.

8.3. Measure and record the ambient temperature at the start and finish of the test. To prevent excessive evaporation of moisture, keep the specimens covered with a suitable material such as damp burlap or a tight-fitting, water-impermeable cover for the duration of the test, except when bleeding water is being removed or penetration tests are being made.

9. PROCEDURE

9.1. Just prior to making a penetration test, remove bleeding water from the surface of the mortar specimens by means of a pipet or suitable instrument. To facilitate collection of bleeding water, tilt the specimen carefully to an angle of about 10 degrees from the horizontal by placing a block under one side 2 minutes prior to removal of the bleeding water.

9.2. Insert a needle of appropriate size, depending upon the degree of setting of the mortar, in the penetration resistance apparatus and bring the bearing surface of the needle into contact with the mortar surface. Gradually and uniformly apply a vertical force downward on the apparatus until the needle penetrates the mortar to a depth of 25 ± 1.5 mm (1 ± 0.0625 in.), as indicated by the scribe mark (Note 4). The time required to penetrate to the 25 mm (1 in.) depth shall be 10 ± 2 seconds. Record the force required to produce the 25 mm (1 in.) penetration and the time of application, measured as elapsed time after initial contact of cement and water. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle, and record the penetration resistance. In subsequent penetration tests take care to avoid areas where the mortar has been disturbed by previous tests. The clear distance between needle impressions shall be at least two diameters of the needle being used, but not less than 13 mm (0.5 in.). The clear distance between any needle impression and the side of the container shall be at least 25 mm (1 in.), but no more than 2 in. [50 mm] as depicted in Figure 1.

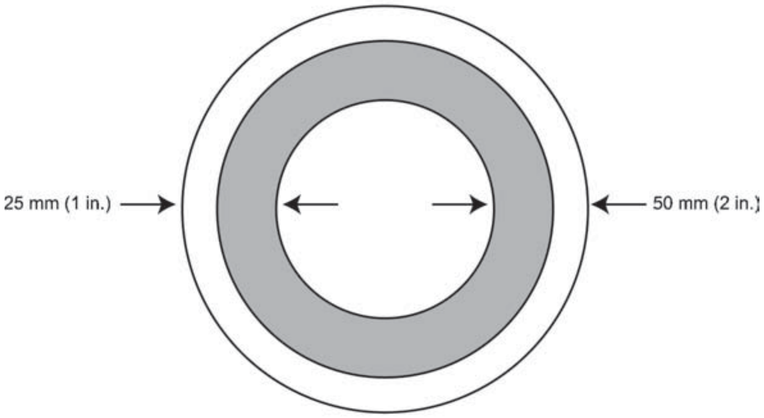
Note 3—For a cylindrical container with the smallest allowable outer diameter of 6 in., the operator can reasonably expect to achieve approximately eight penetrations before impinging upon previous penetrations. This is based on using needles of the following surface areas: 1 at $^1/_2$ (13), 2 at $^1/_4$ (6), 2 at $^1/_{10}$ (2.5), 2 at $^1/_{20}$ (1.3), and 1 at $^1/_{40}$ (0.6) mm^2 (in.^{2}).

Note 4—To facilitate determination of when the required penetration has been attained, a sliding marker may be attached to the needle shaft. For example, a paper clip or masking tape may be placed on the shaft so that it coincides with the scribe mark. The marker should not interfere with the penetration of the needle into the mortar. The position of the marker should be checked prior to making a penetration.

9.3. For conventional concrete mixtures at laboratory temperatures 20 to 25ºC (68 to 77ºF), make the initial test after an elapsed time of 3 to 4 hours after initial contact between cement and water. Subsequent tests should be made at $^1/_2$ to 1-hour intervals. For concrete mixtures containing accelerators, or at temperatures higher than laboratory, it is advisable to make the initial test after an elapsed time of 1 to 2 hours and subsequent tests at $^1/_2$-hour intervals. For concrete mixtures containing retarders, or at temperatures lower than laboratory, the initial test may be deferred until an elapsed time of 4 to 6 hours. In all cases, time intervals between subsequent tests may be adjusted as necessary, depending upon the rate of setting, to obtain the required number of penetrations.

9.4. Make at least six penetrations for each time-of-setting test, with the time intervals of such duration to provide a satisfactory curve of penetration resistance versus elapsed time (Note 5). Continue the tests until at least one penetration resistance reading equals or exceeds of 27.6 MPa [4000 psi].

Note 5—A satisfactory curve is one that represents the overall development of penetration resistance and includes points before and after the times of initial and final setting to improve the accuracy of the required interpolation. For normal setting mixtures, test points are usually at equally spaced time intervals. This may decrease the accuracy of the estimated setting time by biasing the best fit line when regression analysis is used to analyze the penetration resistance data.



Note: Gray shaded areas define where needle penetrations are permitted.

Figure 1—Top View of Mortar Test Specimen

9.5. *Plotting Test Results*—One of two alternative procedures may be used to plot the test results and obtain times of setting (Note 6). Appendix X1 illustrates the application of these procedures.

Note 6—The plot of penetration resistance versus elapsed time provides information on the rate of setting. The plot may be used to select the time for subsequent penetration tests and it can assist in identifying spurious test results. Therefore, it is recommended that the data be plotted as they are being accumulated.

9.5.1. The following procedure is used to determine the times of setting by hand-fitting a smooth curve through the data. Prepare a graph of penetration resistance, as the ordinate, versus elapsed time, as the abscissa, using a scale such that 3.5 MPa (500 psi) and 1 hour are each represented by a distance of at least 13 mm (0.5 in.). Plot the values of penetration resistance as a function of elapsed time.

9.5.2. The following procedure is used to determine the times of setting by linear regression analysis of the logarithms of the data. Using log-log graph paper, prepare a graph of penetration resistance, as the ordinate, versus elapsed time in minutes, as the abscissa. The limits of penetration resistance on the ordinate should extend from 0.1 MPa (10 psi) to 100 MPa (10000 psi), and the limits of elapsed time on the abscissa should extend from 10 to 1,000 minutes. If slow setting mixtures are used, the time limits may have to be 100 to 10,000 minutes. Plot the values of penetration resistance as a function of elapsed time (Note 5).

9.5.3. Use the following procedure if a computer and suitable software are used to plot test results and obtain the times of setting by regression analysis of the data. As the test results are obtained, enter the time and penetration resistance into the computer and plot the penetration resistance as the ordinate and the elapsed time as the abscissa. For software that permits only linear regression analysis, convert the data by taking their logarithms. The converted data will be fitted by a straight line (see Equation 1):

$$\mathrm{Log}(PR) = a + b\,\mathrm{Log}(t) \tag{1}$$

where:

PR = penetration resistance,

t = elapsed time, and

a and b = regression constants.

The data do not have to be converted if the software permits direct fitting of a power function:

$$PR = ct^{d} \tag{2}$$

where:

c and d = regression constants.

9.5.4. The procedures in Sections 9.5.2 and 9.5.3 assume that the data obey Equation 1 or Equation 2. Verify that the data obey one of these relationships. If the correlation coefficient for the regression analysis, after removal of outliers (see Note 7), is less than 0.98, use the procedure in Section 9.5.1.

10. CALCULATION

10.1. For each test variable under investigation, separately plot the results of three or more time-of-setting tests. For each plot prepared according to Section 9.5.1, hand fit a smooth curve to the data points. For each plot prepared according to Section 9.5.2 or 9.5.3, use the method of least squares to obtain the constants of the best-fit relationship given by Equation (1) or Equation (2), whichever is applicable. Disregard data points that are obvious outliers from the trend defined by the rest of the point (Note 7).

Note 7—Outliers may occur because of factors such as: interferences due to the larger particles in the mortar; presence of large voids within the penetration zone; interferences from the impressions created by adjacent penetrations; failure to maintain the instrument perpendicular to the test surface during penetration; errors in reading the load; variations in the penetration depths; or variation in rate of loading. Judgment of the operator is required to identify those points that should not be included in the data analysis.

10.2. For each plot, determine the times of initial and final setting as the times when the penetration resistance equals 3.5 MPa (500 psi) and 27.6 MPa (4000 psi), respectively. For plots made according to Section 9.5.1, determine times of setting by visual inspection of the drawn curves. For plots made according to Section 9.5.2 or 9.5.3, determine the times of setting by interpolation using the best-fit regression. Record the setting times in hours and minutes to the nearest 5 minutes.

10.3. For each variable under investigation, calculate the times of initial and final setting as the average values of the individual test results. Record the average times in hours and minutes to the nearest 5 minutes.

11. REPORT

11.1. *Data on Concrete Mixture*—The report shall include the following information on the concrete mixture:

11.1.1. Brand and type of cementitious materials, mass of cementitious materials, fine aggregate and coarse aggregate per cubic meter (cubic yard) of concrete, nominal maximum aggregate size, and water-cement ratio;

11.1.2. The name, type, and amount of admixture(s) used;

11.1.3. Air content of fresh concrete and method of determination;

11.1.4. Consistency of concrete as determined by the slump test;

11.1.5. Temperature of mortar after sieving;

11.1.6. Record of ambient temperature during the test period; and

11.1.7. Date of test.

11.2. *Time of Setting Results*—The report shall include the following information on the time of setting tests:

11.2.1. A plot of penetration resistance versus elapsed time for each time of setting test;

11.2.2. The times of initial and final setting for each test, reported in hours and minutes to the nearest minute; and

11.2.3. The average times of initial and final setting for each test condition, reported in hours and minutes to the nearest 5 minutes.

---

12. PRECISION AND BIAS

12.1. The data used to develop the precisions statement were obtained using the inch-pound version of this test method. Estimates of time of setting were determined by both graphical methods and regression analysis. The temperature of the laboratory, where the concrete mixtures were sieved and the resulting mortar fraction measured for penetration resistance, was maintained at 73 ± 2°F (23 ± 1°C) for the duration of the test.

12.2. The following precisions values were obtained from an interlaboratory study involving five operators and three concrete mixtures.[2] The average time of initial setting varied between 169 and 252 min, and the average time of final setting varied between 240 and 341 min. Three replicate determinations were made by each operator on specimens made from a single batch of each mixture.

12.3. *Single-Operator Precision*—The single-operator standard deviations of a single test result are shown in Table 1. The results of two properly conducted tests by the same operator are not expected to differ by more than the values shown in the third column of Table 1. The test method calls for reporting three test results. The range (difference between highest and lowest) of the tree test results obtained by the same operator on specimens from the same batch of concrete are not expected to exceed the values shown in the fourth column of Table 1.

Table 1—Single-Operator Precision

Time of Setting	Single-Operator Standard Deviation, min[a]	Acceptable Difference between Two Results, min[a]	Acceptable Range of Three Results, min[b]
Initial	3.5	9.8	11.4
Final	4.4	12.5	14.6

[a] These numbers represent, respectively, the 1s and d2s limits as described in ASTM C 670.

[b] Calculated as described in the section “acceptable range of more than two results” of ASTM C 670.

12.4. *Multi-Operator Precision*—The multi-operator standard deviations of a single test result are shown in Table 2. The results of two properly conducted tests by different operators on the same material are not expected to differ by more than the values shown in the third column of Table 2. The averages of three test results by two different operators obtained on specimens from a single batch of the same concrete are not expected to differ by more than the values in the fourth column of Table 2.

Table 2—Multi-Operator Precision

Time of Setting	Multi-Operator Standard Deviation, min[a]	Acceptable Difference between Two Results, min[a]	Acceptable Difference between Average of Three Results, min[b]
Initial	6.9	19.4	11.1
Final	10.1	28.7	16.4

[a] These numbers represent, respectively, the 1s and d2s limits as described in ASTM C 670.

[b] Calculated as described in the section “multilaboratory precision expressed as a maximum allowable difference between two averages” of ASTM C 670.

12.5. The bias of this test method cannot be determined because times of setting can be defined only in terms of the test method.

APPENDIX

(Nonmandatory Information)

X1. ILLUSTRATIVE EXAMPLES

X1.1. The penetration resistance *PR* and the elapsed time *t* data in Table X1.1 will be used to illustrate the two procedures for determining times of setting.

Table X1.3—Penetration Resistance Data

Penetration Resistance *(PR)*		Elapsed Time (*t*) (min)	Log *(PR)*		Log (*t*)
MPa	(psi)				
0.30	(44)	200	–0.518	(1.643)	2.301
0.76	(110)	230	–0.120	(2.041)	2.362
1.49	(216)	260	0.173	(2.334)	2.415
3.72	(540)	290	0.571	(2.732)	2.462
6.89	(1000)	320	0.839	(3.000)	2.505
13.79	(2000)	350	1.140	(3.301)	2.544
17.65	(2560)	365	1.247	(3.408)	2.562
24.27	(3520)	380	1.385	(3.547)	2.580
30.61	(4440)	395	1.486	(3.647)	2.597

X1.2. *Hand Fit*—Figure X1.1 is a plot of the penetration resistance versus elapsed time values in Table X1.1. The smooth curve was drawn by hand using a flexible drawing curve. The curve was drawn so as to achieve the visual best-fit to the data. Horizontal lines are drawn at penetration resistance values of 3.5 MPa (500 psi) and 27.6 MPa (4000 psi). The intersections of the horizontal lines with the curve define the times of initial and final setting, which in this case are 289 minutes and 389 minutes, respectively.

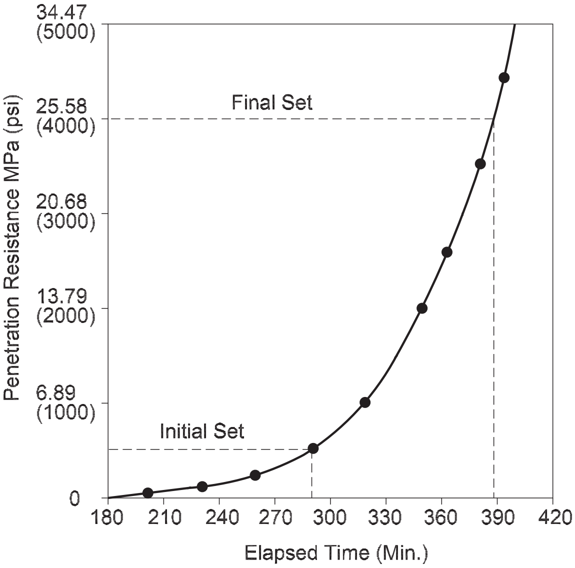


Figure X1.1—Plot of Penetration Resistance versus Elapsed Time and Hand Fit Curve Used to Determine Times of Setting

X1.3. *Regression Analysis*:

X1.3.1. Figure X1.2 is a log-log plot of the penetration resistance versus elapsed time values. The plot shows that for this particular data there is approximately a straight line relationship between the logarithms of penetration resistance and elapsed time. The straight line is obtained by linear regression analysis using the logarithms shown in the third and fourth columns of Table X1.1. The equation for this line is:

$$\mathrm{Log}\left(PR\right) = -16.356 + 6.871\,\mathrm{Log}\left(t\right) \qquad (X1.1)$$

where:

PR = penetration resistance; and

t = elapsed time, and the correlation coefficient is 0.999.

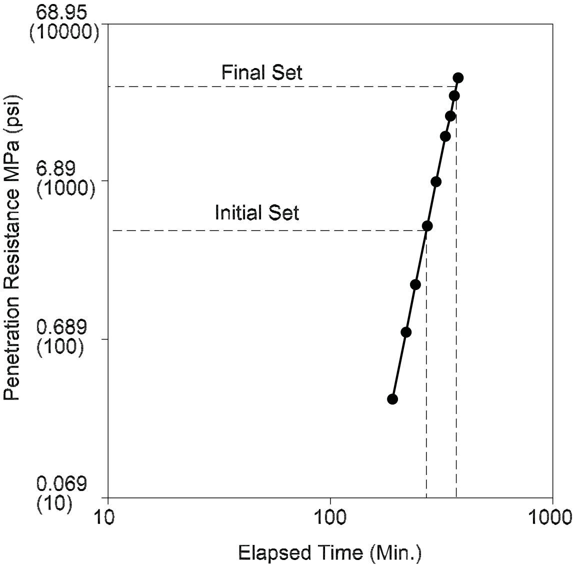


Figure X1.2—Log-Log Plot Showing Straight Line to Determine Times of Setting by Using Regression Analysis

X1.3.2. To obtain the times of setting, the equation is rewritten as:

$$\mathrm{Log}\left(t\right) = \frac{\mathrm{Log}\left(PR\right)\ +\ 6.356}{6.871} \qquad (X1.2)$$

For time of initial setting, substitute the value 3.45 for PR:

$$\mathrm{Log}\left(t\right) = \frac{\mathrm{Log}\left(3.45\right)\ +\ 16.356}{6.871}$$

$$= \frac{0.538\ +\ 16.356}{6.871}$$

$$= 2.459$$

therefore:

$t = (10)2.459 = 288$ minutes

For time of final setting, substitute the value 27.58 for *PR*:

$$\mathrm{Log}\left(t\right) = \frac{\mathrm{Log}\left(27.58\right) \ + \ 16.356}{6.871}$$

$$= \frac{1.441 \ + \ 16.356}{6.871}$$

$$= 2.590$$

therefore:

$t = (10)2.590 = 389$ minutes

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[1] Detailed requirements for this sieve are given in M 92.

[2] Supporting data may be obtained by requesting Research Report RR: C09-1032 from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

Standard Method of Test for

Splitting Tensile Strength of Cylindrical Concrete Specimens

AASHTO Designation: T 198-09
ASTM Designation: C 496/C 496M-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Splitting Tensile Strength of Cylindrical Concrete Specimens

AASHTO Designation: T 198-09
ASTM Designation: C 496/C 496M-04

1. SCOPE

1.1. This test method covers the determination of the splitting tensile strength of cylindrical concrete specimens, such as molded cylinders and drilled cores.

Note 1—For methods of molding cylindrical specimens, see R 39 and T 23. For methods of obtaining drilled cores, see T 24M/T 24.

1.2. The values stated in either inch-pound or SI units are to be regarded separately as standard. The SI units are shown in parentheses. The values stated in each system may not be exactly equivalent; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4. The text of this standard references notes that provide explanatory material. These notes shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

2.2. ASTM Standards:

- C 31/C 31M, Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 39/C 39M, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
- C 42/C 42M, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- C 192/C 192M, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SUMMARY OF TEST METHOD

3.1. This test method consists of applying a diametral compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uniaxial compressive strength test result.

3.2. Thin plywood bearing strips are used to distribute the load applied along the length of the cylinder.

3.3. The maximum load sustained by the specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength.

4. SIGNIFICANCE AND USE

4.1. Splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength (modulus of rupture).

4.2. Splitting tensile strength is used in the design of structural lightweight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement.

5. APPARATUS

5.1. *Testing Machine*—The testing machine shall conform to the requirements of T 22, and be of a type with sufficient capacity that will provide the rate of loading prescribed in Section 7.5.

5.2. *Supplementary Bearing Bar or Plate*—If the diameter or the largest dimension of the upper bearing face or the lower bearing block is less than the length of the cylinder to be tested, a supplementary bearing bar or plate of machined steel shall be used. The surfaces of the bar or plate shall be machined to within ±0.001 in. (0.025 mm) of planeness, as measured on any line of contact of the bearing area. It shall have a width of at least 2 in. (50 mm), and a thickness not less than the distance from the edge of the spherical or rectangular bearing block to the end of the cylinder. The bar or plate shall be used in such manner that the load will be applied over the entire length of the specimen.

5.3. *Bearing Strips*—Two bearing strips of nominal $^1/_8$-in. (3.2-mm) thick plywood, free of imperfections, approximately 1 in. (25 mm) wide, and of a length equal to, or slightly longer than that of the specimen shall be provided for each specimen. The bearing strips shall be placed between the specimen and both the upper and lower bearing blocks of the testing machine or between the specimen and supplemental bars or plates, when used. (See Section 5.2.) Bearing strips shall not be reused.

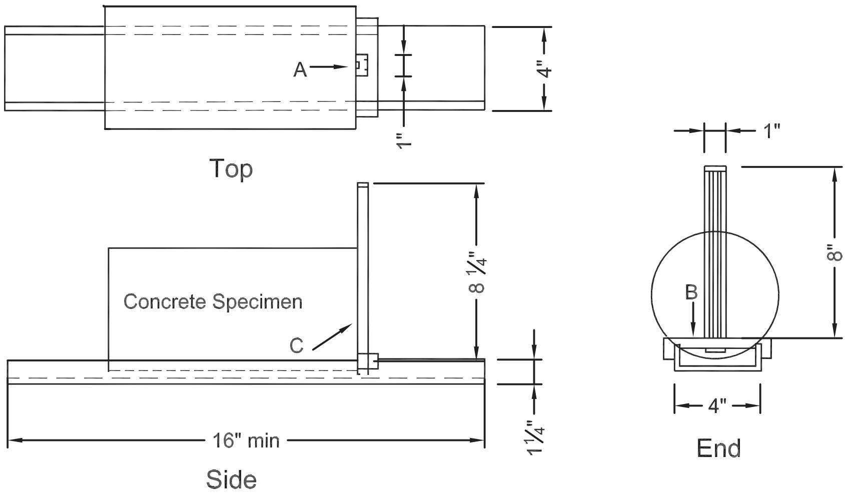
6. TEST SPECIMENS

6.1. The test specimens shall conform to the size, molding, and curing requirements set forth in either T 23 (field specimens) or R 39 (laboratory specimens). Drilled cores shall conform to the size and moisture-conditioning requirements set forth in T 24M/T 24. Moist-cured specimens, during the period between their removal from the curing environment and testing, shall be kept moist by a wet burlap or blanket covering, and shall be tested in a moist condition as soon as practicable.

6.2. The following curing procedure shall be used for evaluations of light-weight concrete: specimens tested at 28 days shall be in an air-dry condition after 7 days moist curing followed by 21 days drying at 73.5 ± 3.5ºF (23.0 ± 2ºC) and 50 ± 5 percent relative humidity.

7. PROCEDURE

7.1. *Marking*—Draw diametral lines on each end of the specimen using a suitable device that will ensure that they are in the same axial plane (Figure 1, Fig. 2 and Note 2), or as an alternative, use the aligning jig shown in Figure 2 (Note 3).



Metric Equivalents

in.	$^{1}/_{16}$	$^{1}/_{8}$	$^{3}/_{16}$	$^{1}/_{4}$	$^{1}/_{2}$	$^{3}/_{4}$	1	$1^{1}/_{4}$	2	$2^{1}/_{2}$	4	$7^{1}/_{2}$	8	$8^{1}/_{4}$	15	16
mm	1.6	3.2	4.8	6.4	13	19	25	32	50	65	100	190	200	205	375	400

Figure 1—Detailed Plans for a Suitable Apparatus for Marking End Diameters Used for Aligning the Specimen

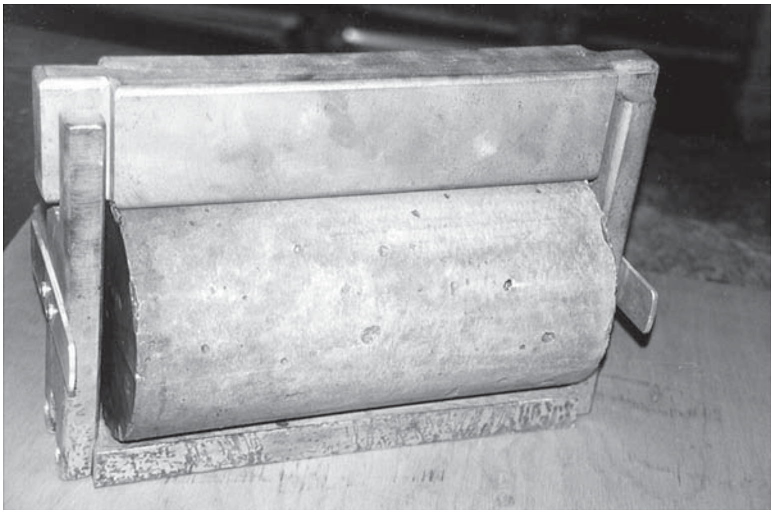


Figure 2—Jig for Aligning Concrete Cylinder and Bearing Strips

Note 2—Figure 1 shows a suitable device for drawing diametral lines on each end of a 6 by 12 in. (152 by 305 mm) cylinder in the same axial plane. The device consists of three parts as follows:

1. A length of 4-in. (100-mm) steel channel, the flanges of which have been machined flat.
2. A section, part *B*, that is grooved to fit smoothly over the flanges of the channel and that includes cap screws for positioning the vertical member of the assembly, and
3. A vertical bar, *C*, for guiding a pencil or marker.

The assembly (part B and part C) is not fastened to the channel and is positioned at either end of the cylinder without disturbing the position of the specimen when marking the diametral lines.

Note 3—Figure 3 is a detailed drawing of the aligning jig shown in Figure 2 for achieving the same purpose as marking the diametral lines. The device consists of:

1. A base for holding the lower bearing strip and cylinder.
2. A supplementary bearing bar conforming to the requirements in Section 4 as to critical dimensions and planeness, and
3. Two uprights to serve for positioning the test cylinder, bearing strips, and supplementary bearing bar.

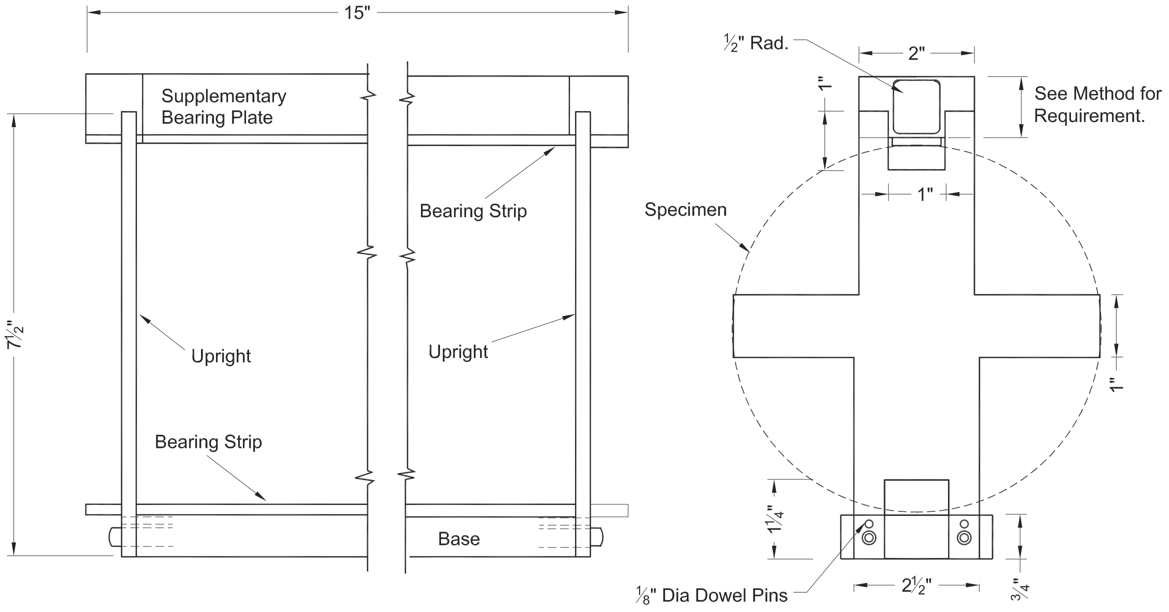


Figure 3—Detailed Plans for a Suitable Aligning Jig for 6 by 12 in. (152 by 305 mm) Specimen

7.2. *Measurements*—Determine the diameter of the test specimen to the nearest 0.01 in. (0.25 mm) by averaging three diameters measured near the ends and the middle of the specimen and lying in the plane containing the lines marked on the two ends. Determine the length of the specimen to the nearest 0.1 in. (2.5 mm) by averaging at least two length measurements taken in the plane containing the lines marked on the two ends.

7.3. *Positioning Using Marked Diametral Lines*—Center one of the plywood strips along the center of the lower bearing block. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip. Place a second plywood strip lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder. Position the assembly to ensure the following conditions:

7.3.1. The projection of the plane of the two lines marked on the ends of the specimen intersects the center of the upper bearing plate, and

7.3.2. The supplementary bearing bar or plate, when used, and the center of the specimen are directly beneath the center of thrust of the spherical bearing block. (See Figure 4.)

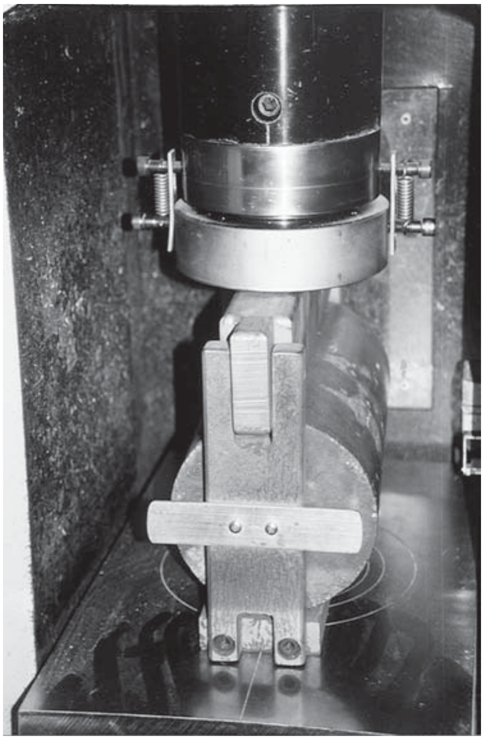


Figure 4—Specimen Positioned in a Testing Machine for Determination of Splitting Tensile Strength

7.4. *Positioning by Use of Aligning Jig*—Position the bearing strips, test cylinder, and supplementary bearing bar by means of the aligning jig as illustrated in Figure 2 and center the jig so that the supplementary bearing bar and the center of the specimen are directly beneath the center of thrust of the spherical bearing block.

7.5. *Rate of Loading*—Apply the load continuously and without shock, at a constant rate within the range 100 to 200 psi (689 to 1380 kPa)/min splitting tensile stress until failure of the specimen (Note 4). Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and the appearance of the concrete.

Note 4—The relationship between splitting tensile stress and applied load is shown in Section 8. The required loading range in splitting tensile stress corresponds to applied total load in the range of 11.300 to 22.600 lbf (50 to 100 kN)/min for 6 by 12 in. (152 by 305 mm) cylinders.

8. CALCULATION

8.1. Calculate the splitting tensile strength of the specimen as follows:

$$T = 2P/\pi\, ld \qquad (1)$$

where:

T = splitting tensile strength, psi (kPa);

P = maximum applied load indicated by the testing machine, lbf (kN);

l = length, in in. (m); and

d = diameter, in in. (m).

9. REPORT

9.1. *Report the following information*:

9.1.1. Identification number;

9.1.2. Diameter and length, in inches (in.) (m);

9.1.3. Maximum load, in lbf (kN);

9.1.4. Splitting tensile strength calculated to the nearest 5 psi (35 kPA);

9.1.5. Estimated proportion of coarse aggregate fractured during the test;

9.1.6. Age of specimen;

9.1.7. Curing history;

9.1.8. Defects in specimen;

9.1.9. Types of fracture; and

9.1.10. Type of specimen.

10. PRECISION AND BIAS

10.1. *Precision*—An interlaboratory study of this test method has not been performed. Available research data, however, suggests that the within batch coefficient of variation is 5 percent (Note 5) for 6 by 12 in. (152 by 305 mm) cylindrical specimens with an average splitting tensile strength of 405 psi (2.8 MPa). Results of two properly conducted tests on the same material, therefore, should not differ by more than 14 percent (Note 5) of their average for splitting tensile strengths of 400 psi (2.8 MPa).

Note 5—These numbers represent, respectively, the (1s percent) and (d2s percent) limits as defined in ASTM C 670.

10.2. *Bias*—The test method has no bias because the splitting tensile strength can be defined only in terms of this test method.

11. KEYWORDS

11.1. Cylindrical concrete specimens; splitting tension; tensile strength.

Standard Method of Test for

Air Content of Freshly Mixed Concrete by the Chace Indicator

AASHTO Designation: T 199-00 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Air Content of Freshly Mixed Concrete by the Chace Indicator

AASHTO Designation: T 199-00 (2009)

1. SCOPE

1.1 This method of test covers the determination of the air content of freshly mixed concrete by displacing the air with alcohol and observing the change in level of the liquid in a tube. The apparatus is light and small, and the test procedure requires only a few minutes.

1.2 This method has been found satisfactory for determining the approximate air content of freshly mixed concrete. It shall not, however, be considered suitable for replacing T 121M/T 121 (gravimetric method), T 152 (pressure method), or T 196M/T 196 (volumetric method). In no case should the value obtained through the use of this method be accepted as determining the compliance of the air content of concrete with the requirements of specifications. The method is most useful for determining whether the concrete has a low, medium, or high air content, and whether the air content is reasonably constant from batch to batch of concrete.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

3. APPARATUS

3.1 *Indicator*—The indicator as shown in Figure 1 consists of three pieces: a glass tube about 75 mm (3 in.) long and 25 mm (1 in.) in diameter with a stem 75 mm (3 in.) long and 6.4 mm (0.25 in.) in diameter at one end resembling a filter tube for Gooch crucibles, a rubber stopper to fit the larger end of the glass tube, and a metal cup mounted on the smaller end of the stopper. The stem of the glass tube is scribed with 11 lines, each pair indicating an approximate volume of 0.08 mL. A reference line is also scribed on the large portion of the tube. The exact stem factor should be determined in accordance with Section 3.2. The brass cup is 19 mm (0.75 in.) in inside diameter, 13 mm (0.5 in.) in depth, and contains a volume of 3.6 mL. When the stopper and cup are inserted into the glass tube, the volume of the latter and stem is about 27 mL.

3.2 *Indicator Stem Factor*—Experience has shown that it is difficult to fabricate indicators to a close tolerance at a reasonable price. Therefore, indicators should be calibrated and inscribed with a calibration factor that represents the percent of the volume of the bowl contained in one graduation on the stem. An indicator can be calibrated in a few minutes by filling the bowl and stem with a liquid, such as alcohol, and noting the quantity of liquid contained in the bowl and in 10 graduations on the stem.

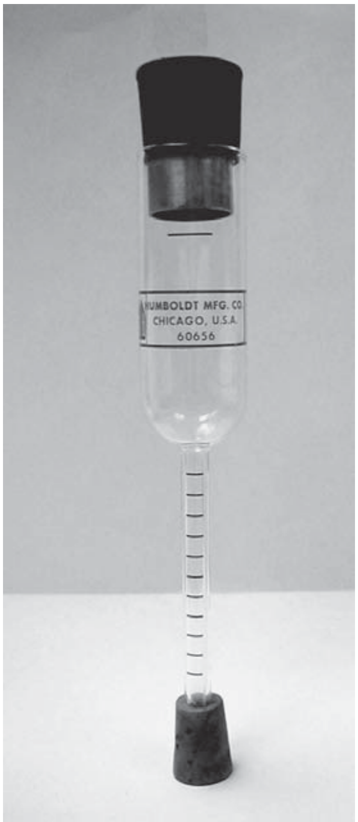


Figure 1—Chace Indicator

3.3 *Alcohol*—70 percent isopropyl alcohol.

3.4 *Dropper*—A medicine dropper having a tip small enough to enter into the graduated stem of the indicator.

4. PROCEDURE

4.1 Fill the brass cup with cement mortar from the concrete to be tested, excluding particles of sand that would be retained on a 2.00-mm (No. 10) sieve. A narrow knife blade is most suitable to pick up the mortar. Rod the mortar in the cup using a thin stiff wire[1] and strike off the mortar flush with the top of the cup. Clean the sides of the cup and stopper of mortar if necessary. Close the smaller end of the indicator with a finger and fill the tube with alcohol to the reference line. Insert the stopper into the tube, invert the indicator, and bring the level of the alcohol to the upper mark of the stem by pushing the stopper in further or by adding alcohol with the medicine dropper. Be certain that no air bubbles are in the stem of the indicator.

4.1.1 Close the opening in the stem with a finger and gently roll the indicator from a vertical to a horizontal position while tapping the side of the indicator with a finger of the other hand. Care shall be taken not to change the setting of the stopper. Continue the rolling and tapping until all of the mortar is dispersed in the alcohol and no more bubbles of air appear. With the indicator held in a vertical position, remove the finger from the end of the stem and read the level of the alcohol in the stem to the nearest half graduation.

5. COMPUTATION OF AIR CONTENT

5.1 The air content can be determined from Table 1 or Figure 2. By noting the mortar content of the concrete and the Chace factor, the stem reading can be multiplied by the appropriate mortar correction factor shown in Table 1 to provide the mortar-corrected air content. The mortar-corrected air content should be increased or decreased by the curve corrections shown in Table 2 to provide the actual air content. For example, if the mortar content is 0.556 (m^3/m^3), the Chace factor is 2.3, and the stem reading is 6.0 percent; multiply the stem reading by 1.26 (1.28), as indicated by Table 1 (based on average of values for Chace factors of 2.2 and 2.4), to give a mortar-corrected air content of 7.6 (7.7) percent. The 7.6 (7.7) percent is increased by 0.9 percent, as indicated by Table 2, to give an air content of 8.5 (8.6) percent.

As an alternative, the air content can be determined from the Chace conversion nomograph shown in Figure 2. For example, enter the nomograph at the lower left side at the Chace factor, which is 2.3, move horizontally to the right to intersect the mortar content, which is 0.556 m^3/m^3, move vertically to intersect the stem reading, which is 6.0 percent, and move horizontally to the left edge of the nomograph to read the air content, which is 8.5 (8.6) percent.

Table 1—Mortar Correction Factors

Mortar Content, m^3/m^3 (ft^3/yd^3)	Chace Factor[a]				
	1.6	1.8	2.0	2.2	2.4
1.00 (27)	1.60	1.80	2.00	2.20	2.40
0.75 (20)	1.20 (1.19)	1.35 (1.33)	1.50 (1.48)	1.65 (1.63)	1.80 (1.78)
0.70 (19)	1.12 (1.13)	1.26 (1.27)	1.40 (1.41)	1.54 (1.55)	1.68 (1.69)
0.65 (18)	1.04 (1.07)	1.17 (1.20)	1.30 (1.33)	1.43 (1.47)	1.56 (1.60)
0.60 (17)	0.96 (1.01)	1.08 (1.13)	1.20 (1.26)	1.32 (1.39)	1.44 (1.51)
0.55 (16)	0.88 (0.95)	0.99 (1.07)	1.10 (1.19)	1.21 (1.30)	1.32 (1.42)
0.50 (15)	0.80 (0.89)	0.90 (1.00)	1.00 (1.11)	1.10 (1.22)	1.20 (1.33)
0.45 (14)	0.72 (0.83)	0.81 (0.93)	0.90 (1.04)	0.99 (1.14)	1.08 (1.24)
0.40 (13)	0.64 (0.77)	0.72 (0.87)	0.80 (0.96)	0.88 (1.06)	0.96 (1.16)
0.35 (12)	0.56 (0.71)	0.63 (0.80)	0.70 (0.89)	0.77 (0.98)	0.84 (1.07)
0.30 (11)	0.48 (0.65)	0.54 (0.73)	0.60 (0.81)	0.66 (0.90)	0.72 (0.98)
0.25 (10)	0.40 (0.59)	0.45 (0.67)	0.50 (0.74)	0.50 (0.81)	0.68 (0.89)

[a] Volume of one graduation on stem as a percentage of the volume of the bowl.

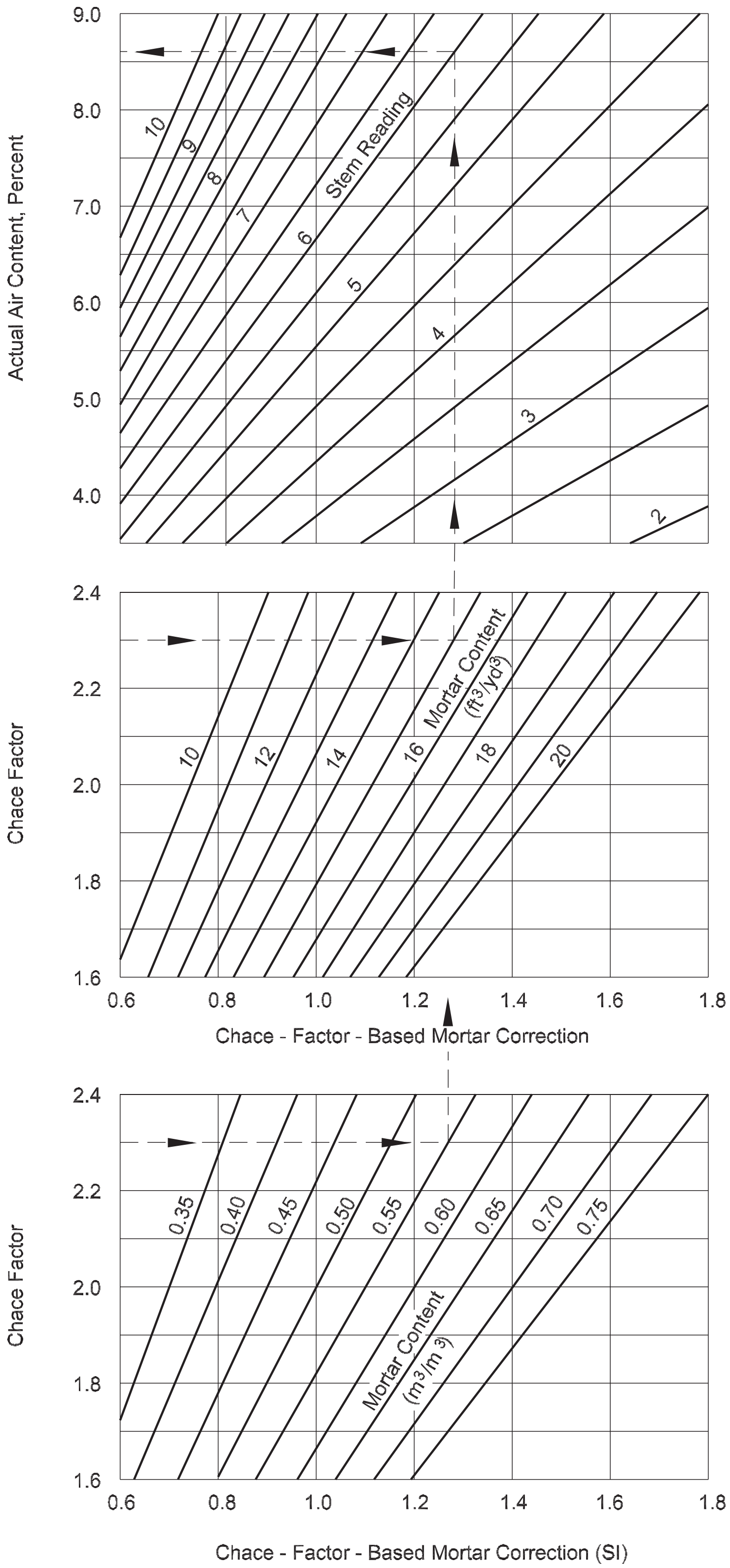


Figure 2—Chase Conversion Nomograph

Table 2—Curve Corrections

Mortar-Corrected Air Content, (%)	Curve Correction, (%)	Mortar-Corrected Air Content, (%)	Curve Correction, (%)
1.0	–0.1	7.0	0.8
2.0	0.0	7.5	0.9
3.0	0.2	8.0	1.0
3.5	0.3	8.5	1.1
4.0	0.3	9.0	1.2
4.5	0.4	9.5	1.3
5.0	0.5	10.0	1.3
5.5	0.6	11.0	1.5
6.0	0.7	12.0	1.7
6.5	0.8	13.0	1.8

6. LIMITATIONS

6.1 Because of the small amount of mortar used in a test, the Chace indicator will not give the air content of concrete as accurately as will the other methods mentioned in Section 1.2. However, a reasonably accurate indication of the air content can be obtained by taking the average of the results of tests on two samples. The average of tests on five samples provides the same statistical level of confidence as one test by T 152 (pressure method).

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[1] The wire in a No. 1 Gem paper clip is suitable.

Standard Practice for

Capping Cylindrical Concrete Specimens

AASHTO Designation: T 231-05 (2009)
ASTM Designation: C 617-98 (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Capping Cylindrical Concrete Specimens

AASHTO Designation: T 231-05 (2009)
ASTM Designation: C 617-98 (2003)

1. SCOPE

1.1 This method covers apparatus, materials, and procedures for capping freshly molded concrete cylinders with neat cement and hardened cylinders and drilled concrete cores with high-strength gypsum plaster or sulfur mortar.

1.2 The values stated in SI units are the preferred standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For specific precaution statements, see Sections 4.3 and 6.2.4.1.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 85, Portland Cement
- M 240, Blended Hydraulic Cement
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm 2-in. Cube Specimens)

2.2 *ASTM Standards*:

- C 287, Standard Specification for Chemical-Resistant Sulfur Mortar
- C 472, Standard Test Methods for Physical Testing of Gypsum, Gypsum Plasters and Gypsum Concrete
- ASTM *Manual of Aggregate and Concrete Testing*

2.3 *ANSI Standard*:

- B 46.1, Standard for Surface Texture, Surface Roughness, Waviness and Lay

3. SIGNIFICANCE AND USE

3.1 This practice describes procedures for providing plane surfaces on the end surfaces of freshly molded concrete cylinders, hardened cylinders, or drilled concrete cores when the end surfaces do not conform with the planeness and perpendicularity requirements of applicable standards.

4. CAPPING EQUIPMENT

4.1 *Capping Plates*—Neat cement caps and high-strength gypsum plaster caps shall be formed against a glass plate of at least 6 mm (0.25 in.) thick, a machined metal plate at least 11 mm (0.45 in.) thick (Note 1), on a polished plate of granite or diabase at least 75 mm (3 in.) thick. Sulfur mortar caps shall be formed against similar metal or stone plates. In all cases, plates shall be at least 25 mm (1 in.) greater in diameter than the test specimen and the working surfaces shall not depart from a plane by more than 0.05 mm (0.002 in.) in 150 mm (6 in.). The surface roughness of newly finished metal plates shall not exceed that set forth in Table 4 of the American National Standard for Surface Texture (ANSI B46.1) or 0.003 mm (125 μ in.) for any type of surface and direction of lay. The surface when new shall be free of gouges, grooves, or indentations beyond those caused by the finishing operation. Metal plates that have been in use shall be free of gouges, grooves, or indentations greater than 0.25 mm (0.010 in.) deep or greater than 32 mm^2 (0.05 $in.^2$) in surface area. If a recess is machined into the metal plate, the thickness of the plate beneath the recessed area shall be at least 13 mm (0.5 in.). In no case shall the recess in the plate be deeper than 13 mm (0.5 in.).

Note 1—In vertical capping devices, use of two-piece metal capping plates is advantageous as this facilitates refinishing of the capping surface should it become necessary to do so. In such devices, the lower section is a solid plate and the upper section has a circular hole that forms the recess. The two sections are customarily fastened together with machine screws. It is advantageous to have the upper surface of the lower plate case hardened. A Rockwell hardness of HRC 48 is suggested.

4.2 *Alignment Devices*—Suitable alignment devices such as guide bars or bull's-eye levels shall be used in conjunction with capping plates to ensure that no single cap will depart from perpendicularity of cylindrical specimen by more than 0.5 degrees [approximately equivalent to 3.2 mm in 305 mm (0.125 in. in 12 in.)]. The same requirement is applicable to the relationship between the axis of the alignment device and the surface of a capping plate when guide bars are used. In addition, the location of each bar with respect to its plate must be such that no cap will be off-centered on a test specimen by more than 1.6 mm (0.06 in.).

4.3 *Melting Pots for Sulfur Mortars*—Pots used for melting sulfur mortars shall be equipped with automatic temperature controls and shall be made of metal or lined with a material that is non-reactive with molten sulfur.

Caution—Melting pots equipped with peripheral heating will ensure against accidents during reheating of cooled sulfur mixtures that have a crusted-over surface. When using melting pots not so equipped, a buildup of pressure under the hardened surface crust on subsequent reheating may be avoided by use of a metal rod that contacts the bottom of the pot and projects above the surface of the fluid sulfur mix as it cools. The rod should be of sufficient size to conduct enough heat to the top of reheating to melt a ring around the rod first and thus avoid the development of pressure. A large metal ladle can be substituted for the rod.

Sulfur melting pots should be used under a hood to exhaust the fumes to outdoors. Heating over an open flame is dangerous because the flash point of sulfur is approximately 227ºC (440ºF) and the mixture can ignite due to overheating. Should the mixture start to burn, covering will snuff out the flame. The pot should be recharged with fresh material after the flame has been extinguished.

5. CAPPING MATERIALS

5.1 The strength of the capping material and the thickness of the caps shall conform to the requirements of Table 1.

Table 1—Compressive Strength and Maximum Thickness of Capping Materials

Cylinder Compressive Strength, MPa (psi)	Minimum Strength of Capping Material	Maximum Average Thickness of Cap	Maximum Thickness Any Part of Cap
3.5 to 50 MPa (500 to 7000 psi)	35 MPa (5000 psi) or cylinder strength, whichever is greater	6 mm (0.25 in.)	8 mm (0.31 in.)
greater than 50 MPa (7000 psi)	Compressive strength not less than cylinder strength, except as provided in Section 5.1.1.	3 mm (0.125 in.)	5 mm (0.20 in.)

5.1.1 If sulfur mortar, high strength gypsum plaster and other materials except neat cement paste are to be used to test concrete with a strength greater than 50 MPa (7000 psi), the manufacturer or the user of the material must provide documentation:

- that the average strength of 15 cylinders capped with the materials is not less than 98 percent of the average strength of 15 companion cylinders capped with neat cement paste or 15 cylinders ground plane to within 0.05 mm (0.002 in.),
- that the standard deviation of the strengths of the capped cylinders is not greater than 1.57 times that of the standard deviation of the reference cylinders,
- that the cap thickness requirements were met in the qualification tests, and
- of the hardening time of the caps used in the qualification tests.

5.1.2 Additionally, the qualification test report must include the compressive strength of 50-mm (2-in.) cubes of the material qualified and of neat cement paste cubes, if used. Capping materials conforming to these requirements are permitted to be used for cylinders with strengths up to 20 percent greater than the concrete tested in these qualification tests. The manufacturer must requalify lots of material manufactured on an annual basis or whenever there is a change in the formulation of the raw materials. The user of the material must retain a copy of the qualification results, and the dates of manufacture of material qualified and of the material currently being used. (See Table 2.)

Table 2—Sample Report of Qualifications of a Capping Material

Note-Manufacturer: Testing Supplies Co.
Capping Material: Super Strong AAA-Sulfur mortar
Lot: 12a45 Date Tested: 11/3/98
Signed by:____(Testing Agency and Responsible Official)

Item	Capping Material	Control Cylinders	Ratio	Criteria	Pass/Fail
Concrete Cylinder Test Data					
Type of Capping Material	Sulfur	Ground			
Average Concrete Strength, MPa (psi)	76.2 (11,061)	75.9 (11,008)	1.005	>0.98 Xc	Pass
Standard Deviation MPa (psi)	2.59 (376)	1.72 (250)	1.504	≤1.57 C	Pass
Number of cylinders tested	15	15			
Cap age when cylinders tested	7 days	n/a			
Capping Material Test Data					
Average cap thickness mm (in.)	2.8 (0.11)	n/a			
Compressive strength of 50-mm (2-in.) cubes, MPa (psi)	91 (12,195)				
Cube age when tested	7 days				
Maximum concrete strength qualified, MPa (psi)				1.2 Av. Str = 91.5 (13,273)[a]	

[a] Nominally a specified strength of 75 MPa (11,000 psi) and perhaps somewhat higher.

5.1.3 The compressive strength of capping materials shall be determined by testing 50-mm (2-in.) cubes following the procedure described in Test Method T 106M/T 106. Except for sulfur mortars, molding procedures shall be as in Test Method T 106M/T 106 unless other procedures are required to eliminate large entrapped air voids. See test methods for alternative compaction procedures. Cure cubes in the same environment for the same length of time as the materials used to cap specimens.

5.1.4 The strength of the capping material shall be determined on receipt of a new lot and at intervals not exceeding three months. If a given lot of the capping material fails to conform to the strength requirements, it shall not be used, and strength tests of the replacement material shall be made weekly until four consecutive determinations conform to specification requirements.

5.2 *Neat Hydraulic Cement Paste*:

5.2.1 Make qualification test of the neat hydraulic cement paste prior to use for capping to establish the effects of water-cement ratio and age on compressive strength of 50-mm (2-in.) cubes (Note 2).

Note 2—The cements used generally conform to Specification M 85 Types I, II, or III; however, Specification M 240 blended cements, calcium aluminate or other hydraulic cements producing acceptable strength may be used.

5.2.2 Mix the neat cement paste to the desired consistency at a water-cement ratio equal to or less than that required to produce the required strength, generally 2 to 4 hours before the paste is to be used (Note 3). Remix as necessary to maintain acceptable consistency (Note 4). Some re-tempering of the paste is acceptable if the required water-cement ratio is not exceeded. Optimum consistency is generally produced at water-cement ratios of 0.32 to 0.36 by mass for Type I and Type II cements and 0.35 to 0.39 by mass for Type III cements.

Note 3—Freshly mixed pastes tend to bleed, shrink, and make unacceptable caps. The 2 to 4 hour period is generally appropriate for portland cements.

Note 4—The required consistency of the paste is determined by the appearance of the cap when it is stripped. Fluid paste results in streaks in the cap. Stiff paste results in thick caps.

5.3 *High-Strength Gypsum Cement Paste*:

5.3.1 No fillers or extenders may be added to neat high-strength gypsum cement paste subsequent to the manufacture of the cement (Note 5). Qualification tests shall be made to determine the effects of water-cement ratio and age on the compressive strength 50-mm (2-in.) cubes. Retarders may be used to extend working time, but their effects on required water-cement ratio and strength must be determined (Note 6.)

Note 5—Low-strength molding plaster, plaster of paris, or mixtures of plaster of paris and portland cement are unsuitable for capping.

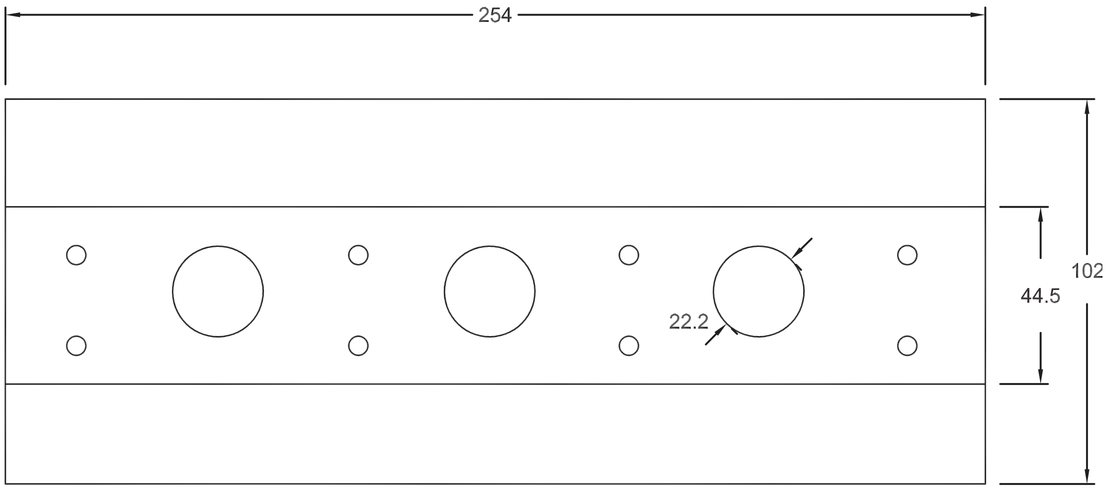
Note 6—The water-gypsum cement ratio should be between 0.26 and 0.30. Use of low water-cement ratios and vigorous mixing will usually permit development of 35 MPa (5000 psi) at ages of 1 to 2 hours. Higher water-gypsum cement ratios extend working time, but reduce strength.

5.3.2 Mix the neat gypsum cement paste at the desired water-cement ratio and use it promptly since it sets rapidly.

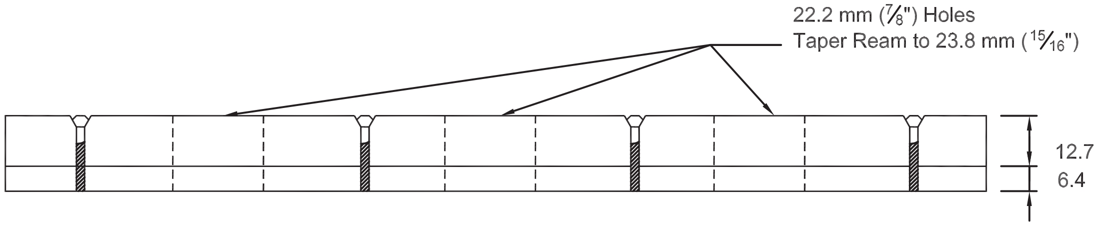
5.4 *Sulfur Mortar*:

5.4.1 Proprietary or laboratory prepared sulfur mortars are permitted if allowed to harden a minimum of 2 hours before testing concrete with strength less than 35 MPa (5000 psi). For concrete strengths of 35 MPa (5000 psi) or greater, sulfur mortar caps must be allowed to harden at least 16 hours before testing, unless a shorter time has been shown to be suitable as specified in Section 5.1.1.

5.4.2 *Determination of Compressive Strength*—Prepare test specimens using a cube mold and base plate conforming to the requirements of T 106M/T106 and a metal cover plate conforming in principle to the design shown in Figure 1 (Note 7). Bring the various parts of the apparatus to a temperature of 20 to 30ºC (68 to 86ºF), lightly coat the surfaces that will be in contact with the sulfur mortar with mineral oil and assemble near the melting pot. Bring the temperature of the molten sulfur mortar in the pot within a range of 129 to 143ºC (265 to 290ºF), stir thoroughly, and begin casting cubes. Using a ladle or other suitable pouring device, quickly fill each of the three compartments until the molten material reaches the top of the filling hole. Allow sufficient time for maximum shrinkage, due to cooling, and solidification to occur (approximately 15 minutes) and refill each hole with molten material (Note 8). After solidification is complete, remove the cubes from the mold without breaking off the knob formed by the filling hole in the cover plate. Remove oil, sharp edges, and fins from the cubes and check the planeness of the bearing surfaces in the manner described in T 106M/T 106. After storage at room temperature to the desired age, but not less than 2 hours, test cubes in compression following the procedure described in T 106M/T 106 and calculate the compressive strength in MPa (psi).



Cover Plate - Plan View



Cover Plate - Front View

Dimensional Equivalents

mm	6.4	12.7	22.2	44.5	100	250
in.	$^{1}/_{4}$	$^{1}/_{2}$	$^{7}/_{8}$	$1^{3}/_{4}$	4	10

Notes: All dimensions shown in millimeters unless otherwise noted.

Figure 1—Sketch of Cover for 50-mm (2-in.) Cube Mold

Note 7—If desired, a plane phenol formaldehyde (bakelite) plate of 3 mm (0.125 in.) thickness, provided with three appropriately spaced filling holes, may be inserted between the cover plate and the mold to slow the rate of cooling of test specimens.

Note 8—The second filling helps to prevent the formation of a large void or shrinkage pipe in the body of a cube. However, such defects may occur no matter how much care is exercised, and it therefore is advisable to inspect the interior of tested sulfur mortar cubes for homogeneity whenever the strength values obtained are significantly lower than anticipated.

6. CAPPING PROCEDURES

6.1 *Freshly Molded Cylinders*—Use only neat portland cement pastes (Note 9) to cap freshly molded cylinders. Make caps as thin as practical. Do not apply the neat paste to the exposed end until the concrete has ceased settling in the molds, generally from 2 to 4 hours after molding. During the molding of the cylinder, strike off the upper end even with or slightly below the plane of the rim of the mold. Mix the neat paste to a stiff consistency 2 to 4 hours before it is to be used in order to allow the paste to go through its period of initial shrinkage. The strength of the paste will depend on the consistency, water-cement ratio, curing, brand, and type of cement. For Type I and Type II cement pastes, the optimum consistency is generally produced at a water-cement ratio of 0.32 to 0.36 by mass. For Type III cement, the water ratio should generally be between 0.35 to 0.39 by mass. The paste will stiffen during the 2 to 4 hours waiting period and the use of re-tempering water is not recommended. However, if retempering water is used, the amount should not increase the water-cement ratio by more than 0.05 by mass. Remove free water and laitance from the top of the specimen immediately before capping. Form the cap by placing a conical mound of paste on the specimen and then gently pressing a freshly oiled capping plate on the conical mound until the plate contacts the rim of the mold. A very slight twisting motion may be required to extrude excess paste and minimize air voids in the paste. The capping plate must not rock during this operation. Carefully cover the capping plate and mold with a double layer of damp burlap and a polyethylene sheet to prevent drying. Removal of the capping plate after hardening may be accomplished by tapping the edge with a rawhide hammer in a direction parallel to the plane of the cap.

Note 9—Type I neat cement caps generally require at least 6 days to develop acceptable strength and Type III neat cement caps at least 2 days. Dry concrete specimens will absorb water from freshly mixed neat cement paste and produce unsatisfactory caps. Neat cement paste caps will shrink and crack on drying and, therefore, should be used only for specimens that are to be moist-cured continuously until time of testing.

6.2 *Hardened Concrete Specimens*:

6.2.1 *General*—Caps should be about 3 mm (0.125 in.) thick, and in no instance shall any part of a cap be more than 8 mm (0.31 in.) thick. If either or both ends of a specimen have coatings or deposits of oily or waxy materials that would interfere with the bond of the cap, remove such coatings or deposits. If necessary, the ends of a specimen may be slightly roughened with a steel file or wire brush to produce proper adhesion of the cap. If desired, capping plates may be coated with a thin layer of mineral oil or grease to prevent the capping material from adhering to the surface of the plate.

Form the caps as described in Section 6.1 using capping plates described in Section 4.1 to achieve the alignment required in Section 4.2 (Note 10). Generally capping plates may be removed within 45 minutes with gypsum cement pastes and after 12 hours with neat cement paste, without visibly damaging the cap.

Note 10—A number of methods have been used to obtain the desired perpendicularity of the cap to the axis of the cylinder. A mound of paste can be placed on a capping plate and the specimen lowered into it. A bull's-eye level on the top of the cylinder helps obtain alignment. A mound of paste can be placed on top of the cylinder and a capping plate pressed into it, again using the bull's-eye level. A better system is to make a half-height mold with a vertical split so that it can be slipped over the hardened cylinder. A clamp is used to position the mold and to ensure the required cap thickness. The mound of paste can then be placed either on a capping plate or on top of the cylinder and pressed until the plate contacts the mold. As noted earlier, very stiff paste may require excessive force and produce thick or defective caps.

6.2.2 *End Condition*—The distance of any point on an uncapped end from a plane that passes through the highest point of the end surface and is perpendicular to the axis of the cylinder shall not exceed 3 mm (0.125 in.) (Note 11). If the end exceeds this limit, the end of the cylinder shall be cut, lapped or ground prior to capping.

Note 11—This provision is to control the difference between the thickest and thinnest parts of a cap. The distance may be checked using a square with one blade touching the cylinder parallel to the cylinder axis and the other blade touching the highest point on the end of the cylinder. The distance between the blade of the square and the lowest point on the end of the cylinder is measured.

6.2.3 *Capping with High-Strength Gypsum Plaster*—Mix high-strength plaster for capping, using the same percent of mixing water as was used in making the qualification test described in Section 5.2.1 (Note 12).

Note 12—High-strength gypsum caps soften and deteriorate on contact with water and cannot be used on freshly mixed concrete or stored in a moist room for more than very brief periods up to 4 hours.

6.2.4 *Capping with Sulfur Mortar*—Prepare sulfur mortar for use by heating to about 130ºC (265ºF), as periodically determined by an all-metal thermometer inserted near the center of the mass. Empty the pot and recharge with fresh material at frequent enough intervals to ensure that the oldest material in the pot has not been used more than five times (Note 13). Fresh sulfur mortar must be dry at the time it is placed in the pot as dampness may cause foaming. Keep water away from molten sulfur mortar for the same reason. The capping plate or device should be warmed slightly before use to slow the rate of hardening and permit the production of thin caps. Oil the capping plate lightly and stir the molten sulfur mortar immediately prior to pouring each cap. The ends of moist-cured specimens shall be dry enough at the time of capping to preclude the formation of steam or foam pockets under or in the cap larger than 6 mm (0.25 in.) in diameter. To ensure that the cap shall be bonded to the surface of the specimen, the end of the specimen shall not be oiled prior to application of the cap. When using a vertical device, pour the mortar onto the surface of the capping plate, lift the cylinder above the plate and contact the cylinder sides with the guides; slide the cylinder down the guides onto the capping plate while keeping constant contact with the alignment guides. The cylinder end should continue to rest on the capping plate with cylinder sides in positive contact with the alignment guides until the mortar has hardened. Use sufficient material to cover the cylinder end after the sulfur mortar solidifies. The sulfur mortar cap may be tapped or rubbed with a light metal implement. If a hollow sound is produced, an unsatisfactory mortar cap is indicated. See Section 25.16 of the ASTM *Manual of Aggregate and Concrete Testing*.

Note 13—Reuse of material must be restricted in order to minimize loss of strength and pourability occasioned by contamination of the mortar with oil, miscellaneous debris, and loss of sulfur through volatilization.

6.2.4.1 **Caution**—Hydrogen sulfide gas may be produced during capping when sulfur mortar is contaminated with organic materials such as paraffin or oil. The gas is colorless and has a notoriously bad odor of rotten eggs; however, the odor should not be relied upon as a warning sign, since the sensitivity to the odor disappears rapidly on exposure. High concentrations are lethal and less concentrated dosages may produce nausea, stomach ache, distress, dizziness, headache, or irritation of the eyes. For this and other reasons, it is desirable that the melting pot be located under a hood or near an exhaust fan and that the capping area be well ventilated.

6.2.5 *Daily Check*—During each day's capping operation, planeness of the caps on at least three specimens representing the start, middle, and end of the run, shall be checked by means of a straightedge and feeler gauge, making a minimum of three measurements on different diameters to ensure that the surfaces of the caps do not depart from a plane by more than 0.05 mm (0.002 in.).

7. PROTECTION OF SPECIMENS AFTER CAPPING

7.1 Moist-cured specimens shall be maintained in a moist condition between the completion of capping and the time of testing by returning them to moist storage or wrapping them with a double layer of wet burlap. Specimens with gypsum plaster caps shall not be immersed in water and shall not be stored in a moist room for more than 4 hours. If stored in a moist room, the plaster caps shall be protected against water dripping on their surfaces.

APPENDIX

(Nonmandatory Information)

X1. COMPOSITION AND DETERMINATION OF LOSS ON IGNITION OF SULFUR MORTAR CAPPING MATERIALS

X1.1. *Composition*:

X1.1.1. Loss on ignition, percent 48 to 70 Residue after ignition, percent 30 to 52.

X1.2. *Determination of Loss on Ignition*—Obtain samples from caps on concrete cylinders or from cast specimens similar to caps in size and thickness. Divide each cap-size specimen into eight approximately equal triangular sections, and secure test samples by breaking either two or four of the triangular sections into small pieces with the fingers. Using a balance capable of determining mass to an accuracy of 0.01 g, measure out 20 to 25 g of fragmented material in a previously ignited, cooled, and tared Coors No. 3, high-form porcelain crucible. Place the crucible on a ring approximately 50 mm (2 in.) above a Terrel-type bunsen burner and adjust the flame so that the sulfur burns slowly without spattering (Note X1). (See Section 4.) When the sulfur has been completely consumed, adjust the burner for high heat and ignite the residue for 30 minutes. Cool the crucible and residue in a desiccator and determine the mass. Continue to ignite, cool, and determine the mass of the crucible until a constant mass is obtained. Calculate the percentage of loss on ignition, C, as follows (Note X2):

$$C = \frac{A}{B} \times 100 \tag{X1.1}$$

where:

A = original mass of sample less mass of the residue after ignition, and

B = original mass of sample.

Note X1—Where the filler is known or found to be composed of carbonate minerals, the ignition test shall be made at a carefully controlled temperature in the range from 600 to 650ºC (1110 to 1200°F), to prevent calcination of the mineral. Small amounts of plasticizer and carbon filler will be included in the reported value for loss on ignition using the simple test herein described.

Note X2—A referee procedure for the determination of the percent of sulfur contained in sulfur mortar may be found in ASTM C 287.

Standard Method of Test for

Coated Dowel Bars

AASHTO Designation: T 253-02 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Coated Dowel Bars

AASHTO Designation: T 253-02 (2007)

1. SCOPE

1.1. These methods are designed to test the qualifications of the organic coating of corrosion-resistant dowel bars to withstand the effects of weathering, deicing chemicals, and the abrading and loading stresses experienced in field joints.

1.2. The units of measure to be used shall be either SI units or inch-pound units (shown in parentheses in this standard) depending on the units used in the applicable material specification.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)

2.2. *ASTM Standards*:

- D 1474, Standard Test Methods for Indention Hardness of Organic Coatings
- G 8, Standard Test Methods for Cathodic Disbonding of Pipeline Coatings
- G 12, Standard Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel
- G 14, Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Mass Test)
- G 20, Standard Test Method for Chemical Resistance of Pipeline Coatings

3. MATERIALS AND APPARATUS

3.1. The concrete design and constituents shall comply with the procedure and specification stated by the purchasing or specifying agency.

3.2. Suitable containers, molds, and miscellaneous concrete mixing equipment necessary for mixing and casting the simulated doweled joints for load, pullout, and corrosion tests to meet condition stated in R 39.

3.3. An abradometer capable of operating at 60 to 70 double strokes per minute using 100-mm (4-in.) long strokes.

3.4. Universal test machine capable of operating accurately in the 0 to 45 kN (10000 lbf) ranges and capable of controlled stress and strain rate loading.

3.5. Suitable hold-down devices for positioning and holding the casting in place without rotation during the flexure tests.

3.6. Freeze–thaw equipment of sufficient capacity to handle the pullout and corrosion–abrasion test specimens.

3.7. Sufficient quantities of chemical to maintain solution for corrosion tests.

4. PREPARATION OF SAMPLES

4.1. The coated dowels for deflection tests may be in support baskets or loose. The coated dowels for the remainder of tests shall be loose.

4.2. Type A-coated dowels shall be cast without additional coating of any kind. Type B-coated dowels shall be covered before casting with the debonding agent specified by the coating manufacturer.

4.3. The prepared dowels shall be cast in the appropriate molds specified for the various tests.

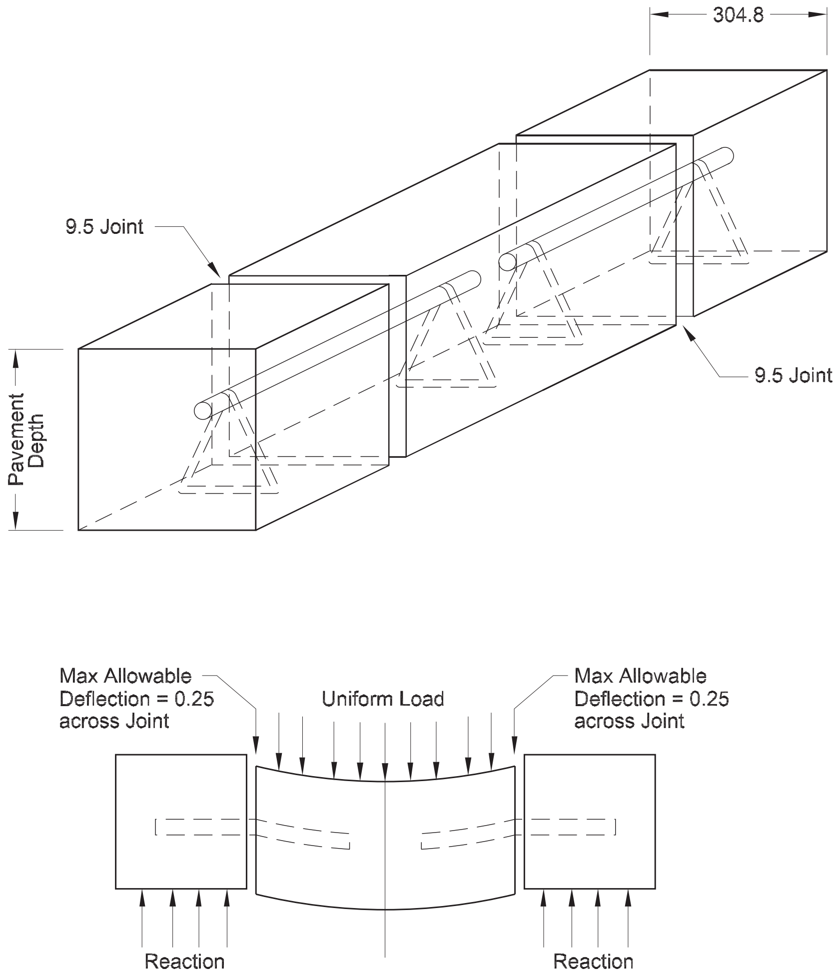
5. LOAD-DEFLECTION TEST PROCEDURE

5.1. Six dowels with basket assemblies, if any, will be utilized in three load-deflection tests. The test will be conducted in accordance with the following procedures:

5.2. Two dowels with basket assemblies, or without basket assemblies in case of loose dowels, shall be cast into each concrete test specimen in a manner to simulate two 305-mm (12-in.) long highway contraction joints. (See Figure 1.) The contraction joints are formed by dividing the mold into three sections with two-piece plates 9.5 mm ($^3/_8$ in.) thick. After the mold has been filled, the concrete shall be consolidated by vibration.

5.3. The concrete test specimens shall be made and cured in accordance with R 39. The specimens shall be removed from the molds after a 24-hour curing period, and shall be further moist-cured for a total of 14 days.

5.4. Upon completion of curing, the simulated joint shall be placed in a testing machine and loaded as illustrated in Figure 1. The end sections will be provided with suitable hold-down devices to prevent rotation. The load shall be applied at the rate of 8.9 kN/min (2000 lbf/min) until a load of 17.8 kN (4000 lbf) is obtained. The relative deflection between the loaded center section and the supported stationary ends will be measured under the 17.8 kN (4000 lbf) maximum load. Record maximum relative deflection under load.



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 1—Load-Deflection Test Specimen and Diagram

6. PULLOUT TEST PROCEDURE

6.1. Three dowels shall be tested in accordance with the following procedures:

6.2. For one-half of its length, each dowel shall be cast into a 152.4-mm (6-in.) diameter concrete cylinder. Care shall be taken to assure that the dowels are on the centerline axis of the concrete cylinder. The concrete shall be consolidated by vibration.

6.3. Cure the molded specimens in accordance with R 39. Remove the molds from the specimens after the first 24 hours of a 48-hour moist-curing period.

6.4. After 48-hour curing ±2 hours, place the concrete cylinder in the testing machine and apply a tensile load parallel to the axis of the dowel. Record the maximum pullout tensile load for the first 12.7 mm (0.5 in.) of movement for each of the three test specimens. The testing machine shall be adjusted to a free-running speed of 0.76 mm/min (0.030 in./min) prior to performing this test and this setting shall be maintained during the test.

6.5. After the first 12.7 mm (0.5 in.) of movement of the dowels, the test specimens will be further cured as before for an additional 12 days. Then the test specimens will be placed in a 10 mass percent sodium chloride solution in such a manner as to inundate half of the cross-section perimeter of the dowels. The sodium chloride solution will be maintained at this level and once a week it will be replaced by a fresh solution. The partially submerged specimens will be subjected to 50 cycles of freezing and thawing consisting of freezing in air for 16 hours at a temperature of –28.9 ± 1.7ºC (–20 ± 3ºF) and thawing in air for 8 hours at a temperature of 22.8 ± 1.7ºC (73 ± 3ºF).

6.6. Upon completion of the freeze–thaw cycling, the test specimens will again be placed in the testing machine and the pullout load redetermined by pulling out the dowels an additional 12.7 mm (0.5 in.) at the rate specified in Section 6.4. Again record the maximum tensile load for each of the specimens.

6.7. After the total 25.4-mm (1-in.) movement of the dowel, remove the concrete by breaking it away from the dowel. The dowel and the concrete–dowel interface will be examined for corrosion, tearing, and perforation.

7. CORROSION–ABRASION TEST PROCEDURE

7.1. Three dowel bars shall be subjected to corrosion–abrasion testing in accordance with the following procedures:

7.2. Abrasion resistance of the dowels will be determined by the use of an abradometer. The abradometer is operated at 60 to 70 double strokes per minute using a 100-mm (4-in.) long stroke. The abrading block is a 4-in. long mortar block made of portland cement and Ottawa sand (T 106) cast to fit over about $^1/_3$ of the perimeter of the test dowel. The test load is the 2500-g mass of the abrading assembly and block. Each dowel will be tested for a total of 10000 double strokes (from the starting point to the far end and returning to the starting point is considered one double stroke).

7.3. Upon completion of the abrading, the dowels will be examined for wear, perforation, and wrinkling.

7.4. After completion of testing in Section 7.3, determine loss of thickness due to abrasion by ASTM G 12. A minimum of five readings shall be taken in both the abraded and unabraded portions of the dowel. The average of the five readings shall determine the respective thickness.

7.5. The abraded dowels will be placed in a 10 mass percent sodium chloride solution so as to inundate half of the cross-section perimeter of the abraded area and expose the upper half to the atmosphere. The sodium chloride solution will be maintained at this level and once a week it will be replaced by a fresh solution. A sufficient length of the coated dowel will be subjected to the test so that not less than 50 mm (2 in.) of unabraded coating is tested at each end of the abraded area. The partially submerged specimens will be subjected to 50 cycles of freezing and thawing as specified in Section 6.5.

7.6. After the 50 cycles of freezing and thawing, the dowel will be removed and thoroughly examined for corrosion under five-power magnification.

8. CHEMICAL RESISTANCE TEST PROCEDURE

8.1. Three dowel bars will be subjected to chemical resistance testing in accordance with the following procedure:

8.2. Sample bars will be tested in the manner described in ASTM G 20, by immersion for 45 days in each of the following: distilled water, an aqueous solution of 3 molar $CaCl_2$, an aqueous solution of 3 molar NaOH, and a solution saturated with $Ca(OH)_2$ at a temperature of 23.9 ± 1.7ºC (75 ± 3ºF).

9. CATHODIC DISBONDING TEST PROCEDURE

9.1. Two dowel bars shall be tested to determine their resistance to cathodic disbonding in the following manner:

9.2. The test procedure shall be Method A of ASTM G 8, except: (1) the cathode and anode shall be dowel bars coated with the same material, (2) the electrolyte shall be an aqueous solution of 7 percent mass NaCl, (3) a potential of two volts shall be applied, and (4) no intentional holes shall be cut except for a single 6.4-mm ($^1/_4$-in.) diameter hole made in the middle of the immersed length in both the anode and the cathode. The test period duration shall be 30 days.

10. COATING HARDNESS TEST PROCEDURE

10.1. Three dowel bars shall be tested in the following manner to determine the hardness of the plastic coating:

10.2. The hardness of the coating shall be determined using the method of ASTM D 1474, using a 100-g (0.22-lb) mass.

11. COATING IMPACT RESISTANCE TEST PROCEDURE

11.1. Three dowel bars shall be tested in the following manner to determine the resistance of the coating to impact:

11.2. The coating shall be subjected to an impact force of 9 J (80 in.-lb) with a 1.8-kg (4-lb) tup at 23.9 ± 1.7ºC (75 ± 3ºF) according to the procedure of ASTM G 14.

12. REPORT

12.1. The report shall show all temperature, load, and miscellaneous data pertinent to the test conditions, including the following:

12.1.1. Maximum relative deflection under a 17.8-kN (4000-lbf) load for each specimen, procedure in Section 5, Load-Deflection Test Procedure.

12.1.2. Maximum kilonewton (lbf) load for pullout of each specimen after 48-hour curing period and after the subsequent 50 cycle freeze–thaw procedure in Section 6, Pullout Test.

12.1.3. Original thickness of coating and abraded thickness, procedure in Section 7, Corrosion–Abrasion Test.

12.1.4. Observation of the condition of each specimen after completion of the freeze–thaw cycling of procedure in Section 6, Pullout Test and procedure in Section 7, Corrosion–Abrasion Test.

12.1.5. Coating condition after completion of procedure in Section 8, Chemical Resistance Test.

12.1.6. Evidence, if any, of hydrogen evolution, corrosion products, undercutting or other film failure resulting from procedure in Section 9, Cathodic Disbonding Test.

12.1.7. Coating hardness as determined by procedure in Section 10, Coating Hardness Test.

12.1.8. Nature of the coating failure, if any, when subjected to procedure in Section 11, Coating Impact Resistance Test.

Standard Method of Test for

Resistance of Concrete to Chloride Ion Penetration

AASHTO Designation: T 259-02 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance of Concrete to Chloride Ion Penetration

AASHTO Designation: T 259-02 (2006)

1. SCOPE

1.1. This method covers the determination of the resistance of concrete specimens to the penetration of chloride ion. It is intended for use in determining the effects of variations in the properties of concrete on the resistance of the concrete to chloride ion penetration. Variations in the concrete may include, but are not limited to, changes in the cement type and content, water–cement ratio, aggregate type and proportions, admixtures, treatments, curing, and consolidation. This test method is not intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

1.2. The values stated in SI units are to be regarded as the preferred standard.

2. TEST SPECIMENS

2.1. The specimens for use in this test shall be slabs made and cured in accordance with the applicable requirements of R 39, Making and Curing Concrete Test Specimens in the Laboratory.

Note 1—This method contemplates the use of a minimum of four specimens for each evaluation with each slab not less than 75 mm (3 in.) thick and a minimum surface area of 17,500 mm^2 (28 $in.^2$).

2.2. For this test the specimens shall be removed from moist curing at 14 days of age unless earlier removal is recommended by the manufacturer of a special concrete. The specimens shall then be stored until 28 days of age in a drying room of the type specified by T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete.

2.3. When the test method is used to evaluate concrete treatments, the slabs shall be fabricated from concrete having a cement factor of 390 kg/m^3 (658 lb/yd^3), a water–cement ratio mass of 0.5, and an air content of 6 ± 1 percent.

The concrete treatment shall be applied at 21 days of age and in accordance with the manufacturer's recommendations for field usage.

Note 2—If field application of a sealer by spraying is recommended, the sealer should be applied to the specimens by spraying rather than brushing.

2.4. When a special overlay material is to be evaluated, the concrete slab shall be cast 50 mm (2 in.) thick using the mix design specified under Section 2.3 and then the special overlay material shall be placed 25 mm (1 in.) thick, unless specified otherwise, according to the manufacturer's recommendations.

3. PROCEDURE

3.1. Immediately after the specified drying period stipulated in Section 2.2 (i.e., 29th day of specimen age), 3.2 ± 1.6 mm (0.125 ± 0.062 in.) of the slab surface shall be abraded using grinding or sandblasting techniques if the concrete or treatment are to be subjected to the wearing effect of vehicular traffic. No water shall be used in the abrading process. If the concrete or treatment is to be used on surfaces not subject to wear from vehicular traffic then the abrading step shall be omitted.

3.2. Place approximately 19 mm (0.75 in.) high by 13 mm (0.5 in.) wide dams around the top edge of all slabs except one, which will then become the control slab. In lieu of this, a dam meeting these dimension requirements may be cast as an integral part of the slab. However, such previously cast dams shall not interfere with the abrasion of the surface as specified under Section 3.1.

3.3. All slabs shall then be returned to the drying room as specified under Section 2.2 for an additional 13 days (i.e., until 42 days of age).

Note 3—The degree of saturation of the specimens at the time of ponding will affect chloride ingress. In general, water saturated concrete will absorb significantly less chloride during the 90 days of ponding than a drier but similar material. Thus, for proper definition of chloride ingress by this method, the requirements in Sections 2.2 and 3.1 through 3.3 (for a total of 28 days of air drying prior to ponding) must be followed.

3.4. The slabs with dams shall be subjected to continuous ponding with 3-percent sodium chloride solution to a depth of approximately 13 mm (0.5 in.) for 90 days. Glass plates shall be placed over the ponded solutions to retard evaporation of the solution. Placement of the glass plates shall not be done in such a manner that the surface of the slab is sealed from the surrounding atmosphere. Additional solution shall be added if necessary to maintain the 13 mm (0.5 in.) depth. All slabs shall then be returned to the drying room as specified under Section 2.2.

3.5. After 90 days of exposure the solution shall be removed from the slabs. The slabs shall be allowed to dry and then the surfaces shall be wire brushed until all salt crystal buildup is completely removed.

3.6. Samples for chloride ion analysis shall then be taken from all slabs in accordance with the procedure described in T 260. These samples shall be obtained from each slab at each of the following depths unless otherwise directed by the specifying agency:

- 1.6 mm (0.0625 in.) to 13 mm (0.5 in.), and
- 13 mm (0.5 in.) to 25 mm (1.0 in.).

The chloride content of each sample shall be determined in accordance with the instructions in T 260.

Note 4—Many starter bits for use inside hollow rotary hammer pulverizing bits are significantly longer than the pulverizing bit. This results in a sampling depth that is greater in the center of the “core hole” than at the edges. To minimize this effect, the chuck end of the starter bit should be cut off such that its overall length does not exceed that of the outside bit by more than 1.6 mm ($^1/_{16}$ in.) (i.e., such that the variation in sampling depth is not greater than 1.6 mm ($^1/_{16}$ in.)). When it is desired to remove only 1.6 mm ($^1/_{16}$ in.) of material from the surface of a test specimen or a bridge deck, it may be more convenient to complete that operation by use of a grinder. The sample can then be taken with the rotary hammer without fear of contamination from the salt on the surface of the item being sampled.

4. CALCULATIONS

4.1. The baseline chloride ion content for the test specimens shall be determined as the average chloride ion content of samples obtained from the 1.6-mm (0.0625 in.) to 13-mm (0.5-in.) and 13-mm (0.5-in.) to 25-mm (1-in.) depths within the slab that was not ponded with 3-percent sodium chloride solution.

4.2. The absorbed chloride ion content of each sample from the ponded slabs shall be determined as the difference between the total chloride ion content of that sample and the baseline value calculated in Section 4.1. If the result is less than zero, the result shall be reported as zero. The average chloride ion absorbed at each sampling depth shall be calculated.

5. REPORT

5.1. Reporting shall include (1) each total chloride ion value determined in Section 3.6, (2) the average and maximum baseline chloride ion (Section 4.1), (3) each calculated absorbed chloride ion value determined in Section 4.2, (4) the average and maximum absorbed chloride ion values calculated in Section 4.2 for each depth, (5) a statement detailing whether or not the surface abrasion described in Section 3.1 was performed.

Standard Method of Test for

Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

AASHTO Designation: T 260-97 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

AASHTO Designation: T 260-97 (2009)

1. SCOPE

1.1. This method covers procedures for the determination of the acid-soluble chloride ion content or the water-soluble chloride ion content of aggregates, portland cement, mortar or concrete.

1.2. The total amount of chloride is usually equal to the acid-soluble chloride. However, organic additives or minerals that contain acid-insoluble chloride may be present in concrete and concrete raw materials. These constituents may become acid soluble during long-term exposure to the alkaline environment in concrete or mortar.

1.3. The age of concrete mortar, or hydrated portland cement at the time of sampling will have an affect on the water-soluble chloride ion content. Therefore, unless early age studies are desired, it is recommended that the material be well cured and at least 28 days of age before sampling.

1.4. This standard provides for the determination of chloride ion content by two procedures: Procedure A, Determination of Acid-Soluble Chloride Ion Content and Water-Soluble Chloride Ion Content by Potentiometric Titration or Ion-Selective Electrode (Laboratory Test Method); and Procedure B, Acid-Soluble Chloride Ion by Atomic Absorption (Laboratory Test Method).

1.5. Sulfides are known to interfere with the determination of chloride content. Blast-furnace slag aggregates and cements contain sulfide sulfur in concentrations that can cause such interference, which can be eliminated by treatment as noted in the test procedures. Other materials that produce a strong odor of H_2S when acid is added to them should be similarly treated.

1.6. The values stated in SI units are to be regarded as the preferred standard.

PROCEDURE A—ACID-SOLUBLE CHLORIDE ION AND WATER-SOLUBLE CHLORIDE ION BY POTENTIOMETRIC TITRATION OR ION SELECTIVE ELECTRODE (LABORATORY TEST METHOD)

2. APPARATUS

2.1. Sampling equipment for Procedures A and B are listed in Sections 2.1.1 or 2.1.2.

2.1.1. Core drill.

2.1.2. Rotary impact-type drill with a depth indicator and drill or pulverizing bits of sufficient diameter to provide a representative sample of sufficient size for testing.

2.1.2.1. Sample containers capable of maintaining the sample in an uncontaminated state.

2.1.2.2. Spoons of adequate size to collect the sample from the drilled holes.

2.1.2.3. A "blow out" bulb or other suitable means of removing excess pulverized material from the hole prior to re-drilling operations.

2.1.2.4. A device capable of determining the location and depth of steel reinforcement to ±3 mm ($\pm^1/_8$ in.).

2.2. *Equipment for Chemical Testing*:

2.2.1. Chloride ion or silver/sulfide ion selective electrode and manufacturer-recommended filling solutions.

Note 1—Suggested electrodes are the Orion 96-17 Combination Chloride Electrode or the Orion 94-6 Silver/Sulfide Electrode or equivalents. The Silver/Sulfide Electrode requires use of an appropriate reference electrode (Orion 90-02 or equivalent).

2.2.2. A millivoltmeter compatible with the ion electrode.

Note 2—Suggested millivoltmeter is the Orion Model 701 A Digital ph/mV meter or equivalent.

2.2.3. Magnetic stirrer and Teflon stirring bars.

2.2.4. Burette with 0.1-mL graduations.

2.2.5. Balance complying with M 231, Class A.

2.2.6. Balance complying with M 231, Class G 2.

2.2.7. Hot plate, 250 to 400ºC heating surface temperature.

2.2.8. Glassware, 100 and 250-mL beakers, filter funnels, stirring rods, watch glasses, dropper, wash bottles.

2.2.9. Sieve, U.S. Standard 300 μm (No. 50).

2.2.10. Whatman No. 40 and No. 41 filter papers (or equivalent).

Note 3—If equivalent filter papers are used, they should be checked to confirm they do not contain chloride, which will contaminate the sample.

3. REAGENTS

3.1. Concentrated HNO_3 (sp gr 1.42).

3.2. Sodium chloride, NaCl, reagent grade (primary standard).

3.3. Standard 0.01 normality NaCl solution. Dry reagent grade NaCl in an oven at 105ºC. Cool, in a desiccator, determine the mass of approximately 0.5844 g to the nearest 0.0001 g, dissolve in distilled H_2O, and transfer to a 1-L volumetric flask. Make up to the mark with distilled H_2O and mix. Calculate the exact normality as follows:

$$N_{\text{NaCl}} = (0.0100)\frac{(W_{\text{actual}})}{0.5844} \tag{1}$$

where:

W_{actual} = actual mass of NaCl, and

N_{NaCl} = normality of NaCl solution.

3.4. Standard 0.01 normality $AgNO_3$. Determine the mass of 1.7 grams of reagent $AgNO_3$, dissolve in distilled H_2O, filter into a 1-L brown glass bottle, fill, and mix thoroughly. Standardize against 25.00 mL of the NaCl solution by the titration method given in Section 5.4. Calculate the exact normality as follows:

$$N_{\text{AgNO}_3} = \frac{(V_{\text{NaCl}})(N_{\text{NaCl}})}{V_{\text{AgNO}_3}} \tag{2}$$

where:

N_{AgNO_3} = normality of $AgNO_3$ solution,

V_{NaCl} = volume (mL) of NaCl solution,

N_{NaCl} = normality of NaCl solution, and

V_{AgNO_3} = volume (mL) of $AgNO_3$ solution.

3.5. Distilled Water.

Note 4—Deionized water may be used in place of distilled water for samples where extreme precision and accuracy are not demanded.

3.6. Methyl orange indicator.

3.7. Ethanol, denatured, or methanol, technical.

3.8. Hydrogen Peroxide (30 percent).

4. METHOD OF SAMPLING

4.1. *Concrete Sample*:

4.1.1. Determine the depth within the concrete for which the chloride content is desired.

Note 5—A convenient method of determining the location and depth of reinforcement bars is a pachometer capable of determining the location and depth of steel reinforcement to ±3 mm (0.125 in.).

4.1.2. *Core Method*—Drill the core to chosen depth and retrieve.

4.1.2.1. When samples are received in the laboratory in other than pulverized condition, the sample shall be crushed and ground to a powder. All sawing or crushing shall be done dry (i.e., without water). All material shall pass a 0.300-mm (No. 50) sieve. All pulverizing tools and sieves shall be washed with alcohol or distilled water and shall be dry before use with each separate sample. (See note following Section 4.1.3.7.)

4.1.3. *Pulverizing Method*:

4.1.3.1. Set the rotary hammer depth indicator so that it will drill to 13 mm (0.5 in.) above the desired depth.

4.1.3.2. Using a drill or pulverizing bit, drill until the depth indicator seats itself on the concrete surface.

4.1.3.3. Thoroughly clean the drilled hole and surrounding area utilizing the “blow out” bulb or other suitable means.

4.1.3.4. Reset the depth indicator to permit 13 mm (0.5 in.) additional drilling.

4.1.3.5. Pulverize the concrete until the depth indicator again seats itself on the concrete.

Note 6—Care must be exercised during this pulverizing operation to prevent the drill bit from abrading concrete from the sides of the hole above the sampling depth. To insure against this, some users utilize a 6-mm (0.25-in.) smaller diameter bit in this step than that used in Section 4.1.3.2.

4.1.3.6. Collect at least 10 g of the material remaining in the hole using a spoon and place in the sample container.

4.1.3.7. If the sample, as collected, does not completely pass a 0.300-mm (No. 50) sieve, additional pulverizing shall be performed in the laboratory until the entire sample is finer than 0.300-mm (No. 50).

Note 7—During sample collection and pulverizing, personnel shall use caution to prevent contact of the sample with hands, or other sources of body perspiration or contamination. Further, all sampling tools (drill bits, spoons, bottles, sieves, etc.) shall be washed with alcohol or distilled water and shall be dry prior to use on each separate sample. Alcohol is normally preferred for washing because of the rapid drying, which naturally occurs.

4.2. *Raw Material Sample*:

4.2.1. Cement samples shall be taken and prepared as prescribed in T 127, Sampling and Amount of Testing Hydraulic Cement.

4.2.2. Coarse and fine aggregate samples shall be taken as prescribed in T 2, Sampling of Aggregates. Samples shall be reduced in accordance with T 248, Reducing Samples of Aggregates to Testing Size.

4.2.3. Test samples shall contain the following minimum sizes:

- cement—100 g,
- sand—300 g,
- coarse aggregate—3000 g.

4.2.4. Coarse aggregate samples shall be crushed to pass a 4.75-mm (No. 4) sieve and then reduced down to about 300 g. The final 300 g of coarse or fine aggregate shall be ground to a minus 0.300-mm (No. 50) sieve.

5. PROCEDURE

Two distinct procedures are presented here for determination of acid-soluble chloride ion or water-soluble chloride ion content. For acid-soluble chloride ion content follow Sections 5.1 and 5.2, then continue with Section 5.4. For water-soluble chloride ion content follow Sections 5.1 and 5.3, then continue with Section 5.4.

5.1. Determine the mass to the nearest milligram of a 3-g powdered sample representative of the material under tests.

Note 8—Some users dry the sample to constant mass in a 105ºC oven and determine the dry sample prior to analysis. This optional procedure provides a constant base for comparison of all results by eliminating moisture content as a variable. It is generally believed that drying is only necessary when very high accuracy is desired. (See Reference 1 for data in this area.)

5.2. *Procedure for Acid-Soluble Chloride Ion Content*:

5.2.1. Transfer the sample quantitatively to a beaker; add 10 mL of distilled H_2O, swirling to bring the powder into suspension. Add 3 mL of concentrated HNO_3 with continued swirling until the material is completely decomposed. Break up any lumps with a stirring rod and dilute with hot H_2O to 50 mL. Stir thoroughly to ensure complete sample digestion.

If the sample contains blast-furnace slag or other sulfide-bearing material, add 3 mL of hydrogen peroxide (30 percent solution).

Add five drops of methyl orange indicator and stir. If yellow to yellow-orange color appears, solution is not sufficiently acidic. Add additional concentrated HNO_3 dropwise with continuous stirring until a faint pink or red color persists in the solution. Cover with a watch glass, retaining the stirring rod in the beaker. Heat the acid solution or slurry to boiling on a hot plate at medium heat (250 to 400ºC) and boil for about 1 minute. Remove from the hot plate, filter through double filter paper (Whatman No. 41 over No. 40 filter paper or equivalent).

5.2.2. Wash the filter paper 10 times with hot distilled H_2O, being careful not to lift the paper away from the funnel surface. Finally, lift the filter paper carefully from the funnel and wash the outside surface of the paper with hot distilled H_2O; then wash the tip of the funnel. The final volume of the filtered solution should be 125 to 150 mL. Cover with a watch glass and allow to cool to room temperature in an HCl fume-free atmosphere.

Note 9—Due to the presence of relatively insoluble materials in the sample, the solution generally will have a strong gray color, making the detection of indicator color difficult at times. Running of several trial samples is suggested to give the analyst practice in detecting the indicator color.

Note 10—A sample prepared to 100 percent passing 0.300-mm (No. 50) sieve should generally allow determination of any expected chloride level with adequate precision and accuracy. Samples containing highly siliceous aggregates may require finer grinding to minimize bumping during the procedure in Section 5.2. This may also be the case when the concrete contains modifiers such as latex or polymer.

5.3. *Procedure for Water-Soluble Chloride Ion Content*:

5.3.1. Transfer the sample quantitatively to a beaker, add 60–70 mL distilled H_2O. Cover the beaker with a watch glass and bring to a boil on a hot plate-magnetic stirrer using a small magnet. Boil for 5 minutes, then let stand for 24 hours in an HCl fume-free atmosphere.

5.3.2. Filter the clear supernatant liquid in the beaker through double filter paper (Whatman No. 41 over No. 40 or equivalent) into a 250-mL beaker; take care to quantitatively transfer any adhering drops on the watch glass, and use a stirring rod to aid transfer. Add sufficient hot distilled H_2O to cover any residue left in the original beaker, stir 1 minute on a magnetic stirrer, and filter into the 250-mL beaker with a swirling action. Wash the beaker and the stirring rod once into the filter with hot distilled H_2O. Wash the filter paper once with hot distilled H_2O. Lift the filter paper carefully from the funnel and wash the outside surface of the paper with hot distilled H_2O. Set aside the paper and wash the interior of the funnel and its tip with hot distilled H_2O. Finally, add 1–2 drops of methyl orange indicator to the 150-mL beaker; then add concentrated HNO_3 dropwise with continuous stirring until a permanent pink to red color is obtained. If the sample contains blast-furnace slag or other sulfide-bearing material, add 3 mL of hydrogen peroxide (30-percent solution). Make up the volume to 125 to 150 mL with distilled H_2O.

5.4. Three alternate methods are available to determine the Cl^- content of the solution. All methods utilize an ion selective electrode (Cl^- or Ag^+) and all methods for the purpose of this analysis give results of essentially equal accuracy and precision.

5.4.1. *Method 1: Potentiometric Titration*—Fill the Cl^- or the Ag^+ electrode with the solution(s) recommended by the manufacturer, plug it into the millivoltmeter (preferably the type with a digital rather than a dial readout), and determine the approximate equivalence point by immersing the electrode in a beaker of distilled H_2O. Note the approximate millivoltmeter reading (which may be unsteady in H_2O). Take the cooled sample beaker from Section 5.3 and carefully add 4.00 mL of 0.0100 normality NaCl, swirling constantly. Remove the beaker of distilled H_2O from the electrode, wipe the electrode with absorbent paper, and immerse the electrode in the sample solution. Place the entire beaker-electrode assembly on a magnetic stirrer and begin gentle stirring. Using a calibrated buret, add gradually and record the amount of standard 0.01 normality $AgNO_3$ solution necessary to bring the millivoltmeter reading to –40 mV of the equivalence point determined in distilled H_2O. Then add standard 0.01 normality $AgNO_3$ solution in 0.10 mL increments recording the millivoltmeter reading after each addition.

As the equivalence point is approached, the equal additions of $AgNO_3$ solution will cause larger and larger changes in the millivoltmeter reading. Past the equivalence point, the changes per unit volume will again decrease. Continue the titration until the millivoltmeter reading is at least 40 mV past the approximate equivalence point.

The endpoint of the titration usually is near the approximate equivalence point in distilled water and may be determined by (1) plotting the volume of $AgNO_3$ solution added versus the millivoltmeter readings. The endpoint will correspond to the point of inflection of the resultant smooth curve, or (2) calculating the differences in millivoltmeter readings between successive $AgNO_3$ additions and calculating the total volume of $AgNO_3$ that corresponds with each difference (i.e., the midpoints between successive additions).

Raw Data		Differences	
Titrant Volume	Millivolt Reading	Titrant Midpoints	Millivolt Difference
4.2 mL	130.0	4.25 mL	5.0
4.3 mL	135.0	4.35 mL	7.0
4.4 mL	142.0	4.45 mL	10.0
4.5 mL	152.0	etc.	
etc.			

The endpoint will be near the midpoint, which produced the largest change in millivoltmeter reading. It may be determined by plotting midpoints versus differences and defining the $AgNO_3$ volume, which corresponds to the maximum difference on a smooth, symmetrical curve drawn through the points. However, it can usually be estimated accurately without plotting the curve by choosing the midpoint, which corresponds to the maximum difference and adjusting for asymmetry, if any. In other words, if the differences on each side of the largest difference are not symmetrical, adjust the endpoint mathematically in the direction of the largest differences. Detailed examples of this adjustment are contained in Reference 1.

5.4.1.1. *Calculations*:

Determine the endpoint of the titration as described in Section 5.4.1 by either plotting a curve or estimating from the numerical data. Calculate the percent Cl^- ion from the equation:

$$Cl^- \text{ percent} = \frac{\left(3.5453\left(V_1N_1 - V_2N_2\right)\right)}{W} \qquad (3)$$

where:

V_1 = endpoint in mL of $AgNO_3$;

N_1 = normality of $AgNO_3$;

W = mass of original concrete sample in grams;

V_2 = volume of NaCl solution added, in mL; and

N_2 = normality of NaCl solution.

5.4.2. *Method II: Gran Plot Method*—This method is compatible with either a Cl^- or Ag^+ ion selective electrode. Attach the electrode of choice to a compatible digital millivoltmeter after filling the required solutions as per the electrode manufacturer's instructions. Clean the electrode with distilled H_2O and pat dry with absorbent paper.

Determine the mass of the solution and beaker from Section 5.3 without the watch glass and record the mass. Using a calibrated buret, titrate the sample to 225 ± 5 mV (Cl^- electrode) or 310 ± 5 mV (Ag^+ electrode) with standard 0.01 normality $AgNO_3$ solution. Record the volume added and the millivoltmeter reading.

Continue to titrate in 0.50-mL increments recording the volume added and the millivoltmeter reading for each increment. Add and record the data for at least five increments. Empty, clean, dry, and determine the mass of the beaker. Subtract beaker mass from beaker + solution mass determined above to define solution mass.

Example shown in Figure 1. Additional information on the Gran Method is given in Reference 2.

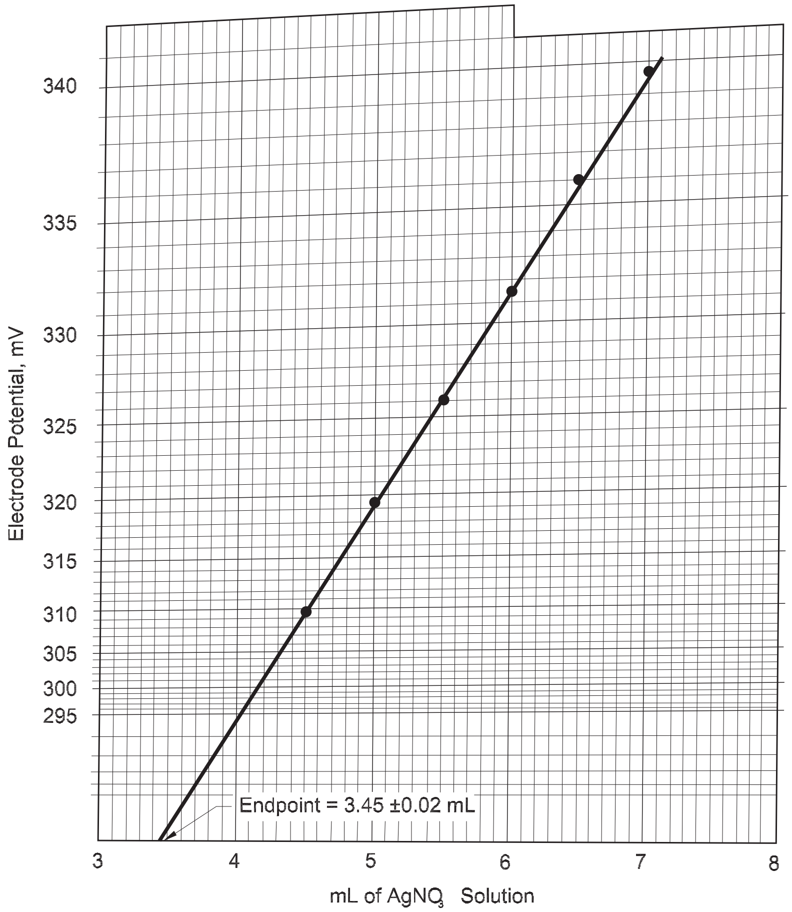


Figure 1—Use of Gran Method to Determine Endpoint in the Potentiometric Titration of an Acid Extract of Concrete

5.4.2.1. *Gran Method Calculations*:

Calculate corrected values for each of the volumes recorded in Section 5.4.2 by the equation:

$$V_{\text{correct}} = \frac{V_{\text{record}}}{W/100} \qquad (4)$$

W = original solution mass in g, and

V_{record} = volumes recorded in mL.

If any of the V correct values are greater than 10, see Section 5.4.2.2. If less than 10, plot these corrected values versus the corresponding millivolt readings on Orion Gran Plot Paper (10 percent volume corrected type with each major vertical scale division equal to five millivolts) or equivalent. Draw the best straight line through the points and read the endpoint at the intersection of the line with the horizontal axis of the graph. Calculate the actual endpoint by the equation:

$$E_a \text{ Actual Endpoint} = E_g\left(\frac{W}{100}\right) \qquad (5)$$

where:

E_g = endpoint determined from graph in mL, and

W = mass of solution in g.

then:

$$\text{Percent Cl} = \frac{3.5453\, E_a N}{W_c} \tag{6}$$

where:

E_a = actual endpoint in mL,

N = normality of $AgNO_3$ solution, and

W_c = concrete sample mass in g.

5.4.2.2. *Supplementary Gran Method Calculations*:

When the V correct volumes determined in Section 5.4.2.1 are greater than 10, discard the values and follow the following procedure.

Choose a constant which, when subtracted from all V record volumes, yields values less than 10 mL.

Note 11—This constant, designated as X in the formulas below, is normally assigned an even value such as 5, 10, 15, 20, etc.

Calculate a revised solution mass (W_r) as:

$$W_r = W + X \tag{7}$$

where:

W = original solution in g, and

X = the constant.

Then calculate corrected volumes for each recorded volume as:

$$V_{\text{correct}} = \frac{V_{\text{record}} - X}{W_r/100} \tag{8}$$

Plot these values and determine the graph endpoint E_g as described in Section 5.4.2.1. The actual endpoint (E_a) is then:

$$E_a = E_g\left(\frac{W_r}{100}\right) + X \tag{9}$$

where:

E_a = actual endpoint in mL,

E_g = endpoint from graph in mL,

W_r = revised solution mass in g, and

X = the constant chosen above.

Calculate the chloride content using the formula given in Section 5.4.2.1.

5.4.3. *Method III: Automatic Titrator*—This method is compatible with either a Cl^- or Ag^+ ion-selective electrode. The millivolt endpoint determination and testing procedure shall be in accordance with the instrument manufacturer's recommendation.

5.4.3.1. *Automatic Titrator Calculations*:

Having determined the endpoint with the automatic titrator, calculations will be identical with Section 5.4.1.1.

5.5. The percent chloride may be converted to kg of Cl/m^3 (lb/yd^3) of concrete as follows:

$$\text{kg Cl}/\text{m}^3 = \text{Percent Cl}\left(\frac{UW}{100}\right) \tag{10}$$

$$\left(\text{lb Cl}^{-}/\text{yd}^{3} = \text{Percent Cl}\left(\frac{UW}{100}\right)\right) \qquad (11)$$

where:

UW = unit mass of concrete per cubic meter (cubic yard).

Note 12—A unit mass of 2323 kg/m^3 (3915 lb/yd^3) is often assumed for normal structural mass concrete when the actual unit mass is unknown.

6. PRECISION

6.1. The precision statements presented below are based on guidelines presented in ASTM C 670, Preparing Precision Statements for Test Methods for Construction Materials. They are, of necessity slightly different since the within-laboratory standard deviation was essentially constant over the chloride levels examined while the between-laboratory precision varied with chloride level. Both statements, however, are based on the difference two-sigma limit, (d2s). The (d2s) index is the difference between two individual test results that would be equaled or exceeded in the long run in only 1 case in 20 in the normal and correct operation of the chemical analysis.

6.2. *Single-Operator*—The single-operator standard deviation has been found to be 0.0024 percent chloride.[1] Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.0068-percent chloride.[1]

6.3. *Multilaboratory Precision*—Criteria for judging the acceptability of chloride ion concentration test results obtained by different laboratories by this test method are given in Table 1.

Table 1—Multilaboratory Precision

Percent Chloride Concentration Multilaboratory Precision	Standard Deviation[a]	Acceptable Range of Two Results[a]
0.0176	0.0030	0.0085
0.0268	0.0031	0.0088
0.0313	0.0032	0.0091
0.0592	0.0037	0.0105
0.1339	0.0048	0.0136
0.2618	0.0069	0.0195

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM 670, Recommended Practice for Preparing Precision Statements for Test Methods for Construction Materials.

Note: The figures given in Column 2 are the standard deviations that have been found to be appropriate for the chloride ion concentrations described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

PROCEDURE B—ACID-SOLUBLE CHLORIDE ION BY ATOMIC ABSORPTION (LABORATORY TEST METHOD)

7. APPARATUS

7.1. See Section 2.1 for sampling equipment.

7.2. *Equipment for Chemical Testing*:

7.2.1. Atomic Absorption Spectrophotometer.

Note 13—The text of this method is most applicable to the use of a Perkin Elmer Model 503 A.A., with a 50-mm (2-in.) path length burner and digital readout. Laboratories using instruments other than Perkin Elmer should utilize the method to the fullest extent possible.

7.2.2. Millipore filter assembly No. XX1104710 (47 mm in diameter), or equivalent. Millipore filter membrane No. HAWPO4700 (0.45-μm membrane), or equivalent.

Note 14—If equivalent filter membranes are used, they should be checked to confirm they do not contain chloride, which will contaminate the sample.

7.2.3. 100-mL volumetric flasks with glass stoppers (clear glass).

7.2.4. 100-mL volumetric flasks (low actinic with glass stoppers).

7.2.5. Pipettes of suitable sizes, which meet or exceed the tolerances specified in NBS circular 602 for Class A Volumetricware.

7.2.6. Analytical balance sensitive to 0.0001 g complying with M 231, Class A.

7.2.7. Fisher filtrator (vacuum) with either a glass or plastic bell jar, tall enough to place a 100-mL volumetric flask underneath.

7.2.8. Hot plates (electric).

7.2.9. Vacuum source.

7.2.10. Vinyl tubing.

8. REAGENTS

8.1. Calcium carbonate, reagent grade.

8.2. Hydrogen peroxide (30 percent).

8.3. Methyl orange.

8.4. Nitric acid, concentrated (sp gr 1.42).

8.5. Silver nitrate, reagent grade (primary standard).

8.6. Sodium chloride, reagent grade (primary standard).

8.7. Sodium nitrate, reagent grade.

8.8. Water, distilled.

9. METHOD OF SAMPLING

9.1. See Section 4 for method of sampling.

10. STANDARDIZATION

10.1. Dry a sufficient quantity of standard materials ($AgNO_3$, NaCl, $CaCO_3$, and $NaNO_3$) at 105ºC to constant mass. Cool and retain in a desiccator.

10.1.1. Determine the mass of a sufficient sample of each of the above standards to effect the following solutions:

- Ag^+, 100 mg/L,
- Cl^-, 100 mg/L,
- Na^+, 100 mg/L, and
- Ca^{++}, 500 mg/L.

10.2. Add 10 mL of 1 + 9 HNO_3 to each of eight 100-mL low actinic volumetric flasks. Aliquot sufficient chloride solution so that each flask will contain a chloride ion concentration of 0.0, 0.1, 0.25, 0.50, 0.75, 1.0, 2.0, and 3.0 mg/L, respectively. The 0.0 concentration will be the 10-mg/L silver standard.

10.3. Proceed with the eight volumetric flasks following Sections 11.7.1 through 11.7.3.

10.4. Set the operating parameters for A.A. in accordance with the manufacturer's procedures when using a silver lamp.

10.5. Aspirate the 10 mg/L Ag^+ standard with a zero chloride ion concentration, and set 10 mg/L in the readout window.

10.6. Aspirate the remaining seven volumetrics containing 0.1 through 3.0 mg/L chloride ion concentrations, and note the readings. Repeat this procedure at least three times on 3 different days to obtain an average reading. Develop the standardization data by aspirating randomly.

10.7. Prepare a curve on linear graph paper, plotting remaining Ag^+ ions determined by A.A. against the seven chloride standards. (See Figure 2a.)

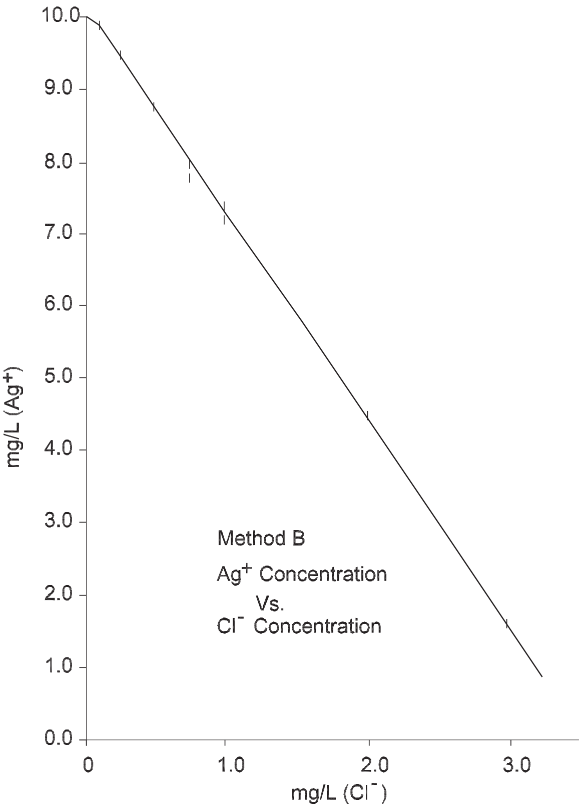


Figure 2a—Method B

11. PROCEDURE

11.1. The sample as received shall be made to pass a 300-µm (No. 50) sieve, after removing any free iron that may have been introduced in sample preparation. If received sample is excessively large, quartering may be necessary before grinding.

11.2. Dry sample at 105ºC to constant mass and cool in desiccator.

11.3. Determine the mass to the nearest mg of a one (1) g powdered sample representative of the material under test. Transfer to a 150-mL beaker, and add 10 mL of dilute nitric acid (1 + 9) to dissolve as much of the sample as possible. Break up any lumps with a stirring rod.

11.4. If carbonates are present, let sample stand until all effervescence is completed.

11.5. If the solution is not acid at this point, add only enough nitric acid to produce a red color with methyl orange.

11.6. Heat the slurry on a hot plate to just under boiling, and digest for 5 minutes or until all reaction ceases. Remove from hot plate and cool. Vacuum filter (Fisher filtrator or equivalent through a 0.45-µm membrane (Millipore filter assembly No. XX1104710, Millipore filter membrane No. HAWP04700, or equivalents) into a 100-mL volumetric flask. (See Figure 2b.) Wash the precipitate with three or four small portions of distilled water. Dilute to volume.

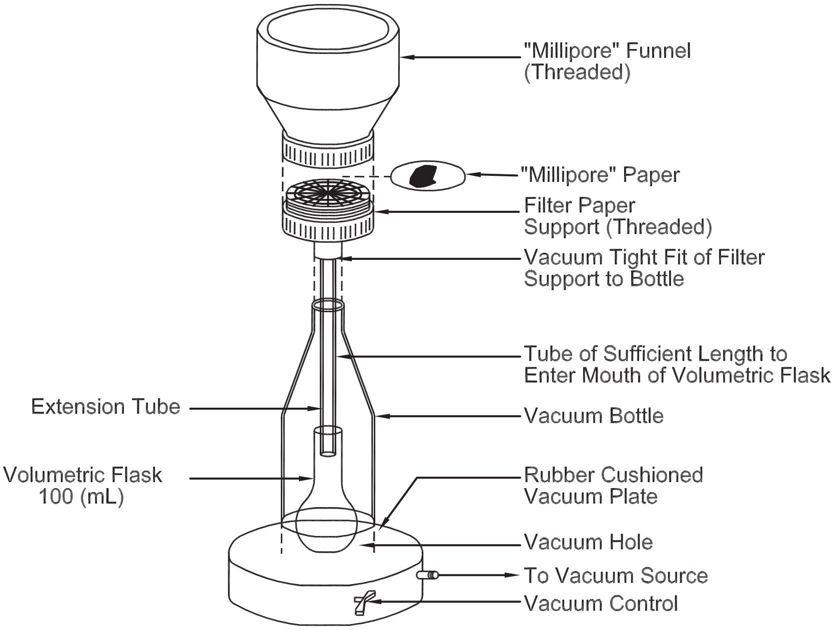


Figure 2b—Schematic Sketch of Filtration Apparatus, Method B

11.7. Aliquot 10 mL of the filtered sample solution into a 100-mL volumetric flask (low actinic). Save balance of the sample; other dilutions may be needed if concentration is relatively high.

11.7.1. Add 1.5-mL hydrogen peroxide and agitate for 1 minute.

11.7.2. Add 10 mL of the 100 mg/L silver nitrate solution. Agitate the flask once again and let stand for 1 hour.

11.7.3. Vacuum filter, using above Millipore or equivalent equipment, into a 100-mL volumetric flask (low actinic) containing 5 mL of the sodium solution and 1 mL of the calcium solution. Wash the precipitate with three or four small portions of distilled water. Dilute to volume. This filtrate contains the unreacted silver ions from the silver chloride precipitation that are found by standard atomic absorption procedures for silver, including measurements of suitable standards during the determinations.

11.7.4. Enter the curve (Figure 1) with Ag^+ remaining, and determine the chloride concentration (mg/L).

12. CALCULATION

Calculate the percentage of chloride in the concrete or concrete raw material, as indicated below:

$$\text{Percent Cl}^- = \left(\frac{1}{V}\right)\left(\frac{\text{mg/L Cl}^-}{W}\right) \qquad (12)$$

where:

V = volume of aliquot used in Section 11.7, in mL; and

W = mass of original concrete sample, in g.

This equation assumes that the aliquot is diluted to 100 mL.

13. PRECISION

Data are being compiled that will be suitable for use in developing precision statements for this method.

14. REFERENCES

14.1. Clear, K. C. *Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair*. Report FHWA-RD-74-5. Federal Highway Administration, U.S. Department of Transportation, February 1974.

14.2. Clemena, G. C., J. W. Reynolds, and R. M. McCormick. *Comparative Studies of Chloride in Hardened Concrete*. Report No. FHWA-RD-77-84 77-R7. Virginia Highway and Transportation Research Council, August 1976.

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[1] The numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

Standard Method of Test for

Density of Plastic and Hardened Portland Cement Concrete In-Place by Nuclear Methods

AASHTO Designation: T 271-83 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density of Plastic and Hardened Portland Cement Concrete In-Place by Nuclear Methods

AASHTO Designation: T 271-83 (2009)

1. SCOPE

1.1. These methods cover the determination of the density of plastic and hardened concrete in-place by gamma radiation.

1.2. Two methods are described as follows:

	Section
Method A—Direct Transmission	7
Method B—Backscatter	8

1.3. The values stated in SI units are to be regarded as the preferred standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

3. SIGNIFICANCE AND USE

3.1. The methods described are useful as rapid, nondestructive techniques for the in-place determination of the density of plastic concrete. The backscatter method is also useful for the same purpose on hardened concrete. The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material under test is homogeneous.

3.2. The methods are suitable for control and acceptance testing during construction, for evaluation subsequent to construction, and for research and development.

3.3. Test results may be affected by reinforcing steel, by chemical composition, and by sample heterogeneity. Results of tests by the backscatter method may also be affected by the density of underlying material. The backscatter method exhibits spatial bias in that the apparatus's sensitivity to the material under it decreases with distance from the surface of the concrete.

4. APPARATUS

4.1. The system shall consist of the following items. The exact details of construction of the apparatus may vary, but the apparatus as a whole shall satisfy the requirements for system precision stated in Section 10.1.

4.1.1. *Gamma Source*—An encapsulated and sealed radioisotopic source such as cesium-137.

4.1.2. *Detector*—Any type of gamma detector such as a Geiger-Muller tube, scintillation crystal, or proportional counter.

4.1.3. *Probe*—For direct transmission measurements, either the gamma source or the detector shall be housed in a probe for inserting in a preformed hole in the material to be tested. The probe shall be marked in increments of 50 mm (2 in.) for tests with probe depths from 50 to 300 mm (2 to 12 in.). The probe shall be so made mechanically that when moved manually to the marked depth desired it would be held securely in position at that depth.

4.1.4. *Readout Instrument*—a suitable scaler or direct readout meter.

4.1.5. *Gauge Housing*—The source, detector, readout instrument and appropriate power supplies shall be in housings of rugged construction that are moisture and dust proof.

4.1.6. *Reference Standard*—A block of uniform, unchanging density provided for checking equipment operation, background count, and count rate reproducibility.

4.1.7. *Guide Plate and Hole-Forming-Device*—For direct transmission measurements, a guide plate and a device, such as a pin or drill rod, having a nominal diameter equal to slightly larger than the probe, for forming a hole normal to the concrete surface.

4.1.8. *Calibration Adjustment Container*—A rigid, watertight container, whose minimum inside dimensions are large enough to allow the calibration curve adjustment procedure (Section 5.2) to be followed with no effect of the finite size of the container on the instrument's response. The volume of the container shall be established following the procedure outlined in T 19M /T 19.

Note 1—For backscatter measurements, a container 450 by 450 by 150 mm (18 by 18 by 6 in.) will meet this requirement for most equipment currently available commercially. For 50 mm (2 in.) depth direct transmission measurements, a container 600 by 600 by 100 mm (24 by 24 by 4 in.) will meet this requirement.

4.1.9. *Scale*—A scale accurate to within 0.2 kg (0.5 lb) of the test load at any point within the range of use. The range of use shall be considered to extend from the mass of the calibration adjustment container empty to the mass of the measure plus the contents at 2600 kg/m^3 (160 lb/ft^3).

4.1.10. *Strike-Off Bar*—A straight steel bar or angle 900 mm (36 in.) long.

5. CALIBRATION

5.1. Calibration curves are established by determining the nuclear count rate of each of several materials at different and known densities, plotting the count rate (or count ratio) versus each known density, and placing a curve through the resulting points. The method used in establishing the curve must be the same as will be used in determining the density. The materials used for calibration must be of uniform density.

5.1.1. Calibration curves are supplied by gauge manufacturers or can be established using blocks of known density or prepared containers of uniform, unchanging material compacted to known densities. Materials considered satisfactory for use in blocks include granite, aluminum, chalk, limestone, and magnesium.

5.2. *Adjusting Calibration Curves*—Prior to use, the instrument's calibration curve may require an adjustment to compensate for the chemical composition effect. This is recommended whenever a change is made either in the chemical composition of the concrete to be tested or in the testing equipment and is recommended particularly for backscatter method measurements. Determine the necessary adjustments using the same mode of operation and at the same depth (if using direct transmission) as that intended for testing. A recommended procedure for making this adjustment is as follows:

5.2.1. Prepare a concrete mix similar in composition to the material to be tested subsequently.

5.2.2. Fill the calibration adjustment container with concrete and consolidate to produce a uniform, homogeneous material with approximately the density that will be achieved in the subsequent construction. Strike off the container with a ground glass plate or metal strike-off bar.

Note 2—Consolidation may be achieved by the procedure used for unit mass testing (T 121M/T 121) or by other methods such as spading the concrete and then dropping the ends of the container alternately on a rigid surface.

5.2.3. Determine the mass of the concrete in the container to the nearest 225 g (0.5 lb) and determine the mass density as follows:

$$W = \frac{W_c}{V} \qquad (1)$$

where:

W = determined mass density of concrete, kg/m^3 (lb/ft^3);

W_c = mass of the concrete in kg (lb); and

V = volume of the container, m^3 (ft^3).

Note 3—Care must be taken to make the concrete surface flat and flush with the container edges. A 1.6-mm ($^1/_{16}$-in.) average difference between the concrete surface and the container edges will produce a 1.0 percent error in *W*.

5.2.4. Take three automatically timed direct transmission or backscatter readings with the instrument centered on the surface of the concrete in the container. Rotate the base of the instrument 90 degrees around the vertical axis, with subsequent rotations of 180 and 270 degrees from the original position, and obtain three additional automatically timed counts at each position. The instrument must be centered over the surface of the concrete in each rotated position to prevent edge effects on the instrument reading.

5.2.5. Using the applicable calibration curve, determine the density from the average of the 12 counts obtained in Section 5.2.4.

5.2.6. Determine the difference between the two density readings obtained in Sections 5.2.3 and 5.2.5.

5.2.7. Repeat Sections 5.2.2 through 5.2.6 on two additional concrete mixes of the same proportions. Determine the adjustment factor by averaging the three values obtained in Sections 5.2.6 and 5.2.7. If one of the three values differs from the average by more than 24 kg/m^3 (1.5 lb/ft^3), discard it as a statistical outlier and recalculate the adjustment factor as the average of the remaining two values.

5.2.8. Use the adjustment factor determined in Section 5.2.7 to plot a corrected count-rate calibration curve that shall be parallel to the original calibration curve and offset by the amount indicated in Section 5.2.7. Alternatively, the value of the adjustment factor shall be attached to the instrument and applied subsequently to all density determinations arrived at from an original (unadjusted) calibration curve.

Note 4—In some circumstances, e.g., where chemical composition changes are minimal, calibration curve adjustments may be established on permanent, uniform, hardened concrete blocks.

6. STANDARDIZATION

6.1. Standardization of equipment on the reference standard is required at the start of each day and whenever test measurements are suspect.

Note 5—In some older instrument models, count rates are strongly influenced by the ambient temperature and frequent standardization may be necessary.

6.2. Warm-up time shall be in accordance with the manufacturer's recommendation.

6.3. Take at least five readings on the reference standard, or more if recommended by the manufacturer, or take one, 4-minute or longer count if the instrument is equipped with automatic standard count storage.

6.4. If more than one of the individual readings is outside the limit set by Equation 2, repeat the standardization. If the second attempt does not satisfy Equation 2, check the system for a malfunction. If no malfunction is found, establish a new N_o, by taking the average of a minimum of 10 counts on the reference standard.

$$\left| N_s - N_o \right| < 1.96 \sqrt{N_o} \qquad (2)$$

where:

N_s = count currently measured in checking the instrument operation, and

N_o = average count previously established on the reference standard.

Note 6—In instruments where the count has been prescaled, that is, divided by a constant factor k before it is displayed, Equation 2 shall be replaced by

$$\left| N_s - N_o \right|^5 1.96 \sqrt{N_o / k} \qquad (3)$$

6.4.1. If automatic standard count storage is used and the newly established count is outside the limit set by Equation 2, repeat the standardization.

6.4.2. If the second attempt does not satisfy Equation 2, check the system for a malfunction.

6.4.3. If no malfunction is found, establish a new N_o, equal to the average count found in Section 6.4.2.

6.5. If a new N_o, differs by more than 10 percent from the standard count at which the calibration curve (Section 5.1) was established, recalibrate the instrument.

METHOD A—DIRECT TRANSMISSION

7. PROCEDURE

7.1. Select a test location such that, when the gauge is placed in test position:

7.1.1. Any point on the source-detector axis shall be at least 230 mm (9 in.) from any pavement edge or object.

7.1.2. Reinforcing steel shall not be present in the volume bounded by the extended probe and the detector tubes.

7.1.3. The test location shall contain concrete to a depth 25 mm (1 in.) greater than that to which the probe will be inserted. In concrete overlay projects, this may require removal of the underlying (original) concrete 25 to 50 mm (1 to 2 in.) down over a small area before placement of the overlay.

7.2. Smooth the surface with a wood float. If necessary, use the guide plate and hole-forming device (Section 4.1.7) to make a hole slightly larger than the probe and perpendicular to the surface. In some concretes, the probe may be inserted directly into the concrete without use of the guide plate and hole-forming device.

7.3. Insert the probe so that the side of the probe facing the center of the gauge is in intimate contact with the side of the hole. Keep all other radioactive sources at such a distance from the gauge that the readings will not be affected. The recommended minimum distance from other nuclear density gauges is 10 m (30 ft).

7.4. Use the same warm-up time as in standardization. Take automatically timed readings, for a minimum of 1 minute, and determine the in-place density from the adjusted calibration curve, or, alternatively, determine the in-place density from the unadjusted calibration curve and then apply the calibration adjustment factor (Section 5.2.8). If the instrument has a direct reading display that is not programmed to apply the calibration adjustment factor (Section 5.2.7), correct the displayed density by applying that factor.

METHOD B—BACKSCATTER

8. PROCEDURE

8.1. Select a test location such that, when the gauge is placed in test position:

8.1.1. Any point on the source-detector axis shall be at least 230 mm (9 in.) from any pavement edge or object.

8.1.2. No reinforcing steel with less than 75 mm (3 in.) of concrete cover shall lie directly under the source-detector axis.

Note 7—The user may find that certain instrument models and operating modes allow gauges to operate over steel with 38 to 75 mm (1.5 to 3 in.) of concrete cover.

8.2. *Prepare the test site in the following manner*:

8.2.1. On plastic concrete, smooth the surface with a wood float.

8.2.2. On hardened concrete, for best results find as smooth a surface as possible. Remove all loose material. The maximum void beneath the gauge shall not exceed 3 mm ($^1/_8$ in.). Use fine sand or other fine material to fill these voids and smooth the surface with a rigid plate or other suitable tool.

8.3. Seat the gauge firmly. Keep all other radioactive sources at such a distance from the gauge that the readings will not be affected.

8.4. Use the same warm-up time as in standardization. Take automatically timed readings, for a minimum of 1 minute, and determine the in-place density from the adjusted calibration curve (Section 5.2.8) or, alternatively, determine the in-place density from the unadjusted calibration curve and then apply the calibration adjustment factor. If the instrument has a direct reading display that is not programmed to apply the calibration adjustment factor (Section 5.2.7), correct the displayed density by applying that factor.

8.5. On lifts less than 75 mm (3 in.) thick, readings may be erroneous if the density of the underlying material differs significantly from that of the concrete being placed. Correction procedures are available for some gauge models.

9. REPORT

9.1. *The report shall include the following*:

9.1.1. Method (direct transmission or backscatter).

9.1.2. Depth of probe, if using direct transmission.

9.1.3. Thickness of layer tested.

9.1.4. Identification of raw materials.

9.1.5. Mix design.

9.1.6. Count rate for standardization.

9.1.7. Count rate for each test reading and the converted mean density value, or the corrected direct reading density value in kg/m^3 (lb/ft^3).

10. PRECISION

10.1. The precision of the instrument is determined from the slope of the calibration curve and the statistical standard deviation of the count rate, as follows:

$$P = \sigma / S \tag{4}$$

where:

P = precision, kg/m^3 (lb/ft^3);
σ = standard deviation, cpm; and
S = slope, cpm/kg/m^3 (cpm/lb/ft^3).

The slope of the calibration curve is determined at the 2240 kg/m^3 (140 lb/ft^3) point and the standard deviation is calculated from 10 individual automatically timed readings taken on 2240 ± 80 kg/m^3 (140 ± 5 lb/ft^3) material. The gauge is not moved after seating for the first count. For a direct reading gauge, the precision, kg/m^3 (lb/ft^3), is the standard deviation of 10 individual automatically timed density readings. The value of P shall be less than 16 kg/m^3 (1.0 lb/ft^3) for backscatter and 8 kg/m^3 (0.5 lb/ft^3) for direct transmission measurements.

APPENDIX

(Nonmandatory Information)

X1. NOTES ON THE NUCLEAR TEST

X1.1. It should be noted that the volume of concrete represented in the measurements is indeterminate and will vary with the source-detector geometry of the equipment used and with the characteristics of the material tested. In general and with all other conditions constant, the denser the material, the smaller the volume involved in a backscatter measurement. The density so determined is not necessarily the average density within the volume involved in the measurement. Typically, backscatter gauge readings are influenced by 75 to 125 mm (3 to 5 in.) of material; the top 25 mm (1 in.) of the material determines 50 to 70 percent of the measured count rate, and the top 50 mm (2 in.) determine 80 to 95 percent. Where these materials are of uniform density, this characteristic of this method is of no effect. However, reinforcing steel and underlying concrete are both often within the volume in which they may influence gauge readings. Also the extent of the influence of vertical density variations, such as those caused by reinforcing steel, depends on the depth at which the steel is located.

X1.2. The use of cesium-137 and other radioisotope sources in density gauges is regulated by the U.S. Nuclear Regulatory Commission or, in agreement states, by state regulatory agencies. The primary objective of these regulations is the use of these materials in a manner safe to the operator, to other workers, and to the general public. While detailed safety procedures are beyond the scope of this method, the originating committee emphasizes its support of these objectives. It strongly recommends that users of this equipment become completely familiar with possible safety hazards and that they establish effective operator instruction and use procedures together with routine safety procedures such as source leak tests, recording and evaluation of film badge data, the use of survey meters, etc., in connection with the operation of this type of equipment.

X1.3. The determination of density by the nuclear means of this method is indirect. The relationship between nuclear gauge count rate and density necessarily is determined by correlation tests on materials at known average densities. Calibration curves established in this manner do not necessarily hold for all concretes because of differences in chemical composition.

This effect is particularly significant for backscatter method measurements. Because of these considerations, provisions are included in this method for adjusting calibration curves on a project-by-project basis.

Standard Method of Test for

Measuring Early-Age Compression Strength and Projecting Later-Age Strength

AASHTO Designation: T 276-10
ASTM Designation: C 918-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Measuring Early-Age Compression Strength and Projecting Later-Age Strength

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1. SCOPE

1.1. This test method covers a procedure for making and curing concrete specimens and for testing them at an early age. The specimens are stored under standard curing conditions and the measured temperature history is used to compute a maturity index that is related to strength gain.

1.2. This test method also covers a procedure for using the results of early-age compressive-strength tests to project the potential strength of concrete at later ages.

1.3. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4. The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.5. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 205M/M 205, Molds for Forming Concrete Test Cylinders Vertically
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 141, Sampling Freshly Mixed Concrete
- T 231, Capping Cylindrical Concrete Specimens

2.2. *ASTM Standards*:

- C 617, Standard Practice for Capping Cylindrical Concrete Specimens
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 1074, Standard Practice for Estimating Concrete Strength by the Maturity Method

- C 1231, Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. Refer to ASTM C 1074 for the definition of the following terms: datum temperature, equivalent age, maturity, maturity function, maturity index, and temperature-time factor.

3.2. *Definition of Terms Specific to This Standard*:

3.2.1. *potential strength*—the strength of a test specimen that would be obtained at a specified age under standard curing conditions.

3.2.2. *prediction equation*—the equation representing the straight-line relationship between compressive strength and the logarithm of the maturity index.

3.2.2.1. *Discussion*—The prediction equation is used to project the strength of a test specimen based upon its measured early-age strength. The general form of the prediction equation used in this test method is:

$$S_M = S_m + b\left(\log M - \log m\right) \qquad (1)$$

where:

S_M = predicted strength at maturity index, M;

S_m = measured compressive strength at maturity index, m;

b = slope of the line;

M = maturity index under standard curing conditions; and

m = maturity index of the specimen tested at early age.

The prediction equation is developed by performing compressive strength tests at various ages, computing the corresponding maturity indices at the test ages, and plotting the compressive strength as a function of the logarithm of the maturity index. A best-fit line is drawn through the data and the slope of this line is used in the prediction equation.

3.2.3. *projected strength*—the potential strength estimated by using the measured early-age strength and the previously established prediction equation.

4. SUMMARY OF TEST METHOD

4.1. Cylindrical test specimens are prepared and cured in accordance with the appropriate section of T 23 or in accordance with R 39. The temperature of a representative specimen is monitored during the curing period. Specimens are tested for compressive strength at an early age beyond 24 hours, and the concrete temperature history is used to compute the maturity index at the time of test.

4.2. A procedure is presented for acquiring a series of compressive strength values and the corresponding maturity indices at different ages. These data are used to develop a prediction equation that is used subsequently to project the strengths at later ages based upon measured early-age strengths.

5. SIGNIFICANCE AND USE

5.1. This test method provides a procedure to estimate the potential strength of a particular test specimen based upon its measured strength at an age as early as 24 hours. The early-age test results provide information on the variability of the concrete production process for use in process control.

5.2. The relationship between early-age strength of a test specimen and strength achieved at some later age under standard curing depends upon the materials comprising the concrete. In this test method, it is assumed that there is a linear relationship between strength and the logarithm of the maturity index. Experience has shown that this is an acceptable approximation for test ages between 24 hours and 28 days under standard curing conditions. The user of this method shall verify that the test data used to develop the prediction equation are represented correctly by the linear relationship. If the underlying relationship between strength and the logarithm of the maturity index cannot be approximated by a straight line, the principle of this test method is applicable provided an approximate equation is used to represent the non-linear relationship.

5.3. Strength projections are limited to concretes using the same materials and proportions as the concrete used to establish the prediction equation.

Note 1—Confidence intervals developed in accordance with the appendix are helpful in evaluating predictions.

5.4. This test method is not intended for estimating the in-place strength of concrete. ASTM C 1074 provides procedures for using the measured in-place maturity index to estimate in-place strength.

6. APPARATUS

6.1. *Equipment and Small Tools*—for fabricating specimens and measuring the characteristics of fresh concrete; shall conform to the applicable requirements of R 39 or T 23.

6.2. *Molds*—shall conform to the requirements for cylinder molds in Specification M 205M/M 205.

6.3. *Temperature Recorder*:

6.3.1. A device is required to monitor and record the temperature of a test specimen as a function of time. Acceptable devices include thermocouples or thermistors connected to a continuous chart recorder or digital data-loggers. For digital instruments, the recording time interval shall be $^1/_2$ hour or less for the first 48 hours and 1 hour or less thereafter. The temperature recording device shall be accurate to within ±1°C (±2°F).

6.3.2. Alternative devices include commercial maturity instruments that automatically compute and display the temperature-time factor or the equivalent age as described in ASTM C 1074.

Note 2—Commercial maturity instruments use specific values of the datum temperature to evaluate the temperature-time factor or of the Q-value to evaluate equivalent age. Refer to the appendix of ASTM C 1074 for additional explanation and recommendations.

7. SAMPLING

7.1. Sample and measure the properties of the fresh concrete in accordance with R 39, T 23, or T 141.

8. PROCEDURE FOR EARLY-AGE AND PROJECTED STRENGTHS

8.1. Mold and cure the specimens in accordance with R 39 or T 23, whichever is applicable. Record the time when molding of the specimens is completed.

8.2. Embed a temperature sensor into the center of one of the specimens of the sampled concrete. Activate the temperature recording device. Continue curing for at least 24 hours. Maintain a record of the concrete temperature during the entire curing period.

8.3. *Capping and Testing*— Remove the specimens from the molds as soon as practical after 24 hours. Cap the specimens in accordance with T 231.

8.3.1. The capping materials after, if used, shall develop, at the age of 30 minutes, a strength equal to or greater than the strength of the cylinder to be tested.

8.3.2. Do not test specimens sooner than 30 minutes after capping.

8.4. Determine the cylinder compressive strength in accordance with T 22 at the age of 24 hours or later. Record the strength and the age at the time of the test. The age of the cylinder is measured to the nearest 15 minutes from the time of molding. Strength at each test age shall be the average strength of at least two cylinders.

8.5. Determine the maturity index at the time of the test by using the manual procedure described in the section titled Maturity Functions in ASTM C 1074 or by using a maturity instrument. Record the maturity index, m, of the early-age test specimens.

8.6. When the data representing the compressive strength and the maturity index, m, are to be used to project the strength of the concrete at some later age, determine the projected strength by using the prediction equation determined in Section 9.

9. PROCEDURE FOR DEVELOPING PREDICTION EQUATION

9.1. Develop a prediction equation for each concrete to be used on the job. Prepare specimens in accordance with R 39. Use the procedure in Section 8 to obtain compressive strength values and the corresponding maturity indices at the time of testing. These data shall include tests at ages of 24 hours and 3,7,14, and 28 days. If the age for which the projected strength is to be determined exceeds 28 days, the data shall include tests at the desired later age (see Section 5.2). Strength at each age shall be the average strength of at least two cylinders.

9.1.1. Field data are acceptable, provided they furnish all of the information in Section 9.1 and provided the specimens are cured in accordance with T 23.

9.2. The constant b for use in the prediction equation (see Equation 1) is established using one of two alternative methods: (1) by regression analysis, or (2) by manual plotting.

9.2.1. *Regression Analysis*—Convert the values of the maturity indices by taking their logarithms. Plot the average cylinder strength versus the logarithm of the maturity index. Compute the best-fit straight line to the point using an appropriate calculator or computer program. The straight line has the following equation:

$$S_m = a + b \log m \qquad (2)$$

where:

S_m = compressive strength at m;

a = intercept of line;

b = slope of line; and

m = maturity index.

9.2.1.1. Plot the best-fit straight line on the same graph as the data to verify that the correct equation has been determined.

9.2.2. *Manual plotting*—Prepare a sheet of semi-log graph paper with the y-axis representing compressive strength and the logarithmic scale (x-axis) representing the maturity index (see Note 3). Plot the strength values from Section 9.1 versus the corresponding maturity index. Determine the best-fitting straight line by drawing a line that visually minimizes the distance between the point and the line. The slope of the line is the vertical distance, in units of stress, between the intersection of the line with the beginning and the end of one cycle on the x-axis (see Figure X1.1) This slope is the value of b for use in the prediction equation (see Equation 1).

Note 3—The scale for the y-axis and the number of cycles in the semi-log graph paper should be chosen so that the data fill up as much of the paper as possible. When the maturity index is expressed as the temperature-time factor in degree-hours, three cycles are generally appropriate. If the maturity index is expressed as the equivalent age in hours, two cycles are appropriate.

9.3. Use the constant, b, and Equation 1 to determine the projected strength based on early-age test results.

Note 4—If it is desired to check the accuracy of the first estimate of the value of b, fabricate companion specimens to those for testing at an early age, cure them in accordance with T 23, record their temperature histories, and test them at 28 days. The value of b is re-estimated by use of the equation:

$$b = \left[\sum \left(S - S_m \middle/ \sum \left(\log M - \log m \right) \right) \right] \qquad (3)$$

where:

Σ = indicating that the values are to be added;

S = measured compression strength at M;

M = maturity index corresponding to test at 28 days;

S_m = measured compressive strength at, m; and

m = maturity index corresponding to early-age test.

10. INTERPRETATION OF RESULTS

10.1. As stated in Section 12, the variability of early-age compressive strength obtained by this test method is the same or less than that obtained from traditional test methods. Thus, results are applicable for rapid assessment of variability for process control and signaling the need for adjustments. Use of the results from this test method to predict specification compliance of strength at later ages must be applied with caution because strength requirements in existing specifications and codes are not based upon early-age testing.

10.2. Develop a one-sided confidence interval for the projected strength for use in the acceptance decision. The confidence interval is based on the measured difference between projected and measured strengths at a designated age. Usually, such an interval is developed at a 95 percent confidence level, and the decision is to accept the concrete as conforming to specification requirements if the following condition is satisfied:

$$S_M > (S_L + K) \qquad (4)$$

where:
S_M = projected strength at designated age; and
S_L = specified lower limit, specifically, the specified strength at the designated age.

$$K = \bar{d} + t_{0.95,\, n-1} \frac{S_d}{\sqrt{n}} \qquad (5)$$

$\bar{d}$ = average difference between the measured and projected strength.

$$\bar{d} = \frac{\sum_{i-1}^{n} \left(S_M - S\right)_i}{n} = \frac{\sum_{i-1}^{n} d_i}{n} \qquad (6)$$

where:
S = measured strength after standard curing up to designated age,
d_i = the difference between the ith pair of strength values,
n = number of paired (S_m and S) values used in the analysis,
$t_{0.95,n-1}$ = value from the t-distribution at the 95 percent level for n–1 degrees of freedom, and
S_d = standard deviation for the difference between the measured and projected strengths.

$$S_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \bar{d})^2}{(n-1)}} \qquad (7)$$

11. REPORT

11.1. *The report of the early-age results shall include the following*:

11.1.1. Identification number of test cylinder;

11.1.2. Diameter (and length, if not standard) of test cylinder, in inches or millimeters;

11.1.3. Cross-sectional area of test cylinder, in square inches or square millimeters;

11.1.4. Maximum test load on cylinder in pounds-force or newtons;

11.1.5. Compressive strength of cylinder calculated to the nearest 10 psi (0.1 MPa);

11.1.6. Type of fracture of cylinder, if other than the usual cone;

11.1.7. Age of cylinder at the time of test;

11.1.8. Initial mix temperature to the nearest 2ºF or 1ºC;

11.1.9. Temperature records; and

11.1.10. Method of transportation used for shipping the specimens to the laboratory.

11.2. If the early-age strength data are used to project later-age strength, the report shall include the following:

11.2.1. The maturity index, *m*, of the early-age specimens at time of test;

11.2.2. The age of the projected strength; and

11.2.3. The projected strength calculated to the nearest 10 psi (0.1 MPa).

12. PRECISION AND BIAS

12.1. *Precision*:

12.1.1. The data used to prepare the following precision statements were obtained using measurements in the inch-pound system.

12.1.2. The single laboratory coefficient of variation has been determined as 3.6 percent for a pair of cylinders (152 by 305 mm (6 by 12 in.)) cast from the same batch. Therefore, results of two properly conducted strength tests by the same laboratory on two individual cylinders made with the same materials should not differ by more than 10 percent of their average.

12.1.3. The single-laboratory, multi-day coefficient of variation has been determined as 8.7 percent for the average of pairs of cylinders (152 by 305 mm (6 by 12 in.)) cast from single batches mixed on 2 days. Therefore, results of two properly conducted strength tests, each consisting of the average of two cylinders from the same batch made in the same laboratory on different days with the same materials and proportions, should not differ by more than 25 percent of their average.

12.2. *Bias*—This test method has no determinable bias, as the values obtained can only be defined in terms of this test method.

13. KEYWORDS

13.1. Compressive strength; early-age strength; maturity; potential strength; projected strength.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE OF USE

X1.1. *Development of Prediction Equation*:

X1.1.1. To establish a reliable relationship between strength and the maturity index, concrete must be made from the actual materials, including admixtures, to be used in the work. While field data are acceptable, the initial data will normally originate in the laboratory before field production begins. Compressive strength specimens will, therefore, normally be made and cured in the laboratory and tested at ages of 24 hours, 3 days, 7 days, 14 days, and 28 days. It is suggested that a minimum of 14 cylinders be made and cured in accordance with R 39.

X1.1.1.1. *Example Data*—An example of age-strength data obtained from these test cylinders (two at each age) is as follows:

Age (No. of Cylinders)	Average Strength, psi
24 h (2)	1370
3 days (2)	2484
7 days (2)	3157
14 days (2)	3714
28 days (6)	4247

X1.1.1.2. In this example, the temperature-time factor, with a datum temperature of 0°C (32°F), is used as the maturity index. Refer to ASTM C 1074 for additional information. The temperature-time factor is calculated from the measured temperature history of the concrete by dividing the age into suitable time intervals and summing the products of the time intervals and the corresponding average temperatures for each interval. For this example, it is assumed that the concrete temperature is 21°C (70°F) prior to stripping the molds and is 23°C (73°F) thereafter. The cumulative temperature-time factor at the various test ages is calculated as shown in Table X1.1.

X1.1.2. The strength data shown in X1.1.1.1 and the temperature-time factor values in Table X1.1 can be plotted using semi-log axes as shown in Figure X1.1, which is a computer-generated plot.

X1.1.3. Determine the best-fit straight line through the plotted points. In this example, the straight line was obtained by regression analysis using a computer program. This line represents the prediction equation that is the assumed relationship between strength and the temperature-time factor for the particular concrete. The equation for this straight line is expressed in the following form:

$$S_M = S_m + b\,(\log M - \log m) \qquad (X1.1)$$

where:

S_M and S_m are strengths at values of the temperature-time factor equal to M and m, respectively.

Table X1.1—Temperature-Time Factor at Test Ages

Age, days	Age Increment, (Δt), h	Temperature T, °C	Temperature-Time Factor Increment, ($T - 0$) $X\,\Delta t$, °C·h	Cumulative Temperature-Time Factor, °C·h (°F·h)
1	24	21	504	504 (1675)
3	48	23	1104	1608 (5198)
7	96	23	2208	3816 (12244)
14	168	23	3868	7680 (24575)
28	336	23	7728	15408 (49237)

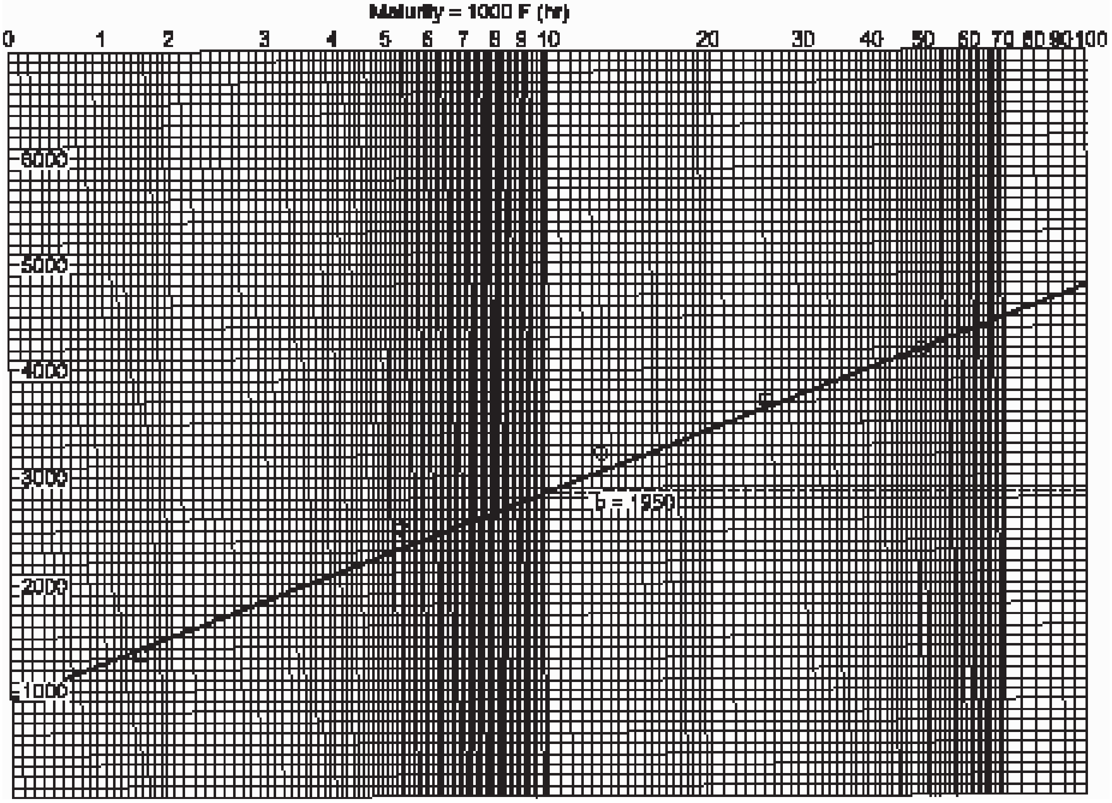


Figure X1.1—Strength Versus Maturity Relationship

X1.1.4. The value *b* is the slope of the prediction equation and the vertical distance, in units of stress, between the intersects of the line with the beginning and the end of the cycle on the *x*-axis (see Figure X1.1). For this particular example, *b* = 13.3 MPa (1930 psi), which represents the strength increase for a tenfold increase in the temperature-time factor.

X1.1.5. Any concrete produced from the same materials and proportions that were used to develop the prediction equation would have the same strength versus temperature-time factor relationship.

X1.2. *Projected Strength*:

X1.2.1. To use the prediction equation to project the strength of field concrete based upon early-age strength, sample and test the fresh concrete in accordance with T 23. Install a temperature recording device into a cylinder to monitor the concrete temperature. Continue for at least 24 hours.

X1.2.2. As soon as practical after the minimum 24-hour curing period, remove the specimens from the molds and prepare for testing in accordance with T 22. Record the age at the time of test. Use this age, together with the recorded temperature history, to determine the maturity index, *m*, at time of test. Report the early-age compressive strength, S_m, as the average of the cylinders tested. The prediction equation is then used to project the strength of the concrete represented by the test specimens.

X1.2.3. As an example:

X1.2.3.1. Compressive strength specimens fabricated in the field were cured for 24 hours under standard conditions at the job site. At the age of 24 hours, the specimens were removed from their molds, capped, and the caps were allowed to harden. The cylinders were tested at an age of 26 hours. The average strength at this age was 9.8 MPa (1420 psi).

X1.2.3.2. Columns 1 and 2 in Table X1.2 show the recorded temperature history obtained from the instrumented specimen. The sixth column shows the increment of temperature-time factor during each age interval. The last column shows the cumulative temperature-time factor. At an age of 26 hours, the cumulative temperature-time factor, *m*, is 616°C·h (1109°F·h).

X1.2.3.3. The temperature-time factor after 28 days of curing at the standard temperature of 23°C (73°F) is:

$$M = (23 - 0)^{\circ}\text{C} \times 28 \text{ days} \times 24 \text{ hours} = 15\,456^{\circ}\text{C·h } (27\,829^{\circ}\text{F·h}) \qquad (X1.2)$$

X1.2.3.4. The projected 28-day strength is calculated as:

$$S_M = S_m + b\,(\log M - \log m) \qquad S_M = 1427 + 1950\,(\log 50000 - \log 1950.5)$$

$$S_M = 1427 + 1950\,(4.699 - 3.290)$$

$$S_M = 1427 + 2747$$

$$S_M = 4174 \text{ psi}$$

Therefore, had the specimens been cured at 23°C (73°F) for the full 28 days, their expected average compressive strength would be 4174 psi, if tested at 28 days.

Table X1.2—Example Temperature Record and Calculations to Determine the Temperature-Time Factor at Test Age

(1) Age, h	(2) Temperature, °C	(3) Age Interval Δ*t*, h	(4) Average Temperature During Age Interval, °C	(5) Temperature, °C	(6) Temperature-Time Factor Increment, °C·h	(7) Cumulative Temperature-Time Factor, °C·h (°F·h)
0	21					
1	21	1	21.0	21.0	21.0	21 (38)
2	20	1	20.5	20.5	20.5	42 (75)
3	20	1	20.0	20.0	20.0	62 (111)
4	21	1	20.5	20.5	20.5	82 (148)
10	24	6	22.5	22.5	135.0	217 (391)
11	24	1	24.0	24.0	24.0	241 (434)
12	25	1	24.5	24.5	24.5	266 (478)
14	25	2	25.0	25.0	50.0	316 (568)
15	26	1	25.5	25.5	25.5	341 (614)
20	26	5	26.0	26.0	130.0	471 (848)
21	25	1	25.5	25.5	25.5	497 (894)
22	25	1	25.0	25.0	25.0	522 (939)
23	24	1	24.5	24.5	24.5	546 (983)
24	24	1	24.0	24.0	24.0	570 (1026)
25	23	1	23.5	23.5	23.5	594 (1068)
26 (test age)	22	1	22.5	22.5	22.5	616 (1109)

Standard Method of Test for

Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

AASHTO Designation: T 277-07
ASTM Designation: C 1202-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

AASHTO Designation: T 277-07
ASTM Designation: C 1202-05

1. SCOPE

1.1. This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test method is applicable to types of concrete where correlations have been established between this test procedure and long-term chloride ponding procedures such as those described in T 259. Examples of such correlations are discussed in References (1–5).[1]

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 259, Resistance of Concrete to Chloride Ion Penetration

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SUMMARY OF TEST METHOD

3.1. This test method consists of monitoring the amount of electrical current passing through 50-mm (2-in.) thick slices of 100-mm (4-in.) nominal diameter cores or cylinders during a 6-hour period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

4. SIGNIFICANCE AND USE

4.1. This test method covers the laboratory evaluation of the electrical conductance of concrete samples to provide a rapid indication of their resistance to chloride ion penetration. In most cases the electrical conductance results have shown good correlation with chloride ponding tests, such as T 259, on companion slabs cast from the same concrete mixtures (References 1–5).

4.2. This test method is suitable for evaluation of materials and material proportions for design purposes and research and development.

4.3. The numerical results (total charge passed, in coulombs) from this test method must be used with caution, especially in applications such as quality control and acceptance testing. The qualitative terms in the right-hand column of Table 1 should be used in most cases unless otherwise noted by the specifying agency.

Table 1—Chloride Ion Penetrability Based on Charge Passed

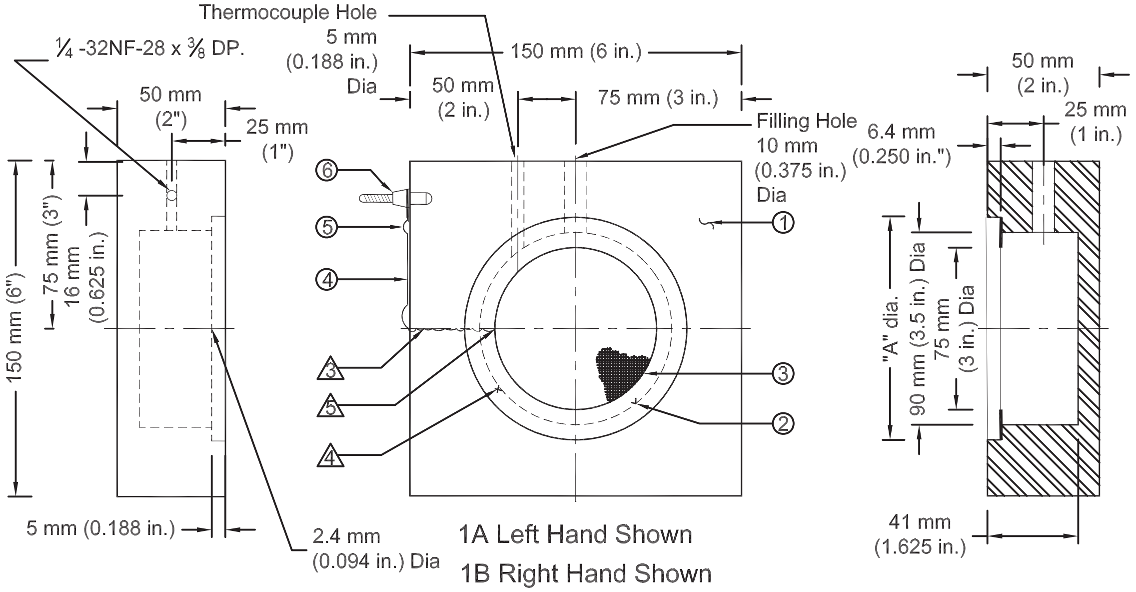
Charge Passed (Coulombs)	Chloride Ion Penetrability
>4000	High
>2000–4000	Moderate
>1000–2000	Low
100–1000	Very low
<100	Negligible

4.4. Care should be taken in interpreting results of this test when it is used on surface-treated concretes, for example, concretes treated with penetrating sealers. The results from this test on some such concretes indicate low resistance to chloride ion penetration, while 90-day chloride ponding tests on companion slabs show a higher resistance.

4.5. The details of the test method apply to 100-mm (4 in.) nominal diameter specimens. This includes specimens with actual diameters ranging from 95 mm (3.75 in.) to 100 mm (4 in.). Other specimen diameters may be tested with appropriate changes in the applied voltage cell design. (See Section 7.5 and Figure 1.)

4.5.1. For specimen diameters other than 95 mm (3.75 in.), the test result value for total charge passed must be adjusted following the procedure in Section 11.2. For specimens with diameters less than 95 mm (3.75 in.), particular care must be taken in coating and mounting the specimens to ensure that the conductive solutions are able to contact the entire end areas during the test.

4.6. Sample age may have significant effects on the test results, depending on the type of concrete and the curing procedure. Most concretes, if properly cured, become progressively and significantly less permeable with time.



△ Notes:
1. Diameter "A" should be 3.2 mm (0.125 in.) larger than outside diameter of specimen.
2. Not to scale
3. Seal Wire in hole with Silicone Rubber Caulk.
4. Screen soldered between Shims.
5. Solder Wire to Brass Shim.
6. Polymethylmethacrylate, e.g., Plexiglas

Equivalents

Item	Qty.	Nomenclature	Specification
1.A 1.B	1 1	Cell Block End	DMMA Sheet
2	4	Shim, Brass	0.5 mm (0.02 in.) THK
3	2	Screen, Brass	0.85 mm (No. 20) mesh. “A” diameter
4	2	Wire, Copper	14, Solid Nylclad
5	2	Terminal	12-10-$^{1}/_{4}$
6	2	Banana Plug	6.4 mm (0.25 in.) male insulated

Figure 1—Applied Voltage Cell (Construction Drawing)

5. INTERFERENCES

5.1. This test method can produce misleading results when calcium nitrite has been admixed into a concrete. The results from this test on some such concretes indicate higher coulomb values, that is, lower resistance to chloride ion penetration, than from tests on identical concrete mixtures (controls) without calcium nitrite. However, long-term chloride ponding tests indicate the concretes with calcium nitrite were at least as resistant to chloride ion penetration as the control mixtures.

Note 1—Other admixtures might affect results of this test similarly. Long-term ponding tests are recommended if an admixture effect is suspected.

5.2. Because the test results are a function of the electrical resistance of the specimen, the presence of reinforcing steel or other embedded electrically conductive materials may have a significant effect. The test is not valid for specimens containing reinforcing steel positioned longitudinally; that is, providing a continuous electrical path between the two ends of the specimen.

6. APPARATUS

6.1. *Vacuum Saturation Apparatus*: (See Figure 2 for example.)

Figure 2—Vacuum Saturation Apparatus

6.1.1. *Separatory Funnel*—or other sealable, bottom-draining container with a minimum capacity of 500 mL.

6.1.2. *Beaker* (1000 mL or larger) or other container—Capable of holding concrete specimen(s) and water and of fitting into vacuum desiccator. (See Section 6.1.3.)

6.1.3. *Vacuum Desiccator*—250-mm (9.8-in.) inside diameter or larger. Desiccator must allow two hose connections, through rubber stopper and sleeve or through rubber stopper only. Each connection must be equipped with a stopcock.

6.1.4. *Vacuum Pump*—Capable of maintaining a pressure of less than 6650 Pa (50 mm Hg) in a desiccator.

Note 2—Because the vacuum will be drawn over water, the pump should be protected with a water trap or pump oil should be changed after each operation.

6.1.5. *Vacuum Gauge or Manometer*—Accurate to ±665 Pa (±5 mm Hg) over range 0 to 13300 Pa (0 to 100 mm Hg) pressure.

6.2. *Coating Apparatus and Materials*:

6.2.1. *Coating*—Rapid setting, electrically nonconductive, capable of sealing side surface of concrete cores.

6.2.2. *Balance or Scale, Paper Cups, Wooden Spatulas, and Disposable Brushes*—For mixing and applying coating.

6.3. *Specimen-Sizing Equipment* (not required if samples are cast to final specimen size).

6.3.1. *Movable Bed Water-Cooled Diamond Saw or Silicon Carbide Saw*.

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7. REAGENTS, MATERIALS, AND TEST CELL

7.1. *Specimen-Cell Sealant*—Capable of sealing concrete to polymethylmethacrylate, for example, Plexiglas, against water and dilute sodium hydroxide and sodium chloride solutions at temperatures up to 90ºC (200ºF); examples include RTV silicone rubbers, silicone rubber caulkings, other synthetic rubber sealants, silicone greases, and rubber gaskets.

7.2. *Sodium Chloride Solution*—3.0 percent by mass (reagent grade) in distilled water.

7.3. *Sodium Hydroxide Solution*—0.3 Normal (reagent grade) in distilled water.

7.3.1. **Warning**—Before using NaOH, review: (1) the safety precautions for using NaOH; (2) first aid for burns; and (3) the emergency response to spills, as described in the manufacturer's Material Safety Data Sheet or other reliable safety literature. NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pin holes.

7.4. *Filter Papers*—90 mm (No. 2) diameter (not required if rubber gasket is used for sealant (Section 7.1) or if sealant can be applied without overflowing from shim onto mesh).

7.5. *Applied Voltage Cell (Figures 1 and 3)*—Two symmetric polymethylmethacrylate chambers, each containing electrically conductive mesh and external connectors. One design in common use is shown in Figures 1 and 3. However, other designs are acceptable, provided that overall dimensions (including dimensions of the fluid reservoir) are the same as shown in Figure 1 and width of the screen and shims are as shown.

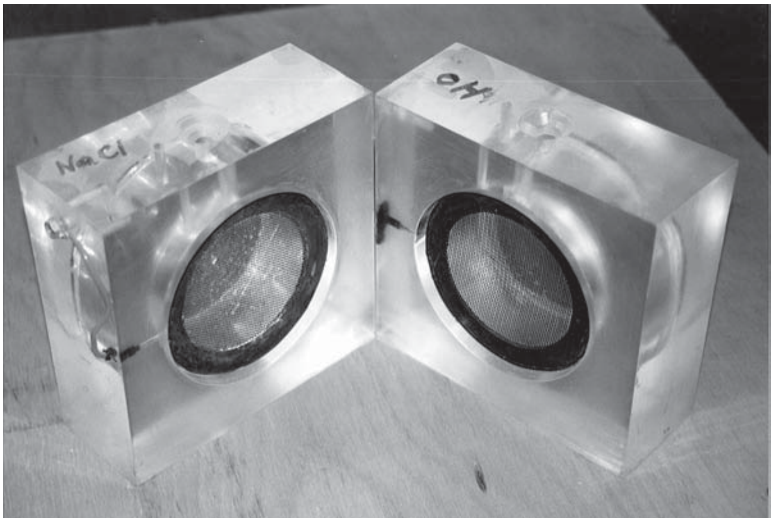

Figure 3—Applied Voltage Cell-Face View

7.6. *Temperature Measuring Device (optional)*—0 to 120ºC (30 to 250ºF) range.

7.7. *Voltage Application and Data Readout Apparatus*—Capable of holding 60 ± 0.1 V dc across applied voltage cell over entire range of currents and of displaying voltage accurate to ±0.1 V and current to ±1 mA. Apparatus listed in Sections 7.7.1 through 7.7.5 is a possible system meeting this requirement.

7.7.1. *Voltmeter*—Digital (DVM), 3 digit, minimum 0-99.9 V range, rated accuracy ±0.1 percent.

7.7.2. *Voltmeter*—Digital (DVM), $4^1/_2$ digit, 0-200 mV range, rated accuracy ±0.1 percent.

7.7.3. *Shunt Resistor*—100 mV, 10A rating, tolerance ±0.1 percent. Alternatively, a 0.01 Ω resistor, tolerance ±0.1 percent, may be used, but care must be taken to establish very low resistance connections.

7.7.4. *Constant Voltage Power Supply*—0-80 V dc, 0-2 A, capable of holding voltage constant at 60 ± 0.1 V over entire range of currents.

7.7.5. *Cable*—Two conductor, 1.6 mm (No. 14), insulated, 600 V.

8. TEST SPECIMENS

8.1. Sample preparation and selection depends on the purpose of the test. For evaluation of materials or their proportions, samples may be (a) cores from test slabs or from large diameter cylinders or (b) 100-mm (4-in.) diameter cast cylinders. For evaluation of structures, samples may be (a) cores from the structure or (b) 100-mm (4-in.) diameter cylinders cast and cured at the field site. Coring shall be done with a drilling rig equipped with a 100-mm (4-in.) diameter diamond-dressed core bit. Select and core samples following procedures in T 24M/T 24. Cylinders cast in the laboratory shall be prepared following procedures in R 39. Unless specified otherwise, moist cure test specimens for 56 days prior to the start of specimen preparation (Note 3). When cylinders are cast in the field to evaluate a structure, care must be taken that the cylinders receive the same treatment as the structure, for example, similar degree of consolidation, curing, and temperature history during curing.

Note 3—This test method has been used with various test durations and curing regimens to meet agency guidelines or specifications. Care should be exercised when comparing results obtained from specimens subjected to differing conditions.

Note 4—The maximum allowable aggregate size has not been established for this test. Users have indicated that test repeatability is satisfactory on specimens from the same concrete batch for aggregates up to 25.0-mm (1-in.) nominal maximum size.

8.2. Transport the cores or field-cured cylinders to the laboratory in sealed (tied) plastic bags. If specimens must be shipped, they should be packed to be properly protected from freezing and damage in transit or storage.

8.3. Using the water-cooled diamond saw or silicon carbide saw, cut a 50 ± 3 mm (2 ± 0.125 in.) slice from the top of the core or cylinder, with the cut parallel to the top of the core. This slice will be the test specimen. Use a belt sander to remove any burrs on the end of the specimen.

8.4. Special processing is necessary for core samples where the surface has been modified, for example, by texturing or by applying curing compounds, sealers, or other surface treatments, and where the intent of the test is not to include the effect of the modifications. In those cases, the modified portion of the core shall be removed and the subsequent 50 ± 3 mm (2 ± 0.125 in.) slice shall be used for the test.

9. CONDITIONING

9.1. Vigorously boil a liter or more of tap water in a large sealable container. Remove container from heat, cap tightly, and allow water to cool to ambient temperature.

9.2. Allow specimen prepared in Section 8 to surface dry in air for at least 1 hour. Prepare approximately 10 g (0.5 oz) of rapid setting coating and brush onto the side surface of specimen. Place the sample on a suitable support while coating to ensure complete coating of sides. Allow coating to cure according to the manufacturer's instructions.

9.3. The coating should be allowed to cure until it is no longer sticky to the touch. Fill any apparent holes in the coating and allow additional curing time, as necessary. Place specimen in beaker or other container (Section 6.1.2), then place container in vacuum desiccator. Alternatively, place specimen directly in vacuum desiccator. Both end faces of specimen must be exposed. Seal desiccator and start vacuum pump. Pressure should decrease to less than 6650 Pa (50 mm Hg) within a few minutes. Maintain vacuum for 3 hours.

9.4. Fill separatory funnel or other container (Section 6.1.1) with the de-aerated water prepared in Section 9.1. With vacuum pump still running, open water stopcock and drain sufficient water into beaker or container to cover specimen. (Do not allow air to enter desiccator through this stopcock.)

9.5. Close water stopcock and allow vacuum pump to run for 1 additional hour.

9.6. Close vacuum line stopcock, then turn off pump. (Change pump oil if a water trap is not being used.) Turn vacuum line stopcock to allow air to re-enter desiccator.

9.7. Soak specimen under water (the water used in Sections 9.4 through 9.6) in the beaker for 18 ± 2 hours.

10. PROCEDURE

10.1. Remove specimen from water, blot off excess water, and transfer specimen to a sealed can or other container, which will maintain the specimen in 95 percent or higher relative humidity.

10.2. Specimen mounting (all sealants other than rubber gaskets: use Section 10.2.2 or Section 10.2.3, as appropriate):

10.2.1. If using two-part specimen-cell sealant, prepare approximately 20 to 40 g (0.7 to 1.4 oz).

10.2.2. *Low-Viscosity, Specimen-Cell Sealant*—If filter paper is necessary, center filter paper over one screen of the applied voltage cell. Trowel sealant over brass shims adjacent to applied voltage cell body. Carefully remove filter paper. Press specimen onto screen; remove or smooth excess sealant that has flowed out of specimen-cell boundary.

10.2.3. *High-Viscosity, Specimen-Cell Sealant*—Set specimen onto screen. Apply sealant around specimen-cell boundary.

10.2.4. Cover exposed face of specimen with an impermeable material such as rubber or plastic sheeting. Place rubber stopper in cell filling hole to restrict moisture movement. Allow sealant to cure per manufacturer's instructions.

10.2.5. Repeat steps in Sections 10.2.2 (or 10.2.3) and 10.2.4 on second half of cell. (Specimen in applied voltage cell now appears as shown in Figure 4.)

10.3. *Specimen Mounting (Rubber Gasket Alternative)*—Place a 100-mm (4-in.) outside diameter by 75-mm (3-in.) inside diameter by 6-mm (0.25-in.) circular vulcanized rubber gasket in each half of the test cell. Insert sample and clamp the two halves of the test cell together to seal.

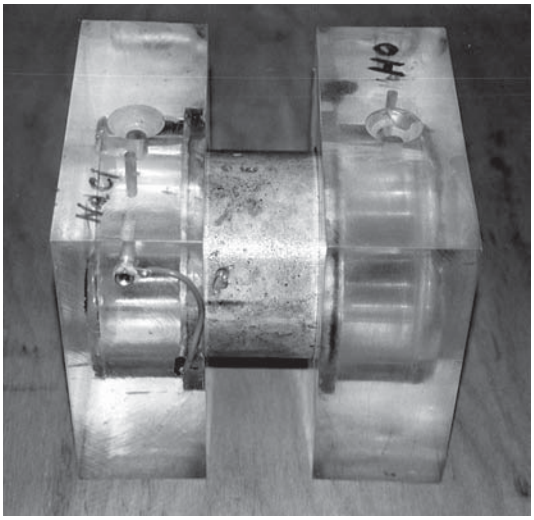

Figure 4—Specimen Ready for Test

10.4. Fill the side of the cell containing the top surface of the specimen with 3.0 percent NaCl solution. (That side of the cell will be connected to the negative terminal of the power supply in Section 10.5.) Fill the other side of the cell (which will be connected to the positive terminal of the power supply) with 0.3 Normal NaOH solution.

10.5. Attach lead wires to cell banana posts. Make electrical connections to voltage application and data readout apparatus as appropriate: for example, for systems listed in Sections 7.7.1 through 7.7.5, connect as shown in Figure 5. Turn power supply on, set to 60.0 ± 0.1 V, and record initial current reading. Temperatures of the specimen, applied voltage cell, and solutions shall be 20 to 25ºC (68 to 77ºF) at the time the test is initiated, that is, when the power supply is turned on.

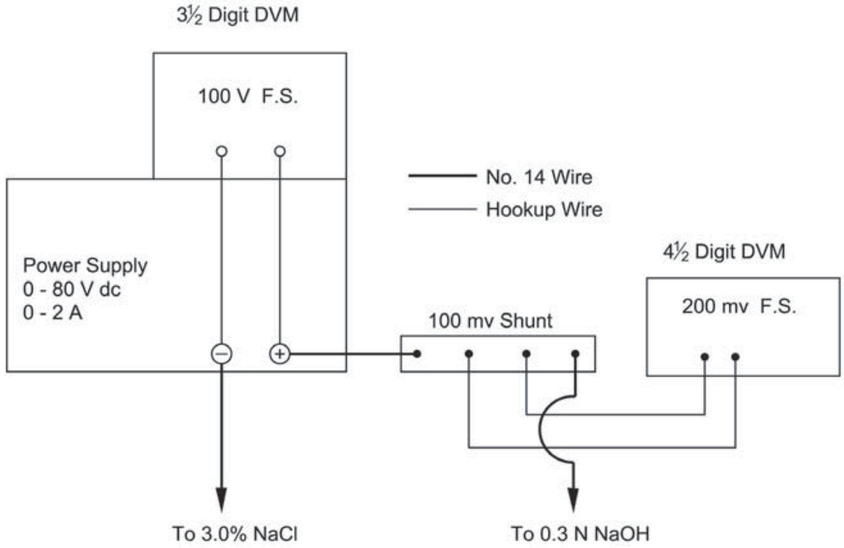

Figure 5—Electrical Block Diagram (example)

10.6. During the test, the air temperature around the specimens shall be maintained in the range of 20 to 25ºC (68 to 77ºF).

10.7. Read and record current at least every 30 minutes. If a voltmeter is being used in combination with a shunt resistor for the current reading (Figure 5), use appropriate scale factors to convert voltage reading to amperes. Each half of the test cell must remain filled with the appropriate solution for the entire period of the test.

Note 5—During the test, the temperature of the solutions should not be allowed to exceed 90ºC (190ºF) in order to avoid damage to the cell and to avoid boiling off the solutions. Although it is not a requirement of the method, the temperature of the solutions can be monitored with thermocouples installed through the 3-mm (0.125-in.) venthole in the top of the cell. High temperatures occur only for highly penetrable concretes. If a test of a 50-mm (2-in.) thick specimen is terminated because of high temperatures, this should be noted in the report, along with the time of termination, and the concrete rated as having very high chloride ion penetrability. (See Section 12.1.9.)

10.8. Terminate test after 6 hours, except as discussed in Note 5.

10.9. Remove specimen. Rinse cell thoroughly in tap water; strip out and discard residual sealant.

11. CALCULATION AND INTERPRETATION OF RESULTS

11.1. Plot current (in amperes) versus time (in seconds). Draw a smooth curve through the data, and integrate the area underneath the curve in order to obtain the ampere-seconds, or coulombs, of charge passed during the 6-hour test period. (See Note 6.) Alternatively, use automatic data processing equipment to perform the integration during or after the test and to display the coulomb value. The total charge passed is a measure of the electrical conductance of the concrete during the period of the test.

Note 6—*Sample Calculation*—If the current is recorded at 30-minute intervals, the following formula, based on the trapezoidal rule, can be used with an electronic calculator to perform the integration:

$$Q = 900\left(I_0 + 2I_{30} + 2I_{60} \cdots + 2I_{300} + 2I_{330} + I_{360}\right) \tag{1}$$

where:

Q = charge passed (coulombs),

I_0 = current (amperes) immediately after voltage is applied, and

I_t = current (amperes) at t min after voltage is applied.

11.2. If the specimen diameter is other than 95 mm (3.75 in.), the value for total charge passed established in Section 11.1 must be adjusted. The adjustment is made by multiplying the value established in Section 11.1 by the ratio of the cross-sectional areas of the standard and the actual specimens. That is:

$$Q_s = Q_x \times \left(\frac{3.75}{x}\right)^2 \tag{2}$$

where:

Q_s = charge passed (coulombs) through a 95-mm (3.75-in.) diameter specimen,

Q_x = charge passed (coulombs) through x mm (in.) diameter specimen, and

x = diameter mm (in.) of the nonstandard specimen.

11.3. Use Table 1 to evaluate the test results. These values were developed from data on slices of cores taken from laboratory slabs prepared from various types of concretes.

11.3.1. Factors that are known to affect chloride ion penetration include: water-cement ratio, the presence of polymeric admixtures, sample age, air-void system, aggregate type, degree of consolidation, and type of curing.

12. REPORT

12.1. *Report the following, if known*:

12.1.1. Source of core or cylinder, in terms of the particular location the core or cylinder represents.

12.1.2. Identification number of core or cylinder and specimen.

12.1.3. Location of specimen within core or cylinder.

12.1.4. Type of concrete, including binder type, water–cement ratio, and other relevant data supplied with samples.

12.1.5. Description of specimen, including presence and location of reinforcing steel, presence and thickness of overlay, and presence and thickness of surface treatment.

12.1.6. Curing history of specimen.

12.1.7. Unusual specimen preparation, for example, removal of surface treatment.

12.1.8. Test results, reported as the total charge passed over the test period (adjusted per Section 11.2), and

12.1.9. The qualitative chloride ion penetrability equivalent to the calculated charge passed (from Table 1).

13. PRECISION AND BIAS[2]

13.1. *Precision*:

13.1.1. *Single-Operator Precision*—The single operator coefficient of variation of a single test result has been found to be 12.3 percent (Note 7). Therefore, the results of two properly conducted tests by the same operator on concrete samples from the same batch and of the same diameter should not differ by more than 42 percent (Note 7).

13.1.2. *Multilaboratory Precision*—The multilaboratory coefficient of variation of a single test result has been found to be 18.0 percent (Note 7). Therefore results of two properly conducted tests in different laboratories on the same material should not differ by more than 51 percent (Note 7). The average of three test results in two different laboratories should not differ by more than 42 percent (Note 8).

Note 7—These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670. The precision statements are based on the variations in tests on three different concretes, each tested in triplicate in 11 laboratories. All specimens had the same actual diameters, but lengths varied within the range 50 ± 3 mm (2 ± 0.125 in.).

Note 8—Although the test method does not require the reporting of more than one test result, testing of replicate specimens is usually desirable. The precision statement for the averages of three results is given because laboratories frequently will run this number of specimens. When averages of three results are established in each laboratory, the multilaboratory coefficient of variation S_{ML} is calculated as:

$$S_{ML} = \text{Square Root of } (S^2_{WL}/3) + S^2_{BL} \qquad (3)$$

where:

S^2_{WL} = within-laboratory variance and

S^2_{BL} = between-laboratory variance

The percentage cited represents the (d2s%) limit based on the value for the multilaboratory coefficient of variation.

13.2. *Bias*—The procedure of this test method for measuring the resistance of concrete to chloride ion penetration has no bias because the value of this resistance can be defined only in terms of a test method.

14. KEYWORDS

14.1. Chloride content; corrosion; deicing chemicals; resistance-chloride penetration.

15. REFERENCES

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15.5. Ozyildirim, C., and W. J. Halstead. Use of Admixtures to Attain Low Permeability Concretes. *Final Report No. FHWA/VA-88-R11*. Virginia Transportation Research Council, NTIS No. PB 88201264, February 1988.

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[1] The numbers in parentheses refer to the list of references at the end of this standard.

[2] Supporting data have been filed at ASTM headquarters (100 Barr Harbor Drive, West Conshohocken, PA 19428-2959) and may be obtained by requesting RR: C-9-1004.

Standard Method of Test for

Bend Test for Bars for Concrete Reinforcement

AASHTO Designation: T 285-89 (2005)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Bend Test for Bars for Concrete Reinforcement

AASHTO Designation: T 285-89 (2005)

1. SCOPE

1.1 This method covers a bend test for evaluating the ductility of bars used for concrete reinforcement.

1.2 The units of measure to be used shall be either SI units or inch-pound units (shown in parentheses in this standard) depending on the units used in the applicable material specification.

1.3 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 31M/M 31, Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
- M 322M/M 322, Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

3. SUMMARY OF THE METHOD

3.1 The test is made by bending test specimens around pins of appropriate diameters until the specified angle of bend has been achieved. Test specimens are expected to withstand bending without cracking. The speed of bending is ordinarily not an important factor. The severity of the test is primarily a function of the angle of bend and inside diameter to which the specimen is bent, and of the cross section of the specimen.

4. APPARATUS

4.1 The bend test apparatus shall provide for:

4.1.1 Continuous and uniform application of force throughout the duration of the bending operation (Note 1).

4.1.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate, or bending about a central pin on a simple span with end supports free to rotate. The end support must be strong enough and sufficiently rigid to resist significant deformation.

4.1.3 Close wrapping of the specimen around the pin during the bending operation.

4.2 The diameter of the pin around which bending occurs shall not differ from the nominal value by more than ±2 percent or 3 mm (0.1 in.), whichever is greater. The pin shall be made of steel, and the surface in contact with the bar shall be uniformly curved around the axis of the pin, free of dents and flat spots.

4.2.1 The nominal diameter of pins shall be as specified in M 31M/M 31, M 322M/M 322, or other specification, as appropriate, based on the nominal diameter of bar.

Note 1—Application of force by hand usually does not satisfy this requirement of the method.

Note 2—Bars of size numbers 45 and 55 (14 and 18) are normally specified for use without bending. Consequently, some laboratories are not equipped to conduct bend tests of such bars.

5. SAMPLING

5.1 Sampling shall be performed in accordance with the requirements of relevant specifications.

5.2 Specimens shall be the full section of the bar as rolled and the length shall be sufficient to permit free bending to the angle specified.

6. CONDITIONING

6.1 The temperature of the room in which tests are performed shall be maintained above 15ºC (60ºF) at all times. Specimens that have been exposed to temperatures of less than 15ºC (60ºF) in the preceding 24 hours shall be brought to test temperature by storage in the laboratory air for at least 24 hours prior to test, or by immersion in water maintained at a temperature of 15 to 32ºC (60 to 90ºF) for at least 1 hour prior to test.

7. PROCEDURE

7.1 Place the specimen in the bend test apparatus in such position that the plane intersecting the longitudinal ribs is parallel to the axis of the pin.

7.2 Apply force to the test specimen continuously and uniformly throughout the bending operation.

7.3 Discontinue the application of force when the angle of bend specified in the material specification has been achieved before rebound.

7.4 Examine the tension surface of the specimen for cracking.

8. REPORT

8.1 *The report shall include the following*:

8.1.1 Specimen identification;

8.1.2 Steel specification designation, grade, and bar size of specimen;

8.1.3 Pin diameter and angle of bend; and

8.1.4 Whether specimen passed or failed to meet requirements.

9. PRECISION

9.1 A precision statement is not made for this method because the test result is a non-numerical report of success or failure.

Standard Method of Test for

Rapid Identification of Alkali-Silica Reaction Products in Concrete

AASHTO Designation: T 299-93 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Rapid Identification of Alkali-Silica Reaction Products in Concrete

AASHTO Designation: T 299-93 (2009)

1. SCOPE

1.1. This test covers the rapid visual detection of the products of alkali-silica reaction (ASR) in portland cement concrete.

1.2. The values stated in SI units are to be regarded as standard.

1.3. *This test involves hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns with its use. It is the responsibility of the user of this test to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 198, Splitting Tensile Strength of Cylindrical Concrete Specimens

3. SIGNIFICANCE AND USE

3.1. This test covers the identification of alkali-silica reaction products in concrete samples by means of visual observation. Test results have shown that the products formed by the reaction of alkalis and a wide variety of reactive aggregates can be identified by this method. The amount and location of the products are indicators of the development of alkali-silica reaction in the concrete sample tested. This test is not meant to be used to detect the products of alkali-carbonate reaction in concrete.

3.2. This test is intended to be used as one in a series of tests to diagnose alakali-silica reaction in a concrete structure. The results of this test will help to confirm or deny the presence of alakali-silica reaction products in the concrete structure under investigation.

3.3. Sodium present in concrete can react with the reagent in this test to form a product that fluoresces with a greenish-yellow color and that can interfere with the interpretation of the results. However, sodium is dispersed rather uniformly in the hydrated cement matrix in concrete whereas the alkali-silica reaction products are formed particularly in and around the aggregate particles. Interference by sodium from the de-icing salts or seawater can be minimized by rinsing the test surface.

3.4. Care should be taken in interpreting the results of this test when it is used on concrete surfaces subjected to wearing, erosion, and abrasion, because these processes may remove reaction products and, therefore, the absence of reaction products may not be indicative of the development of the reaction in the interior of the concrete. Care should also be taken in interpreting the results for concrete showing carbonation or containing fly ash or silica fume. Both fly ash and silica fume can react with alkalies in concrete to produce reaction products similar to those produced by ASR. The extremely fine nature and dispersion of fly ash and silica fume, however, result in a product that is well dispersed. The fluorescence of such products is generally faint and uniform, but may be influenced by the dispersion of fly ash and silica fume.

4. APPARATUS, REAGENTS, AND MATERIALS

4.1. *Specimen Conditioning Apparatus*:

4.1.1. Plastic beaker—500-mL capacity.

4.1.2. Plastic squeeze bottle (for water)—250-mL capacity.

4.1.3. Disposable polyethylene gloves.

4.1.4. Protective clothing (lab coat).

4.1.5. Absorbent paper towels.

4.1.6. Enclosed space for spraying reagent application.

Note 1—A fume hood, glove box, or disposable glove bags have been found to be suitable for this purpose.

4.2. *Specimen Treatment Apparatus*:

4.2.1. Medicine dropper for applying reagent.

4.2.2. Sprayer for water—A small, hand-held sprayer for spraying tap water.

4.3. *Reagent (Uranyl Acetate Solution)*:

4.3.1. Acetic acid solution (1N).

4.3.2. Glass boiling flask—250-mL capacity.

4.3.3. Two polyethylene storage bottles with tight-fitting cap—100-mL capacity.

4.3.4. Polyethylene volumetric flask—100-mL capacity.

4.3.5. Uranyl acetate powder (ACS reagent grade).

4.3.6. The balance shall have sufficient capacity and conform to M 231, Class G 1.

4.3.7. Uranyl acetate solution prepared as follows: Weigh out 5 g of powdered uranyl acetate. Measure 100 mL of acetic acid solution using the 100-mL volumetric flask. (**Caution**—Use proper lab safety precautions in handling the uranyl acetate and the acetic acid.) Transfer the measured acetic acid solution from the volumetric flask to the boiling flask. Add the 5 g of powdered uranyl acetate to the boiling flask. Warm the mixture over a low flame until the powder is dissolved. Do not bring the mixture to a boil. Remove the flask from the burner, cover, and let it cool to room temperature. Store the cooled solution at room temperature in the polyethylene storage bottle with tight-fitting cap. The reagent, when stored as described, will keep for at least one year.

4.4. *Shortwave (254 nm) Ultraviolet (UV) Lamp*—with peak intensity of at least 1200 $\mu W/cm^2$ at 15 cm (6 in.).

4.5. *Viewing Cabinet or a Dark Room*—The viewing cabinet can be a box, approximately 38 cm by 30 cm by 30 cm (15 in. by 12 in. by 12 in.) in size, made of steel, wood, or cardboard with an opening at the top for placing the UV lamp.

4.6. *Goggles* that shield shortwave ultraviolet light.

Note 2—Because of the toxic, carcinogenic, and radioactive nature of uranyl acetate, special caution should be taken in both preparation and application of the reagent. The use of the reagents should be kept to a minimum.

5. SPECIMENS

5.1. Obtain representative samples from the structure to be evaluated in the form of cores or slabs. The number of samples and the location of samples should be specified by the engineer responsible for the service evaluation of the structure. At any given location, however, samples shall be of such a size and shape that exposed interior surfaces for testing of at least 155 cm^2 (24 $in.^2$) can be obtained from the samples. The total area of 155 cm^2 (24 $in.^2$) can be obtained from more than one sample at the given location, if necessary.

5.2. Maintain the field moisture content of the test specimen. Place the samples in plastic bags for transport to the testing location.

5.3. Break or split the specimens to expose interior-fractured surfaces of the concrete. If the specimens are in the form of cores, use the splitting tensile arrangement described in T 198 to expose interior surfaces of the specimens. Conduct the test immediately on exposure of interior surfaces.

Note 3—The interpretation of the results of the test is simplified if the test is conducted immediately.

6. PROCEDURE

6.1. *Conditioning*:

6.1.1. Dampen specimen with a light spray of tap water. Proceed with the conduct of the test while the specimen is still wet.

6.1.2. Prescreening for natural fluorescence.

6.1.3. Wear protective clothing including polyethylene gloves, lab coat, and UV-filtering goggles.

Note 4—Shortwave ultraviolet light can be harmful to the eye. Normal eyeglasses or plastic goggles or face shield will absorb the harmful rays.

6.1.4. If a viewing cabinet is being used, place the ultraviolet lamp in the opening on the top to allow the light to shine directly on the specimen. Place the damp specimen inside the viewing cabinet. If a darkened room is being used, place the damp specimen on the table and turn off the lights in the room.

6.1.5. Turn on the shortwave ultraviolet light in the viewing cabinet or the darkened room and shine it on the damp specimen. Use UV-filtering goggles and observe and note for future comparison whether any of the aggregates fluoresce. *Note the location and nature of any fluorescence.*

Note 5—Nonfluorescent aggregates will appear dark while cement paste and naturally fluorescent aggregates such as opal and some slags will fluoresce mildly.

6.2. *Observation*:

6.2.1. Wear protective clothing, including polyethylene gloves, lab coat, and UV-filtering goggles.

6.2.2. Conduct the test only on interior fractured surfaces of concrete specimens. If the interior surface of the specimen is not damp, dampen it using the water sprayer filled with tap water.

6.2.3. Line the bottom of the glove box, glove bag, or fume hood with absorbent paper towels. Place the squeeze bottle, medicine dropper, 500-mL plastic beaker, and the dampened specimen inside the glove box, glove bag, or fume hood.

6.2.4. Place the specimen on a paper towel. Apply the uranyl acetate solution to the wet interior surface of the specimen with a medicine dropper. Do not apply uranyl acetate on any other surface except the interior surface of the concrete specimen. Attempt to apply a minimal amount of reagent in a controllable fashion to avoid excess.

6.2.5. Allow the uranyl acetate to absorb on the interior surface of the concrete for 60 seconds.

6.2.6. After 60 seconds, hold the specimen in a vertical position over the 500-mL plastic beaker and wash the interior surface with water three times to remove excess uranyl acetate. Use the squeeze bottle filled with water for washing. Collect the wash water from the specimen in the plastic beaker.

6.2.7. Remove the specimen from the glove box, glove bag, or fume hood and place it on a paper towel. Proceed with observation of the specimen immediately after the uranyl acetate treatment is completed.

6.2.8. If a viewing cabinet is being used, place the ultraviolet lamp in the opening on the top to allow the light to shine directly on the specimen. Line the bottom surface of the viewing cabinet with paper towels. If a dark room is being used, line an area of a table top with paper towels.

6.2.9. Dampen the specimen with tap water again using the water sprayer. Place the specimen inside the viewing cabinet on the paper towel. If a dark room is being used, place the wet specimen on the paper towel on the table top in the dark room and turn off the lights in the room.

6.2.10. Turn on the ultraviolet lamp and shine the light on the treated specimen. The specimen surface will fluoresce with a bright greenish-yellow color.

6.2.11. The presence of bright fluorescing areas in and around aggregates indicates the presence of alkali-silica reaction products in the sample. If the fluorescence is present around the coarse aggregates, count the number of aggregates with fluorescence associated with them. Also count the total number of exposed coarse aggregate particles in the test sample. This procedure is not practical if the fluorescence is associated with the fine aggregates.

Note 6—It may be helpful for comparison and confirmation purposes to develop a set of reference samples (and photos), both with and without alkali-silica reaction, for use when performing the test.

6.2.12. Note the presence of reaction products in voids and cracks, and in and around the aggregate.

Note 7—The presence of reaction product in cracks can be indicative of an advanced state of deterioration due to alkali-silica reaction.

Note 8—Sodium in concrete reacts with uranyl acetate to form a product, which fluoresces with greenish-yellow color. However, sodium is dispersed in the cement paste matrix in the concrete and only increases the generally uniform background fluorescence intensity. Evidence of alkali-silica reaction product should be searched in and around the aggregate particles where a distinct greenish-yellow fluorescence should be observed.

Note 9—Carbonated areas of concrete may also fluoresce in the test. The fluorescence due to carbonation products, however, is uniform and is normally only present at the edges of the test specimen. If the test is conducted on a freshly broken interior surface, as prescribed, the interference due to carbonation products is minimized in the interior of the specimen.

Note 10—Fly ash and silica fume can react with alkalis in cement and form reaction products, which fluoresce in the test. Well dispersed fly ash and silica fume, however, cause only an increase in the generally uniform background fluorescence intensity in the paste. If the fly ash and silica fume are not well dispersed or are clumped together, fluorescence will be observed as discrete “points” randomly distributed over the specimen. The size of these “points” is normally very small and can be distinguished from the bright fluorescence of alkali-silica reaction products derived from the coarse and fine aggregates.

7. REPORT

7.1. *The report shall include the following*:

7.1.1. Identification number of the specimen, its source (in terms of the structure, and the particular location in the structure from where it was obtained), its complete description (including presence and location of reinforcing steel, presence and thickness of overlay, and presence of visible cracks and other deterioration), any other relevant data provided (such as the age of concrete, composition, mix proportion, etc.), and the method used to break the specimen to obtain interior surfaces and the approximate area of interior surfaces tested.

7.1.2. Any variation in the test method from that given in this procedure.

7.1.3. Any occurrence of natural fluorescence before treatment with the reagent, and test results reported as the presence or absence of fluorescing reaction products in the test specimen. If fluorescing reaction products are present, detail the presence or absence of reaction products in cracks and voids in the concrete. If the products are associated with coarse aggregate, indicate the total number of coarse aggregate particles in the test surface and the number of particles with fluorescing reaction products. This is done for qualitative purposes only and it does not reflect a quantitative analysis. Also note the presence or absence of fluorescence that may be associated with carbonation products at the edges of the test specimen.

8. PRECISION AND BIAS

8.1. No statement is made about either precision or bias of this test method since the results merely indicate the presence or absence of alkali-silica reaction product in concrete.

9. KEYWORDS

9.1. Alkali-silica reaction; concrete.

Standard Method of Test for

Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

AASHTO Designation: T 303-00 (2008)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

AASHTO Designation: T 303-00 (2008)[1]

1. SCOPE

1.1. This test method allows detection within 16 days of the potential for deleterious expansion of mortar bars due to the alkali-silica reaction.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* A specific precautionary statement is given in Note 3.

1.3. The values stated in SI units are to be regarded as standard. The values in inch–pound units are shown in parentheses, and are for informational purposes only.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- D 1193, Standard Specification for Reagent Water

3. SIGNIFICANCE AND USE

3.1. This test method provides a means of detecting the potential of an aggregate used in concrete for undergoing alkali-silica reaction and resulting in potentially deleterious internal expansion. It is based on the NBRI accelerated test method (Davis and Obserholster, 1987a; Davis and Obserholster, 1987b; Hooton and Rogers, 1989; and Obserholster and Davis, 1986).

3.2. When expansions greater than 0.10 percent are developed within 16 days from casting, it is recommended that supplementary information be developed to confirm that the expansion is actually due to alkali reactivity. Sources of such supplementary information include: (1) petrographic examination of the aggregate by ASTM C 295 to determine if known reactive constituents are present; and (2) examination of the specimens after tests by ASTM C 856 to identify the products of alkali reactivity.

3.3. When it has been concluded from the results of tests performed using this test method and supplementary information that a given aggregate should be considered potentially deleteriously reactive, additional studies, using alternative methods, may be appropriate to develop further information on the potential reactivity.

4. APPARATUS

4.1. The apparatus shall conform to M 210, except as follows:

4.2. *Sieve*—Square hole, woven-wire, cloth sieves, shall conform to the requirements of M 92.

4.3. *Mixer, Paddle, and Mixing Bowl*—Mixer, paddle, and mixing bowl shall conform to the requirements of T 162, except that the clearance between the lower end of the paddle and the bottom of the bowl shall be 5.1 ± 0.3 mm (0.20 ± 0.01 in.).

4.4. *Tamper and Trowel*—The tamper and trowel shall conform to T 106.

4.5. *Containers*—The containers shall permit the test specimens to be totally immersed in either water or 1.0 normal NaOH solution. The containers shall be made of material that can withstand prolonged exposure to 80ºC (176ºF) and shall be inert to a 1.0 normal NaOH solution. The containers shall be equipped with tight-fitting covers, seals, or both. The containers shall be constructed in a manner that permits test specimens to be supported, without using the gauge studs, so that the solution has access to the whole test specimen, and the specimens do not touch the sides of the container or each other.

Note 1—The NaOH solution will corrode glass or metal containers. Polypropylene containers are recommended.

4.6. *Oven*—A thermostatically controlled oven capable of maintaining a temperature of 80.0 ± 1.7ºC (176 ± 3ºF) or a thermostatically controlled water bath capable of maintaining the same temperature range.

4.7. *Moist Room or Closet*—The moist closet or room shall conform to M 201.

5. REAGENTS

5.1. *Sodium Hydroxide (NaOH)*—USP or technical grade may be used, provided the Na^+ and OH^- concentrations are shown by chemical analysis to lie between 0.99 and 1.01 normal.

5.2. *Purity of Water*—Unless otherwise indicated, water shall be reagent Type IV water conforming to ASTM D 1193.

5.3. *Sodium Hydroxide Solution*—Each liter of solution shall contain 40 g of NaOH dissolved in 900 mL of water, and shall be diluted with additional distilled or deionized water to obtain 1 L of solution. The volume proportion of sodium hydroxide solution to mortar bars in a storage container shall be 4.5 ± 1.0 volumes of solution to one volume of mortar bars.

Note 2—The volume of a mortar bar may be taken as 184 mL (11.25 $in.^3$).

Note 3—**Precaution**: Before using NaOH, review: (1) the safety precautions for using NaOH; (2) first aid for burns; and (3) the emergency response to spills, as described in the manufacturer's Material Safety Data Sheet or other reliable safety literature. NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pinholes.

6. CONDITIONING

6.1. Maintain the temperature of the molding room and dry materials at no less than 20ºC (68ºF) and no more than 27.5ºC (81.5ºF). Maintain the temperature of the mixing water, and of the moist closet or moist room, at 23.0 ± 1.7ºC (73.4 ± 3.0ºF).

6.2. The relative humidity of the molding room shall be not less than 50 percent.

6.3. Maintain the storage oven in which the specimens are stored in the containers at a temperature of 80.0º ± 1.7ºC (176 ± 3ºF).

7. SAMPLING AND PREPARATION OF TEST SPECIMENS

7.1. *Selection of Aggregate*—Process materials proposed for use as fine aggregate in concrete as described in Section 7.2 with a minimum of crushing. Process materials proposed for use as coarse aggregate in concrete by crushing to produce as nearly as practical a graded product from which a sample can be obtained. The sample shall have the grading as prescribed in Section 7.2 and be representative of the composition of the coarse aggregate as proposed for use.

7.1.1. When a given quarried material is proposed for use both as coarse and as fine aggregate, test the material only by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect that the coarser size fractions have a different composition than the finer sizes and that these differences might significantly affect expansion due to reaction with the alkalies in cement. In this case, the coarser size fractions shall be tested in a manner similar to that employed in testing the fine aggregate sizes.

7.2. *Preparation of Aggregate*—Grade all aggregates in accordance with the requirements prescribed in Table 1. Crush aggregates for which sufficient quantities of the sizes specified in Table 1 do not exist until the required material has been produced. In the case of aggregates containing insufficient amounts of one or more of the larger sizes listed in Table 1, and if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size as determined from the grading specified in Table 1. Note in the test report when such procedures are required. After the aggregate has been separated into the various sieve sizes, wash each size with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. Dry the portions retained on the various sieves and, unless used immediately, store each portion individually in a clean container. Seal the container to prevent moisture loss or gain.

Table 1—Grading Requirements

Passing Sieve Size	Retained on Sieve Size	Mass, Percent
4.75 mm (No. 4)	2.36 mm (No. 8)	10
2.36 mm (No. 8)	1.18 mm (No. 16)	25
1.18 mm (No. 16)	600 µm (No. 30)	25
600 µm (No. 30)	300 µm (No. 50)	25
300 µm (No. 50)	150 µm (No. 100)	15

7.3. *Selection and Preparation of Cement*—Select a reference cement that meets the requirements of M 85. Pass the reference cement through a 850-µm (No. 20) sieve to remove lumps before use.

7.4. *Preparation of Test Specimens*:

7.4.1. Prepare at least three test specimens for each cement–aggregate combination.

7.4.2. Prepare the specimen molds in accordance with the requirements of M 210, except cover the interior surfaces of the mold with a release agent.

Note 4—A release agent is acceptable if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen. TFE-fluorocarbon tape complies with the requirements for a mold release agent.

7.4.3. Proportion the dry materials for the test mortar using 1 part of cement to 2.25 parts of graded aggregate by mass. Mix 440 g of cement and 990 g of dry aggregate (made up by recombining the portions retained on the various sieves in the grading prescribed in Table 1) at one time to prepare a batch of mortar sufficient for making three specimens. Use a water-to-cement ratio equal to 0.50 by mass.

7.4.4. Mix the mortar in accordance with the requirements of T 162 using water that meets the requirements of Section 5.2.

7.4.5. Mold test specimens with a total elapsed time of not more than 135 s after completion of the original mixing of the mortar batch. Fill the molds with two approximately equal layers, each layer being compacted with the tamper. Work the mortar into the corners, around the gauge studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, cut off the mortar flush with the top of the mold and smooth the surface with a few strokes of the trowel.

8. PROCEDURE

8.1. Place each mold in the moist cabinet or moist room immediately after it has been filled. Cure the specimens in the molds for 24 ± 2 h. Remove the specimens from the molds and, while they are being protected from loss of moisture, properly identify and determine the initial length of each specimen using the length comparator. Record all length measurements to the nearest 0.002 mm (0.0001 in.).

8.2. Place the specimens of each aggregate sample in a storage container with sufficient tap water to totally immerse them. Seal the containers and place them in an oven maintained at 80.0 ± 1.7ºC (176 ± 3ºF) for a period of 24 hours.

8.3. Measure the comparator bar prior to measuring each set of specimens since the heat from the mortar bars may cause the length of the comparator to change. If the length of the comparator bar has changed, wait until the comparator has returned to room temperature before remeasuring the comparator bar. Remove the containers from the oven one at a time. Remove other containers only after the specimens in the first container have been measured and returned to the oven. Remove the specimens one at a time from the water and dry their surface with a towel, paying particular attention to the two metal gauge measuring studs. Record the zero measurements of each specimen immediately after drying, as soon as the specimen is in position. Complete the process of drying and measuring within 15 ± 5 s of removing the specimen from the water. After measurement, leave the specimen on a towel until the remainder of the bars have been measured. Place each set of specimens in separate containers with the 1.0 normal NaOH solution, at 80.0 ± 1.7ºC (176 ± 3ºF) to totally immerse the samples. Seal the containers and return them to the oven.

8.4. Undertake subsequent measurement of the specimens periodically, with at least three intermediate readings, for 14 days after the zero reading, at approximately the same time each day. The measuring procedure is identical to that described in Section 8.3 except that the specimens are returned to their own container after measurement.

9. CALCULATION

9.1. Calculate the difference between the zero length of the specimen and the length at each period of measurement to the nearest 0.001 percent of the effective gauge length and record as the expansion of the specimen for that period. Report the average expansion of the three specimens of a given cement-aggregate combination to the nearest 0.01 percent as the expansion for the combination for a given period.

Note 5—When the mean expansion of the test specimens exceeds 0.10 percent at 16 days from casting (14 days from zero reading), it is indicative of potentially deleterious expansion. This value has been determined from tests of aggregate with known field performance in concrete. When the mean expansion of the test specimens is less than 0.10 percent at 16 days after casting, it is indicative of innocuous behavior (Hooton and Rogers, 1989).

10. REPORT

10.1. *The report shall include the following*:

10.1.1. The type and source of aggregate;

10.1.2. The type and source of portland cement;

10.1.3. The average length change in percent at each reading of the specimens;

10.1.4. Any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in Section 7.2;

10.1.5. Any significant features revealed by examination of the specimens during and after test;

10.1.6. The amount of mixing water expressed as mass percent to cement;

10.1.7. The type, source, proportions and chemical analyses, including Na_2O and K_2O, of any pozzolans employed in the tests; and

10.1.8. A graph of the length change data from the time of the zero reading to the end of the 16-day period.

11. PRECISION AND BIAS

11.1. *Precision*:

11.1.1. *Within-Laboratory Precision*—It has been found that the average within-laboratory, single operator coefficient of variation for materials with an average expansion greater than 0.1 percent at 14 days is 2.94 percent (Note 6). Therefore, the results of two properly conducted tests within the same laboratory on specimens of a sample of aggregate should not differ by more than 8.3 percent (Note 6) of the mean expansion.

11.1.2. *Multilaboratory Precision*—It has been found that the average multilaboratory coefficient of variation for materials with an average expansion greater than 0.1 percent at 14 days is 15.2 percent (Note 6). Therefore, the results of two properly conducted tests in different laboratories on specimens of a sample of aggregate should not differ by more than 43 percent (Note 6) of the mean expansion.

Note 6—These four percentages represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670.

11.2. *Bias*—Since there is no accepted reference material for determining the bias of this test method, no statement on bias is being made.

12. REFERENCES

12.1. Davis, G. and R. E. Obserholster, 1987a. “Use of the NBRI Accelerated Test to Evaluate the Effectiveness of Mineral Admixtures in Preventing the Alkali–Silica Reaction,” *Cement and Concrete Research*, Vol. 17, 1987, *pp*. 97–107.

12.2. Davis, G. and R. E. Obserholster, 1987b. “An Interlaboratory Programme on the NBRI Accelerated Test to Determine the Alkali–Silica Reactivity of Aggregates,” *National Building Research Institute, CSIRO, Special Report BOU 92-1987*, Pretoria, RSA, 1987, *pp*. 16.

12.3. Hooton, R. D. and C. A. Rogers, 1989. “Evaluation of Rapid Test Methods for Detecting Alkali-Reactive Aggregates,” *Proceedings of the Eighth International Conference on Alkali-Aggregate Reaction*, Kyoto, 1989, *pp*. 439–444.

12.4. Obserholster, R. E. and G. Davis, 1986. “An Accelerated Method for Testing the Potential Alkali Reactivity of Siliceous Aggregates,” *Cement and Concrete Research*, Vol. 16, 1986, *pp*. 181–189.

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[1] This standard is based on SHRP Product 2009.

Standard Method of Test for

Temperature of Freshly Mixed Hydraulic Cement Concrete

AASHTO Designation: T 309M/T 309-10
ASTM Designation: C 1064/C 1064M-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Temperature of Freshly Mixed Hydraulic Cement Concrete

AASHTO Designation: T 309M/T 309-10
ASTM Designation: C 1064/C 1064M-05

1. The values stated in SI units are to be regarded as the standard.
2. All references to ASTM standards contained in ASTM C 1064/C 1064M-05, listed in the following table, shall be replaced with the corresponding AASHTO standard.

Referenced Standards	
ASTM	AASHTO
C 172	T 141

3. Replace Sections 4.2 and 4.4 of ASTM C 1064/C 1064M-05 with the following:

   4.2 *Temperature Measuring Device*—The temperature measuring device shall be capable of measuring the temperature of the freshly mixed concrete to ±0.5ºC (±1ºF) throughout the entire temperature range likely to be encountered in the fresh concrete. Liquid-in-glass thermometers having a range of –18 to 49ºC (0 to 120ºF) are satisfactory. Other thermometers of the required accuracy, including the metal immersion type, are acceptable.

   4.4 *Reference Temperature Measuring Device*—The reference temperature measuring device shall be a thermometric device readable to 0.2ºC (0.5ºF) that has been verified and calibrated. The calibration certificate or report indicating conformance to the requirements of ASTM E 77 shall be available for inspection.

4. Replace Section 5 of ASTM C 1064/C 1064M-05 with the following:

   5. *Calibration of Temperature Measuring Device*

   5.1 Each temperature measuring device used for determining temperature of freshly mixed concrete shall be calibrated annually, or whenever there is a question of accuracy. This calibration shall be performed by comparing the readings on the temperature measuring device at two temperatures at least 15ºC (27ºF) apart.

Standard Method of Test for

Water Content of Freshly Mixed Concrete Using Microwave Oven Drying

AASHTO Designation: T 318-02 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Water Content of Freshly Mixed Concrete Using Microwave Oven Drying

AASHTO Designation: T 318-02 (2007)

1. SCOPE

1.1. This method covers the measurement of total water content of fresh concrete. It consists of drying a test specimen of fresh concrete using a relatively high-power microwave oven within a short period of time. The difference in mass between the fresh and dry concrete test specimen will be the water content of that test specimen. Water content per unit volume of concrete can be determined by knowing the unit weight of that concrete.

1.2. This standard is applicable to both laboratory and field tests as long as a power source is available.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SUMMARY OF TEST METHOD

3.1. A test specimen of freshly mixed concrete is wrapped in a fiberglass cloth and dried in a microwave oven using a minimum of three intervals. The test specimen is broken up, separating the coarse aggregate from the mortar, and the mortar is ground with a pestle after the first drying interval. The test specimen is stirred and its mass is determined after subsequent drying intervals. The water content of the test specimen is calculated based on loss in mass of the test specimen at completion of the test. Total drying time is usually less than 15 minutes.

4. SIGNIFICANCE AND USE

4.1. This test is for both laboratory and field measurements of water content in fresh concrete. The test results have been shown to correlate with the actual water content in freshly mixed concrete.

4.2. This test can be used as a quality control tool to check the water content of as-delivered concrete and to calculate the water/cement ratio if the cement content of the tested concrete is known.

Note 1—If it is desired to calculate the net water content of concrete from results of this test, the water absorption of coarse and fine aggregates used in the concrete must be determined.

5. APPARATUS

5.1. *Microwave Oven*—A microwave oven with a power setting of 900 watts, a turntable, and sufficient capacity to accept the specified tray and test specimen.

Note 2—A commercial microwave oven (such as the SHARP Model R-9H93) with a capacity of 0.042 m^3 (1.5 ft^3) and turntable system is suitable.

5.2. *Glass Tray*—A heat-resistant glass tray with dimensions of approximately 230 × 230 × 50 mm (9 × 9 × 2 in.).

5.3. *Balance*—A balance of sufficient capacity meeting the requirements of M 231.

5.4. *Metal Scraper*—A small metal scraper having a sharp edge and a blade approximately 25 mm (1 in.) wide.

5.5. *Grinding Pestle*—A pestle having a porcelain grinding head with a diameter of approximately 50 mm (2 in.).

6. MATERIALS

6.1. *Fiberglass Cloth*—Plain weave fiberglass cloth having a mass of 0.34 kg/m^2 (10 oz/yd^2) and a thickness of 0.35 mm (14 mils).

7. HAZARDS

7.1. Microwave radiation can be hazardous. Follow the safety precautions provided by the microwave oven manufacturer and OSHA at all times. Refer to the caution statements in T 255.

8. SAMPLING TEST SPECIMENS

8.1. Obtain 1500 ± 100 g test specimens from a sample of freshly mixed concrete as described in T 141.

9. PROCEDURE

9.1. Cut a piece of fiberglass cloth large enough to completely wrap a 1500 ± 100 g test specimen of freshly mixed concrete.

Note 3—The minimum size fiberglass cloth that has generally been found to be adequate is 0.5 m by 0.5 m (20 in. by 20 in.).

9.2. Place the fiberglass cloth on the heat-resistant glass tray with the cloth uniformly overhanging the outside edges of the tray.

9.3. Determine the mass of the tray and cloth together (WS). Make this mass determination and all subsequent mass determinations to the nearest 0.1 g.

9.4. Leave the tray and cloth on the balance. Record the tare weight. Place the 1500 ± 100 g test specimen on the fiberglass cloth and wrap the test specimen completely with the cloth.

9.5. Determine the mass of the tray, cloth, and freshly mixed concrete test specimen together (WF).

9.6. Place the tray with the completely wrapped test specimen on the turntable in the microwave oven. Dry the test specimen with the turntable rotating for a period of 5.0 ± 0.5 minutes at the 900-W-power setting.

9.7. At the end of the first drying period, remove the tray and test specimen from the microwave oven and quickly unwrap the test specimen. With the edge of the scraper, break the mass of concrete until the coarse aggregate is separated from the mortar. Carefully grind the mortar with the pestle for no more than 60 s to expose a greater surface area. Avoid losing any material.

9.8. Rewrap the test specimen. Place the tray with the completely wrapped test specimen on the turntable in the microwave oven and dry it with the turntable rotating for 5.0 ± 0.5 minutes at the 900-W-power setting.

9.9. Remove the tray and test specimen from the microwave oven and unwrap the test specimen. Stir the test specimen with the scraper and determine the mass of the tray, fiberglass cloth, and sample together.

9.10. Rewrap the test specimen. Place the tray with the completely wrapped test specimen on the turntable in the microwave oven and dry it with the turntable rotating for 2.0 ± 0.5 minutes at the 900-W-power setting.

9.11. Remove the tray containing the test specimen from the microwave oven and determine the mass. If the change in mass is 1 g or more, repeat the 2-minute drying period until the change in mass is less than 1 g. Record the mass of the tray, cloth, and dry test specimen together (WD).

10. CALCULATIONS

10.1. *Water Content Percentage*—Calculate the water content percentage as follows:

$$WC = 100\,(WF - WD) / (WF - WS) \qquad (1)$$

where:

WC = water content percentage;

WF = mass of the tray + cloth + fresh test specimen;

WD = mass of the tray + cloth + dry test specimen; and

WS = mass of the tray + cloth.

10.2. *Total Water Content*—Calculate the total water content as follows:

10.2.1. For kg/m^3 use:

$$WT = [(WC)(UW)]/100 \qquad (2)$$

10.2.2. For lb/yd^3 use:

$$WT = (27)(WC)(UW)/100 \qquad (3)$$

where:

WT = total water content, kg/m^3 (lb/yd^3);

UW = unit mass of the fresh concrete kg/m^3 (lb/ft^3); and

27 = ft^3/yd^3, a constant (not used for SI calculation).

11. REPORT

11.1. *Report the following information*:

11.1.1. Sample identification information;

11.1.2. Percent water content, nearest tenth of a percent; and

11.1.3. Total water content, nearest kg/m^3 (lb/yd^3).

12. PRECISION AND BIAS

12.1. *Single Operator Precision*—The single operator within-laboratory standard deviation has been found to be 1.6 kg/m^3 (2.7 lb/yd^3). Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 4.5 kg/m^3 (7.6 lb/yd^3).

Note 4—These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

12.2. *Multilaboratory Precision*—Multilaboratory estimates of precision have not been determined.

12.3. *Bias*—The bias of this method has not been determined.

Standard Method of Test for

Estimating the Strength of Concrete in Transportation Construction by Maturity Tests

AASHTO Designation: T 325-04 (2008)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Estimating the Strength of Concrete in Transportation Construction by Maturity Tests

AASHTO Designation: T 325-04 (2008)

1. SCOPE

1.1. This standard provides procedures for estimating concrete strength in roads, bridges, and other transportation structures through the use of a maturity index.

1.2. This standard requires determination of the strength-maturity relationship of the approved concrete job mix in the laboratory, and determination of the temperature history subsequent to placement in the field.

1.3. *This standard may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 9, Acceptance Sampling Plans for Highway Construction
- T 276, Measuring Early-Age Compression Strength and Projecting Later-Age Strength

2.2. *ASTM Standards*:

- C 1074, Standard Practice for Estimating Concrete Strength by the Maturity Method
- D 3665, Standard Practice for Random Sampling of Construction Materials
- E 105, Standard Practice for Probability Sampling Of Materials
- E 122, Standard Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
- E 141, Standard Practice for Acceptance of Evidence Based on the Results of Probability Sampling

3. TERMINOLOGY

3.1. *equivalent age*—the number of days or hours at a specified temperature that would equal the maturity of a concrete at the actual age and temperature history that has been measured.

3.2. *maturity*—the extent of development of concrete properties that are dependent on cement hydration and pozzolanic reactions.

3.3. *maturity function*—a mathematical expression that converts the temperature history of concrete to an index, which indicates its maturity.

3.4. *maturity index*—an index, calculated by using a maturity function, that can be used as an indicator of strength development in concrete.

3.5. *strength-maturity relationship*—an empirical relationship between concrete strength and its maturity index, usually determined by comparing the strength of concrete cylinders, made from a specific concrete mix, to their maturity index at time of strength testing.

4. SIGNIFICANCE AND USE

4.1. This standard can be used to estimate the strength of concrete placed in pavements and structures. These estimates provide guidance useful in making decisions concerning opening to traffic, form removal, post tensioning, termination of curing procedures, and initiation of strength tests on the in-place concrete such as coring and pullout tests.

4.2. The most critical limitations of the procedures presented are (1) batching or placement errors that are not detected, (2) curing errors other than those that affect temperature that are not detected, and (3) the actual strength of the concrete that is not measured.

Note 1—Concrete must be cured in a condition that supports cement hydration/pozzolanic reactions.

4.3. This standard provides technical personnel with a coordinated procedure for (1) developing a strength-maturity relationship for the approved concrete job mix in the laboratory, (2) determining the temperature history of the in-place concrete, (3) determining the maturity index of the in-place concrete, and (4) using the strength-maturity relationship and the maturity index to estimate the strength of the in-place concrete.

5. APPARATUS

5.1. *Laboratory Requirements*:

5.1.1. Personal safety equipment required by the laboratory or OSHA, or both, for work in the laboratory concrete mixing and testing areas.

5.1.2. Temperature sensors suitable for embedment in the center of cylindrical concrete test specimens and a device suitable for monitoring and recording the temperature.

5.1.3. A computer terminal for input of laboratory test data or a supply of concrete test reports.

5.2. *Field Requirements*:

5.2.1. Personal safety equipment required by the laboratory/field organization or OSHA, or both, for work in the field concrete placement areas.

5.2.2. Temperature probes/sensors suitable for embedment in the concrete placement.

5.2.3. A device suitable for monitoring and recording the temperature of the concrete. The device may be a system with a computer remote from the job site that reads and logs the probes/sensors through a modem for necessary calculations; a system with a computer at the job site that automatically reads, logs, and makes the necessary calculations; or a system with a device that automatically reads the probe/sensor signals, calculates the maturity index, and digitally displays the data on demand.

Note 2—SHRP researchers identified eleven reusable maturity meters and three disposable maturity meters, all commercially available. Seven used the Arrhenius maturity function, six used the Nurse-Saul maturity function, and one used either that was chosen.

6. HAZARDS

6.1. Observe the safety procedures required by the laboratory/field agency or OSHA, or both, for each laboratory and field operation, as applicable.

7. FIELD SAMPLING

7.1. Select the temperature sampling sites for installing probes/sensors by determining the quantity of concrete that is to be evaluated and dividing the concrete placement into lots that approximate the quantities indicated in Table 1. For the purposes of this standard, the quantity of pavement shall be estimated in square meters and the quantity of structural concrete shall be estimated in cubic meters.

Table 1—Minimum Number of Probes/Sensors Required to Be Placed in Each Concrete Lot

Structure Component	Quantity of Concrete in Lot	Number of Probes/Sensors
Slabs, beams, and abutment walls	100 m^3	5
Columns	2–10 m^3	1
Columns	More than 10 m^3	2
Pavement, pavement overlays	1000 m^2	2
Pavement repairs	Per repair or per 750 m^2, whichever is smaller	2

7.2. Select temperature sampling alternates in the following manner:

7.2.1. When the maturity of all lots is to be determined, use a stratified random selection procedure in determining where to place the temperature probes/sensors in each concrete lot to be evaluated, as indicated in Table 1.

7.2.2. When the maturity of only a fraction of the total lots is to be measured, determine the number of lots in accordance with Equation 1:

$$L_1 = FT - L_L \qquad (1)$$

where:

L_1 = lots to be randomly chosen,

F = fraction of lots to be sampled for maturity testing,

T = total number of lots, and

L_L = last lot placed.

7.2.2.1. Round L_1 to the next higher whole number. Then randomly select the number of lots, L_1, from the available lots, excluding the last lot placed, L_L. Add L_L to the list of randomly chosen lots scheduled for maturity testing. Finally, use a stratified random selection procedure to determine where to place each of the temperature probes/sensors, as indicated in Table 1, in each concrete lot scheduled for evaluation.

Note 3—*Example*: if $T = 10$, and $F = {}^{1}/_{8}$, then $L_1 = 0.25$. Rounding to the next higher whole number, $L_1 = 1$. Then, excluding the last lot placed, there are $(10 - L_L) = 9$ lots from which L_1 is randomly selected. Assume that lot number 4 is the randomly selected lot, and that lot number 10 is L_L, the last lot placed. Then lots numbered 4 and 10 are scheduled for maturity testing. The purpose for excluding L_L from the random selection of lots scheduled for testing and then specifically including L_L in the list of lots scheduled for testing is to assure that the lot containing the last concrete placed is one of those evaluated in the maturity testing process. If all other factors are equal, L_L will be the weakest lot at the times likely to be of interest during the construction process. A similar approach should be followed with regard to a lot(s) that will be exposed to significantly more adverse curing conditions than other lots under evaluation.

Note 4—ASTM D 3665 contains a table of random numbers, including instructions for use. AASHTO R 9 and ASTM E 105, E 122, and E 141 contain additional information concerning sampling practices.

8. PREPARATIONS

8.1. *Laboratory Operations*—Prior to the initiation of the laboratory concrete placement operation, check to ensure that an adequate supply of temperature sensors is available for the scheduled work and prepare the concrete temperature monitoring and recording device for attachment to the temperature sensors immediately after they are embedded in the concrete cylinders.

8.2. *Field Operations*—Prior to the initiation of the field concrete placement operation (1) select which sampling alternate is to be used, (2) check to ensure that an adequate supply of temperature probes/sensors is available for the scheduled concrete placement, (3) determine the locations at which the temperature probes/sensors will be installed, and (4) prepare the concrete temperature monitoring and recording system for attachment to the temperature probes/sensors immediately after placement of the concrete lot.

9. STANDARDIZATION

9.1. Verify the calibration of systems used for monitoring the maturity of concrete on a periodic basis.

Note 5—System verification can be accomplished by placing the temperature probe/sensor in a controlled temperature water bath and recording whether the indicated result agrees with the known temperature of the water bath. Use at least three different temperature points (e.g., 5°C, 25°C, and 45°C).

10. PROCEDURE

10.1. Develop the strength-maturity relationship for the approved concrete job mix in accordance with the Strength Maturity Relationship section of ASTM C 1074.

Note 6—Other standards that use strength-maturity relationships include T 276.

10.2. Determine the temperature history of concrete after placement in the field as follows:

10.2.1. Insert the active end of the temperature probe/sensor in the fresh concrete at the predetermined location(s). If the probe/sensor is installed prior to placement of the concrete, tie the sensor wire for reinforcement to prevent displacement during the placement of the concrete. Probes/sensors can be inserted through an open surface of the concrete or through very small holes in forms.

10.2.2. Generally, probes/sensors should be placed 50 to 100 mm from any surface of the concrete placement. In a pavement overlay, place probes/sensors at mid-depth.

10.2.3. Protect wires connecting the probes/sensors to meter locations from construction operations. In critical locations, use duplicate probes/sensors with separated wiring runs.

Note 7—SHRP research indicated that if a concrete surface is protected from a high rate of heat loss, the difference in maturity indexes between the center and surface of pavements, bridge decks, and structures 300 mm or less thick is negligible.

10.2.4. Make final maturity system connections with the probes/sensors immediately after concrete placement and activate the system.

10.3. After placement of the concrete in the field, determine the maturity index at each probe/sensor location by reading the appropriate channel(s) of the maturity monitoring system.

Note 8—SHRP researchers recommend that all maturity meters used for highway pavement and structures should use the Arrhenius function, because the Arrhenius function is better able to represent the effects of temperature on strength development than the Nurse-Saul function. Meters using the Nurse-Saul function will increasingly produce less accurate estimates of strength gain as the temperature deviates from the standard temperature used to establish the strength-maturity relationship.

10.4. Estimate the in-place strength of concrete in the field using the strength-maturity relationship and the maturity index.

10.4.1. Compare the maturity index determined in Section 10.3 to the strength-maturity relationship determined in Section 10.1. The concrete strength value of the strength-maturity relationship that corresponds to the measured maturity index from a particular probe/sensor location is the estimated concrete strength at that location.

10.4.2. Determine the estimated strength of a concrete lot using Equation 2:

$$S_{L(est)} = \frac{\sum_{i=1}^{i=n} X_i}{n} \qquad (2)$$

where:

$S_{L(est)}$ = estimated strength of the concrete lot,

X_i = estimated strength of the concrete at a specific probe/sensor location,

i = individual probe/sensor, and

n = number of probes/sensors in the concrete lot.

11. REPORT

11.1. *Report the following laboratory information*:

11.1.1. Identification of the laboratory and date of testing;

11.1.2. Identification of the concrete job mix used for laboratory tests;

11.1.3. Strength of each test specimen and the average strength of test specimens at each test age;

11.1.4. Maturity index for each instrumented test specimen and the average maturity index for the instrumented specimens at each test age;

11.1.5. A graph of the average compressive strength versus the average value of the maturity index as described in the Strength-Maturity Relationship section of ASTM C 1074; and

11.1.6. Any other information required by the laboratory organization.

11.2. *Report the following field information*:

11.2.1. Project and route number; and

11.2.2. A list for each concrete lot evaluated, identifying the concrete job mix used and showing the following:

11.2.2.1. Station numbers;

11.2.2.2. Offset;

11.2.2.3. Item number;

11.2.2.4. Quantity of concrete;

11.2.2.5. Number (how many) and location of each probe/sensor installed;

11.2.2.6. Maturity index determined for each probe/sensor location;

11.2.2.7. Estimated strength determined for each probe/sensor location; and

11.2.2.8. Estimated average strength for each concrete lot.

11.3. *Optional*—Any additional data required by the laboratory/field organization responsible for estimating the concrete strength by means of the maturity method.

12. PRECISION AND BIAS

12.1. The research required to determine the precision and bias of this standard has not been performed.

13. KEYWORDS

13.1. Concrete; estimating concrete strength; maturity, maturity index; strength-maturity relationship.

Standard Method of Test for

Determining Chloride Ions in Concrete and Concrete Materials by Specific Ion Probe

AASHTO Designation: T 332-07[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Chloride Ions in Concrete and Concrete Materials by Specific Ion Probe

AASHTO Designation: T 332-07[1]

1. SCOPE

1.1 This method covers the procedures for determining acid-soluble chloride ions in concrete and concrete mix ingredients.

1.2 The age of concrete, mortar, or hydrated portland cement at the time of sampling will have an effect on the acid-soluble chloride ion content. Therefore, unless early age studies are desired, it is recommended that the material be well cured and at least 28 days of age before sampling.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 260, Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

2.2 *ASTM Standards*:

- D 1193, Standard Specification for Reagent Water
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. SUMMARY OF TEST METHOD

3.1 A 3.0-g drilled concrete powder sample is digested in 20 mL of an acid digestion solution and stabilized by the addition of 80 mL of a stabilizing solution. Millivolt readings, taken for the sample solution using a specific chloride ion probe, are converted mathematically into equivalent total percent chloride content or chloride content in kg/m^3 (lb/yd^3) of concrete.

4. INTERFERENCES

4.1 The operational response of the specific ion electrode is subject to interference by the presence of OH^-, S^{2-}, Br^-, I^-, and CN^- in the measured solution and is based on the electrode manufacturer's allowable chloride interference ratio.

4.2 Sulfides are known to interfere with the determination of chloride in solution. This test procedure is, therefore, unsuitable for determining the chloride content of concrete containing mineral aggregates containing significant quantities of pyrite.

5. SIGNIFICANCE AND USE

5.1 This method provides a rapid means of sampling and testing for total chloride ions in concrete in the field.

6. APPARATUS

6.1 *Impact Hammer*—A heavy-duty rotary impact hammer with a drilling stop gauge is used. See Figures 1 through 3.

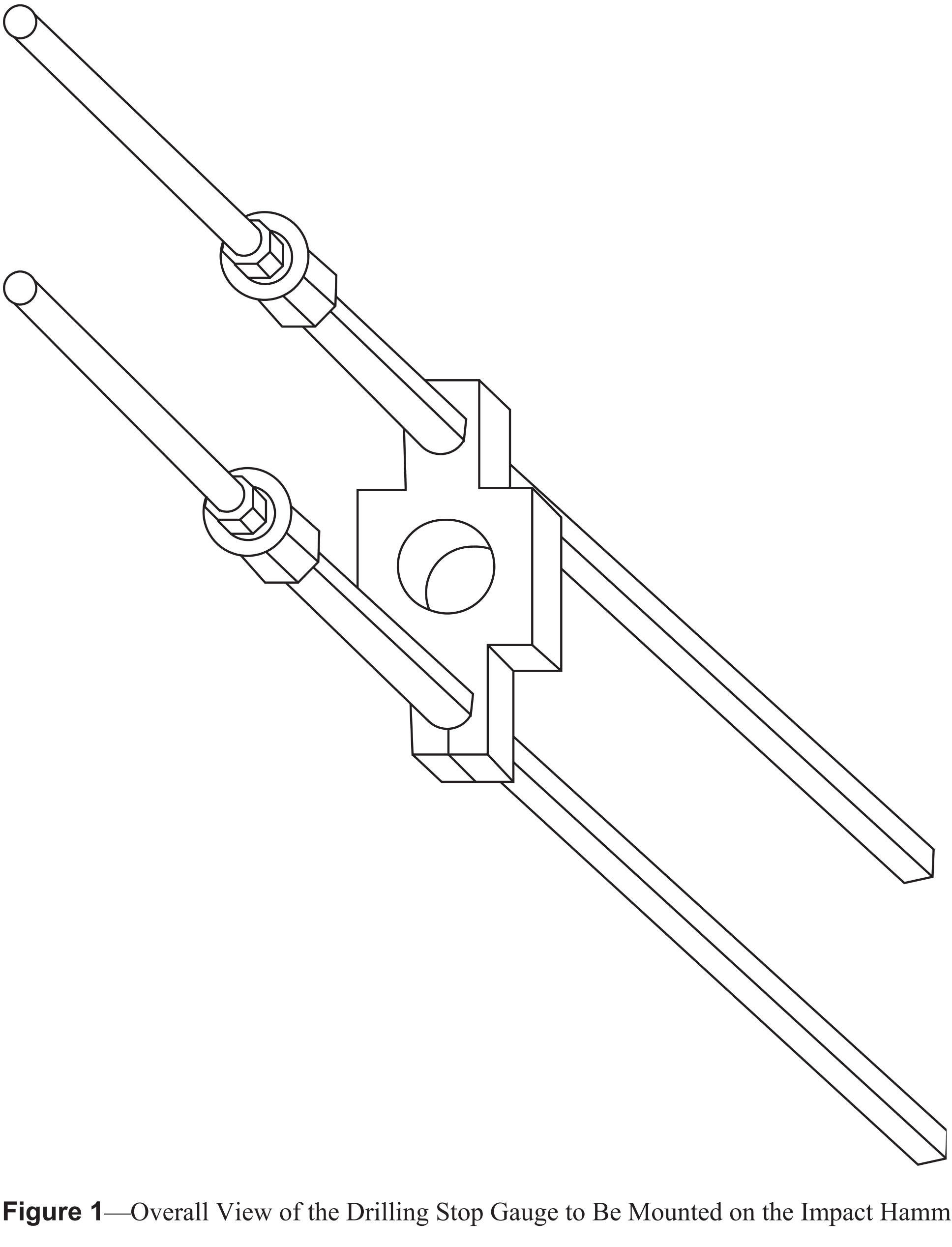
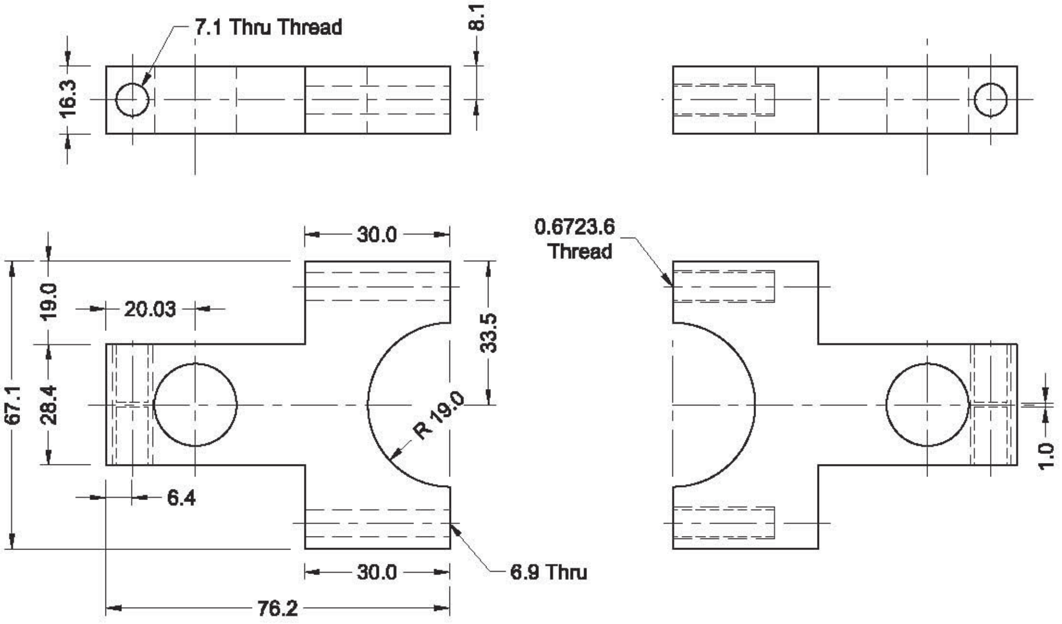
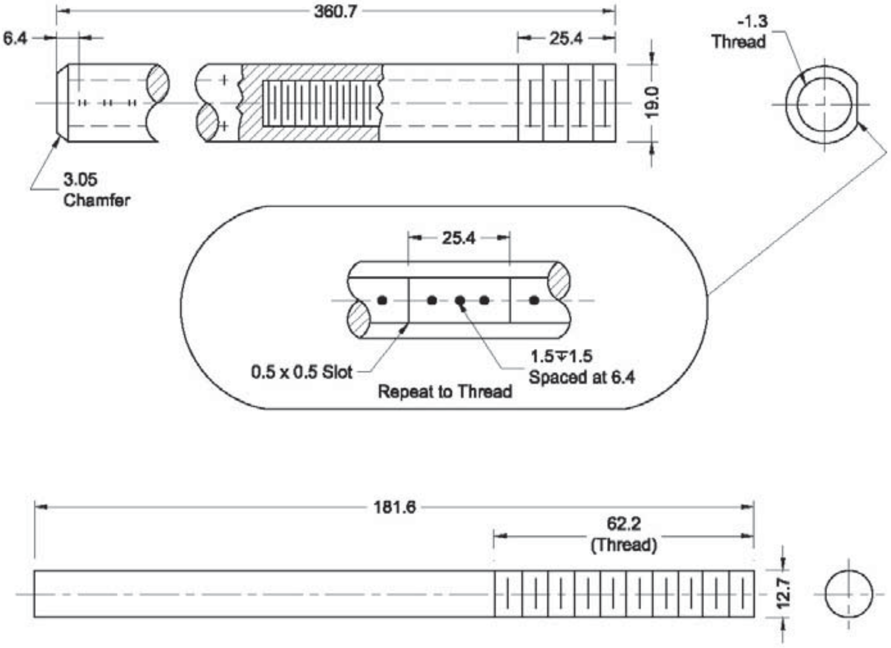


Figure 1—Overall View of the Drilling Stop Gauge to Be Mounted on the Impact Hammer



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 2—Details of the Split Ring Collar for the Drilling Stop Gauge



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 3—Details of the Depth Rods for the Drilling Stop Gauge

6.2 *Bit*—A vacuum bit with a diameter equivalent to 1.5 times the maximum aggregate size in the concrete is used. A 28-mm (1.25-in.) bit size is recommended for a maximum coarse aggregate size of 19 mm (0.75 in.). The bit grinds the concrete to a fineness of 99 percent passing the 850-μm (No. 20) sieve conforming to M 92. The finely ground powder is drawn into the collection unit through a coaxial hole in the bit.

6.3 *Sample Collection Unit*—A cylindrical polymethyl methacrylate vacuum chamber is connected to the carbide bit through a vacuum hose for sample collection. Vacuum is provided by a 2.25-HP wet/dry shop vacuum unit. Figures 4 through 8 present the details of the sample collection unit that is to be attached to the wet/dry shop vacuum unit.

6.4 *Filter*—An inexpensive coffee filter is adequate for collecting the powdered concrete samples in the polymethyl methacrylate chamber.

6.5 *Plastic Bottles/Containers*—Widemouth polypropylene bottles with screw caps in the following two sizes are needed:

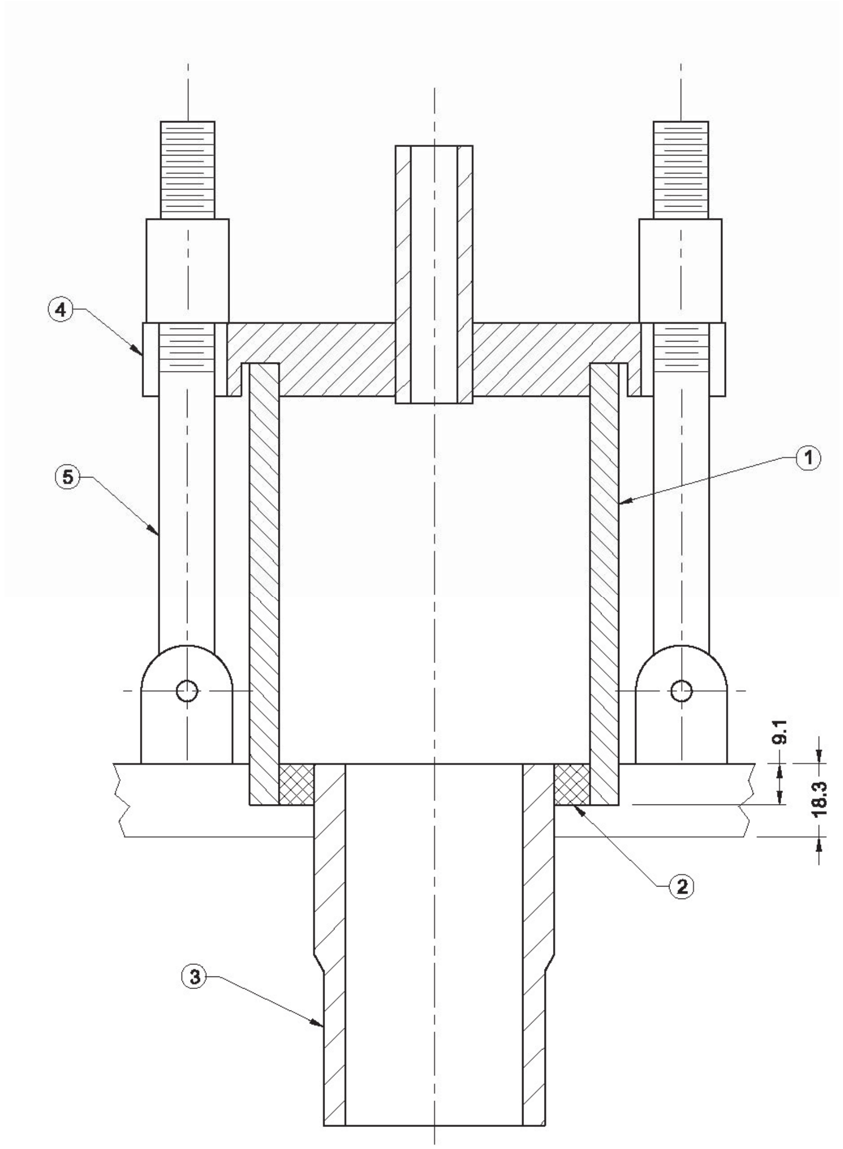
6.5.1 For calibration solutions and for storing powdered concrete samples: 30 mL.

6.5.2 For digestion solution: 125 mL.

6.6 *Weighing Papers*—76 by 76 mm (3 by 3 in.) size weighing papers are needed for determining the mass of the powdered concrete samples.

6.7 *Spatula*—A stainless steel small spoon spatula is needed for transferring small quantities of the powdered concrete samples from the plastic container for mass determinations.

6.8 *Balances*—An electronic balance sensitive to 0.1 g is needed to determine the mass of the specimens. An electronic balance sensitive to 0.0001 g is needed to determine the mass of sodium chloride for the calibration and stabilizing solutions.

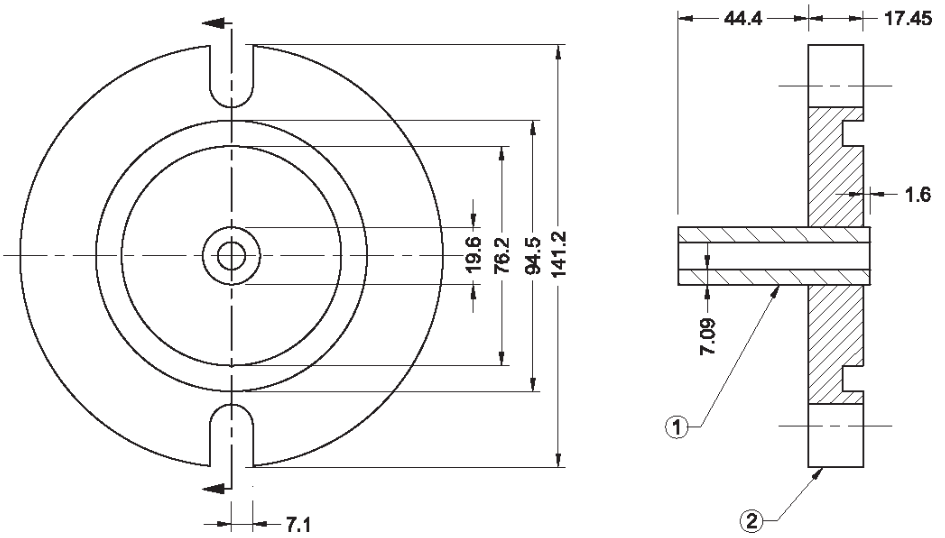


Legend

Name
1. Collection Cylinder
2. Ring
3. Vacuum Cylinder
4. Cap
5. Clamp

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 4—Sample Collection Unit

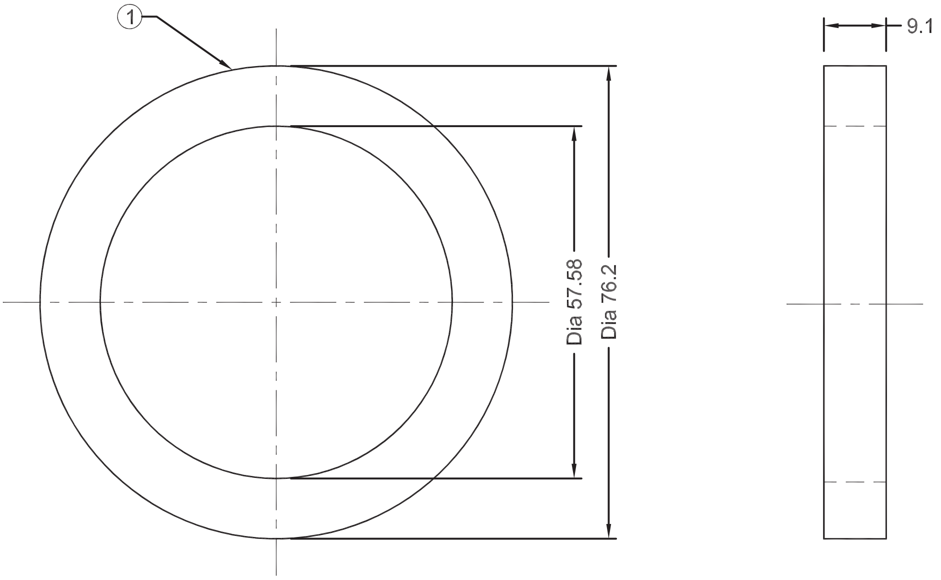


Details of Cap

Name	Required	Material
1. Entry Cylinder	1	Plexiglas
2. Cap Base	1	Plexiglas

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 5—Sample Collection Unit (Details of Cap)

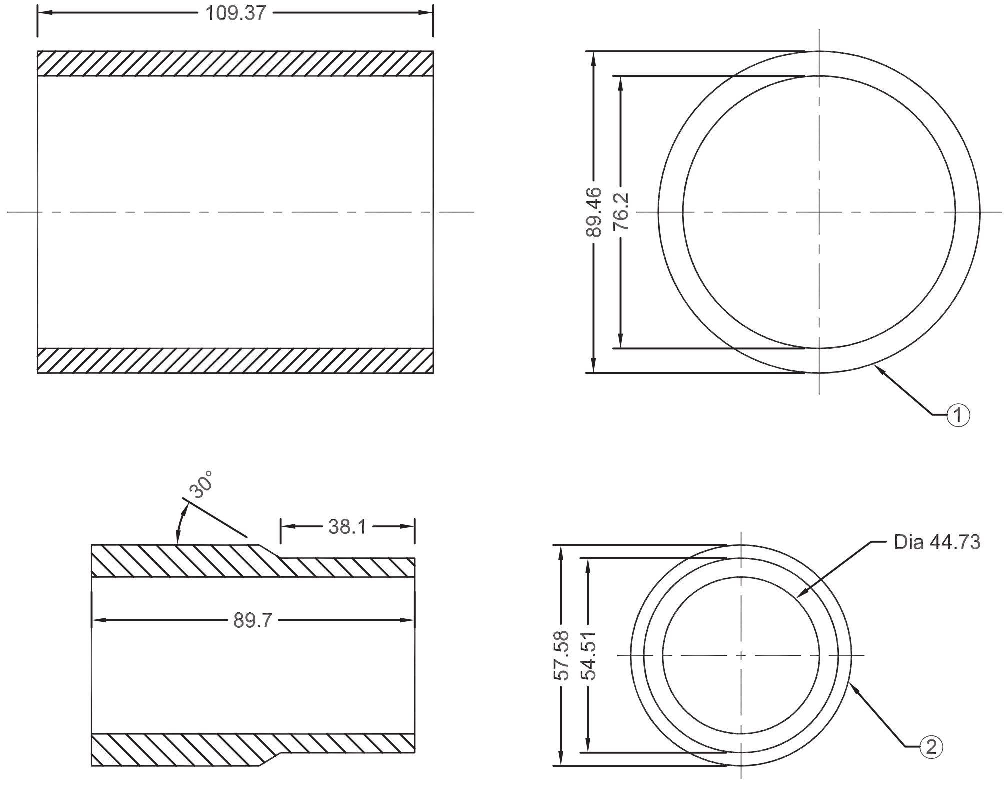


Details of Ring

Name	Required	Material
1. Ring	1	Plexiglas

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 6—Sample Collection Unit (Details of Ring)

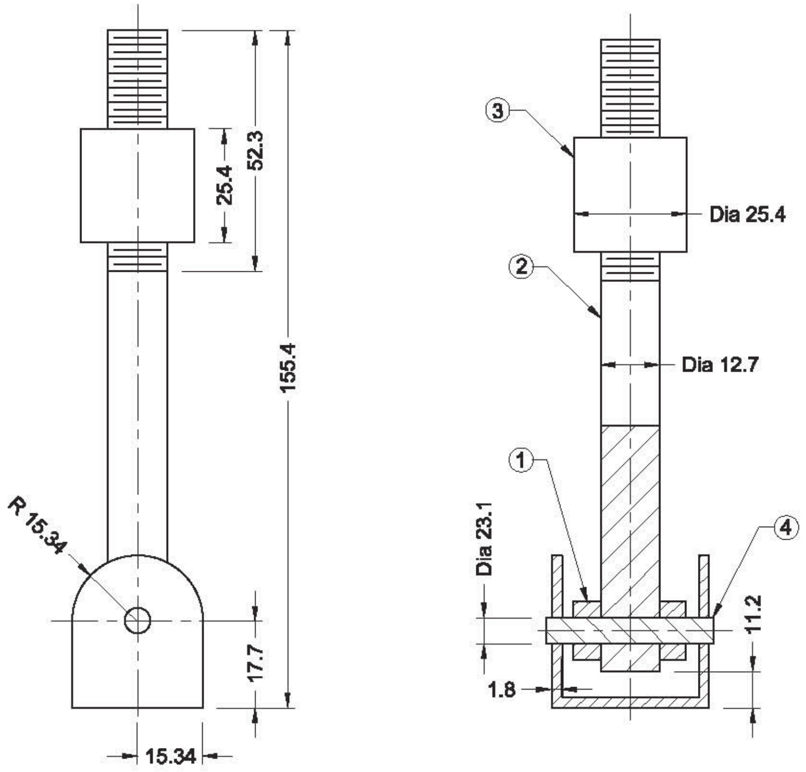


Details of Collection Cylinder and Vacuum Cylinder

Name	Required	Material
1. Collection Cylinder	1	Plexiglas
2. Vacuum Cylinder	1	Plexiglas

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 7—Sample Collection Unit (Details of Collection Cylinder and Vacuum Cylinder)



Details of Clamp (2 required)

Name	Required	Material
1. Spacer	2	Rubber
2. Shaft	1	Steel
3. Nut	1	Steel
4. Spring Pin	1	Steel

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 8—Sample Collection Unit (Details of Clamp)

6.9 *Specific Chloride Ion Electrode*—The specific ion electrode for measuring the chloride ion concentration in solution must conform to the following specifications:

6.9.1 Concentration measuring range 5×10^{-5} to 1 mol, or 1.8 to 35 mg/L.

6.9.2 The electrode resistance shall be less than 1.0 megohm.

6.9.3 Reproducibility shall be ±2 percent.

6.9.4 Operating temperature range shall be 10 to 100°C by thermometers specified in ASTM E 1.

Note 1—A suitable specific chloride ion electrode is the Orion Combination Chloride Electrode Model 96-17B with chamber filling solution number 900017 (for use with chloride solution concentrations up to 355 mg/L).

6.10 *Multimeter*—The multimeter used in the procedure must conform to the following specifications:

6.10.1 Maximum common mode voltage shall be 1500 VDC or peak AC.

6.10.2 Resolution at minimal range shall be 100 μV.

6.10.3 Accuracy shall be ± (0.25 percent of the reading + 1 digit).

6.10.4 Operating temperature range shall be 0 to 50°C (32 to 122°F).

6.10.5 Input impedance shall be greater than 2 MΩ.

Note 2—The Orion Model 250A is a suitable meter.

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7. MATERIALS AND REAGENTS

7.1 *Sodium Chloride*—Reagent grade.

7.2 *Ethyl Alcohol*—Reagent grade.

7.3 *Acetic Acid*—Glacial acetic acid having the following properties:

Note 3—In the use of acetic acid, the operator must use caution to avoid injuries to hands and eyes. Wear safety goggles and gloves.

7.3.1 Specific gravity at 25°C 1.05.

7.3.2 Chloride content: ≤0.4 mg/L.

7.3.3 Normality: 17.4.

7.4 *Isopropyl Alcohol*—Reagent grade having the following properties:

7.4.1 Specific Gravity at 25°C: 0.781 to 0.783.

7.4.2 Boiling Point: 82.3 ± 0.1°C.

7.5 *Distilled Water*—Distilled water conforming to ASTM D 1193, Type IV.

7.6 *Concrete Samples*—The concrete sample to be analyzed shall be in powdered form, 99 percent passing the 850-μm (No. 20) sieve, as taken from the rotary impact hammer extraction procedure.

7.7 *Digestion Solution*—The digestion solution is prepared by combining acetic acid, isopropyl alcohol, and distilled water. Take 800 mL of distilled water in a 1-L measuring flask, and add 60 mL of glacial acetic acid and 60 mL of isopropyl alcohol to the flask. Thoroughly stir the solution and make up the volume to 1 L by adding distilled water. Allow the solution to cool to room temperature. Dispense the solution in 20-mL volumes into the 125-mL polypropylene bottles.

7.8 *Calibration Solutions*—The calibration solutions are prepared by dissolving sodium chloride in distilled water. The concentration levels are 1.25, 0.6, 0.3, 0.03, and 0.01 percent chloride ions by mass of concrete, based on a 3.0-g concrete sample. To obtain the respective concentration levels, dissolve the following quantities of sodium chloride each in 1 L of distilled water: 0.6169 g, 0.2961 g, 0.1481 g, 0.0148 g, and 0.0049 g. (This will result in solutions with chloride ion concentrations of 374, 180, 90, 9, and 3 mg/L, respectively, which in turn correspond to the above-noted percentages by mass of concrete.) Dispense 20 mL of each of the calibration solutions into a separate 30-mL polypropylene bottle, and label each bottle accordingly.

7.9 *Stabilizing Solution*—The stabilizing solution is a diluted standard chloride solution. It is prepared as follows: Dissolve 0.1545 g of sodium chloride in distilled water in a 1-L flask and make up the volume to 1 L with distilled water. Take 40 mL of this solution and dilute it further to 1 L by adding distilled water.

7.10 *Solution Temperature*—The temperature of the solution during testing significantly affects the determined chloride concentration. To minimize errors caused by temperature variations, ensure that the calibration, digestion, and stabilizing solutions are maintained at 22.2 ± 1.1°C (72 ± 2°F).

8. FIELD SAMPLING

8.1 Obtain a sample from the concrete structure using the rotary impact hammer with depth gauge and the carbide vacuum bit.

8.2 Using the sample collection unit, collect at least 10.0 g of powdered concrete in the filter. A hole, drilled about 28.6 mm ($1^1/_8$ in.) in diameter and 12.7 mm ($^1/_2$ in.) deep, will yield approximately 25 g of powdered concrete sample.

8.3 Place the filter containing the sample in the 30-mL polypropylene bottle.

9. CALIBRATION PROCEDURE

9.1 The measurement of the calibration solutions determines the response characteristics of the specific ion electrode in combination with the multimeter. Mathematical regression of the responses produces a representative equation for the combination used to determine the chloride contents of powdered concrete samples. A minimum of five calibration solution concentrations is needed to adequately calibrate the equipment combination. Any alterations to equipment combinations shall require recalibration and the formulation of a new calibration equation.

9.2 Determine the electrode response to chloride ion concentration of the calibration solutions as described below. Start with the calibration solution with the lowest chloride ion concentration.

9.2.1 Place chloride ion electrode halfway into the calibration solution, and wait for 3 minutes to allow the millivolt reading to stabilize. The millivolt reading is stable when it oscillates by less than ±0.5 mV. Record at least five readings and calculate average value to be used for determining the calibration equation.

9.2.2 Repeat the above process (Step 9.2.1) for each of the remaining calibration solutions.

9.3 The calibration equation is determined as follows:

9.3.1 Calculate the $\log_{10}$ of the mg/L chloride concentrations of the calibration solutions, e.g., $\log_{10}$ (374 mg/L Cl) = 2.573.

9.3.2 Perform a linear regression of the millivolt responses (X) versus the $\log_{10}$ of the chloride concentrations of the respective calibration solutions (Y), producing Equation 1 in the following format:

$$\log_{10}(\text{mg/L Cl}) = \text{constant} + \text{coefficient} \times \text{mV} \qquad (1)$$

Note 4—The constant and coefficient will vary with varying equipment combinations. However, the constant is numerically characterized by x.xxx and the coefficient is characterized by -0.0^{xxx}, where *x* represents digits. The slope should be between 54 and 60 mV/decade at 25°C. If not, consult the troubleshooting section of the electrode operation manual or the manufacturer.

9.3.3 The percent chloride is determined from the logarithmic inverse of the regression equation (Equation 1) minus the chloride added by the stabilizing solution, converted to percent chloride by mass of concrete, as follows in Equation 2:

$$\%\text{Cl} = \left[10^{x\ xxx\ +\ 0.0xxx\text{mV}} - 3.0\ \text{mg/L}\right](0.00333) \qquad (2)$$

9.4 Although unnecessary for calibration, measurements of the calibration solutions, both at the beginning and the end of testing, are recommended as a check on the operational integrity of the instrument combination. A deviation in the calibration solution millivolt response indicates a problem involving one or more of the following:

9.4.1 Contamination of calibration solutions.

9.4.2 Contamination of the internal filling solution of the specific ion electrode.

9.4.3 Defective specific ion electrode.

9.4.4 Defective multimeter.

9.5 The percent chloride is based on a 3.0-g powdered concrete sample, and the mg/L chloride is the resulting concentration of a 100-mL solution. The allowable deviations of the specific ion electrode for various chloride ion concentrations are presented in Table 1:

Table 1—Allowable Deviations of Ion Electrodes

% Cl Concentration	Allowable Deviation (mV)
1.25 (374 mg/L)	1.5
0.60 (180 mg/L)	1.5
0.30 (90 mg/L)	1.5
0.03 (9 mg/L)	1.5
0.01 (3 mg/L)	4.5

10. TEST MEASUREMENTS

10.1 Place 20 mL of the digestion solution in a clean, dry 125-mL polypropylene bottle.

10.2 Transfer the powdered concrete sample from the filter to a 30-mL polypropylene storage container, and discard the filter. Stir the powdered sample with a spatula to provide a uniformly mixed sample. Measure a mass of 3.0 ± 0.1 g on a weighing paper.

10.3 Place the measured concrete sample in the bottle containing the 20-mL digestion solution. Place the cap on the bottle, and shake vigorously to suspend the powder in the solution. Let the powder digest for approximately 10 minutes. The bottle may be opened after shaking to relieve pressure for the effervescence due to the reaction, and should be closed immediately.

10.4 Carefully remove the bottle cap and add 80 mL of the stabilizing solution (a 3.75-mg/L chloride solution).

10.5 Replace the cap and shake vigorously for 1 minute.

10.6 Remove the bottle cap and place the electrode halfway into the digested sample suspension.

10.7 Wait for 3 minutes and record the stable millivolt reading. The millivolt reading is stable when it oscillates by less than ±0.5 mV.

10.8 After each sample measurement, the electrode shall be rinsed clean with distilled water.

11. CALCULATIONS

11.1 Calculate the percent chloride content in the sample as follows in Equations 3 and 4:

$$\%\mathrm{Cl} - (A + By) \qquad (3)$$

in which:

$$y = [10^{(C + D\,\mathrm{mV})} - 3.0](0.00333) \qquad (4)$$

and:

A and B = unique values for a combination of a probe and meter determined from the comparison between a standard titration method and this rapid specific ion electrode method; typical values of A and B are 0.0094 and 0.7645, respectively. The procedure for establishing factors A and B is given in Section 11.2.

C and D = the constant and the coefficient, respectively, in the calibration regression equation (Equation 1); typical values are 3.103 and –0.01957, respectively.

11.2 To establish factors A and B of Equation 3, determine the chloride content of a set of concrete samples by T 260, Method A (Standard Titration Method) and this specific ion electrode method (Equation 2). A minimum of 10 samples, with chloride contents covering the range of calibration solutions (Section 7), is recommended for this comparison. Perform a linear regression of the values obtained by the specific ion electrode method (X) versus those by the standard titration method (Y). A and B are the constant and the coefficient, respectively, in this regression equation. The values of A and B will remain valid as long as a particular probe and meter combination is not changed, but will need to be redetermined in case of any equipment replacement or change.

12. REPORT

12.1 Report the percent chloride content to the third decimal (thousandth of a percent). To convert percent chloride into kg/m^3, use a multiplying factor of 23.22. For conversion into lb/yd^3, multiply by 39.15.

13. PRECISION AND BIAS

13.1 *Precision*—The single-operator within-laboratory standard deviation was found to be 1.91 mV (1s). Therefore, the results of two properly conducted tests by the same operator on the same material should not differ by more than 5.40 mV (d2s).

13.2 *Bias*—The test method was found to have no bias in comparing experimental results with reference values determined in accordance to T 260, Method A.

14. SIGNIFICANCE OF RESULTS

14.1 This test method permits determination of the chloride contamination level of concrete structures as a function of depth. Using the values obtained, the chloride diffusion constant can be calculated and the time to corrosion of embedded steel reinforcement can be estimated.

Note 5—A statistical number of samples should be taken on a structure to provide a valid determination of the chloride content of the concrete in the structure. A minimum of 10 samples from a concrete structure is recommended.

15. KEYWORDS

15.1 Chloride content; chloride profile; concrete bridges; on-site testing; reinforcement corrosion; specific ion probe.

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[1] Formerly TP 55.

Standard Method of Test for

Estimating the Cracking Tendency of Concrete

AASHTO Designation: T 334-08[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Estimating the Cracking Tendency of Concrete

AASHTO Designation: T 334-08[1]

1. SCOPE

1.1. This method covers the determination of the cracking tendency of restrained concrete specimens. The procedure determines the effects of variations in the properties of concrete as related to the time-to-cracking of concrete when restrained. The procedure is comparative and not intended to determine the time of initial cracking of concrete cast in a specific type of structure.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete

2.2. *ASTM Standards*:

- A 53/A 53M, Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
- A 501, Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing

3. SIGNIFICANCE AND USE

3.1. This test can determine the effects of concrete variations on cracking tendency. These variations might include aggregate source, aggregate gradation, aggregate-paste bond, cement type, cement content, water content, mineral admixtures, silica fume admixtures, fiber reinforcement, or chemical admixtures.

3.2. Actual cracking in service depends on many variables including bridge type, degree of restraint, hydration effects, construction and curing methods, and environmental factors. The method is useful for determining the relative likelihood of early concrete cracking and for aiding in the selection of concrete mixtures that are less likely to crack. The test method may also be modified to evaluate other factors that may affect cracking such as curing time, curing method, evaporation rate, or temperatures.

3.3. The test method measures the strain in a steel ring as a surrounding concrete ring shrinks. The time-to-cracking of the concrete ring is measured as the time when an abrupt drop in strain is seen in the steel ring. Simple visual monitoring of the time-to-first-cracking may also be useful, but it is less accurate and more time-consuming than monitoring strains, and large errors may result with visual monitoring. The test can also evaluate environmental and construction factors by modifying the test environment or curing procedures.

3.4. Other concrete tests that may be related to cracking tendency are unrestrained free-shrinkage according to T 160, compressive strength, tensile strength, elastic modulus, Poisson's ratio, and creep.

4. APPARATUS

4.1. *Steel Ring*—The standard steel ring shall have a wall thickness of 12.7 mm ± 0.4 mm ($^1/_2$ in. ± $^1/_{64}$ in.), an outside diameter of 305 mm (12 in.), and a height of 152 mm (6 in.). As shown in Figure 1, the inner and outer faces shall be machined smooth, round and true, and polished.

Note 1—Theoretical elastic analysis indicates that decreasing the steel thickness increases stresses in the steel significantly but only slightly affects concrete stresses. Bond strain gauges at four equidistant midheight locations on the interior of the steel ring.

Note 2—Structural steel pipe conforming to ASTM A 501 or A 53M/A 53 12-in. extra-strong pipe with an outside diameter of 324 mm (12$^3/_4$ in.) and wall thickness of 13 mm ($^1/_2$ in.) may be substituted, if its inner and outer faces are machined to a smooth, polished surface.

4.2. *Data Acquisition*—The data acquisition unit shall be compatible with the strain instrumentation and automatically record each strain gauge independently.

Note 3—Often when cracking occurs, only one or two gauges indicate significant strain relief.

4.3. *Forms*—The forms shall be nonabsorbent. Fabricate the base forms of resin-coated or polyethylene-coated plywood to minimize friction restraint of the concrete. Thin 3-mm ($^1/_8$-in.) polyethylene sheeting works well as the outside radius form.

4.4. *Curing*—Wet cure the top surface, using prewetted burlap covered with plastic.

4.5. *Curing and Test Room*—After wet curing, store the samples in a controlled-environment room with a constant air temperature of 21 ± 1.7°C (73.4 ± 3°F) and a relative humidity of 50 ± 4 percent. Note and record the evaporation rate near the ring surfaces as described in T 160.

5. SPECIMEN FABRICATION

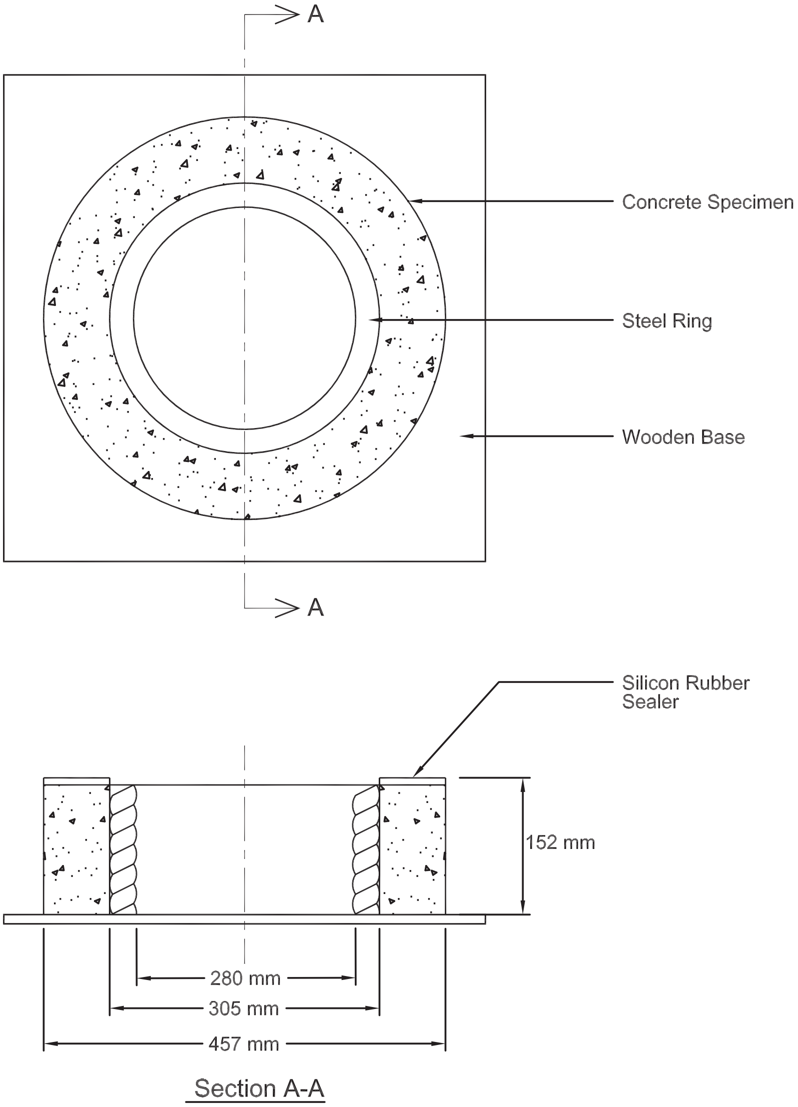
5.1. Secure the steel ring to the base with a central hold-down device during casting.

5.2. Coat the steel ring surface in contact with the concrete with a release agent such as paraffin wax dissolved in solvent or other suitable form-release agent. Do not use form-release agents on the outside radius form.

5.3. Make and cure the test ring specimens following the applicable requirements of M 210 and R 39.

5.4. Cast at least two concrete rings, using the apparatus shown in Figures 1a and 1b, for each batch. Rod the concrete into the molds in three equal lifts, using a 16-mm ($^5/_8$-in.) diameter round-nosed rod. Rod the concrete equidistantly 75 times per layer, ensuring that the rod slightly penetrates into the previous layer. Spade the inside and outside surfaces of the mold after each lift to eliminate large voids along the form faces. Lightly tap the base of the mold with a rubber mallet to close any holes left by rodding and to release any large air bubbles; do not tap on the exterior radius of the molds or on the steel ring.

Note 4—While not recommended, if external or internal vibration is used, vibrate the concrete following R 39 and record the vibration frequency and time.



Notes: 1. Not to scale.
2. Assume a tolerance of ±5 mm throughout.

Figure 1a—Cracking-Tendency Test Apparatus

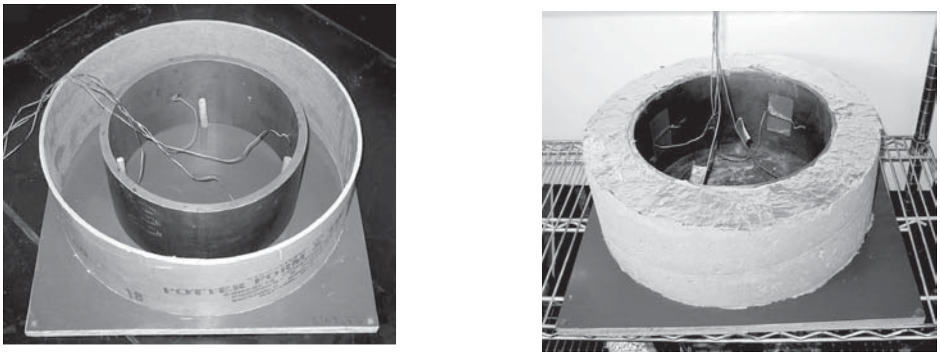


Figure 1b—Cracking-Tendency Test Apparatus (Left–Empty; Right–Full of Concrete)

5.5. After consolidation, strike off and wood-float the concrete surface. Clean any excess concrete from the top and sides of the forms to achieve a level surface. Finish with minimum manipulation necessary to achieve a finished, flat, and even surface. Immediately transfer the specimens to the cure room.

5.6. Loosen the tie-down holding the steel ring to the base form. Connect and begin monitoring the strain instrumentation immediately after placing the specimens in the cure room, cleaning the strain gauge, and connecting wires with an emery cloth before attachment. After the concrete hardens sufficiently to resist indentation of the burlap, cover the specimens with wet burlap followed by plastic. Leave undisturbed for 24 hours. Keep the burlap wet until the forms are removed.

5.7. Remove the forms from the concrete rings at an age of 24 ± 1 hours. Gently slide the ring or lift and tap the base to break the specimen free from the base form. Check that no debris is caught between the concrete and the base form. Keep the ring in contact with the base during testing or seal the bottom to prevent drying. Lightly dress the top outside edge of the concrete to remove sharp edges. Seal the top surface by running a bead of silicon caulk on the inside and outside edge of the top of the concrete ring and pressing a rubber mat or plastic into the caulk. Because some silicone caulks will corrode the steel ring, protect the top edge of the steel ring with a coat of varnish or do not allow the caulk to contact the steel.

6. TESTING

6.1. Record ambient temperatures.

6.2. Temperature compensation for the steel ring gauge readings shall be performed by monitoring a strain gauge mounted on an unstressed piece of steel.

6.3. Monitor the strains in the rings as soon after casting as practical, recording strains every 30 minutes. Measure each strain gauge separately. Every 2 to 3 days, review the strain measurements and visually inspect the ring for cracking.

Note 5—A strain decrease of more than 30 microstrain in one or more gauges usually indicates cracking.

6.4. After cracking, note the cracking pattern and crack widths on the exterior radial face. Monitor the specimens for two additional weeks after cracking, measuring crack widths so the strain decrease and crack pattern can be characterized.

6.5. Measure crack width at three equidistant locations 33, 76, and 114 mm (1.3, 3.0, and 4.5 in.) across the height of the ring and calculate the average width.

7. CALCULATION

7.1. Time-to-cracking is the age when strains measured by one or more of the strain gauges mounted on the steel ring suddenly decrease. Average the results from each specimen cast from the batch, and report the age at cracking to one-tenth of a day. If compressive strain increases in the steel ring are followed by gradual decreases and the concrete rings do not crack, report the results as "no cracking" and record the age when the test was terminated.

7.2. Plot the free-shrinkage strain of the unrestrained samples and determine the unrestrained shrinkage at the average time-to-cracking measured in accordance with T 160 (optional).

8. REPORT

8.1. *Report the following information as pertinent to the variables studied*:

8.1.1. *Properties of the Concrete Mixture*—batch materials and proportions, air content, consistency, and unit weight of fresh concrete;

8.1.2. Variations in ring dimensions, forming, casting, or curing;

8.1.3. Steel ring thickness and outside diameter;

8.1.4. Casting and curing temperatures;

8.1.5. Temperature, relative humidity, and evaporation rate of the test room;

8.1.6. Time-to-cracking in days for each specimen, and the average to one-tenth of a day;

8.1.7. Average strain of steel ring at cracking;

8.1.8. Plots of steel ring strain versus time; and

8.1.9. Average unrestrained free-shrinkage at the average time-to-cracking.

8.2. *Optional*—Pattern of the cracking and the measured crack widths on the exterior face.

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[1] Formerly AASHTO Provisional Standard PP 34.

Standard Method of Test for

Coefficient of Thermal Expansion of Hydraulic Cement Concrete

AASHTO Designation: T 336-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Coefficient of Thermal Expansion of Hydraulic Cement Concrete

AASHTO Designation: T 336-10[1]

1. SCOPE

1.1 This test method covers determination of the coefficient of thermal expansion (CTE) of hydraulic cement concrete cores and cylinders. Since it is known that the degree of saturation of concrete influences its measured coefficient of thermal expansion, the moisture condition of the concrete specimens must be controlled. For this test procedure, the specimens must be in a saturated condition.

1.2 The values stated in SI units shall be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

3. SUMMARY OF TEST METHOD

3.1 This method determines the CTE of a cylindrical concrete specimen, maintained in a saturated condition, by measuring the length change of the specimen due to a specified temperature change. The measured length change is corrected for any change in length of the measuring apparatus (previously determined), and the CTE is then calculated by dividing the corrected length change by the temperature change and then the specimen length, as described in the section on calculations.

4. SIGNIFICANCE AND USE

4.1 Measurement of the CTE permits assessment of the potential for length/volume change of concrete due to a uniform temperature change and of the potential deformation of a concrete structure due to a temperature gradient through the concrete. As an example, for pavement slabs on grade, uniform temperature change will affect the openings at joints and a temperature gradient through the thickness of these same slabs will produce curling of the slabs. Using the results of this test, better estimates of slab movement and stress development due to temperature change can be obtained.

Note 1—When using version 1.0 of the MEPDG software, AASHTO TP 60-00 (2007) should be used instead of T 336-09.

5. APPARATUS

5.1 *Concrete Saw*—Capable of sawing the ends of a cylindrical specimen perpendicular to the axis and parallel to each other.

5.2 *Balance*—A scale or balance having a capacity of 20 kg (44 lb) and an accurateness of 0.1 percent over its range.

5.3 *Caliper*—Comparator or other suitable device to measure the specimen length to the nearest 0.1 mm (0.004 in.).

5.4 *Water Bath*—A controlled-temperature water bath with a temperature range of 10 to 50°C (50 to 122°F), capable of controlling the temperature to 0.1°C (0.2°F).

5.5 *Support Frame*—A rigid support frame for the specimen to be used during length change measurement. The frame should be designed to have minimal influence on the length change measurements obtained during the test and should support the specimen such that the specimen is allowed to freely adjust to any change in temperature. A suitable support frame is described in detail in Appendix X1.

5.6 *Temperature Measuring Devices*—Four submersible temperature measuring devices with a resolution of 0.1°C (0.2°F) and an accurateness of 0.2°C (0.4°F).

5.7 *Gauge*—A submersible LVDT gauge head with excitation source and digital readout, with a minimum resolution of 0.00025 mm (0.00001 in.), and a range suitable for the test (for ease in setting up the apparatus, a range of ±3 mm (0.1 in.) has been found practical) (Note 1).

Note 2—Linear variable differential transformers (LVDTs) with the appropriate associated electronic actuating and indicating apparatus appear to give the best results with respect to stability, sensitivity, and reliability. Multichannel recording of outputs has been found to be practical and efficient. As an alternative, a data logger can be used to excite the LVDT and record the LVDT and both temperature and time outputs. The data can be stored directly in a personal computer for graphing of test results.

5.8 *Micrometer*—A micrometer or other suitable device for calibrating the LVDT over the range to be used in the test and with a minimum resolution of 0.00025 mm (0.00001 in.).

6. TEST SPECIMENS

6.1 Test specimens shall consist of drilled 100-mm (4-in.) nominal diameter cores sampled from the concrete structure being evaluated or 100-mm (4-in.) nominal diameter cylinders. Cores shall be obtained in accordance with T 24. Cylinders shall be cast in accordance with T 23 or R 39. The specimens shall be sawed perpendicular to the axis at a suitable length. A length of 180 ± 2 mm (7.0 ± 0.1 in.) has been found acceptable. The standard reference materials used for calibration and specification (see Appendix X2) shall be the same length and diameter as the test specimen so that the frame does not have to be adjusted between calibration/verification and testing. The length of the calibration specimen should be within 2.5 mm (0.1 in) of the concrete specimens intended to be tested. The sawed ends shall be flat and parallel, according to AASHTO T 22. At least two specimens should be tested per mixture.

7. PROCEDURE

7.1 *Specimen Conditioning*—The specimens shall be conditioned by submersion in saturated limewater at 23 ± 2°C (73 ± 4°F) for not less than 48 hours and until two successive weighings of the surface-dried sample at intervals of 24 hours show an increase in weight of less than 0.5 percent. A surface-dried sample is obtained by removing the surface moisture with a towel.

7.2 *LVDT Calibration*—The LVDTs should be calibrated according to the manufacturer's recommendations every 6 months or in circumstances where the CTE results are inconsistent.

7.3 *Equation Verification*—In order to verify the proper function of the LVDT and overall equipment operations, the CTE set up should be verified every month by testing a verification specimen of known CTE other than the calibration specimen. The reference specimen should have a CTE value at least 5×10^{-6} /°C less or greater than the certified value. The calibration factor should be determined again using the procedure outlined in Appendix X2.

7.4 *Testing Procedure*:

7.4.1 Place the measuring apparatus, with the LVDT attached, in the water bath and fill the bath with cold tap water. Place the four temperature sensors in the bath at locations that will provide an average temperature for the bath as a whole. The height of the water should remain constant throughout the test and be set to the same level as that used to calibrate the frame. To avoid any sticking at the points of contact with the specimen, put a very thin film of silicon grease on the end of the support buttons and the LVDT tip.

7.4.2 Remove the specimen from the saturation tank and measure its length at room temperature to the nearest 0.1 mm (0.004 in.). After measuring the length, place the specimen in the measuring apparatus located in the controlled-temperature bath, making sure that the lower end of the specimen is firmly seated against the support buttons and that the LVDT tip is seated against the upper end of the specimen (Note 2).

Note 3—The desired range of travel is the linear range of the LVDT over which it has been calibrated. The LVDT travel during the test should remain well within this range to ensure accurate results.

7.4.3 Set the temperature of the water bath to 10 ± 1°C (50 ± 2°F). When the bath reaches this temperature, allow the bath to remain at this temperature until thermal equilibrium of the specimen has been reached, as indicated by consistent readings of the LVDT to the nearest 0.00025 mm (0.00001 in.) taken every 10 minutes over a one-half hour period. Also at this time, check that the specimen is firmly seated against the support buttons, as confirmed by the LVDT reading.

7.4.4 Record the temperature readings from the four sensors to the nearest 0.1°C (0.2°F). Record the LVDT reading to the nearest 0.00025 mm (0.00001 in.). These are the initial readings.

7.4.5 Set the temperature of the water bath to 50 ± 1°C (122 ± 2°F). Once the bath has reached 50 ± 1°C (122 ± 2°F), allow the bath to remain at this temperature until thermal equilibrium of the specimen has been reached, as indicated by consistent readings of the LVDT to the nearest 0.00025 mm (0.00001 in.) taken every 10 minutes over a one-half hour period.

7.4.6 Record the temperature readings from the four sensors to the nearest 0.1°C (0.2°F). Record the LVDT reading to the nearest 0.00025 mm (0.00001 in.). These are the second readings.

7.4.7 Set the temperature of the water bath to 10 ± 1°C (50 ± 2°F). When the bath reaches this temperature, allow the bath to remain at this temperature until thermal equilibrium of the specimen has been reached, as indicated by consistent readings of the LVDT to the nearest 0.00025 mm (0.00001 in.) taken every 10 minutes over a one-half hour period.

7.4.8 Record the temperature readings from the four sensors to the nearest 0.1°C (0.2°F). Record the LVDT reading to the nearest 0.00025 mm (0.00001 in.). These are the final readings.

8. CALCULATIONS

8.1 *Coefficient of Thermal Expansion*—Calculate the CTE of one expansion or contraction test segment of a concrete specimen as follows (reported in micro strains/°C):

$$CTE = \left(\Delta L_a / L_o\right) / \Delta T \qquad (1)$$

where:

ΔL_a = actual length change of specimen during temperature change, mm, (see Equation 2);

L_o = measured length of specimen at room temperature, mm; and

ΔT = measured temperature change (average of the four sensors), °C (increase = positive, decrease = negative).

$$\Delta L_a = \Delta L_m + \Delta L_f \qquad (2)$$

where:

ΔL_m = measured length change of specimen during temperature change, mm (increase = positive, decrease = negative); and

ΔL_f = length change of the measuring apparatus during temperature change, mm. (See Equation 3.)

$$\Delta L_f = C_f \times L_o \times \Delta T \qquad (3)$$

where:

C_f = correction factor accounting for the change in length of the measurement apparatus with temperature, in.$^{-6}$/in./°C. (See Appendix X2.)

8.2 For the expansion test segment, the initial and second readings are used in the calculations. For the contraction test segment, the second and final readings are used in the calculations.

8.3 The test result is the average of the two CTE values obtained from the two test segments, provided the two values are within 0.3 micro strain/°C (0.2 micro strain/°F) of each other. If the two values are not within 0.3 micro strain/°C (0.2 micro strain/°F) of each other, one or more additional test segments are completed until two successive test segments yield CTE values within 0.3 micro strain/°C (0.2 micro strain/°F) of each other. The test result is the average of these two CTE values (Note 3).

$$CTE = \left(CTE_1 + CTE_2\right)/2 \qquad (4)$$

Note 4—Differences in successive CTEs greater than the required value sometimes occur during the first few cycles of temperature change due to minor misalignment or lack of proper initial seating of the specimen. This is usually self-correcting during the first few temperature cycles. However, it does point out the importance of carefully positioning the specimen at the start of the test.

9. REPORT

9.1 *The report shall include the following information*:

9.1.1 Identification number;

9.1.2 Specimen type, description, and source;

9.1.3 Specimen dimensions, including length and diameter;

9.1.4 Mixture proportions and aggregate type, if available;

9.1.5 All temperature and length measurements collected during the test;

9.1.6 All calculated values, including CTE data and the final CTE value;

9.1.7 The frame's correction factor, C_f, as well as the reference material used and its thermal coefficient;

9.1.8 Date of test;

9.1.9 Place of test;

9.1.10 Technician conducting the test; and

9.1.11 Any other pertinent information.

10. PRECISION AND BIAS

10.1 *Precision*—No precision has been established for this test method.

10.2 *Bias*—No bias can be established because no reference material is available for this test.

APPENDIXES

(Nonmandatory Information)

X1. SPECIMEN MEASURING APPARATUS

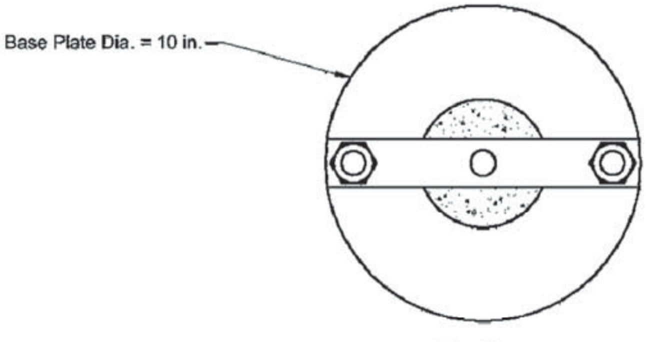
X1.1. The measuring apparatus consists of two primary components: a frame and a length change measuring device.

X1.2. *Frame*:

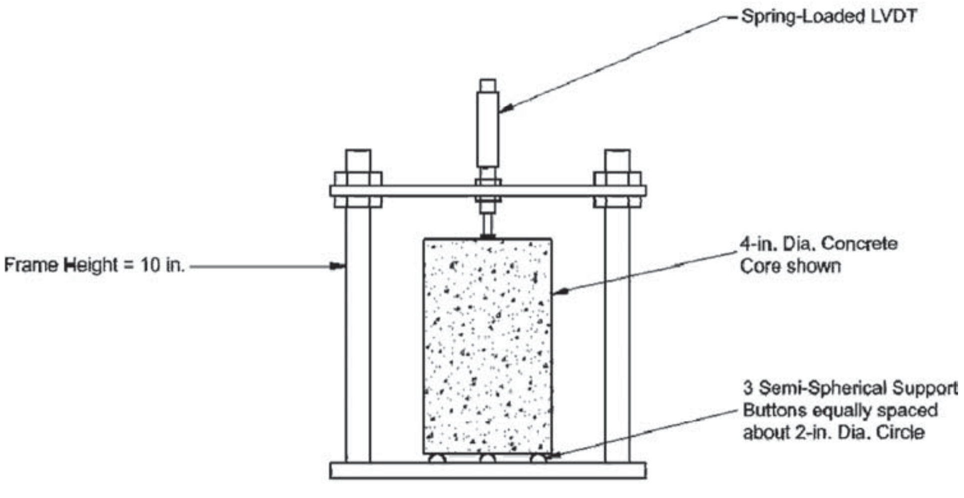
X1.2.1. Figure X1.1 shows a schematic of a suitable measuring frame. Any specimen measuring frame should be constructed with the following features in mind:

X1.2.2. Because the frame will be submerged in water throughout the test, components should be made of a noncorroding material such as stainless steel. Insofar as possible, the portions of the frame, that directly affect measurement over a change in temperature, should be constructed of Invar and protected from corrosion as necessary.

X1.2.3. The frame may be designed to be adjustable to accommodate different sample lengths; however, calibrations will be required after each adjustment.



Top View



Front View

Figure X1.1—Schematic of a Measuring Frame

X1.3. *Length Change Measurement Devices*:

X1.3.1. The sample length change may be measured using any suitable apparatus that can be submerged in water, has sufficient resolution, and gives reproducible results. Some apparatus use a submersible spring-loaded LVDT gauge head for length change measurement.

X1.3.2. Appropriate signal conditioning equipment will be required if an LVDT or other electronic transducer is used for length change measurements. A voltmeter or a computer and data acquisition software may also be required if the signal conditioning equipment does not have a digital readout. The LVDT will require calibration using a micrometer to relate the digital readout output (which may be in volts or arbitrary units) to actual length changes.

X1.3.3. The contact tip (at the point of contact between the measuring device and the specimen) must be attached to the length change measuring device with a suitable adhesive to prevent loosening during a test.

X2. REFERENCE TEST FOR DETERMINATION OF CORRECTION FACTOR

X2.1. The test procedure described in Section 7.2 is used to determine a correction factor to account for expansion of the measuring apparatus during the test. A calibration specimen with a known coefficient of thermal expansion should be used. The specimen should be composed of a material that is essentially linearly elastic, noncorroding, non-oxidizing, nonporous, and nonmagnetic, and it should have a known thermal coefficient as close as possible to that of concrete [e.g., a range of 9 to 18 × $10^{-6}/^{o}C$ within the temperature range of 10 to $50^{o}C$ (304 stainless steel is a suitable material)]. An ISO 9001 or equivalent laboratory should determine the CTE of the calibration specimen according to ASTM E 228-06 or ASTM E 289-04 within the temperature range of 10 to $50^{o}C$ and provide a certificate of the CTE value including the lot number of the sample tested. The CTE shall be marked permanently on the calibration specimen. The calibration sample should also be of the same nominal dimensions as the test samples so that no adjustment of the frame and/or the LVDT is necessary between calibration and testing.

X2.2. *Calculation of the Correction Factor*:

X2.3. Assuming that the length change of the apparatus varies linearly with temperature, the correction factor C_f is defined as:

$$C_f = \Delta L_f / L_{cs} / \Delta T \qquad (X2.1)$$

where:

ΔL_f = length change of the measuring apparatus during temperature change, mm (see Equation X2.2);

L_{cs} = measured length of calibration specimen at room temperature, mm; and

ΔT = measured temperature change, °C (increase = positive, decrease = negative).

$$\Delta L_f = \Delta L_a - \Delta L_m \qquad (X2.2)$$

where:

ΔL_a = actual length change of calibration specimen during temperature change, mm (see Equation X2.3); and

ΔL_m = measured length change of calibration specimen during temperature change, mm (increase = positive, decrease = negative).

$$\Delta L_a = L_{cs} \times \alpha_c \times \Delta T \qquad (X2.3)$$

where:

α_c = CTE of calibration specimen, °C (known).

Note X1—It is recommended that at least three calibration tests be performed and that the average of the correction factors calculated for each test be used for calculations on actual concrete tests.

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[1] Formerly AASHTO Provisional Standard TP 60.

Standard Method of Test for

Fineness of Portland Cement by the Turbidimeter

AASHTO Designation: T 98-99 (2008)[1]
ASTM Designation: C 115-96a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Fineness of Portland Cement by the Turbidimeter

AASHTO Designation: T 98-99 (2008)[1]
ASTM Designation: C 115-96a

1. SCOPE

1.1. This test method covers determination of the fineness of portland cement as represented by a calculated measure of specific surface, expressed as square centimeters of total surface area per gram, or square meters of total surface area per kilogram, of cement, using the Wagner turbidimeter.[2]

1.2. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3. The values stated in SI units are to be regarded as the standard. The inch-pound equivalents may be approximate.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- T 105, Chemical Analysis of Hydraulic Cement
- T 192, Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve

2.2. *ASTM Standard*:
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. SIGNIFICANCE AND USE

3.1. The purpose of this test method is to determine whether or not the hydraulic cement under test meets the Wagner turbidimetric fineness requirements of the applicable hydraulic cement specification for which the test is being made. Fineness of the cement component is only one of the many characteristics that influence the strength capabilities of concrete.

4. APPARATUS

4.1. *Nature of Apparatus*—The Wagner turbidimeter consists essentially of a source of light maintained at constant intensity and adjusted so that approximately parallel rays of light pass through a suspension of the cement to be tested and impinge upon the sensitive plate of a photoelectric cell. The current generated in the cell is measured by means of a microammeter and the indicated reading is a measure of the turbidity of the suspension. General considerations indicate that turbidity is in turn a measure of the surface area of the suspended sample of cement. The apparatus shall consist specifically of the parts described in Sections 4.2 through 4.7 and shall be constructed in accordance with the detailed design and dimensional requirements shown in Figure 1 and Table 1, except that the case may be either of wood or of metal.

Table 1—Turbidimeter Apparatus Dimensions (see Figure 1)

Letter	mm	in.	Letter	mm	in.
A	445	$17^{1}/_{2}$	T	51	2
B	438	$17^{1}/_{4}$	U	22	$^{7}/_{8}$
C	381	15	V	35	$1^{3}/_{8}$
D	105	$4^{1}/_{8}$	W	13	$^{1}/_{2}$
E	3	$^{1}/_{8}$	X	38	$1^{1}/_{2}$
F	29	$1^{1}/_{8}$	Y	16	$^{5}/_{8}$
G	86	$3^{3}/_{8}$	Z	38 ± 0.76	$1^{1}/_{2}$ ± 0.03
H	33	$1^{5}/_{16}$	AA	51 ± 2.5	2 ± 0.10
I	102	4	AB	267	$10^{1}/_{2}$
J	40	$1^{9}/_{16}$	AC	—	$^{5}/_{8}$[a]
K	56	$2^{3}/_{16}$	AD	—	11[a]
L	65	$2^{9}/_{16}$	AE	40	$1^{9}/_{16}$
M	29	$1^{1}/_{8}$	AF	56	$2^{3}/_{16}$
N	3	$^{1}/_{8}$	AG	67	$2^{5}/_{8}$
O	51	2	AH	203	8
P	51	2	AI	24	0.93
Q	3	$^{1}/_{8}$	AJ	1.38[a]	$3^{1}/_{2}$[a]
R	61	$2^{13}/_{32}$	AK	cm[a]	in.[a]
S	70	$2^{3}/_{4}$			

[a] These are pure numbers such as part of a thread designation and numbers of links per unit; consequently, they do not correspond with column titles.

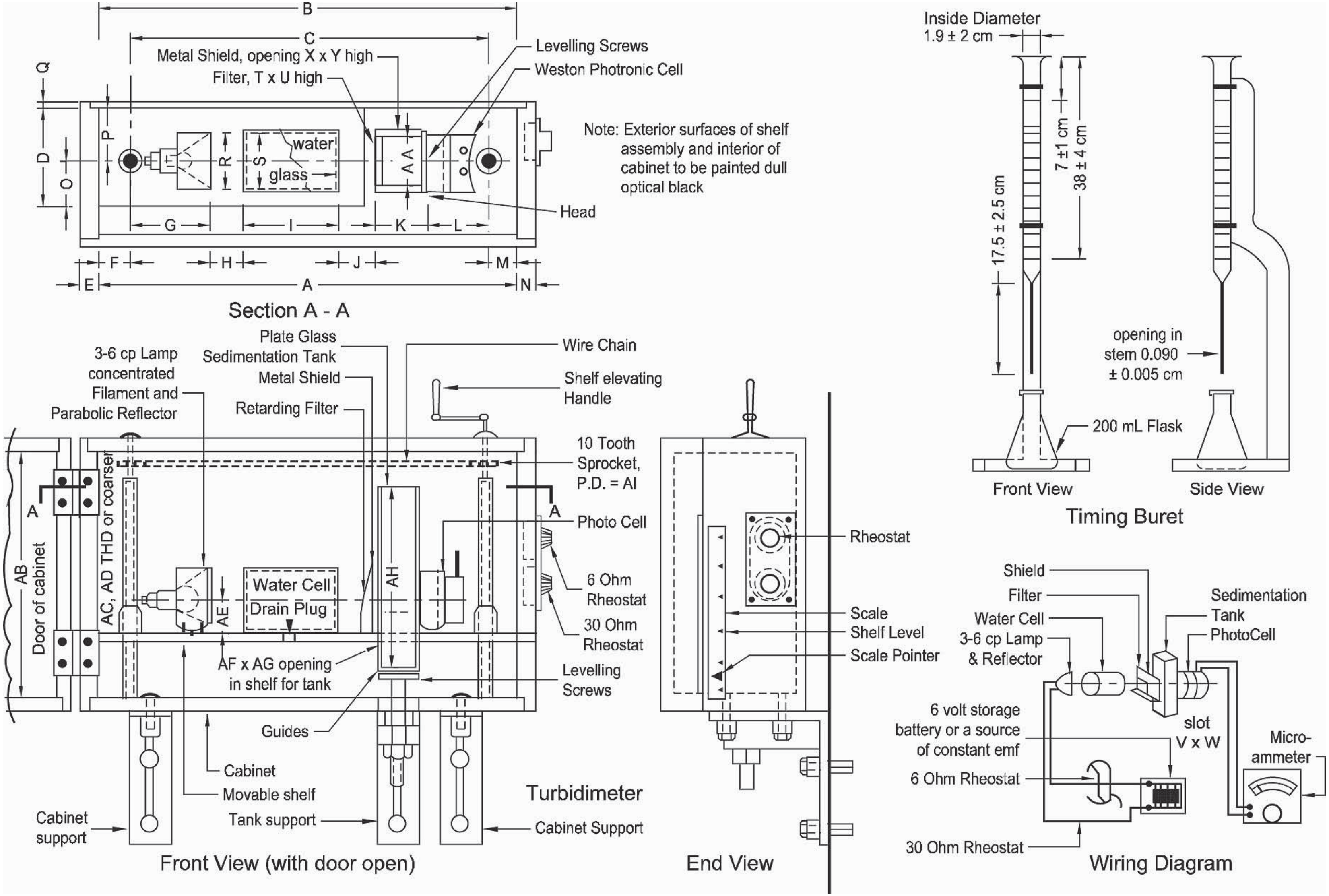


Figure 1—Dimensional Details of Turbidimeter Fineness Test Apparatus (see Table 1)

4.2. *Turbidimeter*—Mounted in a suitable wood or metal case including the following features:

4.2.1. *Source of Light*—The source of light (Figure 1) shall consist of a concentrated-filament electric lamp of between 3 and 6 cp operated by a source of constant emf. The lamp shall be mounted rigidly in the socket. A clean, bright parabolic metallic reflector shall be rigidly mounted behind the lamp, focused so that approximately parallel rays of light will pass through the sedimentation tank and impinge upon the photoelectric cell. The light intensity shall be regulated by two rheostats of approximately 6 and 30 Ω, respectively, and they shall possess such characteristics that uniform changes in light intensity may be obtained over the full range of resistance. The rheostats shall be mounted in parallel with each other and in series with the lamp.

4.2.2. *Heat-Absorbing Device*—The light shall pass through a suitable heat-absorbing device before entering the sedimentation tank in order that radiant heat from the beam shall be absorbed, the device being either (1) a water cell or (2) a special heat-absorbing glass filter. The water cell shall be made from 76-mm (3-in.) outside diameter seamless brass tubing, 3-mm ($^1/_8$-in.) thick wall, 102 mm (4 in.) in length with glass windows sealed in the ends. The cell shall contain a hole for filling with distilled water. The hole shall be sealed with a metal plug. The cell, when mounted on the movable shelf, may have the plug in either the top or bottom position. The heat-absorbing device shall be so arranged that essentially all rays of light entering the sedimentation tank shall first pass through the heat-absorbing device.

4.2.3. *Retarding Filter*—A light-retarding glass or other device shall be provided that will reduce the intensity of light from that corresponding to 100 μA to a reading of 20 to 30 μA. The light intensity shall be uniformly retarded over the entire area of that portion of the cell which is exposed to light during a test. The retarding filter shall be mounted in a carrier on the shield and shall be capable of being swung out of the light path by means of a handle.

4.2.4. *Sedimentation Tank*—The sedimentation tank shall be either (1) constructed of 5- to 6-mm ($^3/_{16}$- to $^1/_4$-in.) plate glass or borosilicate glass cemented or sealed together to form a rectangular tank, or (2) a molded glass tank having walls approximately 5 mm ($^3/_{16}$ in.) thick with plane surfaces. The inside dimensions of the rectangular tank shall be 51 by 38 mm (2 by $1^1/_2$ in.) by 203 mm (8 in.) in height. The permissible variation on the inside dimensions of the tank shall be ±2.5 mm (0.1 in.) in length and ±0.76 mm (0.03 in.) in width. The 51-mm faces of the tank shall be equidistant within 0.25 mm (0.01 in.) at all points. A mark shall be placed on the side of the tank to indicate a volumetric content of 335 mL, which is the level to which the tank will be filled in a test. A tank filled to the mark with clear kerosine and placed in the turbidimeter light beam shall yield uniform microammeter readings, within ±0.1 μA, for the entire usable portion of the tank.

4.2.5. *Photoelectric Cell*—The means of measuring the light intensity shall be a sensitive photoelectric cell[3] connected directly to a microammeter. A hood with a horizontal slot 13 mm ($^1/_2$ in.) in height by 35 mm ($1^3/_8$ in.) in width shall be mounted over the photoelectric cell. The front of the hood shall be 25 ± 1 mm (1 ± $^1/_{16}$ in.) in front of the face of the cell. The face of the photocell shall be parallel to the tank faces within 0.5 mm (0.02 in.)

4.2.6. *Shield*—A metallic shield having a slot 16 mm ($^5/_8$ in.) in height by 38.1 mm ($1^1/_2$ in.) in width, as indicated in Figure 1, shall be placed between the heat-absorbing device and the sedimentation tank.

4.2.7. *Elevating Device*—The source of the light, the heat-absorbing device, the photoelectric cell, the retarding filter, and the shield shall be mounted on a movable shelf which may be raised or lowered by two connected lead screws, and which may be readily and accurately adjusted so that the turbidity of the suspension may be determined at any desired depth. The center of the light source, the heat-absorbing device, the photocell, the center of the slots of the metal shield, and the hood shall be on a straight line, which is parallel to the shelf. The sedimentation tank shall be mounted on a base, which is independent of the rest of the apparatus so that the tank shall be free from vibration caused by moving the shelf. Care shall be taken that the shelf shall be level at all points of elevation and that the tank shall be normal to the shelf. The distance between the tank and the edges of the opening in the shelf shall vary not more than 0.4 mm ($^1/_{64}$ in.) between the "30–50" and "0" positions. The level of the light beam with reference to the surface of the suspension shall be indicated by a pointer, which will travel along a scale mounted on the cabinet. The zero of the scale shall indicate that position at which the center lines of the slots for the light beam are at the same elevation as the surface of the liquid in the tank when filled to the 335-mL level. The lines on the scale to be marked 7.5, 10, 15, 20, 25, and 30–50 shall be located at distances from the zero mark equal to suspension depth values, *h*, in Table 2.

The scale, when compared with a standard scale accurate to within 0.1 mm at all points, shall not show a deviation at any point greater than 0.25 mm and shall indicate the positions at which the pointer should be located when turbidity readings for these values of *h* are taken. The interior of the turbidimeter cabinet and the exterior surfaces of the shelf, the parabolic reflector, the heat-absorbing device, the shield, and the photoelectric cell hood shall be painted with a dull flat black paint.

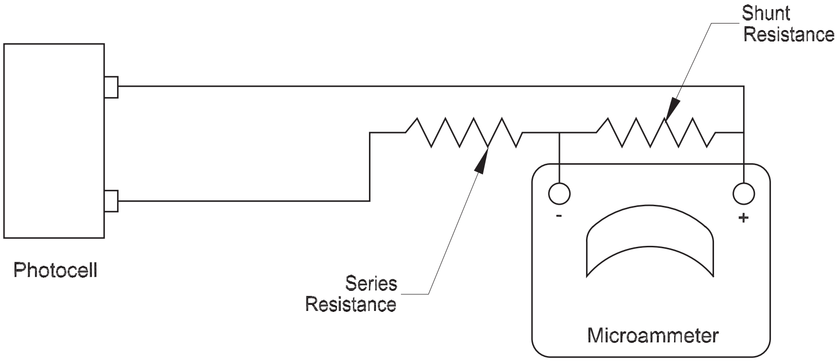
Note 1—The requirement of the 0 to 50 markings on the scale shall apply only to new Wagner Turbidimeters and not to equipment in use that meets the other requirements of this method.

Table 2—Values of *h*, *d*, and h/d^2 to Be Used in Calibration of the Turbidimeter Apparatus

Particle Diameter, *d*, μm	Depth of Suspension, *h*, cm	h/d^2
50	15	0.00600
45	15	0.00741
40	15	0.00938
35	15	0.01224
30	15	0.01667
25	13.1	0.0210
20	10	0.0250
15	6.6	0.0293
10	3.3	0.0330
7.5	2.1	0.0373

4.3. *Microammeters*:

4.3.1. D'Arsonval-Type Microammeters shall have a range from 0 to 50 μA and shall be readable to 0.1 μA. New microammeters shall be accurate to ±0.5 percent of full scale value at any part of the scale at 25ºC (77ºF). For microammeters, in use, the accuracy shall be the same as for new instruments except that the accuracy at 40 and 50 μA shall be ±1 percent of full scale. The internal resistance of the microammeter shall be between 50 and 150 Ω. The microammeter shall not be mounted upon a working surface containing or consisting of iron or steel, or near other magnetic influence.



Microammeter Internal Resistance = 90 Ω

Shunt Equivalent Resistance:

$$470\ \Omega \text{ in Parallel with } 100\Omega = \frac{470 \times 100}{470 + 100} = 82\Omega$$

Meter & Shunt Equivalent + Resistance:

$$90\ \Omega \text{ in Parallel with } 82\Omega = \frac{90 \times 82}{90 + 82} = 43\Omega$$

Series Resistance = 90 - 43 = 47Ω

Figure 2—Illustrated Example of D'Arsonval Meter Circuit for I_r Determination

4.3.2. *Digital Microammeter*:

Note 2—A meter with a range of 199.9 μA is satisfactory for use and enables the operator to read the theoretical *Io* directly without supplementary devices. The high internal resistance of the digital microammeter does not affect the linearity of readings at the light intensity levels encountered in a Wagner turbidimetric determination of fineness.

4.4. *Source of Current*—A 6-V automobile starting and lighting storage battery or a source of constant emf shall be used for supplying current to the lamp.

4.5. *Sieve*—The sieve shall conform to the requirements of T 192.

4.6. *Stirring Apparatus*—The stirring apparatus shall consist of either (1) a cylindrical brush, 19 mm ($^3/_4$ in.) in diameter and about 45 mm (1$^3/_4$ in.) in length, with an end approximately fitting the contour of the bottom of a 22-mm ($^7/_8$-in.) diameter test tube, or (2) any other stirring device that will be equally efficient in dispersion as measured by specific surface determinations on a standard sample. The stirring apparatus shall rotate at a speed of approximately 3500 r/min.

4.7. *Timing Buret*—The time of settling for the different-sized particles shall be obtained by use of a buret from which kerosine is allowed to flow. The buret shall consist of a glass tube having a capillary tube fused into the lower end. The upper end of the large tube shall be flared to serve as a funnel for introducing kerosine into the tube. The buret shall conform to the limiting dimensions given in Table 3. The graduation lines on the buret shall be complete circles. A filter made of 45-μm (No. 325) wire cloth shall be used with the timing buret and a cover shall be placed over the top of the buret when it is not in use.

4.8. *Standard Masses and Balances*—shall conform to the requirements of T 105.

Table 3—Buret Dimensions[a]

	Dimension, cm	Permissible Variation, cm
Length of large tube	38	±4
Inside diameter of large tube	1.9	±0.2
Length of capillary	17.5	±2.5
Diameter of capillary	0.09	±0.005
Top of buret to zero line	7	±1

[a] Since glass tubing of desired dimensions is not always obtainable, the wide permissible variations listed above allow selection of dimensions to produce a buret having a duration of flow which will permit calibration as described in Section 7.1.1.

5. MATERIALS

5.1. *Suspending Liquid*—Clear white kerosine shall be used with the turbidimeter apparatus. The kerosine shall not be reused.

6. TEST SPECIMEN OR SAMPLE

6.1. *Size of Test Sample*—Select the size of the sample of cement for test so that the initial microammeter reading is between 12 and 20 μA.

Note 3—The following approximations will be helpful in many instances in selecting the size of the sample: 0.25 g for normal fineness cements and 0.20 g for high fineness cements.

7. CALIBRATION

7.1. *Calibration of Turbidimeter*—Calibrate the turbidimeter apparatus in accordance with the following procedure:

7.1.1. *Calibration of Buret Scale*:

7.1.1.1. For calibration of the buret scale use a kerosine having a known viscosity and density for the temperature at which the calibration is to be made. Density and viscosity of the kerosine should be determined. Calculate the times of flow from the buret that correspond to the times of settling for the different sized particles, from the following equation:

$$t = [1{,}837{,}000\eta/(\rho_1 - \rho_2)] \times (h/d^2) \qquad (1)$$

where:

t = time of settling, or time of flow, s;
η = density of cement particles, Mg/m^3 (g/cm^3) = 3.15 for portland cement (Note 4);
ρ_1 = density of cement particles, Mg/m^3 (g/cm^3) = 3.15 for portland cement (Note 4);
ρ_2 = density of kerosine, Mg/m^3 at the temperature of calibration;
h = depth of the suspension to level of light, cm; and
d = diameter of particle, μm.

Values of h/d^2 are given in Table 2.

7.1.1.2. Fill the buret with kerosine at the calibrating temperature, start a timing clock at the instant the kerosine in the buret drains past the zero line, and mark on the buret the levels reached by the draining kerosine for each of the time intervals, t, calculated as described above. At these marks, etch permanent lines and numbers on the buret indicating the corresponding diameters (Note 5). The construction and the graduation of the buret shall be such that at the temperature of calibration the time required for the kerosine to pass the permanent lines of the buret agrees with the calculated time of settling within one percent, except that the permissible variation shall be not less than one second.

Note 4—The density of portland cement does not vary greatly and in this work it is considered constant at 3.15. A variation of 0.15 from this value when substituted in Stokes' law gives a variation of 2.5 percent in the diameter of the particle measured.

Note 5—By using the calibrated buret the apparatus may be used within the normal range of room temperatures without further correction, the change in rate of flow of the kerosine from the buret automatically compensating for change in viscosity of the suspension due to temperature. The temperature of the kerosine in the buret and that of the suspension should be kept the same within 0.5ºC (1ºF). This condition will ordinarily exist if the supply of kerosine is kept in the same room as the apparatus.

Care must be taken to ascertain that only clean kerosine is used in the buret, and, in addition, the capillary should be examined frequently to make sure that no small pieces of lint or other foreign material have become lodged in it.

7.1.2. *Calibration of 45-μm (No. 325) Sieve*—Calibration shall be made in accordance with T 192, basing the percentage sieve correction on the difference between the test residue obtained and the assigned residue value indicated by the electroformed sheet sieve fineness specified for the standard sample, expressed as a percentage of the test residue.

7.1.3. *Determination of the Proper Light Intensity, I_r:*

7.1.3.1. Fill the sedimentation tank to the mark with clear kerosine.

7.1.3.2. For a turbidimeter equipped with a digital-type microammeter with a range of 199.9 μA, place the sedimentation tank containing clear kerosine against the guides of the tank support in the turbidimeter. Set the light intensity so that the microammeter reads 100.0 μA. Readjust the light intensity until equilibrium is established at this reading. Place the light-retarding filter in the path of the light beam. When equilibrium is established, record this meter reading as I_r. This meter reading becomes the reference value for the intensity of the light. Meter readings are also taken at the beginning and end of each test through the light retarding filter alone to check the requirements of Section 8.3.8.

7.1.3.3. For a turbidimeter equipped with a D'Arsonval-type microammeter, place the sedimentation tank containing clear kerosine against the guides of the turbidimeter. Set the light intensity so that the microammeter reads 50.0 μA with the light-retarding filter removed from the light path. Readjust the light intensity until equilibrium is established at this reading. Connect resistors or resistor combinations as indicated in Figure 2 so that the meter reading is reduced to an equilibrium value between 23.0 and 25.0 μA. Increase the light intensity until the equilibrium light reading obtained between 23.0 and 25.0 μA is exactly doubled. Readjust the light intensity until the equilibrium is established at this doubled meter reading level. Place the light-retarding filter in the path of the light beam. Remove the resistors from the meter circuit. When equilibrium is established, record this meter reading as I_r. This becomes the reference value for the intensity of the light. Adjust the rheostats at the beginning of each test to give this meter reading through the filter plus the tank of clear kerosine. This meter reading corresponds to a meter reading of 100.0 μA through the tank containing clear kerosine with the light filter removed from the light path. Meter readings are also taken at the beginning and at the end of each test through the light retarding filter alone to check the requirements of Section 8.3.8.

Note 6—A half-watt carbon resistor preferably with 5 percent tolerance limits can be used to obtain the desired meter readings. The shunt resistor or resistor combination as shown in Figure 2 shall have a resistance value between 85 and 100 percent of the value of the internal resistance of the meter as printed on the card in the meter cover. The series resistor shall have a resistance value equal to the difference between the internal resistance of the meter and the calculated resistance of the meter and shunt combination.

Note 7—A less exact, but still acceptable procedure for determining a meter setting that corresponds to a current of 100.0 μA through the meter with the light filter removed from the light path can be achieved by eliminating the series resistor in the meter circuit. The internal resistance of the photocell is sufficiently large to cause only a minor error of approximately 0.5 percent in the desired setting when the series resistor is omitted from the circuit.

7.1.3.4. *Example*—If the internal resistance of the meter is 90 Ω, and the meter is shunted with a 470-Ω resistor in parallel with a 100-Ω resistor, the combined resistance of the meter and shunts would be reduced to 43 Ω. This would reduce the meter reading from 50.0 μA to a calculated value of 23.9 μA.

7.1.4. *Determination of the Value of K in the Specific Surface Equation*—Using the regular procedure in Sections 8.1, 8.2, and 8.3; and with the light adjusted in accordance with the appropriate procedure in Section 7.1.3, make a specific surface determination on the current lot of National Institute of Standards and Technology's Reference Material No. 114.[4] Determine the value of *K* in the specific surface equation in Section 10.1.1 by dividing the assigned specific surface of the standard sample by the value obtained for the expression in brackets [ ]. Repeat this calibration procedure twice more. Use the average of the three results (Note 8) obtained for the value of *K* during calibration in the specific surface equation in Section 10.1.1.

Note 8—The three individual values of *K* determined during calibration should not vary from the average value by more than 1.5 percent.

7.1.5. *Frequency of Calibration*—The turbidimeter apparatus shall be calibrated within six months prior to testing a cement sample.

8. PROCEDURE

8.1. *Sieve Determination*—Make a 45-μm (No. 325) sieve determination on a 1-g sample of cement in accordance with the procedure stated in T 192. Record the percentage (corrected) of cement passing the sieve as *r*.

8.2. *Preparation of the Suspension*:

8.2.1. *Dispersion of the Sample*—Place the cement sample in a test tube together with 10 to 15 mL of kerosine and five drops of dispersing agent—oleic acid or aged linseed oil (Note 9). Stir the mixture for 60 seconds, using the apparatus described in Section 4.6, and then transfer to the sedimentation tank. Wash the stirring apparatus and the tube with clear kerosine, which is then added together with additional clear kerosine until the total volume of the suspension in the tank is 335 mL (Note 10).

Note 9—The oleic acid, if used, shall be of USP grade. The aged linseed oil, if used, shall have a density in the range from 0.948 to 0.953 Mg/m^3 (g/cm^3). These dispersing agents have slight or no effect on the viscosity of the kerosine. Each of these dispersing agents changes with age or with exposure to heat and light—hence should be kept in well-stoppered, dark-glass bottles. Dropping bottles should be emptied, thoroughly cleaned, dried, and refilled periodically. Where conditions are such that poor dispersion is obtained with oleic acid or when foaming of the suspension occurs (possibly due to traces of water in the kerosine), aged linseed oil shall be used as the dispersing agent. The same dispersing agent shall be used for both the instrument calibration and the fineness determination.

Note 10—Since it is important that the level of the liquid in the tank coincide with the zero mark on the scale of the instrument (see Section 4.2.7), it is correspondingly important that the volume of the suspension be close to 335 mL, as specified. This may be accomplished by the use of a flask, calibrated to deliver 335 mL, from which all the kerosine used in making up a suspension is taken; or a point gage may be used, consisting essentially of a flat plate approximately 50 by 63 mm (2 by $2^1/_2$ in.), to the center of which is attached vertically a metal pin of such length that, when the plate is placed in position on top of the tank, the point of the pin is at the 335-mL level. Either of these methods should ensure the position of the liquid level within a few tenths of a millimeter.

8.2.2. *Agitation of the Suspension*—Just before placing the tank in the path of the light beam, agitate the contents to effect a uniformity of the suspension. Cover the tank with a ground-glass cover and oscillate 180º about a horizontal axis through the center of the tank, turning the tank upside down and back again to its original upright position approximately once each second for about 60 seconds (Note 11). Take care to prevent loss of kerosine (Note 12). The suspension is then ready to place in its proper position in the path of the light beam.

Note 11—The procedure described for oscillating the suspension shall be carefully followed. The procedure used in shaking a cocktail shall not be employed.

Note 12—The lid to the tank shall fit so that no kerosine drains down the outside faces of the tank. The faces of the glass tank shall be clean when the suspension is added, and care shall be taken to avoid the necessity of cleaning the faces until the determination is complete.

8.3. *Operation of Turbidimeter*—Operate the turbidimeter apparatus in accordance with the following procedure:

8.3.1. With retarding filter and sedimentation tank containing approximately 100 mL of clear kerosine in the light path, adjust the light to the intensity, I_r, as determined in Section 7.1.3, by taking repeated readings at 60-second intervals until an unchanging value indicates that the lamp and the photoelectric cell are in equilibrium. Remove the tank, check and record the intensity of the lamp.

Note 13—To protect the microammeter, the lamp shall be turned on only with a suspension or the retarding filter in position to reduce the light intensity to a value within the range of the microammeter. A freshly charged storage battery should be momentarily short-circuited to reduce the voltage to constant value. If the microammeter indication continues to fluctuate, look for loose connections in the lamp and photoelectric cell circuits, see that the rheostat contacts are clean, and make certain that the lamp, socket, and reflector are rigidly fixed in their mounting.

8.3.2. Determine the mass of the sample of cement in the appropriate amount and record the mass to the nearest 0.0002 g. Prepare a suspension in accordance with Section 8.2.

8.3.3. Place the shelf-level pointer at the 30–50 μm position.

8.3.4. Fill the buret to the predetermined height with kerosine from the same lot and at the same temperature as the kerosine used in the suspension, and start oscillation of the tank containing the suspension in accordance with Section 8.2.2. Continue the oscillation until the kerosine drains to the zero line on the buret; then stop the agitation. Immediately place the tank in position in the path of the light beam.

8.3.5. Immediately remove the retarding filter from the light path and close the cabinet door.

8.3.6. Read the microammeter to the nearest 0.1 µA at the instant the kerosine in the buret drains past marks 50, 45, 40, 35, and 30.

8.3.7. Raise the shelf successively to the marks 25, 20, 15, 10, and 7.5 on the pointer scale, reading the microammeter at each position as the kerosine drains past the corresponding mark on the buret.

8.3.8. Lower the shelf to the 30–50 µm position. Replace the filter in the path of the light beam, remove the tank, and check the intensity of the lamp. If the microammeter indication has shifted more than 0.3 µA from the initial setting through the filter alone, the test must be repeated.

9. DATA RECORDING

9.1. The form shown in Table 4 is suggested for the recording of turbidimeter data and for the calculation of specific surface.

Table 4— Illustrative Form for Recording Turbidimeter Test Data and Calculation of Specific Surface (See Note 14.)

Sample Identification	Sample
	X
Passing 45-µm (No. 325) sieve, *r*, corrected, *T*	90.4
Calibration factor, *K*	33.9
Meter reading through filter alone, µA:	
Before test	17.5
After test	17.5
Mass of sample tested, g	0.25

Particle Size, µm	*I*, µA	log *I*
50	17.3	1.238[a]
45	17.4	1.241
40	17.6	1.246
35	17.9	1.253
30	18.4	1.265
25	19.1	1.281
20	20.1	1.303
15	21.6	1.334
10	23.9	1.378
7.5	25.6	1.408[a]
	0.75 × 1.408	1.506
		1.500
	Sum =	12.857
	9.5 × 1.238	11.761
	Difference =	1.096

$S = (33.9 \times 90.4 \times 0.762)/1.096 = 2131\ \text{cm}^2/\text{g}$
(Round to 2130 cm2/g or 213 m2/kg)

[a] For convenience in calculation, log I_{50} and log $I_{7.5}$ are rounded in a separate column.

Note 14—Values shown in Table 4 are for purpose of illustration only.

10. CALCULATION

10.1. *Calculation of Specific Surface*:

10.1.1. Calculate the turbidimeter specific surface as follows:

$$S = K\left(\frac{r(2 - \log I_{50})}{1.5 + 0.75 \log I_{7.5} + \log I_{10} + \log I_{15} \ldots + \log I_{45} - 9.5 \log I_{50}}\right) \qquad (2)$$

where:

S = specific surface of the sample, m^2/kg;
K = calibration factor as determined in Section 7.1.4; and
r = corrected mass percent of sample passing the 45-μm (No. 325) sieve (Note 15), and $I_{7.5}$, I_{10}, $I_{15}\ldots$, I_{50} = microammeter readings, μA, that correspond to the particle diameters 7.5, 10, 15…, 50 μm.

Note 15—The value of K as determined in Section 7.1.3 applies only to a material having the density of portland cement (approximately 3.15 Mg/m^3 or g/cm^3). For any other material, the corresponding value must be calculated for this factor which, in the derivation of the formula, varies inversely as the density of the particles (g/cm^3).

10.1.2. To calculate the specific surface values in square meters per kilogram, multiply the surface area in cm^2/g by the factor of 0.1.

10.1.3. Round values in cm^2/g to the nearest 10 units (in m^2/kg to the nearest unit).

10.2. *Specific Surface from First Turbidity Reading* I_{50}—This test method may be used or successive determinations from the same plant, provided that the same size test samples are used and that there is no great change in fineness, color, or other properties of the cement. Under these conditions the specific surface of a sample may be calculated from the first turbidity reading, I_{50}, by using the following equation:

$$S = c(2 - \log I_{50}) \qquad (3)$$

where:

S = specific surface of the sample, m^2/kg;
I_{50} = microammeter reading corresponding to particle diameter of 50 μm; and
c = transmittancy constant for the particular plant.

Note 16—The transmittancy constant, c, may be evaluated by substituting in the above equation known values of S and $2 - \log I_{50}$ as determined from a complete turbidimeter test. The average of not less than five values of c, as determined from complete tests, should be used in the above equation.

10.3. If fineness of a sample as determined in accordance with Section 10.2 fails to conform with the specification requirements for fineness, a retest shall be made using the complete procedure in Sections 8.3, 9.1, and 10.1.

11. PRECISION AND BIAS

11.1. *Single-Operator Precision*—The single-operator coefficient of variation has been found to be 2.6 percent (Note 17). Therefore, results of two properly conducted tests by the same operator on the same sample should not differ by more than 7.3 percent (Note 13) of their average.

11.2. *Multilaboratory Precision*—The multilaboratory coefficient of variation has been found to be 3.8 percent (Note 17). Therefore, results of two different laboratories on identical samples of a material should not differ from each other by more than 10.6 percent (Note 17) of their average.

Note 17—These numbers represent, respectively, the (d1s percent) and (d2s percent) limits as described in Recommended Practice ASTM C 670.

11.3. Since there is no accepted reference material suitable for determining any bias that may be associated with this test method, no statement on bias is being made.

12. KEYWORDS

12.1. Fineness; portland cement; turbidimeter; Wagner.

APPENDIX

(Nonmandatory Information)

X1. CALCULATION OF PARTICLE-SIZE DISTRIBUTION

X1.1. For research or comparative purposes, particle-size distributions to a minimum of 7.5 µm may be of value.

X1.2. *Calculate the particle-size distribution as follows*:

The form shown in Table X1.1 is suggested for the calculation of particle-size distribution.

Table X1.1—Illustrative Form for Calculation of Particle-Size Distribution from Record Turbidimetric Test Data

Particle Size, µm	*I*, µA	$\log_1$	Difference	Average Particle Size, d_1	d_1 × Difference	Mass, Percent	
						Fractional	Cumulative
50	17.3	1.238	0.003	47.5	0.143	2.34	90.4
45	17.4	1.241	0.005	42.5	0.213	3.49	88.1
40	17.6	1.246	0.007	37.5	0.263	4.31	84.6
35	17.9	1.253	0.012	32.5	0.390	6.39	80.3
30	18.4	1.265	0.016	27.5	0.440	7.21	73.9
25	19.1	1.281	0.022	22.5	0.495	8.11	66.7
20	20.1	1.303	0.031	17.5	0.543	8.89	58.6
15	21.6	1.334	0.044	12.5	0.550	9.01	49.7
10	23.9	1.378	0.030	8.75	0.263	4.31	40.7
7.5	25.6	1.408	0.592	3.75	2.220	36.36	36.4
(0)	(100.0)	(2.000)			—		
					5.520		

$F = r/Sum\ (d_1 \times diff) = 90.4/5.520 = 16.377$

Percent fraction = $F\ (d_1 \times diff)$

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[1] Except for the use of SI units, this method agrees with ASTM C 115-96a.

[2] This turbidimeter was developed by L. A. Wagner, Research Associate of the Cement Reference Laboratory, National Institute of Standards and Technology, Washington, DC. A description of the apparatus and the original mathematical derivations of formulas used are given in the paper: Wagner, L. A., "A Rapid Method for the Determination of the Specific Surface of Portland Cement," Proceedings, ASTM, ASTEA, Vol 33, Part II, 1933, *p*. 553.

[3] Weston Photronic type, Model 594YY, is acceptable.

[4] Obtainable at the National Institute of Standards and Technology, Gaithersburg, MD 20899.

Standard Method of Test for

Chemical Analysis of Hydraulic Cement

AASHTO Designation: T 105-09[1]
ASTM Designation: C 114-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Chemical Analysis of Hydraulic Cement

AASHTO Designation: T 105-09[1]
ASTM Designation: C 114-07

1. SCOPE

1.1. These test methods cover the chemical analyses of hydraulic cements. Any test methods of demonstrated acceptable precision and bias may be used for analysis of hydraulic cements, including analyses for referee and certification purposes, as explained in Section 3. Specific chemical test methods are provided for ease of reference for those desiring to use them. They are grouped as Reference Test Methods and Alternate Test Methods. The reference test methods are long accepted classical chemical test methods, which provide a reasonably well-integrated basic scheme of analysis for hydraulic cements. The alternative test methods generally provide individual determination of specific components and may be used alone or as alternates and determinations within the basic scheme at the option of the analyst and as indicated in the individual method. The individual analyst must demonstrate achievement of acceptable precision and bias, as explained in Section 3, when these methods are used.

1.2. *Contents*:

Section	Reference Test Methods (continued)
9	Phosphorus Pentoxide
10	Titanium Dioxide
11	Zinc Oxide
12	Aluminum Oxide
13	Calcium Oxide
14	Magnesium Oxide
15	Sulfur
15.1	Sulfur Trioxide
15.2	Sulfide
16	Loss on Ignition
16.1	Portland Cement
16.2	Portland Blast-Furnace Slag Cement and Slag Cement
17	Sodium and Potassium Oxides
17.1	Total Alkalies
17.2	Water-Soluble Alkalies
18	Manganic Oxide
19	Chloride
20	Chloroform-Soluble Organic Substances
	Alternative Test Methods
21	Calcium Oxide
22	Carbon Dioxide (Reference Test Method)
23	Magnesium Oxide
24	Loss on Ignition
24.1	Portland Blast Furnace Slag Cement and Slag Cement
25	Titanium Dioxide
26	Phosporus Pentoxide
27	Manganic Oxide
28	Free Calcium Oxide

Appendixes	Title
X1	Example of Determination of Equivalence Point for the Chloride Determination
X2	CO_2 Determinations in Hydraulic Cements

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See Sections 6.3.2.1 and 14.4.1 for specific caution statements.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 240, Blended Hydraulic Cement

- T 98, Fineness of Portland Cement by the Turbidimeter
- T 127, Sampling and Amount of Testing of Hydraulic Cement

2.2. *ASTM Standards*:

- C 25, Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime
- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 275, Standard Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers
- E 350, Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron
- E 617, Standard Specification for Laboratory Weights and Precision Mass Standards
- E 832, Standard Specification for Laboratory Filter Papers

3. NUMBER OF DETERMINATIONS AND PERMISSIBLE VARIATIONS

3.1. *Referee Analyses*—The referee methods that follow in Sections 5 through 20, or other test methods qualified according to Section 3.3, are required for referee analysis in those cases where conformance to chemical specification requirements are questioned. In these cases, a cement shall not be rejected for failure to conform to chemical requirements unless all determinations of constituents involved and all necessary separations prior to the determination of any one constituent are made entirely by referenced test methods prescribed in the appropriate sections of this test method or by other qualified test methods, except when specific test methods are prescribed in the standard specification for the cement in question. The test methods actually used for the analysis shall be designated.

3.1.1. Referee analyses, when there is a question regarding acceptance, shall be made in duplicate and the analyses shall be made on different days. If the two results do not agree within the permissible variation given in Table 1, the determination shall be repeated until two or three results agree within the permissible variation. When two or three results do agree within the permissible variation, their average shall be accepted as the correct value. When an average of either two or three results can be calculated, the calculation shall be based on the three results. For the purpose of comparing analyses and calculating the average of acceptable results, the percentages shall be calculated to the nearest 0.01 (or 0.001 in the case of chloroform-soluble organic substances), although some of the average values are reported to 0.1 as indicated in the methods. When a blank determination is specified, one shall be made with each individual analysis or with each group of two or more samples analyzed on the same day for a given component.

3.1.2. Referee analyses or analyses intended for use as a basis for acceptance or rejection of a cement or for manufacturer's certification shall be made only after demonstration of precise and accurate analyses by the methods in use by meeting the requirements of Section 3.1.3, except when demonstrated under Section 3.3.2.1. Such demonstration may be made concurrently with analysis of the cement being tested and must have been made within the preceding two years. The requirements for verification of equipment and personnel are summarized in Table 2. The demonstration is required only for those constituents being used as a basis for acceptance, rejection, or certification of a cement, but may be made for any constituent of cement for which a standard exists.

Table 1—Maximum Permissible Variation in Results[a]

(Column 1) Component	(Column 2) Maximum Difference between Duplicates[d]	(Column 3) Maximum Difference of the Average of Duplicates from CRM Certificate Values[b,c,d]
SiO_2 (silicon dioxide)	0.16	±0.20
Al_2O_3 (aluminum oxide)	0.20	±0.20
Fe_2O_3 (ferric oxide)	0.10	±0.10
CaO (calcium oxide)	0.20	±0.30
MgO (magnesium oxide)	0.16	±0.20
SO_3 (sulfur trioxide)	0.10	±0.10
LOI (loss on ignition)	0.10	±0.10
Na_2O (sodium oxide)	0.03	±0.05
K_2O (potassium oxide)	0.03	±0.05
TiO_2 (titanium dioxide)	0.02	±0.03
P_2O_5 (phosphorus pentoxide)	0.03	±0.03
ZnO (zinc oxide)	0.03	±0.03
Mn_2O_3 (manganic oxide)	0.03	±0.03
S (sulfide sulfur)	0.01	[f]
Cl (chloride)	0.02	[f]
IR (insoluble residue)	0.10	[f]
Cx (free calcium oxide)	0.20	[f]
Alk_{sol} (water-soluble alkali)[e]	$0.75/^{w}$	[f]
Chl_{sol} (chloroform-soluble organic substances)	0.004	[f]

[a] When all seven CRM cements are required, as for demonstrating performance of rapid test methods, at least six of the seven shall be within the prescribed limits and the seventh shall differ by no more than twice that value. When more than seven CRMs are used, as for demonstrating the performance of rapid test methods, at least 77 percent shall be within the prescribed limits, and the remainder no more than twice the value. When a lesser number of CRM cements are required, all of the values shall be within the prescribed limits.

[b] Interelement corrections may be used for any oxide standardization provided improved accuracy can be demonstrated when correction is applied to all seven CRM cements.

[c] Where an CRM certificate value includes a subscript number, that subscript number shall be treated as a valid significant figure.

[d] Where no value appears in Column 3, CRM certificate values do not exist. In such cases, only the requirement for differences between duplicates shall apply.

[e] w = mass, in grams, of samples used for the test.

[f] Not Applicable. No certificate value given.

3.1.3. Initial qualification of the operator/analyst shall be demonstrated by analysis of each constituent of concern in at least one CRM cement (Note 1) no matter what test method is used (for example, gravimetric, instrumental). Duplicate samples shall be run on different days. The same test methods to be used for analysis of cement being tested shall be used for analysis of the CRM cement. If the duplicate results do not agree within the permissible variation given in Table 1, the determinations shall be repeated, following identification and correction of problems or errors, until a set of duplicate results do agree within the permissible variation.

Note 1—The term CRM (Certified Reference Material) samples refers to National Institute of Standards and Technology (NIST) Hydraulic-Cement Chemical Standard Reference Materials, or other acceptable reference cement as defined in Section 3.1.6.

Table 2—Minimum Number of CRMs Required for Qualification of Chemical Testing

	Method Type	
	Reference[a]	Other[b]
Equipment Qualification	None	7
Operator Qualification[c]	1	1

[a] Reference Methods are those outlined in Sections 5 through 20.

[b] These may be any test method as described in Section 3.2 or any instrumental or rapid test method, which must be qualified in accordance with Section 3.3.

[c] Each operator performing acceptance or reference analyses must be qualified in accordance with Section 3.1.3 at a frequency of two years. If qualification of the instrument is completed by a single operator, the operator has demonstrated individual qualifications per Section 3.1.3.

3.1.4. The average of the results of acceptable duplicate determinations for each constituent may differ from the CRM value by no more than the value shown in Column 2 of Table 1 after correction for minor components when needed.

3.1.5. Data demonstrating that precise and accurate results were obtained with CRM cements by the same analyst making the acceptance determination shall be made available on request to all parties concerned when there is a question of acceptance of a cement. If the CRM used is not a NIST cement, the traceability documentation of the CRM used shall also be made available on request.

3.1.6. Acceptable reference cements are NIST CRMs (Note 1), or other reference cements traceable to the NIST CRMs. The reference cement must have an assigned value for the analyte being determined. Traceability consists of documentary evidence that the assigned values of the reference cement are compatible with the certified values of NIST CRMs. To demonstrate traceability for a given analyte, perform a referee analysis (as defined in Section 3.1) on the proposed reference cement, using a NIST CRM for demonstration of precision and accuracy. The reference cement is acceptable if its assigned value agrees with the average referee value within the limits given in Column 3 of Table 1. If the reference cement, as supplied, has no documented guarantee of homogeneity, establish its homogeneity by analyzing at least six randomly selected samples. No result shall deviate from the assigned value by more than the limits given in Column 2 of Table 1. Acceptable reference cement must be accompanied by a document showing the data produced in demonstrating traceability and homogeneity.

3.2. *Optional Analyses*—The alternative test methods provide, in some cases, procedures that are shorter or more convenient to use for routine determination of certain constituents than are the referenced test methods (Note 2). Longer, more complex procedures, in some instances, have been retained as alternative test methods to permit comparison of results by different procedures or for use when unusual materials are being examined, where unusual interferences may be suspected, or when unusual preparation for analysis is required. Test results from alternative test methods may be used as a basis for acceptance or rejection when it is clear that a cement does or does not meet the specification requirement. Any change in test method procedures from those procedures listed in Sections 5 through 28 requires method qualification in accordance with Section 3.3.

Note 2—It is not intended that the use of reference test methods be confined to referee analysis. A reference test method may be used in preference to an alternate test method when so desired. A reference test method must be used where an alternate method is not provided.

3.2.1. Duplicate analyses and blank determinations are not required when using the alternative test methods. If, however, a blank determination is desired for an alternative test method, one may be used and it need not have been obtained concurrently with the analysis. The final results, when corrected for blank values, should, in either case, be so designated.

3.3. *Performance Requirements for Rapid Test Methods*:[2]

3.3.1. *Definition and Scope*—Where analytical data obtained in accordance with this test method are required, any method may be used that meets the requirements of Section 3.3.2. A test method is considered to consist of the specific procedures, reagents, supplies, equipment, instrument, etc., selected and used in a consistent manner by a specific laboratory. See Note 3 for examples of procedures.

Note 3—Examples of methods used successfully by their authors for analysis of hydraulic cement are given in the list of references. Included are test methods using atomic absorption X-ray spectrometry, and spectrophotometry-EDTA.

3.3.1.1. If more than one instrument, even though substantially identical, is used in a specific laboratory for the same analyses, use of each instrument shall constitute a separate test method and each must be qualified separately.

3.3.2. *Qualification of a Test Method*—Prior to use for analysis of hydraulic cement, each test method (see Section 3.3.1) must be qualified individually for such analysis. Qualification data, or if applicable, requalification data, shall be made available pursuant to the Manufacturer's Certification Section of the appropriate hydraulic cement specification.

3.3.2.1. Using the test method chosen, make single determinations for each oxide under consideration on at least any seven of the CRM samples (Note 1). Complete two rounds of tests on nonconsecutive days repeating all steps of sample preparations. Calculate the differences between values and averages of the values from the two rounds of tests.

3.3.2.2. When seven CRMs are used in the qualification procedure, at least six of the seven differences between duplicates obtained of any single component shall not exceed the limits shown in Column 2 of Table 1 and the remaining differences by no more than twice that value. When more than seven CRMs are used, the values for at least 77 percent of the samples shall be within the prescribed limits, while the values for the remainder shall differ by no more than twice that value.

3.3.2.3. For each component and each CRM, the average obtained shall be compared to the certified concentrations. Where a certificate value includes a subscript number, that subscript shall be assumed to be a significant number. When seven CRMs are used in the qualification procedure, at least six of the seven averages for each component (oxide) shall not differ from the certified concentrations by more than the value shown in Column 3 of Table 1, and the remaining average by more than twice that value. When more than seven CRMs are used in the qualification procedure, at least 77 percent of the averages for each component (oxide) shall not differ from the certified concentrations by more than the value shown in Column 3 of Table 1, and the remaining average(s) by more than twice that value.

3.3.2.4. The standardization, if needed, used for qualification and for analysis of each constituent shall be determined by valid curve-fitting procedures. The qualification testing shall be conducted with newly prepared specimens. A point-to-point, saw-tooth curve that is artificially made to fit a set of data points does not constitute a valid curve-fitting procedure. A complex polynomial drawn through the points is similarly not valid. For the same reason, empirical inter-element corrections may be used only if $\leq (N - 3)/2$ are employed, where N is the number of different standards used. The qualification testing shall be conducted with specimens newly prepared from scratch, including all the preparation stages applicable for analysis of an unknown sample, and employing the reagents currently in use for unknown analyses.

3.3.3. *Partial Results*—Test methods that provide acceptable results for some components but not for others may be used only for those components for which acceptable results are obtained.

3.3.4. *Report of Results*—Chemical analyses obtained by qualified rapid test methods and reported pursuant to the Manufacturer's Certification Section of the appropriate hydraulic cement specification shall be indicated as having been obtained by rapid methods and the type of test method used shall be designated.

3.3.5. *Rejection of Material*—See Sections 3.1 and 3.2.

3.3.6. *Requalification of a Test Method*:

3.3.6.1. Requalification of a test method shall be required upon receipt of substantial evidence that the test method may not be providing data in accordance with Table 1 for one or more constituents. Such requalification may be limited to those constituents indicated to be in error and shall be carried out prior to further use of the test method for analysis of those constituents.

3.3.6.2. Substantial evidence that a test method may not be providing data in accordance with Table 1 shall be considered to have been received when a laboratory is informed that analysis of the same material by Reference Test Methods run in accordance with Section 3.1.1, the final average of a CCRL sample, a certificate value of an NIST CRM, the assigned value of an alternate CRM or an accepted value of a known secondary standard differs from the value obtained by the test method in question by more than twice the value shown in Column 2 of Table 1 for one or more constituents. When indirect test methods are involved, as when a value is obtained by difference, corrections shall be made for minor constituents in order to put analyses on a comparable basis prior to determining the differences. (See Note 4.) For any constituents affected, a test method also shall be requalified after any substantial repair or replacement of one or more critical components of an instrument essential to the test method.

Note 4—Instrumental analyses can usually detect only the element sought. Therefore, to avoid controversy, the actual procedure used for the elemental analyses should be noted when actual differences with reference procedures can exist. For example, P_2O_5 and TiO_2 are included with Al_2O_3 in the usual wet test method and sulfide sulfur is included in most instrumental procedures with SO_3.

3.3.6.3. If an instrument or piece of equipment is replaced, even if by one of identical make or model, or is significantly modified, a previously qualified test method using such new or modified instrument or equipment shall be considered a new test method and must be qualified in accordance with Section 3.3.2.

3.4. *Precision and Bias*—Different analytical test methods are subject to individual limits of precision and bias. It is the responsibility of the user to demonstrate that the test methods used at least meet the limits of precision and bias shown in Table 1.

4. GENERAL

4.1. *Interferences and Limitations*:

4.1.1. These test methods were developed primarily for the analysis of portland cements. However, except for limitations noted in the procedure for specific constituents, the reference test methods provide for accurate analyses of other hydraulic cements that are completely decomposed by hydrochloric acid or where a preliminary sodium carbonate fusion is made to ensure complete solubility. Some of the alternate test methods may not always provide accurate results because of interferences from elements that are not removed during the procedure.

4.1.2. When using a test method that determines total sulfur, such as most instrumental test methods, sulfide sulfur will be determined with sulfate and included as such. In most hydraulic cements, the difference resulting from such inclusion will be insignificant, less than 0.05 percent weight. In some cases, notably slags and slag-containing cements but sometimes other cements as well, significant levels of sulfide may be present. In such cases, especially if there is a question of meeting or not meeting a specification limit or when the most accurate results are desired, analytical test methods shall be chosen so that sulfate and sulfide can be reported separately.

4.2. *Apparatus and Materials*:

4.2.1. *Balance*—The analytical balance used in the chemical determinations shall conform to the following requirements:

4.2.1.1. The balance shall have a capacity of not more than 200 g. It may be of conventional design, either with or without "quick-mass determination" devices, or it may be a constant-load, direct-reading type. It shall be capable of reproducing results within 0.2 mg with an accuracy of ±0.2 mg. Direct-reading balances shall have a sensitivity not exceeding 0.1 mg (Note 5). Conventional two-pan balances shall have a maximum sensibility reciprocal of 0.3 mg. Any rapid mass determination device that may be provided, such as a chain, damped motion, or heavy riders, shall not increase the basic inaccuracy by more than 0.1 mg at any reading and with any load within the rated capacity of the balance.

Note 5—The sensitivity of a direct-reading balance is the mass required to change the reading one graduation. The sensibility reciprocal for a conventional balance is defined as the change in mass required on either pan to change the position of equilibrium one division on the pointer scale at capacity or at any lesser load.

4.2.2. *Standard Masses*—Standard masses used for analysis shall conform to Types I or II, Grades S or O, Classes 1, 2, or 3 as described in ASTM E 617. They shall be checked at least once a year, or when questioned, and adjusted at least to within allowable tolerances for Class 3 standard masses (Note 6). For this purpose each laboratory shall also maintain, or have available for use, a reference set of standard masses from 50 g to 10 mg, which shall conform at least to Class 3 requirements and be calibrated at intervals not exceeding five years by the National Institute of Standards and Technology (NIST). After initial calibration, recalibration by NIST may be waived provided it can be shown by documented data obtained within the time interval specified that a mass comparison between summations of smaller masses and a single larger mass nominally equal to that summation, establishes that the allowable tolerances have not been exceeded. All new sets of weights purchased shall have the masses of 1 g and larger made of stainless steel or other corrosion-resisting alloy not requiring protective coating, and shall meet the density requirements for Grades S or O.

Note 6—The scientific supply houses do not presently list masses as meeting ASTM E 617. They list masses as meeting NIST or International Organization of Legal Metrology (OIML) standards. The situation with regard to masses is in a state of flux because of the trend toward internationalization. Hopefully, this will soon be resolved. NIST Classes S and S-1 and OIML Class F_1 masses meet the requirements of this standard.

4.2.3. *Glassware and Laboratory Containers*—Standard volumetric flasks, burets, and pipets should be of precision grade or better. Standard-taper, interchangeable, ground-glass joints are recommended for all volumetric glassware and distilling apparatus, when available. Wherever applicable, the use of special types of glassware, such as colored glass, for the protection of solutions against light, alkali-resistant glass, and high-silica glass having exceptional resistance to thermal shock is recommended. Polyethylene containers are recommended for all aqueous solutions of alkalies and for standard solutions where the presence of dissolved silica or alkali from the glass would be objectionable. Such containers shall be made of high-density polyethylene having a wall thickness of at least 1 mm.

4.2.4. *Desiccators*—Desiccators shall be provided with a good desiccant, such as magnesium perchlorate, activated alumina, or sulfuric acid. Anhydrous calcium sulfate may also be used provided it has been treated with a color-change indicator to show when it has lost its effectiveness. Calcium chloride is not a satisfactory desiccant for this type of analysis.

4.2.5. *Filter Paper*—Filter paper shall conform to the requirements of ASTM E 832, Type II, Quantitative. When coarse-textured paper is required, Class E paper shall be used; when medium-textured paper is required, Class F paper shall be used; and when retentive paper is required, Class G shall be used.

4.2.6. *Crucibles*—Platinum crucibles for ordinary chemical analysis should preferably be made of pure unalloyed platinum and be of 15 to 30-mL capacity. Where alloyed platinum is used for greater stiffness or to obviate sticking of crucible and lid, the alloyed platinum should not decrease in mass by more than 0.2 mg when heated at 1200°C for one hour.

4.2.7. *Muffle Furnace*—The muffle furnace shall be capable of operation at the temperatures required and shall have an indicating pyrometer accurate within ±25°C, as corrected, if necessary, by calibration. More than one furnace may be used provided each is used within its proper operating temperature range.

4.3. *Reagents*:

4.3.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[3] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

4.3.2. Unless otherwise indicated, references to water shall mean water conforming to the numerical limits for type II reagent water described in ASTM D 1193.

4.3.3. *Concentration of Reagents*:

4.3.3.1. *Prepackaged Reagents*—Commercial prepackaged standard solutions or diluted prepackaged concentrations of a reagent may be used whenever that reagent is called for in the procedures provided that the purity and concentrations are as specified. Verify purity and concentration of such reagents by suitable tests.

4.3.3.2. *Concentrated Acids and Ammonium Hydroxide*—When acids and ammonium hydroxide are specified by name or chemical formula only, it shall be understood that concentrated reagents of the following specific gravities or concentrations by mass are intended:

Acetic acid ($HC_2H_3O_2$)	99.5 percent
Hydrochloric acid (HCl)	sp gr 1.19
Hydrofluoric acid (HF)	48 percent
Nitric acid (HNO_3)	sp gr 1.42
Phosphoric acid (H_3PO_4)	85 percent
Sulfuric acid (H_2SO_4)	sp gr 1.84
Ammonium hydroxide (NH_4OH)	sp gr 0.90

4.3.3.3. The desired specific gravities or concentrations of all other concentrated acids shall be stated whenever they are specified.

4.3.4. *Diluted Acids and Ammonium Hydroxide*—Concentrations of diluted acids and ammonium hydroxide, except when standardized, are specified as a ratio stating the number of volumes of the concentrated reagent to be added to a given number of volumes of water, for example: HCl (1 + 99) means 1 volume of concentrated HCl (sp gr 1.19) added to 99 volumes of water.

4.3.5. *Standard Solutions*—Concentrations of standard solutions shall be expressed as normalities (*N*) or as equivalents in grams per milliliter of the component to be determined, for example: 0.1 (*N*) $Na_2S_2O_3$ solution or $K_2Cr_2O_7$ (1 mL = 4 mg Fe_2O_3). The average of at least three determinations shall be used for all standardizations. When a material is used as a primary standard, reference has generally been made to the standard furnished by NIST. However, when primary standard grade materials are otherwise available they may be used or the purity of a salt may be determined by suitable tests.

4.3.6. *Nonstandardized Solutions*—Concentrations of nonstandardized solutions prepared by dissolving a given mass of the solid reagent in a solvent shall be specified in grams of the reagent per liter of solution, and it shall be understood that water is the solvent unless otherwise specified, for example: NaOH solution (10 g/L) means 10 g of NaOH dissolved in water and diluted with water to 1 L. Other nonstandardized solutions may be specified by name only, and the concentration of such solutions will be governed by the instructions for their preparation.

4.3.7. *Indicator Solutions*:

4.3.7.1. *Methyl Red*—Prepare the solution on the basis of 2 g of methyl red/L of 95 percent ethyl alcohol.

4.3.7.2. *Phenolphthalein*—Prepare the solution on the basis of 1 g of phenolphthalein/L of 95 percent ethyl alcohol.

4.4. *Sample Preparation*:

4.4.1. Before testing, pass representative portions of each sample through an 850-µm (No. 20) sieve, or any other sieve having approximately eight openings per 10 mm (20 openings per l in.) in order to mix the sample, break up lumps, and remove foreign materials. Discard the foreign materials and hardened lumps that do not break up on sieving or brushing.

4.4.2. By means of a sample splitter or by quartering, the representative sample shall be reduced to a laboratory sample of at least 50 g. Where larger quantities are required for additional determinations such as water-soluble alkali, chloride, duplicate testing, etc., prepare a sample of at least 100 g.

4.4.3. Pass the laboratory sample through a 150-µm (No. 100) sieve. Further grind the sieve residue so that it also passes the 150-µm sieve determinations. Homogenize the entire sample by again passing it through the sieve.

4.4.4. Transfer the sample to a clean, dry glass container with an airtight lid and further mix the sample thoroughly.

4.4.5. Expedite the above procedure so that the sample is exposed to the atmosphere for a minimum time.

4.5. *General Procedures*:

4.5.1. *Mass Determinations*—The calculations included in the individual test methods assume that the exact mass specified has been used. Samples that are approximately but not exactly equal to the mass specified may be used provided appropriate corrections are made in the calculations. Unless otherwise stated, the mass of all samples and residues should be recorded to the nearest 0.1 mg.

4.5.2. *Tared or Weighed Crucibles*—The tare mass of crucibles shall be determined by preheating the empty crucible to constant mass at the same temperature and under the same conditions as shall be used for the final ignition of a residue and cooling in a desiccator for the same period of time used for the crucible containing the residue.

4.5.3. *Constancy of the Mass of Ignited Residues*—To definitely establish the constancy of mass of an ignited residue for referee purposes, the residue shall be ignited at the specified temperature and for the specified time, cooled to room temperature in a desiccator, and its mass determined. The residue shall then be reheated for at least 30 minutes, cooled to room temperature in a desiccator, and its mass determined. If the two masses do not differ by more than 0.2 mg, constant mass is considered to have been attained. If the difference in mass is greater than 0.2 mg, additional ignition periods are required until two consecutive mass determinations agree within the specified limits. For ignition loss, each reheating period shall be five minutes.

4.5.4. *Volatilization of Platinum*—The possibility of volatilization of platinum or alloying constituents from the crucibles must be considered. On reheating, if the crucible and residue lose the same mass (within 0.2 mg) as the crucible containing the blank, constant mass can be assumed. Crucibles of the same size, composition, and history shall be used for both the sample and the blank.

4.5.5. *Calculation*—In all operations on a set of observed values such as manual multiplication or division, retain the equivalent of at least two more places of figures than in the single observed values. For example, if observed values are read or determined to the nearest 0.1 mg, carry numbers to the nearest 0.001 mg in calculation. When using electronic calculators or computers for calculations, perform no rounding, except in final report value.

4.5.6. *Rounding Figures*—Rounding of figures to the number of significant places required in the report should be done after calculations are completed, in order to keep the final results substantially free of calculation errors. The rounding procedure should follow the principle outlined in ASTM E 29.[4] In assessing analyst-and method-qualification in accordance with Section 3, the individual duplicate results, the difference between them, the average of duplicates on CRMs, and the difference of this average from the certificate value shall be left un-rounded for comparison with the required limits. Round results for reporting as shown in Table 3 (Note 7).

Note 7—The rounding procedure referred to in Section 4.5.6, in effect, drops all digits beyond the number of places to be retained if the next figure is less than five. If it is more than five, or equal to five and subsequent places contain a digit other than zero, then the last retained digit is increased by one. When the next digit is equal to five and all other subsequent digits are zero, the last digit to be retained is unchanged when it is even and increased by one when it is odd. For example, 3.96 (50) remains 3.96, but 3.95 (50) becomes 3.96.

4.6. *Recommended Order for Reporting Analyses*—The following order is recommended for reporting the results of chemical analysis of portland cement:

4.6.1. *Major Components*:

- SiO_2 (silicon dioxide)
- Al_2O_3 (aluminum oxide)
- Fe_2O_3 (ferric oxide)
- CaO (calcium oxide)
- MgO (magnesium oxide)
- SO_3 (sulfur trioxide)
- LOI (loss on ignition)

4.6.2. *Minor Components*:

- Na_2O (sodium oxide)
- K_2O (potassium oxide)
- TiO_2 (titanium dioxide)
- P_2O_5 (phosphorus pentoxide)
- ZnO (zinc oxide)
- Mn_2O_3 (manganic oxide)
- S (sulfide sulfur)

4.6.3. *Separate Determinations*:

- IR (insoluble residue)
- Cx (free calcium oxide)
- CO_2 (carbon dioxide)
- Alk_{sol} (water soluble alkali)
- Chl_{sol} (chloroform-soluble organic substances)

REFERENCE TEST METHODS

5. INSOLUBLE RESIDUE (REFERENCE TEST METHOD)

5.1. *Summary of Test Method*:

5.1.1. In this test method, insoluble residue of a cement is determined by digestion of the sample in hydrochloric acid followed, after filtration, by further digestion in sodium hydroxide. The resulting residue is ignited and the mass is determined (Note 8).

Note 8—This test method or any other test method designed for the estimation of an acid-insoluble substance in any type of cement is empirical, because the amount obtained depends on the reagents and the time and temperature of digestion. If the amount is large, there may be a little variation in duplicate determination. The procedure should be followed closely in order to reduce the variation to a minimum.

5.1.2. When the test method is used on blended cement, the decomposition in acid is considered to be complete when the portland cement clinker is decomposed completely. An ammonium nitrate solution is used in the final washing to prevent finely ground insoluble material from passing through the filter paper.

5.2. *Reagents*:

5.2.1. *Ammonium Nitrate Solution* (20 g NH_4NO_3/L).

5.2.2. *Sodium Hydroxide Solution* (10 g NaOH/L).

Table 3—Rounding of Reported Results

Component	Decimal Places
SiO_2 (silicon dioxide)	1
Al_2O_3 (aluminum oxide)	1
Fe_2O_3 (ferric oxide)	2
CaO (calcium oxide)	1
MgO (magnesium oxide)	1
SO_3 (sulfur trioxide)	2
LOI (loss on ignition)	1
Na_2O (sodium oxide)	2
K_2O (potassium oxide)	2
SrO (strontium oxide)	2
TiO_2 (titanium dioxide)	2
P_2O_5 (phosphorous pentoxide)	2
ZnO (zinc oxide)	2
Mn_2O_3 (manganic oxide)	3
S (sulfide sulfur)	2
Cl (chloride)	3
IR (insoluble residue)	2
Cx (free calcium oxide)	1
CO_2 (carbon dioxide)	1
Alk_{sol} (water-soluble alkali)	2
Chl_{sol} (chloroform-soluble organic substances)	3

5.3. *Procedure*:

5.3.1. To 1 g of the sample (Note 9) add 25 mL of cold water. Disperse the cement in the water and while swirling the mixture, quickly add 5 mL of HCl. If necessary, warm the solution gently, and grind the material with the flattened end of a glass rod for a few minutes until it is evident that decomposition of the cement is complete (Note 10). Dilute the solution to 50 mL with hot water (nearly boiling) and heat the covered mixture rapidly to near boiling by means of a high-temperature hot plate. Then digest the covered mixture for 15 minutes at a temperature just below boiling (Note 11). Filter the solution through a medium-textured paper into a 400-mL beaker, wash the beaker, paper, and residue thoroughly with hot water, and reserve the filtrate for the sulfur trioxide determination, if desired (Note 12). Transfer the filter paper and contents to the original beaker, add 100 mL of hot (near boiling) NaOH solution (10 g/L), and digest at a temperature just below boiling for 15 minutes. During the digestion, occasionally stir the mixture and macerate the filter paper. Acidify the solution with HCl using methyl red as the indicator and add an excess of four or five drops of HCl. Filter through medium-textured paper and wash the residue at least 14 times with hot NH_4NO_3 solution (20 g/L) making certain to wash the entire filter paper and contents during each washing. Ignite the residue in a tared platinum crucible at 900 to 1000°C, cool in a desiccator, and determine the mass.

Note 9—If sulfur trioxide is to be determined by turbidimetry it is permissible to determine the insoluble residue on a 0.5-g sample. In this event, the percentage of insoluble residue should be calculated to the nearest 0.01 by multiplying the mass of residue obtained by 200. However, the cement should not be rejected for failure to meet the insoluble residue requirement unless a 1-g sample has been used.

Note 10—If a sample of portland cement contains an appreciable amount of manganic oxide, there may be brown compounds of manganese which dissolve slowly in cold diluted HCl but rapidly in hot HCl in the specified strength. In all cases, dilute the solution as soon as decomposition is complete.

Note 11—In order to keep the solutions closer to the boiling temperature, it is recommended that these digestions be carried out on an electric hot plate rather than in a steam bath.

Note 12—Continue with the sulfur trioxide determination (Sections 15.1.2.1 through 15.1.3) by diluting to 250 or 200 mL as required by the appropriate section.

5.3.2. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

5.4. *Calculation*—Calculate the percentage of the insoluble residue to the nearest 0.01 by multiplying the mass in grams of the residue (corrected for the blank) by 100.

6. SILICON DIOXIDE (REFERENCE TEST METHOD)

6.1. *Selection of Test Method*—For cements other than portland and for which the insoluble residue is unknown, determine the insoluble residue in accordance with Section 5 of these test methods. For portland cements and other cements having an insoluble residue less than 1 percent, proceed in accordance with Section 6.2. For cements having an insoluble residue greater than 1 percent proceed in accordance with Section 6.3.

6.2. *Silicon Dioxide in Portland Cements and Cements with Low Insoluble Residue*:

6.2.1. *Summary of Test Method*—In this test method silicon dioxide (SiO_2) is determined gravimetrically. Ammonium chloride is added and the solution is not evaporated to dryness. This test method was developed primarily for hydraulic cements that are almost completely decomposed by hydrochloric acid and should not be used for hydraulic cements that contain large amounts of acid-insoluble material and require a preliminary sodium carbonate fusion. For such cements or if prescribed in the standard specification for the cement being analyzed, the more lengthy procedure in Section 6.3 shall be used.

6.2.2. *Reagent*—Ammonium chloride (NH_4Cl).

6.2.3. *Procedure*:

6.2.3.1. Mix thoroughly 0.5 g of the sample and about 0.5 g of NH_4Cl in a 50-mL beaker, cover the beaker with a watch glass, and add cautiously 5 mL of HCl, allowing the acid to run down the lip of the covered beaker. After the chemical action has subsided, lift the cover, add 1 or 2 drops of HNO_3, stir the mixture with a glass rod, replace the cover, and set the beaker on a steam bath for 30 minutes (Note 13). During this time of digestion, stir the contents occasionally and break up any remaining lumps to facilitate the complete decomposition of the cement. Fit a medium-textured filter paper to a funnel, transfer the jelly-like mass of silicic acid to the filter as completely as possible without dilution, and allow the solution to drain through. Scrub the beaker with a policeman and rinse the beaker and policeman with hot HCl (1 + 99). Wash the filter two or three times with hot HC1 (1 + 99) and then with ten or twelve small portions of hot water, allowing each portion to drain through completely. Reserve the filtrate and washings for the determination of the ammonium hydroxide group (Note 14).

Note 13—A hot plate may be used instead of a steam bath if the heat is so regulated as to approximate that of a steam bath. Under conditions where water boils at a lower temperature than at sea level, such as at higher elevations, 30 minutes may not be sufficient to recover all of the silica. In such cases, increase the time of digestion as necessary to get complete recovery of the silica. In no case should this time exceed 60 minutes.

Note 14—Determine the ammonium hydroxide group in accordance with the procedure described in Sections 7.1 through 7.3.

6.2.3.2. Transfer the filter paper and residue to a tared platinum crucible, dry, and ignite, at first slowly until the carbon of the paper is completely consumed without inflaming and finally at 1100° to 1200°C for one hour. Cool in a desiccator and determine the mass. Re-ignite to constant mass. Treat the SiO_2 thus obtained, which will contain small amounts of impurities, in the crucible with 1 or 2 mL of water, 2 drops of H_2SO_4 (1 + 1), and about 10 mL of HF, and evaporate cautiously to dryness. Finally, heat the small residue at 1050° to 1100°C for five minutes, cool in a desiccator, and determine the mass. The difference between this mass and the mass previously obtained represents the mass of SiO_2. Consider the mass of the residue remaining after the volatilization of SiO_2 as combined aluminum and ferric oxides and add it to the result obtained in the determination of the ammonium hydroxide group.

6.2.3.3. If the HF residue exceeds 2 mg, the silica determination shall be repeated, steps should be taken to ensure complete decomposition of the sample before a silica separation is attempted, and the balance of the analysis (ammonium hydroxide group, CaO, and MgO) determined on the new silica filtrate provided the new silica determination has an HF residue of 2 mg or less except as provided in Sections 6.2.3.4 and 6.2.3.5.

6.2.3.4. If two or three repeated determinations of a sample of portland cement consistently show HF residues higher than 2 mg, this is evidence that contamination has occurred in sampling or the cement has not been burned properly during manufacture. In such a case, do not fuse the large HF residue with pyrosulfate for subsequent addition to the filtrate from the silica separation. Instead, report the value obtained for the HF residue. Do not ignite the ammonium hydroxide group in the crucible containing this abnormally large HF residue.

6.2.3.5. In the analysis of cements other than portland, it may not always be possible to obtain HF residues under 2 mg. In such cases, add 0.5 g of sodium or potassium pyrosulfate ($Na_2S_2O_7$ or $K_2S_2O_7$) to the crucible and heat below red heat until the small residue of impurities is dissolved in the melt (Note 15). Cool, dissolve the fused mass in water, and add it to the filtrate and washings reserved for the determination of the ammonium hydroxide group.

Note 15—A supply of non-spattering pyrosulfate may be prepared by heating some pyrosulfate in a platinum vessel below red heat until the foaming and spattering cease, cooling, and crushing the fused mass.

6.2.3.6. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

6.2.4. *Calculation*—Calculate the percentage of SiO_2 by multiplying the mass in grams of SiO_2 by 200 (100 divided by the mass (See Section 6.2.3.1) or equivalent mass (See Section 6.3.2.1) of the sample used (0.5 g). Round off in accordance with Table 3.

6.3. *Silicon Dioxide in Cements with Insoluble Residue Greater Than One Percent:*

6.3.1. *Summary of Test Method*—This test method is based on the sodium carbonate fusion followed by double evaporation to dryness of the hydrochloric acid solution of the fusion product to convert silicon dioxide (SiO_2) to the insoluble form. The solution is filtered and the insoluble siliceous residue is ignited and the mass determined. Silicon dioxide is volatilized by hydrofluoric acid and the loss of mass is reported as pure SiO_2.

6.3.2. *Procedure*:

6.3.2.1. Determine the mass of a quantity of the ignited sample equivalent to 0.5 g of the as-received sample calculated as follows:

$$W = \left[0.5\left(100.00 - I\right)/100\right] \qquad (1)$$

where:

W = mass of ignited sample, g; and

I = loss on ignition, percent.

The ignited material from the loss on ignition determination may be used for the sample. Thoroughly mix the sample with 4 to 6 g of Na_2CO_3 by grinding in an agate mortar. Place a thin layer of Na_2CO_3 on the bottom of a platinum crucible of 20- to 30-mL capacity, add the cement-Na_2CO_3 mixture, and cover the mixture with a thin layer of Na_2CO_3. Place the covered crucible over a moderately low flame and increase the flame gradually to a maximum (approximately 1100°C) and maintain this temperature until the mass is quiescent (about 45 minutes). Remove the burner, lay aside the cover of the crucible, grasp the crucible with tongs, and slowly rotate the crucible so that the molten contents spread over the sides and solidify as a thin shell on the interior. Set the crucible and cover aside to cool. Rinse off the outside of the crucible and place the crucible on its side in a 300-mL casserole about one-third full of water. Warm the casserole and stir until the cake in the crucible disintegrates and can be removed easily. By means of a glass rod, lift the crucible out of the liquid, rinsing it thoroughly with water. Rinse the cover and crucible with HCl (1 + 3); then add the rinse to the casserole. Very slowly and cautiously add 20 mL of HCl (sp gr 1.19) to the covered casserole. Remove the cover and rinse. If any gritty particles are present, the fusion is incomplete and the test must be repeated, using a new sample.

Warning—Subsequent steps of the test methods must be followed exactly for accurate results.

6.3.2.2. Evaporate the solution to dryness on a steam bath (there is no longer a gelatinous appearance). Without heating the residue any further, treat it with 5 to 10 mL of HCl, wait at least two minutes, and then add an equal amount of water. Cover the dish and digest for 10 minutes on the steam bath or a hot plate. Dilute the solution with an equal volume of hot water, immediately filter through medium-textured paper, and wash the separated SiO_2 thoroughly with hot HCl (1 + 99), then with hot water. Reserve the residue.

6.3.2.3. Again evaporate the filtrate to dryness, and bake the residue in an oven for one hour at 105° to 110°C. Cool, add 10 to 15 mL of HCl (1 + 1), and digest on the steam bath or hot plate for 10 minutes. Dilute with an equal volume of water, filter immediately on a fresh filter paper, and wash the small SiO_2 residue thoroughly as described in Section 6.3.2.2. Stir the filtrate and washings and reserve for the determination of the ammonium hydroxide group in accordance with Sections 7.1 through 7.3.

6.3.2.4. Continue the determination of silicon dioxide in accordance with Section 6.2.3.2.

7. AMMONIUM HYDROXIDE GROUP (REFERENCE TEST METHOD)

7.1. *Summary of Test Method*—In this test method aluminum, iron, titanium, and phosphorus are precipitated from the filtrate, after SiO_2 removal, by means of ammonium hydroxide. With care, little if any manganese will be precipitated. The precipitate is ignited and the mass determined as the oxides.

7.2. *Procedure*:

7.2.1. To the filtrate reserved in accordance with Section 6.2.3.1 (Note 16) which should have a volume of about 200 mL, add HCl if necessary to ensure a total of 10 to 15 mL of the acid. Add a few drops of methyl red indicator and heat to boiling. Then treat with NH_4OH (1 + 1) (Note 17), dropwise until the color of the solution becomes distinctly yellow, and add one drop in excess (Note 18). Heat the solution containing the precipitate to boiling and boil for 50 to 60 seconds. In the event difficulty from bumping is experienced while boiling the ammoniacal solution, a digestion period of 10 minutes on a steam bath, or on a hot plate having the approximate temperature of a steam bath, may be substituted for the 50 to 60 seconds boiling period. Allow the precipitate to settle (not more than five minutes) and filter using medium-textured paper (Note 19). Wash with hot ammonium nitrate (NH_4NO_3, 20 g/L) (Note 20) twice for a small precipitate to about four times for a large one.

Note 16—If a platinum evaporating dish has been used for the dehydration of SiO_2, iron may have been partially reduced. At this stage, add about 3 mL of saturated bromine water to the filtrate and boil the filtrate to eliminate the excess bromine before adding the methyl red indicator. If difficulty from bumping is experienced during the boiling, the following alternate techniques may be helpful: (1) a piece of filter paper, approximately 1 cm^2 in area, positioned where the bottom and side of the beaker merge and held down by the end of a stirring rod may solve the difficulty, and (2) use of 400-mL beakers supported inside a cast aluminum cup has also been found effective.

Note 17—The NH_4OH used to precipitate the hydroxides must be free of contamination with carbon dioxide (CO_2).

Note 18—It usually takes one drop of NH_4OH (1 + 1) to change the color of the solution from red to orange and another drop to change the color from orange to yellow. If desired, the addition of the indicator may be delayed until ferric hydroxide ($Fe(OH)_3$) is precipitated without aluminum hydroxide ($Al(OH)_3$) being completely precipitated. In such a case, the color changes may be better observed. However, if the content of Fe_2O_3 is unusually great, it may be necessary to occasionally let the precipitate settle slightly so that the color of the supernatant liquid can be observed. If the color fades during the precipitation, add more of the indicator. Observation of the color where a drop of the indicator strikes the solution may be an aid in the control of the acidity. The boiling should not be prolonged as the color may reverse and the precipitate may be difficult to retain on the filter. The solution should be distinctly yellow when it is ready to filter. If it is not, restore the yellow color with more NH_4OH (1 + 1) or repeat the precipitation.

Note 19—To avoid drying of the precipitate with resultant slow filtration, channeling, or poor washing, the filter paper should be kept nearly full during the filtration and should be washed without delay.

Note 20—Two drops of methyl red indicator solution should be added to the NH_4NO_3 solution in the wash bottle, followed by NH_4OH (1 + 1) added dropwise until the color just changes to yellow. If the color reverts to red at any time due to heating, it should be brought back to yellow by the addition of a drop of NH_4OH (1 + 1).

7.2.2. Set aside the filtrate and transfer the precipitate and filter paper to the same beaker in which the first precipitation was effected. Dissolve the precipitate with hot HCl (1 + 2). Stir to thoroughly macerate the paper and then dilute the solution to about 100 mL. Reprecipitate the hydroxides as described in Section 7.2.1. If difficulty from bumping is experienced while boiling the acid solution containing the filter paper, it may be obviated by diluting the hot 1 + 2 solution of the mixed oxides with 100 mL of boiling water and thus eliminate the need for boiling. Filter the solution and wash the precipitate with about four 10-mL portions of hot NH_4NO_3 solution (20 g/L) (Note 20). Combine the filtrate and washings with the filtrate set aside and reserve for the determination of CaO in accordance with Section 13.3.1.

7.2.3. Place the precipitate in a tared platinum crucible, heat slowly until the papers are charred, and finally ignite to constant mass at 1050° to 1100°C with care to prevent reduction, and determine the mass as the ammonium hydroxide group.

7.2.4. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

7.3. *Calculation*—Calculate the percentage of ammonium hydroxide group to the nearest 0.01 by multiplying the mass in grams of ammonium hydroxide group by 200 (100 divided by the mass of sample used (0.5 g)).

8. FERRIC OXIDE (REFERENCE TEST METHOD)

8.1. *Summary of Test Method*—In this test method, the Fe_2O_3 content of the cement is determined on a separate portion of the cement by reducing the iron to the ferrous state with stannous chloride ($SnCl_2$) and titrating with a standard solution of potassium dichromate ($K_2Cr_2O_7$). This determination is not affected by any titanium or vanadium that may be present in the cement.

8.2. *Reagents*:

8.2.1. *Barium Diphenylamine Sulfonate Indicator Solution*—Dissolve 0.3 g of barium diphenylamine sulfonate in 100 mL of water.

8.2.2. *Potassium Dichromate, Standard Solution* (1 mL = 4 mg Fe_2O_3)—Pulverize and dry primary standard potassium dichromate ($K_2Cr_2O_7$) reagent, the current lot of NIST 136, at 180° to 200°C to constant mass. Accurately determine the mass of an amount of dried reagent equal to 2.45700 g times the number of liters of solution to be prepared. Dissolve in water and dilute to exactly the required volume in a single volumetric flask of the proper size. This solution is a primary standard and requires no further standardization (Note 21).

Note 21—Where large quantities of standard solution are required, it may be desirable for certain laboratories to use commercially produced primary standard potassium dichromate for most determinations. Such a material may be used provided that the first solution made from the container is checked, as follows: Using a standard solution of NIST 136, prepared as described in Section 8.2.2, analyze, in duplicate, samples of a NIST CRM cement (Note 1), by the procedure given in Sections 8.3.1.3 and 8.3.1.4. Repeat using a similar solution prepared from the commercial primary standard dichromate. The average percentages of Fe_2O_3 found by each test method should not differ by more than 0.06 percent.

8.2.3. *Stannous Chloride Solution*—Dissolve 5 g of stannous chloride ($SnCl_2 \cdot 2H_2O$) in 10 mL of HCl and dilute to 100 mL. Add scraps of iron-free granulated tin and boil until the solution is clear. Keep the solution in a closed dropping bottle containing metallic tin.

8.3. *Procedure*—For cements other than portland and for which the insoluble residue is unknown, determine the insoluble residue in accordance with the appropriate sections of these test methods. When insoluble residue is known, proceed in accordance with Section 8.3.1 or 8.3.2 as is appropriate for the cement being analyzed.

8.3.1. For portland cements and cements having insoluble residue lower than 1 percent, weigh 1 g of the sample into a 500-mL Phillips beaker or other suitable container. Add 40 mL of cold water and, while the beaker is being swirled, add 10 mL of HCl. If necessary, heat the solution and grind the cement with the flattened end of a glass rod until it is evident that the cement is completely decomposed. Continue the analysis in accordance with Section 8.3.3.

8.3.2. For cements with insoluble residue greater than 1 percent, weigh a 0.500 g sample, blend with 1 g $LiBO_2$ using a mortar and pestle, and transfer to a previously fired 8-mL carbon crucible that has 0.1 g $LiBO_2$ sprinkled in the bottom (Note 22). Cover with 0.1 g $LiBO_2$ that was used to chemically wash the mortar and pestle (Note 23). Place the uncovered crucible in a furnace set at 1100°C for 15 minutes. Remove the crucible from the furnace and check for complete fusion (Note 24). If the fusion is incomplete, return the crucible to the furnace for another 30 minutes. Again, check for complete fusion. If the fusion is still incomplete, discard the sample and repeat the fusion procedure using 0.250 g sample or a smaller quantity with the same amount of $LiBO_2$. When the fusion is complete, gently swirl the melt and pour into a 150-mL glass beaker containing 10 mL concentrated HCl and 50 mL water. Stir continuously until the fusion product is dissolved, usually 10 minutes or less (Note 25). If a stirring bar is used, remove and rinse the bar. Continue the analysis in accordance with Section 8.3.3.

Note 22—The firing loosens the carbon on the surface, reducing the possibility of the fusion product sticking to the crucible.

Note 23—A chemical wash is a dry rinse of the equipment in which the blending was done so that any sample adhering to this equipment will be loosened and transferred to the crucible.

Note 24—When fusion is incomplete, the sample may not be completely melted or there may be particles on top of the bead. Usually, if the bead forms a small smooth spherical ball when taken from the furnace and before it is swirled, the sample is completely fused.

Note 25—There are usually some carbon particles that are in suspension, undissolved in the solution, but they will not interfere with the completion of the analysis.

8.3.3. Heat the solution to boiling and treat it with the $SnCl_2$ solution, added dropwise while stirring and boiling, until the solution is decolorized. Add one drop in excess and cool the solution to room temperature by placing the beaker in a pan of cool water. After cooling and without delay, rinse the inside of the vessel with water, and add all at once 10 mL of a cool, saturated mercuric chloride ($HgCl_2$) solution. Stir the solution vigorously for one minute by swirling the beaker and add 10 mL of H_3PO_4 (1 + 1) and two drops of barium diphenylamine sulfonate indicator. Add sufficient water so that the volume after titration will be between 75 and 100 mL. Titrate with the standard $K_2Cr_2O_7$ solution. The end point shall be taken as the point at which a single drop causes an intense purple coloration that remains unchanged on further addition of standard $K_2Cr_2O_7$ solution.

8.3.4. *Blank*—Make a blank determination following the same procedure and using the same amounts of reagents. Record the volume of $K_2Cr_2O_7$ solution required to establish the end point as described in Section 8.3.3. As some iron must be present to obtain the normal end point, if no definite purple color is obtained after the addition of four drops of the standard $K_2Cr_2O_7$ solution, record the blank as zero.

8.4. *Calculation*:

8.4.1. Calculate the percentage of Fe_2O_3 as follows:

$$\mathrm{Fe_2O_3}, \% = E\left(V - B\right) \times 100 / W \qquad (2)$$

where:

E = Fe_2O_3 equivalent of the $K_2Cr_2O_7$ solution, g/mL;
V = milliliters of $K_2Cr_2O_7$ solution required by the sample determination;
B = milliliters of $K_2Cr_2O_7$ solution required by the blank determination; and
W = mass of sample within 0.1 mg.

Round in accordance with Table 3.

9. PHOSPHORUS PENTOXIDE (REFERENCE TEST METHOD)

9.1. *Summary of Test Method*—This colorimetric test method is applicable to the determination of P_2O_5 in portland cement. Under the conditions of the test, no constituent normally present in portland cement will interfere.

9.2. *Apparatus*:

9.2.1. *Spectrophotometer* (Note 26):

9.2.1.1. The instrument shall be equipped to measure absorbency of solutions at a spectral wavelength of 725 nm.

9.2.1.2. Wavelength measurements shall be repeatable within ±1 nm or less.

9.2.1.3. In the absorbance range from 0.1 to 1.0, the absorbance measurements shall be repeatable within ±1 percent or less.

9.2.1.4. To establish that the spectrophotometer will permit a satisfactory degree of accuracy, qualify the instrument in accordance with Section 3.3.2 using the procedure in Sections 9.4.1 through 9.4.9.

Note 26—For the measurement of the performance of the spectrophotometer, refer to ASTM E 275.

9.3. *Reagents*:

9.3.1. *Ammonium Molybdate Solution*—Into a 1-L volumetric flask introduce 500.0 mL of 10.6 normal H_2SO_4 (Section 9.3.7). Dissolve 25.0 g of ammonium molybdate ($(NH_4)_6\ MO_7O_{24}\cdot 4H_2O$) in about 250 mL of warm water and transfer to the flask containing the H_2SO_4, while swirling the flask. Cool, dilute to 1 L with water, and store in a plastic bottle.

9.3.2. *Ascorbic Acid Powder*—For ease in dissolving, the finest mesh available should be used.

9.3.3. *Hydrochloric Acid, Standard* (6.5 ± 0.1 *N*)—Dilute 540 mL of concentrated HCl (sp gr 1.19) to 1 L with water. Standardize against standard NaOH solution (Section 9.3.6) using phenolphthalein as indicator. Determine the exact normality and adjust to 6.5 ± 0.1 *N* by dilution with water. Restandardize to ensure that the proper normality has been achieved.

9.3.4. *Phosphate, Standard Solution A*—Dissolve 0.1917 g of oven-dried potassium dihydrogen phosphate (KH_2PO_4) in water and dilute to 1 L in a volumetric flask.

9.3.5. *Phosphate, Standard Solution B*—Dilute 50.0 mL of phosphate solution A to 500 mL with water.

9.3.6. *Sodium Hydroxide, Standard Solution* (1 *N*)—Dissolve 40.0 g of sodium hydroxide (NaOH) in water, add 10 mL of a freshly filtered saturated solution of barium hydroxide ($Ba(OH)_2$), and dilute to 1 L with water that has been recently boiled and cooled. Shake the solution from time to time during a several-hour period, and filter into a plastic bottle. Keep the bottle tightly closed to protect the solution from CO_2 in the air. Standardize against acid potassium phthalate or benzoic acid acidimetric standards furnished by NIST (standard samples 84f and 350), using the test methods in the certificates accompanying the standard samples. Determine the exact normality of the solution.

9.3.7. *Sulfuric Acid, Standard* (10.6 ± 0.1 *N*)—To a 1-L volumetric flask cooled in water add about 600 mL of water and then, slowly, with caution, 300 mL of concentrated H_2SO_4 (sp gr 1.84). After cooling to room temperature, dilute to 1 L with water. Standardize against the standard NaOH solution (Section 9.3.6) using the phenolphthalein as indicator. Determine the normality and adjust to 10.6 ± 0.1 *N* by dilution with water. Restandardize to ensure that the proper normality has been achieved.

9.4. *Procedure*:

9.4.1. Prepare a series of phosphate solutions to cover the range from 0 to 0.5 percent P_2O_5. Prepare each solution by adding a suitable volume of standard phosphate solution B and 25.0 mL of the 6.5 *N* hydrochloric acid to a 250-mL volumetric flask (Note 27). Dilute to the mark with water.

Note 27—One milliliter of standard phosphate solution B 250 mL of solution is equivalent to 0.004 percent P_2O_5 for a 0.25-g cement sample. Aliquots of 0, 12.5, 25, 50, 75, 100, and 125 mL are equivalent to P_2O_5 contents in the sample of 0, 0.05, 0.10, 0.20, 0.30, 0.40, and 0.50 percent.

9.4.2. Prepare a blank by adding 25.0 mL of the standard HCl to a 250-mL volumetric flask and diluting to 250 mL with water.

9.4.3. Develop colors in the series of phosphate solutions, and in the blank, in accordance with Sections 9.4.6 through 9.4.8.

9.4.4. Plot the net absorbance (absorbance of standard minus that of the blank) values obtained as ordinates and the corresponding P_2O_5 concentrations as abscissas. Draw a smooth curve through the points (Note 28).

Note 28—A suitable paper for plotting the calibration curve is a 254 by 381-mm (10 by 15-in.) linear cross section paper having 8 by 8 divisions to 10 mm (20 by 20 divisions to 1 in.). The percentage of P_2O_5 can then be plotted on the long dimension using five divisions equal to 0.01 percent P_2O_5. A scale of one division equal to 0.005 absorbance units is suitable as the ordinate (short dimension of the paper). Scales other than this may be used but under no circumstances should a scale division less than 1.3 mm ($^1/_{20}$ in.) be used for 0.005 units of absorbance or for 0.005 percent P_2O_5. A separate calibration curve should be made for each spectrophotometer used, and the calibration curve checked against standard phosphate solution whenever a new batch of ammonium molybdate reagent is used.

9.4.5. Transfer 0.250 g of the sample to a 250-mL beaker and moisten with 10 mL of cold water to prevent lumping. Add 25.0 mL of the standard HCl and digest with the aid of gentle heat and agitation until solution is complete. Filter into a 250-mL volumetric flask and wash the paper and the separated silica thoroughly with hot water. Allow the solution to cool and then dilute with water to 250 mL.

9.4.6. Transfer a 50.0-mL aliquot (Note 29) of the sample solution to a 250-mL beaker, add 5.0 mL of ammonium molybdate solution and 0.1 g of ascorbic acid powder. Mix the contents of the beaker by swirling until the ascorbic acid has dissolved completely. Heat the solution to vigorous boiling and then boil, uncovered, for 90 ± 30 seconds. Cool to room temperature and transfer to a 50-mL volumetric flask. Rinse the beaker with one small portion of water and add the rinse water to the flask. Dilute to 50 mL with water.

Note 29—The range of the test can be extended by taking a smaller aliquot of the sample solution. In such instances the decrease in the aliquot volume must be made up by the blank solution (Section 9.4.5) to maintain the proper acidity of the final solution. Thus, if a 25-mL aliquot of the sample solution is taken (instead of the usual 50 mL), a 25-mL aliquot of the blank solution should be added before proceeding with the test. The result of the test must then be calculated accordingly.

9.4.7. Measure the absorbance of the solution against water as the reference at 725.0 nm.

9.4.8. Develop a 50.0-mL aliquot of the blank solution prepared in Section 9.4.2 in the same manner as was used in Section 9.4.6 for the sample solution. Measure the absorbance in accordance with Section 9.4.7 and subtract this absorbance value from that obtained for the sample solution in Section 9.4.6 in order to obtain the net absorbance for the sample solution.

9.4.9. Using the net absorbance value found in Section 9.4.8, record the percentage of P_2O_5 in the cement sample as indicated by the calibration curve. Report the percentage of P_2O_5 rounded in accordance with Table 3.

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10. TITANIUM DIOXIDE (REFEREE TEST METHOD)

10.1. *Summary of Test Method*—In this test method titanium dioxide (TiO_2) in portland cement is determined colorimetrically using Tiron reagent. Under the conditions of the test iron is the only constituent of portland cement causing a very slight interference equivalent to 0.01 percent for each 1 percent of Fe_2O_3 present in the sample.

10.2. *Apparatus*:

10.2.1. *Spectrophotometer* (Note 30):

10.2.1.1. The instrument shall be equipped to measure absorbance of solutions at a spectral wavelength of 410 nm.

10.2.1.2. Wavelength measurements shall be repeatable within ±1 nm or less.

10.2.1.3. In the absorbance range from 0.1 to 1.0, the absorbance measurements shall be repeatable within ±1 percent or less.

10.2.1.4. To establish that the spectrophotometer will permit a satisfactory degree of accuracy, qualify the instrument in accordance with Section 3.3.2 using the procedure in Sections 10.4.1 through 10.4.6 of this test method.

Note 30—For the measurement of the performance of the spectrophotometer, refer to ASTM E 275.

10.3. *Reagents*:

10.3.1. *Buffer* (pH 4.7)—68 g of $NaC_2H_3O_2{\cdot}3H_2O$ (sodium acetate trihydrate), plus 380 mL of water, plus 100 mL of 5.0 *N* CH_3COOH (acetic acid).

10.3.2. *Ethylenedinitrilo Tetraacetic Acid Disodium Salt, Dihydrate* (0.2 *M* EDTA)—Dissolve 37.5 g of EDTA in 350 mL of warm water, and filter. Add 0.25 g of $FeCl_3{\cdot}6H_2O$ (ferric chloride hexahydrate) and dilute to 500 mL.

10.3.3. *Hydrochloric Acid* (1 + 6).

10.3.4. *Hydrochloric Acid, Standard* (6.5 *N*)—Dilute 540 mL of concentrated HCl (sp gr 1.19) to 1 L with water.

10.3.5. *Ammonium Hydroxide* (NH_4OH, 1 + 1).

10.3.6. *Potassium Pyrosulfate* ($K_2S_2O_7$).

10.3.7. *Titanium Dioxide, Stock Solution A*—Fuse slowly in a platinum crucible over a very small flame 0.0314 g of NIST CRM 154b (TiO_2 = 99.74 percent) or its replacements with about 2 or 3 g of $K_2S_2O_7$. Allow to cool, and place the crucible in a beaker containing 125 mL of H_2SO_4 (1 + 1). Heat and stir until the melt is completely dissolved. Cool, transfer to a 250-mL volumetric flask, and dilute the solution to volume.

10.3.7.1. *Titanium Dioxide, Dilute Standard Solution B* (1 mL = 0.0125 mg TiO_2)—Pipet 50 mL of stock TiO_2 solution into a 500-mL volumetric flask, and dilute to volume. One milliliter of this solution is equal to 0.0125 mg of TiO_2, which is equivalent to 0.05 percent TiO_2 when used as outlined in Sections 10.4.4 through 10.4.6.

10.3.8. *Sulfuric Acid* (1 + 1).

10.3.9. *Tiron* (disodium-1, 2-dihydroxybenzene-3, 5 disulfonate).

10.4. *Procedure*:

10.4.1. Prepare a series of TiO_2 solutions to cover the range from 0 to 1.0 percent TiO_2. Prepare each solution in a 50-mL volumetric flask (Note 31).

Note 31—One milliliter of dilute TiO_2 standard solution B per 50 mL (Section 10.3.7.1) is equivalent to 0.05 percent TiO_2 for a 0.2500-g cement sample. Aliquots of 0, 5, 10, 15, and 20 mL of dilute TiO_2 standard solution are equivalent to TiO_2 contents in the sample of 0, 0.25, 0.50, 0.75, and 1.0 percent. Dilute each to 25 mL with water.

10.4.2. Develop color in accordance with Section 10.4.4 starting with second sentence. Measure absorbance in accordance with Section 10.4.5.

10.4.3. Plot absorbance values obtained as ordinates and the corresponding TiO_2 concentrations as abscissas. Draw a smooth curve through the points (Note 32).

Note 32—A suitable paper for plotting the calibration curve is a linear cross-section paper having 10 × 10 divisions to 10 mm. A scale division equivalent to 0.002 absorbance and 0.002 percent TiO_2 should be used. A separate calibration curve should be made for each spectrophotometer used.

10.4.4. Transfer a 25.0-mL aliquot of the sample solution prepared in Section 9.4.5 into a 50-mL volumetric flask (Note 33). Add 5 mL tiron and 5 mL EDTA, mix, and then add NH_4OH (1 + 1) dropwise, mixing thoroughly after each drop, until the color changes through yellow to green, blue, or ruby red. Then, *just restore* the yellow color with HCl (1 + 6) *added dropwise and mixing after each drop*. Add 5 mL buffer, dilute to volume and mix.

10.4.5. Measure the absorbance of the solution against water as the reference at 410 nm.

Note 33—The range of the test can be extended by taking a smaller aliquot. The results of the test must then be calculated accordingly.

10.4.6. Using the absorbance value determined in Section 10.4.5, record the percentage of TiO_2 in the cement sample as indicated by the calibration curve to the nearest 0.01. Correct for the iron present in the sample to obtain the true TiO_2 as follows: True TiO_2 = measured % TiO_2 – (0.01 × % Fe_2O_3). Report the percent of TiO_2 rounded in accordance with Table 3.

11. ZINC OXIDE (REFERENCE TEST METHOD)[5]

11.1. Any test method may be used that meets the requirements of Section 3.3 and Table 1.

11.2. Report the result rounded in accordance with Table 3.

12. ALUMINUM OXIDE (REFERENCE TEST METHOD)

Note 34—In the referee test method, Al_2O_3 is calculated from the ammonium hydroxide group by subtracting the separately determined constituents that usually are present in significant amounts in the ammonium hydroxide precipitate. These are Fe_2O_3, TiO_2 and P_2O_5. Most instrumental test methods for Al_2O_3 analysis give Al_2O_3 alone if standardized and calibrated properly.

12.1. *Calculation*:

12.1.1. Calculate the percentage of Al_2O_3 by deducting the percentage of the sum of the Fe_2O_3, TiO_2, and P_2O_5 from the percentage of ammonium hydroxide group, using un-rounded values of all four quantities. All determinations shall be by referee test methods described in the appropriate sections herein. All percentages shall be calculated to the nearest 0.01 percent. Report the Al_2O_3 rounded in accordance with Table 3. For nonreferee analyses, the percentages of Fe_2O_3 TiO_2, and P_2O_5 can be determined by any procedure for which qualification has been shown.

13. CALCIUM OXIDE (REFERENCE TEST METHOD)

13.1. *Summary of Test Method*:

13.1.1. In this test method, manganese is removed from the filtrate after the determination of SiO_2 and the ammonium hydroxide group. Calcium is then precipitated as the oxalate. After filtering, the oxalate is redissolved and titrated with potassium permanganate ($KMnO_4$).

Note 35—For referee analysis or for the most accurate determinations, removal of manganese in accordance with Section 13.3.2 must be made. For less accurate determinations and when only insignificant amounts of manganese oxides are believed present, Section 13.3.2 may be omitted.

13.1.2. Strontium, usually present in portland cement as a minor constituent, is precipitated with calcium as the oxalate and is subsequently titrated and calculated as CaO. If the SrO content is known and correction of CaO for SrO is desired as, for example, for research purposes or to compare results with CRM certificate values, the CaO obtained by this test method may be corrected for SrO. In determining conformance of a cement to specifications, the correction of CaO for SrO should not be made.

13.2. *Reagents*:

13.2.1. *Ammonium Oxalate Solution* (50 g/L).

13.2.2. *Potassium Permanganate, Standard Solution* (0.18 *normal*)—Prepare a solution of potassium permanganate ($KMnO_4$) containing 5.69 g/L. Let this solution stand at room temperature for at least one week or boil and cool to room temperature. Siphon off the clear solution without disturbing the sediment on the bottom of the bottle; then filter the siphoned solution through a bed of glass wool in a funnel or through a suitable sintered glass filter. Do not filter through materials containing organic matter. Store in a dark bottle, preferably one that has been painted black on the outside. Standardize the solution against 0.7000 to 0.8000 g of primary standard sodium oxalate, according to the directions furnished with the sodium oxalate and record the temperature at which the standardization was made (Note 36).

13.2.2.1. Calculate the CaO equivalent of the solution as follows:

1 mL of 1*N* $KMnO_4$ solution is equivalent to 0.6701 g of pure sodium oxalate.

$$\text{Normality of } KMnO_4 = \frac{\text{mass of sodium oxalate} \times \text{fraction of its purity}}{\text{mL of } KMnO_4 \text{ solution} \times 0.06701} \qquad (3)$$

1 mL of 1 *N* $KMnO_4$ solution is equivalent to 28.04 mg of CaO.

$$F = \frac{\text{normality of } KMnO_4 \text{ solution} \times 0.02804 \times 100}{0.5}$$

where:

F = CaO equivalent of the $KMnO_4$ solution in percent CaO/mL based on a 0.5-g sample of cement.

Note 36—Because of the instability of the $KMnO_4$ solution, it is recommended that it be restandardized at least bimonthly.

13.3. *Procedure*:

13.3.1. Acidify the combined filtrates obtained in the precipitations of the ammonium hydroxide group (Section 7.2.2). Neutralize with HCl to the methyl red end point, make just acid, and add six drops of HCl in excess.

13.3.2. *Removal of Manganese*—Evaporate to a volume of about 100 mL. Add 40 mL of saturated bromine water to the hot solution and immediately add NH_4OH until the solution is distinctly alkaline. Addition of 10 mL of NH_4OH is generally sufficient. A piece of filter paper, about 1 cm^2 in area, placed in the heel of the beaker and held down by the end of a stirring rod aids in preventing bumping and initiating precipitation of hydrated manganese oxides (MnO). Boil the solution for five minutes or more, making certain that the solution is distinctly alkaline at all times. Allow the precipitate to settle, filter using medium-textured paper, and wash with hot water. If a precipitate does not appear immediately, allow a settling period of up to one hour before filtration. Discard any manganese dioxide that may have been precipitated. Acidify the filtrate with HCl using litmus paper as an indicator, and boil until all the bromine is expelled (Note 37).

13.3.3. Add 5 mL of HCl, dilute to 200 mL, and add a few drops of methyl red indicator and 30 mL of warm ammonium oxalate solution (50 g/L) (Note 38). Heat the solution to 70° to 80°C, and add NH_4OH (1 + 1) dropwise, while stirring until the color changes from red to yellow (Note 39). Allow the solution to stand without further heating for 60 ± 5 minutes (no longer), with occasional stirring during the first 30 minutes.

13.3.4. Filter, using retentive paper, and wash the precipitate 8 to 10 times with hot water, the total amount of water used in rinsing the beaker and washing not to exceed 75 mL. During this washing, water from the wash bottle should be directed around the inside of the filter paper to wash the precipitate down, then a jet of water should be gently directed towards the center of the paper in order to agitate and thoroughly wash the precipitate. Acidify the filtrate with HCl and reserve for the determination of MgO.

13.3.5. Place the beaker in which the precipitation was made under the funnel, pierce the apex of the filter paper with the stirring rod, place the rod in the beaker, and wash the precipitate into the beaker by using a jet of hot water. Drop about 10 drops of H_2SO_4 (1 + 1) around the top edge of the filter paper. Wash the paper five more times with hot water. Dilute to 200 mL, and add 10 mL of H_2SO_4 (1 + 1). Heat the solution to a temperature just below boiling, and titrate it immediately with the 0.18 *N* $KMnO_4$ solution (Note 40). Continue the titration slowly until the pink color persists for at least 10 seconds. Add the filter paper that contained the original precipitate and macerate it. If the pink color disappears, continue the titration until it again persists for at least 10 seconds.

Note 37—Potassium iodide starch paper may be used to indicate the complete volatilization of the excess bromine. Expose a strip of moistened paper to the fumes from the boiling solution. The paper should remain colorless. If it turns blue, bromine is still present.

Note 38—If the ammonium oxalate solution is not perfectly clear, it should be filtered before use.

Note 39—This neutralization must be made slowly, otherwise precipitated calcium oxalate may have a tendency to run through the filter paper. When a number of these determinations are being made simultaneously, the following technique will assist in ensuring slow neutralization. Add two or three drops of NH_4OH to the first beaker while stirring, then two or three drops to the second, and so on, returning to the first beaker to add two or three more drops, etc., until the indicator color has changed in each beaker.

Note 40—The temperature of the 0.18 *N* $KMnO_4$ solution at time of use should not vary from its standardization temperature by more than 5.5°C (10°F). Larger deviations could cause serious error in the determination of CaO.

13.3.6. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents (Note 41), and record the milliliters of $KMnO_4$ solution required to establish the end point.

Note 41—When the amount of calcium oxalate is very small, its oxidation by $KMnO_4$ is slow to start. Before the titration, add a little $MnSO_4$ to the solution to catalyze the reaction.

13.4. *Calculation*:

13.4.1. Calculate the percentage of CaO as follows:

$$\text{CaO, \%} = E\left(V - B\right) \tag{4}$$

where:

E = CaO equivalent of the $KMnO_4$ solution in percent CaO/mL based on a 0.5-g sample,

V = milliliters of $KMnO_4$ solution required by the sample, and

B = milliliters of $KMnO_4$ solution required by the blank.

Report the results rounded in accordance with Table 3.

13.4.2. If desired calculate the percentage of CaO corrected for SrO as follows:

$$\text{CaO}_c\,\% = \text{CaO}_i\,\% - 0.54\ \text{SrO}\ \% \tag{5}$$

where:

CaO_c= CaO corrected for SrO,

CaO_i= initial CaO as determined in Section 13.4.1, and

$$0.54 = \frac{56.08}{103.62} = \text{molecular mass ratio, } \frac{\text{CaO}}{\text{SrO}}.$$

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14. MAGNESIUM OXIDE (REFERENCE TEST METHOD)

14.1. *Summary of Test Method*—In this test method, magnesium is precipitated as magnesium ammonium phosphate from the filtrate after removal of calcium. The precipitate is ignited and the mass is determined as magnesium pyrophosphate ($Mg_2P_2O_7$). The MgO equivalent is then calculated.

14.2. *Reagent*—Ammonium phosphate, dibasic (100 g/L) $(NH_4)_2HPO_4$.

14.3. *Procedure*:

14.3.1. Acidify the filtrate from the determination of CaO (Section 13.3.4) with HCl and evaporate by boiling to about 250 mL. Cool the solution to room temperature, add 10 mL of ammonium phosphate, dibasic, $(NH_4)_2HPO_4$ (100 g/L), and 30 mL of NH_4OH. Stir the solution vigorously during the addition of NH_4OH and then for 10 to 15 minutes longer. Let the solution stand for at least eight hours in a cool atmosphere and filter. Wash the residue five or six times with NH_4OH (1 + 20) and ignite in a tared platinum or porcelain crucible, at first slowly until the filter paper is charred and then burned off (see Section 14.4.1), and finally at 1100°C for 30 to 45 minutes. Determine the mass of the residue as magnesium pyrophosphate ($Mg_2P_2O_7$).

14.3.2. *Blank*—Make a blank determination following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

14.4. *Calculation*:

14.4.1. Calculate the percentage of MgO as follows:

$$\text{MgO, \%} = W \times 72.4 \qquad (6)$$

where:

W = grams of $Mg_2P_2O_7$, and

72.4 = molecular ratio of 2 MgO to $Mg_2P_2O_7$ (0.362) divided by the mass of sample used (0.5 g) and multiplied by 100.

Report the results rounded in accordance with Table 3.

Warning—Extreme caution should be exercised during this ignition. Reduction of the phosphate precipitate can result if carbon is in contact with it at high temperatures. There is also danger of occluding carbon in the precipitate if ignition is too rapid.

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15. SULFUR (SEE NOTE 42)

15.1. *Sulfur Trioxide (Reference Test Method)*:

15.1.1. *Summary of Test Method*—In this test method, sulfate is precipitated from an acid solution of the cement with barium chloride ($BaCl_2$). The precipitate is ignited and the mass is determined as barium sulfate ($BaSO_4$) and the SO_3 equivalent is calculated.

15.1.2. *Procedure*:

15.1.2.1. To 1 g of the sample add 25 mL of cold water and, while the mixture is stirred vigorously, add 5 mL of HCl (Note 43). If necessary, heat the solution and grind the material with the flattened end of a glass rod until it is evident that decomposition of the cement is complete (Note 44). Dilute the solution to 50 mL and digest for 15 minutes at a temperature just below boiling. Filter through a medium-textured paper and wash the residue thoroughly with hot water. Dilute the filtrate to 250 mL and heat to boiling. Add slowly, dropwise, 10 mL of hot $BaCl_2$ (100 g/L) and continue the boiling until the precipitate is well formed. Digest the solution for 12 to 24 hours at a temperature just below boiling (Note 45). Take care to keep the volume of solution between 225 and 260 mL and add water for this purpose if necessary. Filter through a retentive paper, wash the precipitate thoroughly with hot water, place the paper and contents in a weighed platinum crucible, and slowly char and consume the paper without inflaming. Ignite at 800° to 900°C, cool in a desiccator, and determine the mass.

Note 42—When an instrument test method is used for sulfur or when comparing results of classical wet and instrumental test methods, consult Section 4.1.2 of these test methods.

Note 43—The acid filtrate obtained in the determination of the insoluble residue (Section 5.3.1) may be used for the determination of SO_3 instead of using a separate sample.

Note 44—A brown residue due to compounds of manganese may be disregarded. (See Note 10.)

Note 45—If a rapid determination is desired, immediately after adding the $BaCl_2$, place the beaker with the solution in an ultrasonic bath for 5 minutes, and then continue the determination starting with "Filter through a retentive paper…". Qualify the method in accordance with the Performance Requirements for Rapid Test Methods.

15.1.3. *Blank*—Make a blank determination following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

15.1.4. *Calculation*—Calculate the percentage of SO_3 as follows:

$$\mathrm{SO_3}, \% = W \times 34.3 \qquad (7)$$

where:

W = grams of $BaSO_4$, and

34.3 = molecular ratio of SO_3 to $BaSO_4$ (0.343) multiplied by 100.

Report the results rounded in accordance with Table 3.

15.2. *Sulfide (Reference Test Method)*:

15.2.1. *Summary of Test Method*—In this test method sulfide sulfur is determined by evolution as hydrogen sulfide (H_2S) from an acid solution of the cement into a solution of ammoniacal zinc sulfate ($ZnSO_4$) or cadmium chloride ($CdCl_2$). The sulfide sulfur is then titrated with a standard solution of potassium iodate (KIO_3). Sulfites, thiosulfates, and other compounds intermediate between sulfides and sulfates are assumed to be absent. If such compounds are present, they may cause an error in the determination.

15.2.2. *Apparatus*:

15.2.2.1. *Gas-Generating Flask*—Connect a dry 500-mL boiling flask with a long-stem separatory funnel and a small connecting bulb by means of a rubber stopper. Bend the stem of the funnel so that it will not interfere with the connecting bulb, adjust the stem so that the lower end is close to the bottom of the flask, and connect the opening of the funnel with a source of compressed air. Connect the bulb with an L-shaped glass tube and a straight glass tube about 200 mm in length. Insert the straight glass tube in a tall-form, 400-mL beaker. A three-neck distilling flask with a long glass tubing in the middle opening, placed between the source of compressed air and the funnel, is a convenient aid in the regulation of the airflow. Rubber used in the apparatus shall be pure gum grade, low in sulfur, and shall be cleaned with warm HCl.

15.2.3. *Reagents*:

15.2.3.1. *Ammoniacal Cadmium Chloride Solution*—Dissolve 15 g of cadmium chloride ($CdCl_2 \cdot 2H_2O$) in 150 mL of water and 350 mL of NH_4OH. Filter the solution after allowing it to stand at least 24 hours.

15.2.3.2. *Ammoniacal Zinc Sulfate Solution*—Dissolve 50 g of zinc sulfate ($ZnSO_4 \cdot 7H_2O$) in 150 mL of water and 350 mL of NH_4OH. Filter the solution after allowing it to stand at least 24 hours.

15.2.3.3. *Potassium Iodate, Standard Solution* (0.03 *N*)—Prepare a solution of potassium iodate (KIO_3) and potassium iodide (KI) as follows: Dry KIO_3 at 180°C to constant mass. Dissolve 1.0701 g of the KIO_3 and 12 g of KI and dilute to 1 L in a volumetric flask. This is a primary standard and requires no standardization (Note 46). One milliliter of this solution is equivalent to 480.9 μg of sulfur.

Note 46—The solution is very stable, but may not maintain its titer indefinitely. Whenever such a solution is over one year old it should be discarded or its concentration checked by standardization.

15.2.3.4. *Stannous Chloride Solution*—To 10 g of stannous chloride ($SnCl_2 \cdot 2H_2O$) in a small flask, add 7 mL of HCl (1 + 1), warm the mixture gently until the salt is dissolved, cool the solution, and add 95 mL of water. This solution should be prepared as needed, as the salt tends to hydrolyze.

15.2.3.5. *Starch Solution*—To 100 mL of boiling water, add a cool suspension of 1 g of soluble starch in 5 mL of water and cool. Add a cool solution of 1 g of sodium hydroxide (NaOH) in 10 mL of water, then 3 g of potassium iodide (KI), and mix thoroughly.

15.2.4. *Procedure*:

15.2.4.1. Place 15 mL of the ammoniacal $ZnSO_4$ or $CdCl_2$ solution (Note 47) and 285 mL of water in a beaker. Put 5 g of the sample (Note 48) and 10 mL of water in the flask and shake the flask gently to wet and disperse the cement completely. This step and the addition of $SnCl_2$ should be performed rapidly to prevent the setting of the cement. Connect the flask with the funnel and bulb. Add 25 mL of the $SnCl_2$ solution through the funnel and shake the flask. Add 100 mL of HCl (1 + 3) through the funnel and shake the flask. During these shakings keep the funnel closed and the delivery tube in the ammoniacal $ZnSO_4$ or $CdCl_2$ solution. Connect the funnel with the source of compressed air, open the funnel, start a slow stream of air, and heat the flask and contents slowly to boiling. Continue the boiling gently for five or six minutes. Cut off the heat, and continue the passage of air for three or four minutes. Disconnect the delivery tube and leave it in the solution for use as a stirrer. Cool the solution to 20° to 30°C (Note 49), add 2 mL of the starch solution and 40 mL of HCl (1 + 1), and titrate immediately with the 0.03 *N* KIO_3 solution until a persistent blue color is obtained (Note 50).

Note 47—In general the $ZnSO_4$ is preferable to the $CdCl_2$ solution because $ZnSO_4$ is more soluble in NH_2OH than is $CdCl_2$. The $CdCl_2$ solution may be used when there is doubt as to the presence of a trace of sulfide sulfur, as the yellow cadmium sulfide (CdS) facilitates the detection of a trace.

Note 48—If the content of sulfur exceeds 0.20 or 0.25 percent, a smaller sample should be used so that the titration with the KIO_3 solution will not exceed 25 mL.

Note 49—The cooling is important as the end point is indistinct in a warm solution.

Note 50—If the content of sulfur is appreciable but not approximately known in advance, the result may be low due to the loss of H_2S during a slow titration. In such a case the determination should be repeated with the titration carried out more rapidly.

15.2.4.2. Make a blank determination, following the same procedure and using the same amounts of reagents. Record the volume of KIO_3 solution necessary to establish the end point as described in Section 15.2.4.1.

15.2.5. *Calculation*—Calculate the percentage of sulfide sulfur (Section 15.2.1) as follows:

$$\text{Sulfide, \%} = E\left(V - B\right) \times 20 \qquad (8)$$

where:

E = sulfide equivalent of the KIO_3 solution, g/mL;

V = milliliters of KIO_3 solution required by the sample;

B = milliliters of KIO_3 solution required by the blank; and

20 = 100 divided by the mass of sample used (5 g).

Report the result rounded in accordance with Table 3.

16. LOSS ON IGNITION (REFERENCE TEST METHOD)

16.1. *Portland Cement*:

16.1.1. *Summary of Test Method*—In this test method, the cement is ignited in a muffle furnace at a controlled temperature. The loss is assumed to represent the total moisture and CO_2 in the cement. This procedure is not suitable for the determination of the loss on ignition of portland blast-furnace slag cement and of slag cement. A test method suitable for such cements is described in Sections 16.2.1 through 16.2.3.

16.1.2. *Procedure*—Weigh 1 g of the sample in a tared platinum crucible. Cover and ignite the crucible and its contents to constant mass in a muffle furnace at a temperature of 950° ± 50°C. Allow a minimum of 15 minutes for the initial heating period and at least five minutes for all subsequent periods.

16.1.3. *Calculation*—Calculate the percentage of loss on ignition by multiplying the loss of mass in grams by 100. Report the result rounded in accordance with Table 3.

16.2. *Portland Blast-Furnace Slag Cement and Slag Cement*:

16.2.1. *Summary of Test Method*—Since it is desired that the reported loss on ignition represent moisture and CO_2, this test method provides a correction for the gain in mass due to oxidation of sulfides usually present in portland blast-furnace slag cement and slag cement by determining the increase in SO_3 content during ignition. An optional test method providing for a correction based on the decrease in sulfide sulfur during ignition is given in Sections 24.1.1 through 24.1.3.

16.2.2. *Procedure*:

16.2.2.1. Weigh 1 g of cement into a tared platinum crucible and ignite a muffle furnace at a temperature of 950° ± 50°C for 15 minutes. Cool to room temperature in a desiccator and determine the mass. Without checking for constant mass, carefully transfer the ignited material to a 400-mL beaker. Break up any lumps in the ignited cement with the flattened end of a glass rod.

16.2.2.2. Determine the SO_3 content by the test method given in Sections 15.1.2 through 15.1.4 (Note 51). Also determine the SO_3 content of a portion of the same cement that has not been ignited, using the same procedure.

Note 51—Some of the acid used for dissolving the sample may first be warmed in the platinum crucible to dissolve any adhering material.

16.2.3. *Calculation*—Calculate the percentage loss of mass occurring during ignition and add 0.8 times the difference between the percentages of SO_3 in the ignited sample and the original cement (Note 52). Report the corrected percentage, rounded in accordance with Table 3, as loss on ignition.

Note 52—If a gain in mass is obtained during ignition, subtract the percentage gain from the correction for SO_3.

17. SODIUM AND POTASSIUM OXIDE (REFERENCE TEST METHOD)

17.1. *Total Alkalies*:

17.1.1. *Summary of Test Method*—This test method covers the determination of sodium oxide (Na_2O) and potassium oxide (K_2O) by flame photometry or atomic absorption.[6]

Note 53—This test method is suitable for hydraulic cements that are completely decomposed by hydrochloric acid and should not be used for determination of total alkalies in hydraulic cements that contain large amounts of acid-insoluble material, for example, pozzolan cements. It may be used to determine acid-soluble alkalies for such cements. An alternate test method of sample dissolution for such cements is in preparation.

17.1.2. *Apparatus*:

17.1.2.1. *Instrument*—Any type flame photometer or atomic absorption unit may be used provided it can be demonstrated that the required degree of accuracy and precision is as indicated in Section 17.1.3.

Note 54—After such accuracy is established, for a specific instrument, further tests of instrument accuracy are not required except in cases of dispute when it must be demonstrated that the instrument gives results within the prescribed degree of accuracy by a single series of tests using the designated standard samples.

Note 55—For normal laboratory testing, it is recommended that the accuracy of the instrument be routinely checked by the use of either a National Institute of Standards and Technology cement or cement of known alkali content.

17.1.2.2. The instrument shall consist of an atomizer and burner; suitable pressure-regulating devices and gauges for fuel and oxident gas; an optical system capable of preventing excessive interference from wavelengths of light other than that being measured; and a photosensitive indicating device.

17.1.3. *Initial Qualification of Instrument*— Qualify the instrument in accordance with Section 3.3.2. to establish that an instrument provides the desired degree of precision and accuracy.

17.1.4. *Reagents and Materials*:

17.1.4.1. *Laboratory Containers*—All glassware shall be made of borosilicate glass and all polyethylene shall comply with the requirements of Section 4.2.3.

17.1.4.2. *Calcium Carbonate*—The calcium carbonate ($CaCO_3$) used in the preparation of the calcium chloride stock solution (Section 17.1.5.1) shall contain not more than 0.020 percent total alkalies as sulfate.

Note 56—Materials sold as a primary standard or ACS "low alkali" grade normally meet this requirement. However, the purchaser should assure himself that the actual material used conforms with this requirement.

17.1.4.3. *Potassium Chloride* (KCl).

17.1.4.4. *Sodium Chloride* (NaCl).

17.1.4.5. Commercially available solutions may be used in place of those specified in Section 17.1.5.

17.1.5. *Preparation of Solutions*:

17.1.5.1. *Calcium Chloride Stock Solution*—Add 300 mL of water to 112.5 g of $CaCO_3$ in a 1500-mL beaker. While stirring, slowly add 500 mL of HCl. Cool the solution to room temperature, filter into a 1-L volumetric flask, dilute to 1 L, and mix thoroughly. This solution contains the equivalent of 63,000 mg/L (6.30 percent) CaO.

17.1.5.2. *Sodium-Potassium Chloride Stock Solution*—Dissolve 1.8858 g of sodium chloride (NaCl) and 1.583 g of potassium chloride (KCl) (both dried at 105° to 110°C for several hours prior to the mass determination) in water. Dilute to 1 L in a volumetric flask and mix thoroughly. This solution contains the equivalent of 1000 mg/L (0.10 percent) each of Na_2O and K_2O. Separate solutions of Na_2O and of K_2O may be used provided that the same concentration solutions are used for calibration for cement analysis as were used for the calibration when qualifying the instrument in accordance with Section 17.1.3.

17.1.5.3. *Standard Solutions*—Prepare the standard solutions prescribed for the instrument and method used. Measure the required volume of NaCl-KCl stock solutions in calibrated pipets or burets. The calcium chloride stock solutions, if needed, may be measured in appropriate graduated cylinders. If the instrument being used requires an internal standard, measure the internal standard solution with a pipet or buret. Place each solution in a volumetric flask, dilute to the indicated volume, and mix thoroughly.

17.1.5.4. If more dilute solutions are required by the method in use, pipet the required aliquot to the proper sized volumetric flask, add any necessary internal standard, dilute to the mark, and mix thoroughly.

17.1.6. *Calibration of Apparatus*:

Note 57—No attempt is made in this section to describe in detail the steps for putting the instrument into operation since this will vary considerably with different instruments. The manufacturer's instructions should be consulted for special techniques or precautions to be employed in the operation, maintenance, or cleaning of the apparatus.

17.1.6.1. Turn on the instrument and allow it to warm up in accordance with the manufacturer's instructions. (A minimum of 30 minutes is required for most instruments.) Adjust the fuel and oxidant gas pressures as required by the instrument being used. Light and adjust the burner for optimum operation. Make any other adjustments that may be necessary to establish the proper operating conditions for the instrument.

17.1.7. *Procedure*:

17.1.7.1. *Solution of the Cement*—Prepare the solution of the cement in accordance with the procedure specified by the instrument manufacturer. If no procedure is specified, or if desired, proceed as specified in Section 17.1.7.1.1 or 17.1.7.1.2 (Note 58).

Note 58—The presence of SiO_2 in solution affects the accuracy of some flame photometers. In cases where an instrument fails to provide results within the prescribed degree of accuracy outlined in Sections 3.3.2.1 through 3.3.3, tests should be made on solutions from which the SiO_2 has been removed. For this removal proceed as in Section 17.1.7.1.2.

17.1.7.1.1. Place 1.000 ± 0.001 g of the cement in a 150-mL beaker and disperse with 20 mL of water using a swirling motion of the beaker. While still swirling, add 5.0 mL of HCl all at once. Dilute immediately to 50 mL with water. Break up any lumps of cement remaining undispersed with a flat-end stirring rod. Digest on a steam bath or hot plate for 15 minutes, then filter through a medium-textured filter paper into a 100-mL volumetric flask. Wash beaker and paper thoroughly with hot water, cool contents of the flask to room temperature, dilute to 100 mL, and mix the solution thoroughly. Continue as stated in Section 17.1.7.2.

17.1.7.1.2. Place 1.000 ± 0.001 g of cement into a platinum evaporating dish and disperse with 10 mL of water using a swirling motion. While still swirling, add 5.0 mL of HCl all at once. Break up any lumps with a flat-end stirring rod and evaporate to dryness on a steam bath. Make certain that the gelatinous appearance is no longer evident. Treat the residue with 2.5 mL of HCl and about 20 mL of water. Digest on a steam bath for 5 to 10 minutes and filter immediately through a 9-cm medium-textured filter paper into a 100-mL volumetric flask. Wash thoroughly with repeated small amounts of hot water until the total volume of solution is 80 to 95 mL. Cool to room temperature, dilute to the mark, and mix thoroughly.

When it has been demonstrated that the removal of SiO_2 is necessary to obtain the required accuracy described in Sections 3.3.2.1 through 3.3.3 for a specific flame photometer, SiO_2 must always be removed when making analyses that are used as the basis for rejection of a cement for failure to comply with specifications or where specification compliance may be in question. Where there is no question as to specification compliance, analyses may be made by such instruments without SiO_2 removal provided the deviations from certificate values obtained by the tests prescribed in Sections 3.3.2.1 through 3.3.3 are not more than twice the indicated limits.

17.1.7.2. If the test method in use requires more dilute solutions, an internal standard, or both, carry out the same dilutions as in Section 17.1.5.4 as needed. The standard and the sample solutions to be analyzed must be prepared in the same way and to the same dilution as the solutions of standard cements analyzed for the qualification of the instrument.

17.1.7.3. *Procedure for Na_2O* (Note 60)—Warm up and adjust the instrument for the determination of Na_2O as described in Section 17.1.6.1. Immediately following the adjustment and without changing any instrumental settings, atomize the cement solution and note the scale reading (Note 59). Select the standard solutions which immediately bracket the cement solution in Na_2O content and observe their readings. Their values should agree with the values previously established during calibration of the apparatus. If not, recalibrate the apparatus for that constituent. Finally, alternate the use of the unknown solution and the bracketing standard solutions until readings of the unknown agree within one division on the transmission or meter scale, or within 0.01 mass percent for instruments with digital readout, and readings for the standards similarly agree with the calibration values. Record the average of the last two readings obtained for the unknown solution.

Note 59—The order in determining Na_2O or K_2O is optional. In all cases, however, the determination should immediately follow the adjustment of the instrument for that particular constituent.

17.1.7.4. If the reading exceeds the scale maximum, either transfer a 50-mL aliquot of the solution prepared in Section 17.1.7.1 to a 100-mL volumetric flask or, if desired, prepare a new solution by using 0.500 g of cement and 2.5 mL of HCl (instead of 5.0 mL) in the initial addition of acid. In the event silica has to be removed from the 0.5-g sample of cement, treat the dehydrated material with 1.25 mL of HCl and about 20 mL of water, then digest, filter, and wash. In either case, add 5.0 mL of calcium chloride stock solution (Section 17.1.5.1) before diluting to mark with water. Dilute to the mark. Proceed as in Section 17.1.5.4 if more dilute solutions are required by the test method in use. Determine the alkali content of this solution as described in Section 17.1.7.3 and multiply the percentage of alkali oxide by a factor of 2.

17.1.7.5. *Procedure for K_2O*—Repeat the procedure described in Section 17.1.7.3 except that the instrument shall be adjusted for the determination of K_2O. For instruments that read both Na_2O and K_2O simultaneously, determine K_2O at the same time as determining Na_2O.

17.1.8. *Calculation and Report*—From the recorded averages for Na_2O and K_2O in the unknown sample, report each oxide rounded in accordance with Table 3.

17.2. *Water-Soluble Alkalies*:

Note 60—The determination of water-soluble alkali should not be considered as a substitute for the determination of total alkali according to Sections 17.1.2.1 through 17.1.8. Moreover, it is not to be assumed that in this method all water-soluble alkali in the cement will be dissolved. Strict adherence to the procedure described is essential where there is a specified limit on the content of water-soluble alkali or where several lots of cement are compared on the basis of water-soluble alkali.

17.2.1. *Procedure*:

17.2.1.1. Weigh 25.0 g of sample into a 500-mL Erlenmeyer flask and add 250 mL of water. Stopper the flask with a rubber stopper and shake continuously for 10 minutes at room temperature. Filter through a Büchner funnel that contains a well-seated retentive, dry filter paper into a 500-mL filtering flask, using a weak vacuum. Do not wash.

17.2.1.2. Transfer a 50-mL aliquot (Note 61) of the filtrate to a 100-mL volumetric flask and acidify with 0.5 mL of concentrated HCl (sp gr 1.19). Add 9.0 mL of stock $CaCl_2$ solution (63,000 mg/L CaO), described in Section 17.1.5.1, to the 100-mL flask, and dilute the solution to 100 mL. If the test method in use requires more dilute solutions, an internal standard, or both, carry out the same dilutions as in Section 17.1.5.4. as needed. Determine the Na_2O and K_2O contents of this solution as described in Sections 17.1.7.3 and 17.1.7.5. Record the parts per million of each alkali in the solution in the 100-mL flask.

Note 61—The aliquot of the filtrate taken for the analysis should be based on the expected water-soluble alkali content. If the expected level of either K_2O or Na_2O is more than 0.08 mass percent of cement, or if the water soluble alkali level is unknown, a 50-mL aliquot as given in Section 17.2.1.2 should be used to make up the initial test solution. If either the Na_2O or K_2O exceeds

0.16 percent, place a 50-mL aliquot of the solution from Section 17.2.1.2 in a 100-mL volumetric flask, add 5 mL of $CaCl_2$ stock solution and dilute to 100 mL. When the level of either K_2O or Na_2O is less than 0.08 percent, take a 100-mL aliquot from the original filtrate (obtained by Section 17.2.1.1), add 1 mL of HCl, and evaporate on a hot plate in a 250-mL beaker to about 70 mL. Add 8 mL of stock $CaCl_2$ solution and transfer the sample to a 100-mL volumetric flask, rinsing the beaker with a small portion of distilled water. Cool the solution to room temperature and dilute to 100 mL.

17.2.2. *Calculations*—Calculate the percentage of the water-soluble alkali, expressed as Na_2O, as follows:

$$\text{Total Water-Soluble Alkali, as } Na_2O = A + E \tag{9}$$

$$A = B/(V \times 10)$$

$$C = D/(V \times 10)$$

$$E = C \times 0.658$$

where:

A = percentage of water-soluble sodium oxide (Na_2O),
B = parts per million of Na_2O in the solution in the 100-mL flask,
V = milliliters of original filtrate in the 100-mL flask,
C = percent of water-soluble potassium oxide (K_2O),
D = parts per million of K_2O in the 100-mL flask,
E = percentage Na_2O equivalent to K_2O determined, and
0.658 = molecular ratio of Na_2O to K_2O.

Report the result rounded in accordance with Table 3.

18. MANGANIC OXIDE (REFERENCE TEST METHOD)

18.1. *Summary of Test Method*—In this procedure, manganic oxide is determined volumetrically by titration with sodium arsenite solution after oxidizing the manganese in the cement with sodium metabismuthate ($NaBiO_3$).

18.2. *Reagents*:

18.2.1. *Sodium Arsenite, Standard Solution* (1 mL = 0.3 mg Mn_2O_3)—Dissolve in 100 mL of water 3.0 g of sodium carbonate (Na_2CO_3) and then 0.90 g of arsenic trioxide (As_2O_3), heating the mixture until the solution is as complete as possible. If the solution is not clear or contains a residue, filter the solution. Cool it to room temperature, transfer to a volumetric flask, and dilute to 1 L.

18.2.1.1. Dissolve 0.58 g of potassium permanganate ($KMnO_4$) in 1 L of water and standardize it against about 0.03 g of sodium oxalate ($Na_2C_2O_4$) oxidimetric standard furnished by NIST (Standard Sample No. 40 or its replacement) according to the directions furnished with the sodium oxalate. Put 30.0 mL of the $KMnO_4$ solution in a 250-mL Erlenmeyer flask. Add 60 mL of HNO_3 (1 + 4) and 10 mL of sodium nitrite ($NaNO_2$, 50 g/L) to the flask. Boil the solution until the HNO_2 is completely expelled. Cool the solution, add $NaBiO_3$, and finish by titrating with the standard sodium arsenite ($NaAsO_2$) solution as described in Section 18.3.2. Calculate the manganic oxide (Mn_2O_3) equivalent of the $NaAsO_2$ solution, g/mL, as follows:

$$E = \left(A \times 7.08\right)/BC \tag{10}$$

where:

E = Mn_2O_3 equivalent of the $NaAsO_2$ solution, g/mL;

A = grams of $Na_2C_2O_4$ used;
B = milliliters of $KMnO_4$ solution required by the $Na_2C_2O_4$;
C = milliliters of $NaAsO_2$ solution required by 30.0 mL of $KMnO_4$ solution; and
7.08 = molecular ratio of Mn_2O_3 to 5 $Na_2C_2O_4$ (0.236) multiplied by 30.0 (milliliters of $KMnO_4$ solution).

18.2.2. *Sodium Metabismuthate* ($NaBiO_3$).

18.2.3. *Sodium Nitrite Solution* (50 g $NaNO_2$/L).

18.3. *Procedure*:

18.3.1. Weigh 1.0 to 3.0 g of the sample (Note 62) into a 250-mL beaker and treat it with 5 to 10 mL of water and then with 60 to 75 mL of HNO_3 (1 + 4). Boil the mixture until the solution is as complete as possible. Add 10 mL of $NaNO_2$ solution (50 g/L) to the solution and boil it until the nitrous acid is completely expelled (Note 63), taking care not to allow the volume of the solution to become so small as to cause the precipitation of gelatinous SiO_2. There may be some separated SiO_2, which may be ignored, but if there is still a red or brown residue, use more $NaNO_2$ solution (50 g/L) to effect a complete decomposition, and then boil again to expel the nitrous acid. Filter the solution through a medium-textured paper into a 250-mL Erlenmeyer flask and wash the filter paper with water.

Note 62—The amount of cement taken for analysis depends on the content of manganese, varying from 1 g for about 1 percent of Mn_2O_3 to 3 g for 0.25 percent or less of Mn_2O_3.

Note 63—When $NaNO_2$ is added, the expulsion of HNO2 by boiling must be complete. If any HNO_2 remains in the solution, it will react with the added $NaBiO_3$ and decrease its oxidizing value. If there is any manganese in the cement, the first small quantity of $NaBiO_3$ should bring out a purple color.

18.3.2. The solution should have a volume of 100 to 125 mL. Cool it to room temperature. To the solution add a total of 0.5 g of $NaBiO_3$ in small quantities, while shaking intermittently. After the addition is completed, shake the solution occasionally for five minutes and then add to it 50 mL of cool HNO_3 (1 + 33) which has been previously boiled to expel nitrous acid. Filter the solution through a pad of ignited asbestos in a Gooch crucible or a carbon or fritted-glass filter with the aid of suction. Wash the residue four times with the cool HNO_3 (1 + 33). Titrate the filtrate immediately with the standard solution of $NaAsO_2$. The end point is reached when a yellow color is obtained free of brown or purple tints and does not change upon further addition of $NaAsO_2$ solution.

18.3.3. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

18.4. Calculate the percentage of Mn_2O_3, as follows:

$$\mathrm{Mn_2O_3},\ \% = \left(EV/S\right) \times 100 \qquad (11)$$

where:

E = Mn_2O_3 equivalent of the $NaAsO_2$ solution, g/mL;
V = milliliters of $NaAsO_2$ solution required by the sample; and
S = grams of sample used.

Report the result rounded in accordance with Table 3.

19. CHLORIDE (REFERENCE TEST METHOD)

19.1. *Summary of Test Method*—In this test method, acid-soluble chloride content of cement is determined by the potentiometric titration of chloride with silver nitrate (see Note 64). The procedure is also applicable to clinker and portland cement raw mix. Under the conditions of the test, no constituent normally present in these materials will interfere (see Note 65).

Note 64—In most cases acid-soluble chloride content of a portland cement is total chloride content.

Note 65—Species that form insoluble silver salts or stable silver complexes in acid solution interfere with potentiometric measurements. Thus, iodides and bromides interfere while fluorides will not. Sulfide salts in concentrations typical of these materials should not interfere because they are decomposed by acid treatment.

19.2. *Apparatus*:

19.2.1. *Chloride, Silver/Sulfide Ion Selective Electrode*—or a silver billet electrode coated with silver chloride (Note 66), with an appropriate reference electrode.

19.2.2. *Potentiometer*—with millivolt scale readable to 1 mV or better. A digital read-out is preferred but not required.

19.2.3. *Buret*—Class A, 10-mL capacity with 0.05-mL divisions. A buret of the potentiometric type, having a displaced delivery tip, is convenient, but not required.

Note 66—Suitable electrodes are available from Orion, Beckman Instruments, and Leeds and Northrup. Carefully following the manufacturer's instructions, add filling solution to the electrodes. The silver billet electrodes must be coated electrolytically with a thin, even layer of silver chloride. To coat the electrode, dip the clean silver billet of the electrode into a saturated solution of potassium chloride (about 40 g/L) in water and pass an electric current through the electrode from a 1.5 to 6-V dry cell with the silver billet electrode connected to the positive terminal of the battery. A carbon rod from an all-dry cell or other suitable electrode is connected to the negative terminal and immersed in the solution to complete the electrical circuit. When the silver chloride coating wears off, it is necessary to rejuvenate the electrode by repeating the above procedure. All of the old silver chloride should first be removed from the silver billet by rubbing it gently with fine emery paper followed by water rinsing of the billet.

19.3. *Reagents*:

19.3.1. *Sodium Chloride* (NaCl), primary standard grade.

19.3.2. *Silver Nitrate* ($AgNO_3$), reagent grade.

19.3.3. *Potassium Chloride* (KCl), reagent grade (required for silver billet electrode only).

19.3.4. *Reagent Water* conforming to the requirements of ASTM D 1193 for Type III reagent water.

19.4. *Preparation of Solutions*:

19.4.1. *Sodium Chloride, Standard Solution* (0.05 *N* NaCl)—Dry sodium chloride (NaCl) at 105° to 110°C to a constant mass. Weigh 2.9222 g of dried reagent. Dissolve in water and dilute to exactly

1 L in a volumetric flask and mix thoroughly. This solution is the standard and requires no further standardization.

19.4.2. *Silver Nitrate, Standard Solution* (0.05 *N* $AgNO_3$)—Dissolve 8.4938 g of silver nitrate ($AgNO_3$) in water. Dilute to 1 L in a volumetric flask and mix thoroughly. Standardize against 5.00 mL of standard 0.05 *N* sodium chloride solution diluted to 150 mL with water following the titration test method given in Section 19.5.4 beginning with the second sentence. The exact normality shall be calculated from the average of three determinations as follows:

$$N - 0.25/V \tag{12}$$

where:

N = normality of $AgNO_3$ solution;

0.25 = milliequivalents NaCl (5.0 mL × 0.05 *N*); and

V = volume of $AgNO_3$ solution, mL.

Commercially available standard solutions may be used provided the normality is checked according to the standardization procedure.

19.4.3. *Methyl Orange Indicator*—Prepare a solution containing 2 g of methyl orange per liter of 95 percent ethyl alcohol.

19.5. *Procedure*:

19.5.1. (Note 67). Disperse the sample with 75 mL of water. Without delay slowly add 25 mL of dilute (1 + 1) nitric acid, breaking up any lumps with a glass rod. If the smell of hydrogen sulfide is strongly evident at this point, add 3 mL of hydrogen peroxide (30 percent solution) (Note 68). Add three drops of methyl orange indicator and stir. Cover the beaker with a watch glass and allow to stand for 60 to 120 seconds. If a yellow to yellow-orange color appears on top of the settled solids, the solution is not sufficiently acidic. Add additional dilute nitric acid (1 + 1) dropwise while stirring until a faint pink or red color persists. Then add 10 drops in excess. Heat the covered beaker rapidly to boiling. Do not allow to boil for more than a few seconds. Remove from the hot plate (Note 69).

Note 67—Use a 5-g sample for cement, and other materials having an expected chloride content of less than about 0.15 percent Cl. Use proportionally smaller samples for materials with higher chloride concentrations. Use cement and other powdered materials as is without grinding. Coarse samples require grinding to pass a 0.850-mm (No. 20) sieve. If a sample is too fine, excessive silica gel may form during digestion with nitric acid, thereby slowing subsequent filtration.

Note 68—Slags and slag cements contain sulfide sulfur in concentrations that can interfere with the determination.

Note 69—It is important to keep the beaker covered during heating and digestion to prevent the loss of chloride by volatilization. Excessive amounts of acid should not be used since this results in early removal of the silver chloride coating from the silver billet electrode. A slurry that is only slightly acidic is sufficient.

19.5.2. Wash a 9-cm coarse-textured filter paper with four 25-mL increments of water using suction filtering provided by a 250-mL or 500-mL Büchner funnel and filtration flask. Discard the washings and rinse the flask once with a small portion of water. Reassemble the suction apparatus and filter the sample solution. Rinse the beaker and the filter paper twice with small portions of water. Transfer the filtrate from the flask to a 250-mL beaker and rinse the flask once with water. The original beaker may be used (Note 70). Cool the filtrate to room temperature. The volume should not exceed 175 mL.

Note 70—It is not necessary to clean all the slurry residue from the sides of the beaker nor is it necessary that the filter remove all of the fine material. The titration may take place in a solution containing a small amount of solid matter.

19.5.3. For instruments equipped with dial readout it is necessary to establish an approximate "equivalence point" by immersing the electrodes in a beaker of water and adjusting the instrument to read about 20 mV lower than mid scale. Record the approximate millivoltmeter reading. Remove the beaker and wipe the electrodes with absorbent paper.

19.5.4. To the cooled sample (Note 71) beaker from Section 19.5.2, carefully pipet 2.00 mL of standard 0.05 *N* NaCl solution. Place the beaker on a magnetic stirrer and add a TFE-fluorocarbon-coated magnetic stirring bar. Immerse the electrodes into the solution taking care that the stirring bar does not strike the electrodes; begin stirring gently. Place the delivery tip of the 10-mL buret, filled to the mark with standard 0.05 *N* silver nitrate solution, in (preferably) or above the solution (Note 72).

Note 71—It is advisable to maintain constant temperature during measurement, for the solubility relationship of silver chloride varies markedly with temperature at low concentrations.

Note 72—If the tip of the buret is out of the solution, any adhering droplet should be rinsed onto the beaker with a few milliliters of water following each titration increment.

19.5.5. Gradually titrate, record the amount of standard 0.05 *N* silver nitrate solution required to bring the millivoltmeter reading to –60.0 mV of the equivalence point determined in the water.

19.5.6. Continue the titration with 0.20-mL increments. Record the buret reading and the corresponding millivoltmeter reading in Columns 1 and 2 of a four-column recording form like that shown in Appendix X1. Allow sufficient time between each addition for the electrodes to reach equilibrium with the sample solution. Experience has shown that acceptable readings are obtained when the minimum scale reading does not change within a five-second period (usually within 120 seconds).

19.5.7. As the equivalence point is approached, the equal additions of $AgNO_3$ solution will cause larger and larger changes in the millivoltmeter readings. Past the equivalence point, the change per increment will again decrease. Continue to titrate until three readings past the approximate equivalence point have been recorded.

19.5.8. Calculate the difference in millivolt readings between successive additions of titrant and enter the values in Column 3 of the recording form. Calculate the difference between consecutive values in Column 3 and enter the results in Column 4. The equivalence point of the titration will be within the maximum ΔmV interval recorded in Column 3. The precise equivalence point can be interpolated from the data listed in Column 4 as shown in Appendix X1.

19.5.9. *Blank*—Make a blank determination using 75 mL of water in place of the sample, following the same procedure starting with the third sentence of Section 19.5.1 without delay. Correct the results obtained in the analysis accordingly (Note 73) by subtracting the blank.

19.6. *Calculations*—Calculate the percent chloride as follows:

$$Cl,\% = \frac{3.5453(V_1 - V_2)\,N}{W} \qquad (13)$$

where:

V_1 = milliliters of 0.05 *N* $AgNO_3$ solution used for sample titration (equivalence point),

V_2 = milliliters of 0.05 *N* $AgNO_3$ solution used for blank titration (equivalence point),

N = exact normality of 0.05 *N* $AgNO_3$ solution, and

W = weight of sample, g.

Report the result rounded in accordance with Table 3.

Note 73—For nonreference analysis the blank may be omitted.

20. CHLOROFORM-SOLUBLE ORGANIC SUBSTANCES (REFERENCE TEST METHOD)

20.1. *Summary of Test Method*—This test method was specially designed for the determination of Vinsol resin and tallow in portland cement, although mineral oil, common rosin, calcium stearate, and other fatty acid compounds, and probably some other substances, if present, will be included in the determination.[7] Extreme care is necessary in the entire procedure. The test method may be applied to types of cement other than portland cement, although if the cement contains a large amount of acid-insoluble matter, the emulsions may separate slowly, and less vigorous shaking, more chloroform, and more washing may be necessary.

20.2. *Reagents*:

20.2.1. *Chloroform*—If the blank determination as described in Section 20.3.5 exceeds 1.5 mg, the chloroform should be distilled before use. Chloroform recovered in the procedure may be slightly acid but can be reused for the portions to be shaken with the aqueous acid solution of the sample in the 1-L funnel. Chloroform used for washing the filter and transferring the extract should be fresh or distilled from fresh chloroform.

20.2.2. *Stannous Chloride* ($SnCl_2$).

20.3. *Procedure*:

20.3.1. Place 40 g of cement in a 1-L Squibb separatory funnel (Note 74) and mix it with 520 mL of water added in two approximately equal portions. Shake vigorously immediately after the addition of the first portion to effect complete dispersion. Then add the second portion and shake again. At once add rapidly 185 mL of HCl in which 10 g of $SnCl_2$ (Note75) have been dissolved, rapidly insert the stopper in the funnel, invert, and shake with a swirling motion for a few seconds to loosen and disperse all the cement, taking care to avoid the development of great internal pressure due to unnecessarily violent shaking. Release internal pressure immediately by opening and closing the stopcock. Repeat the shaking and release the pressure until the decomposition of the cement is complete. If necessary, break up persistent lumps with a long glass rod. Cool to room temperature rapidly by allowing tap water to run on the flask.

Note 74—The use of grease to lubricate the stopcocks and glass stoppers of the separatory funnels should be avoided. Wetting the stopcocks with water before using will assist in their easy operation.

Note 75—The purpose of the $SnCl_2$ is to prevent the oxidation of sulfide sulfur to elemental sulfur, which is soluble in chloroform.

20.3.2. Add 75 mL of chloroform to the solution, stopper the funnel, shake it vigorously for five minutes, and allow the water and chloroform to stand 15 minutes to separate. Draw off the lower chloroform layer into a 125-mL Squibb separatory funnel, including the scum (Note 76) and a few milliliters of the aqueous layer, making certain that all the scum is transferred. Keep the amount of the aqueous layer transferred to an absolute minimum, since excessive water in the 125-mL funnel may result in incomplete extraction of the scum and may cause an emulsion which does not separate readily. Shake the funnel vigorously to ensure the complete extraction of the scum. Allow the chloroform to separate, and draw it into a 250-mL Squibb separatory funnel which contains 50 mL of water and a few drops of HCl, making sure to keep the scum behind in the 125-mL funnel. Shake the 250-mL funnel, and draw the chloroform into another 250-mL funnel that contains 50 mL of water and a few drops of HCl. Shake this funnel as in the case of the first 250-mL funnel. When the chloroform separates, draw it into a standard-taper flat-bottom boiling flask (Note 77), taking care not to allow any water to enter the flask.

Note 76—There is usually a dark-colored scum at the liquid interface. It may contain chloroform-soluble organic substance after shaking in the funnel, where the proportion of water to chloroform is great. It may be concentrated and confined to a small volume by gently twirling the funnel after the scum has been drawn into the narrower part of the funnel.

Note 77—The liquid is later distilled. No cork or rubber stoppers should be used. A 250- or 300-mL soil analysis flask, fitted with a condenser tube by means of a ground joint, is satisfactory. The tube may be bent near the neck and the remaining part fitted with a water-cooling jacket. Chloroform thus recovered may be reused as described in Section 20.2.1.

20.3.3. Add 25 mL of chloroform to the solution in the original 1-L separatory funnel, and carry out the operations as described in Section 20.3.2, retaining the original wash water in the 250-mL funnels. Repeat, using another 25-mL portion of chloroform.

20.3.4. Distill the combined chloroform extracts in the boiling flask until their volume is reduced to 10 to 15 mL. Filter the remaining liquid into a tared 100-mL glass beaker or platinum dish (Note 78) through a small medium-textured filter paper that has been washed with fresh chloroform. Rinse the flask and wash the paper with several small portions of fresh chloroform. Evaporate the extracts at a low temperature (not over 63°C) to dryness (Note 79) and heat it in an oven at 57° to 63°C for three minutes. Pass dry air into the vessel for 15 seconds, cool, and determine the mass. Repeat the heating and mass determinations until two successive mass determinations do not differ by more than 1 mg. The higher of the last two mass determinations shall be taken as the true mass.

Note 78—A platinum dish is preferable, as it quickly attains the temperature of the balance. If a glass beaker is used, it should be allowed to stand in the case of the balance for at least 20 minutes before determining the mass.

Note 79—Care should be taken in drying the extract, as many of the chloroform-soluble organic substances are somewhat volatile when heated for a long time at even moderate temperatures. With protection from the accumulation of dust, the solution may be evaporated on room temperature overnight.

When a quick evaporation is desired, the solution may be evaporated on a hot plate at low heat under a stream of dry air through a glass tube (about 10 mm in inside diameter) until it is about 3 mm in depth. Then remove the vessel from the hot plate and continue a slow stream of dry air until the residue appears dry. Then continue with a more rapid stream of dry air for five minutes at room temperature before placing the vessel in the oven at 57° to 63°C. After each three-minute heating period in the oven, pass dry air into the vessel for about 15 seconds before determining the mass. The air may be dried by passing it through a cheap desiccant, such as calcium chloride or sulfuric acid, followed by a desiccant of high efficiency, such as magnesium perchlorate or anhydrous calcium sulfate, with care taken to avoid the carrying of dust from the desiccant by the air. Instead of using compressed air, which is often contaminated with oil, dirt, and moisture, one can place the chloroform solution under a bell glass and induce a stream of air through the desiccants by means of an aspirator or vacuum pump.

When Vinsol resin is known to be the only substance present, the residue is more stable and may be heated at 100° to 105°C, instead of 57° to 63°C, in order to expel all possible traces of chloroform.

20.3.5. *Blank*—Make a blank determination. Ignite a 40-g sample of the cement at 950 to 1000°C for one hour (Note 80) and regrind. Treat this ignited sample by the same procedure and using the same reagents as in the analysis and correct the results accordingly.

Note 80—Care should be taken to completely burn off the organic substance. A 100-mL flat platinum dish, in which the sample is well spread out, and a muffle furnace are advised for this purpose. If such a furnace is not available, a large high-temperature burner of the Meker type may be used. Thorough stirring of the sample should be done frequently—every five minutes when a burner is used.

20.4. *Calculation*—Calculate the percentage of chloroform-soluble organic substances to the nearest 0.001 by multiplying the mass in grams of residue (Note 81) by 2.5 (100 divided by the mass of the sample used (40 g)). Report the result rounded in accordance with Table 3.

Note 81—If the organic substance in the cement is tallow, the residue is the fatty acids resulting from the hydrolysis of the tallow in the hot acid solution, and its mass should be multiplied by 1.05 to give the mass of the original glycerides in the tallow. If the original substance is calcium stearate, the residue is stearic acid, and its mass multiplied by 1.07 gives the mass of calcium stearate.

ALTERNATIVE TEST METHODS

21. CALCIUM OXIDE (ALTERNATIVE TEST METHOD)

21.1. *Summary of Test Method*:

21.1.1. This test method covers the gravimetric determination of CaO after removal of SiO_2 and the ammonium hydroxide groups and double precipitation of calcium as the oxalate. The precipitate is converted to CaO by ignition and the mass is determined.

21.1.2. Strontium, usually present in portland cement as a minor constituent, is precipitated with calcium as the oxalate and is subsequently calculated as CaO. If the SrO content is known and correction of CaO for SrO is desired, as, for example, for research purposes or to compare results with CRM certificate values, the CaO obtained by this test method may be corrected by subtracting percent SrO. In determining conformance of a cement to specifications, the correction of CaO for SrO should not be made.

21.2. *Procedure* (Note 82):

21.2.1. Acidify the combined filtrates obtained in the determination of the ammonium hydroxide group (Sections 7.1 through 7.3) and, if necessary, evaporate to a volume of about 200 mL. Add 5 mL of HCl, a few drops of methyl red indicator solution, and 30 mL of warm ammonium oxalate solution (50 g/L) (Note 38). Heat the solution to 70° to 80°C and add NH_4OH (1 + 1) dropwise while stirring until the color changes from red to yellow. (See Note 39.) Allow the solution to stand without further heating for 1 hour (not longer), with occasional stirring during the first 30 minutes. Filter using a retentive paper and wash moderately with cold ammonium oxalate solution (1 g/L). Reserve the filtrate and washings.

Note 82—When analyses are being made for determining conformity to specifications and there is a possibility that sufficient manganese will be present to cause the percentage of magnesium determined by optional test methods to exceed the specification limit, manganese may be removed as directed in Section 13.3.2 before CaO is determined by this alternative test method.

21.2.2. Transfer the precipitate and filter paper to the beaker in which the precipitation was made. Dissolve the oxalate in 50 mL of hot HCl (1 + 4) and macerate the filter paper. Dilute to 200 mL with water, add a few drops of methyl red indicator and 20 mL of ammonium oxalate solution, heat the solution nearly to boiling, and precipitate calcium oxalate again by neutralizing the acid solution with NH_4OH as described in Section 21.2.1. Allow the solution to stand one to two hours (standing for two hours at this point does no harm), filter, and wash as before. Combine the filtrate with that already obtained and reserve for the determination of MgO (Section 14.3.1).

21.2.3. Dry the precipitate in a tared covered platinum crucible. Char the paper without inflaming, burn the carbon at as low a temperature as possible, and, finally, heat with the crucible tightly covered in an electric furnace or over a blast lamp at a temperature of 1100° to 1200°C. Cool in a desiccator and determine the mass as CaO. Repeat the ignition to constant mass.

21.2.4. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

21.3. *Calculation*:

21.3.1. Calculate the percentage of CaO to the nearest 0.1 by multiplying the mass in grams of CaO by 200 (100 divided by the mass of sample used (0.5 g)).

21.3.2. Correct the percent CaO for SrO, if desired, by subtracting the percent SrO.

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22. CARBON DIOXIDE (REFERENCE TEST METHOD)

22.1. Any test method may be used, provided that acceptable performance has been demonstrated in accordance with Section 22.2. See Appendix X2 for guidance on methods.

22.2. Demonstrate performance by analysis, in duplicate, of at least on portland cement. Prepare three standards, each in duplicate: Standard A shall be the selected portland cement; Standard B shall be Standard A containing 2.00 percent Certified $CaCO_3$ (such as NIST 915a); Standard C shall be Standard A containing 5.00 percent Certified $CaCO_3$. Prepare duplicate specimens of each standard. Assign the CO_2 content of Standard A as the average of the two values determined, provided they agree within the required limit of Table 1, Column 2. Assign CO_2 values to Standards B and C as follows: multiply the Certified $CaCO_3$ value (Y) for CO_2 (from the certificate value) by the mass fraction of Certified $CaCO_3$ added to that standard (percentage added divided by 100); multiply the value determined for Standard A by the mass fraction of Standard A in each of the other standards (that is, 0.98 and 0.95 for Standards B and C, respectively); add the two values for Standard A and for Standard B, respectively; call these values B and C. Example:

$$B = 0.98A + 0.02Y$$
$$C = 0.95A + 0.05Y$$

where for Certified $CaCO_3$, if Y = 44.01%

$$B = 0.98A + 0.88\% \text{ by mass}$$
$$C = 0.95A + 2.20\% \text{ by mass}$$

The difference between the duplicate CO_2 values for Standards B and C, respectively, shall not exceed 0.17 and 0.24 percent by mass. The difference between the average of the duplicate values for Standards B and C and their assigned values (B and C) shall not exceed 0.13 and 0.26 percent by mass respectively.

22.3. Report the results rounded in accordance Table 3.

23. MAGNESIUM OXIDE (ALTERNATIVE TEST METHOD)

23.1. *Summary of Test Method*—This alternative test method is a volumetric procedure suitable for use when the determination of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), and calcium oxide (CaO) are omitted.

23.2. *Rapid Volumetric Test Method (Titration of Magnesium Oxyquinolate)*:

23.3. *Reagents*:

23.3.1. *Ammonium Nitrate Solution* (20 g NH_4NO_3/L).

23.3.2. *Ammonium Oxalate Solution* (50 g/L).

23.3.3. *Hydroxyquinoline Solution*—Dissolve 25 g of 8-hydroxyquinoline in 60 mL of acetic acid. When the solution is complete, dilute to 2 L with cold water. One milliliter of this solution is equivalent to 1.6 mg of MgO.

23.3.4. *Potassium Bromate-Potassium Bromide, Standard Solution* (0.2 *normal*)—Dissolve 20 g of potassium bromide (KBr) and 5.57 g of potassium bromate ($KBrO_3$) in 200 mL of water and dilute to 1 L. Obtain the ratio of the strength of this solution to that of the 0.1 *N* $Na_2S_2O_3$ solution (Section 23.3.6) as follows: To 200 mL of water in a 500-mL Erlenmeyer flask add 25.0 mL of the 0.2 *N* $KBrO_3$-KBr solution, measured from a pipet or buret. Add 20 mL of HCl, stir, and add immediately 10 mL of potassium iodide (KI) (250 g/L). Mix well and titrate at once with the $Na_2S_2O_3$ solution until nearly colorless. Add 2 mL of starch solution and titrate to the disappearance of the blue color. Calculate the ratio in strength of the $KBrO_3$-KBr solution to the $Na_2S_2O_3$ solution by dividing the volume of $Na_2S_2O_3$ solution by the volume of $KBrO_3$-KBr solution used in the titration.

23.3.5. *Potassium Iodide Solution* (250 g KI/L).

23.3.6. *Sodium Thiosulfate, Standard Solution* (0.1 *N*)—Dissolve 25 g of sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in 200 mL of water, add 0.1 g of sodium carbonate (Na_2CO_3), and dilute to 1 L. Let stand at least seven days. Standardize this solution directly against primary standard potassium dichromate ($K_2Cr_2O_7$). One milliliter of 0.10 N $Na_2S_2O_3$ solution is equivalent to 504 µg of MgO.

23.3.7. *Starch Solution*—To 500 mL of boiling water add a cold suspension of 5 g of soluble starch in 25 mL of water, cool to room temperature, add a cool solution of 5 g of sodium hydroxide (NaOH) in 50 mL of water, add 15 g of KI, and mix thoroughly.

23.4. *Procedure*:

23.4.1. Disperse 0.5 g (Note 83) of the sample of cement in a 400-mL beaker with 10 mL of water, using a swirling motion. While still swirling, add 10 mL of HCl all at once. Dilute immediately to 100 mL. Heat gently and grind any coarse particles with the flattened end of a glass rod until decomposition is complete, add two or three drops of HNO_3 and heat to boiling (Note 84).

Note 83—If SiO_2, ammonium hydroxide group, and CaO are separated and determined in accordance with the appropriate sections for either the reference or alternative test methods, the remaining filtrate may be used for the determination of MgO as described in Section 23.4.1, starting with the third from the last sentence of Section 23.4.2. "Add 5 mL of HCl…".

Note 84—In the case of cements containing blast-furnace slag or a significant quantity of sulfide sulfur, add 12 drops of HNO_3 and boil for 20 minutes to oxidize iron and remove sulfide.

23.4.2. Add three drops of methyl red indicator to the solution and then add NH_4OH until the solution is distinctly yellow. Heat this solution to boiling and boil for 50 to 60 seconds. In the event difficulty from bumping is experienced while boiling the ammoniacal solution, a digestion period of 10 minutes on a steam bath, or a hot plate having the approximate temperature of a steam bath, may be substituted for the 50- to 60-second boiling period. Remove from the burner, steam bath, or hot plate and allow to stand until the precipitate has settled. Using medium-textured paper, filter the solution without delay, wash the precipitate twice with hot NH_4NO_3 (20 g/L), and reserve the filtrate. Transfer the precipitate with the filter paper to the beaker and dissolve in 10 mL of HCl (1 + 1). Macerate the filter paper. Dilute to about 100 mL and heat to boiling. Reprecipitate, filter, and wash the hydroxides as above. Combine this filtrate and washings with those from the first precipitation taking care that the volume does not exceed 300 mL (Note 85). Add 5 mL of HCl, a few drops of methyl red indicator solution and 30 mL of warm ammonium oxalate solution (50 g/L). Heat the solution to 70° to 80°C and add NH_4OH (1 + 1) dropwise, while stirring, until the color changes from red to yellow. (See Note 39.) Allow the solution to stand without further heating for 15 minutes on a steam bath.

Note 85—In the case of cements containing blast-furnace slag, or which are believed to contain a significant quantity of manganese, acidify with HCl, evaporate to about 100 mL, and remove the manganese, using the procedure described in Section 13.3.1.

23.4.3. Add 10 to 25 mL of the 8-hydroxyquinoline reagent (Note 86) and then 4 mL of NH_4OH/100 mL of solution. Stir the solution on a mechanical stirring machine for 15 minutes and set aside until the precipitate has settled (Note 87). Filter the solution using medium-textured paper and wash the precipitate with hot NH_4OH (1 + 40). Dissolve the precipitate in 50 to 75 mL of hot HCl (1 + 9) in a 500-mL Erlenmeyer flask. Dilute the resulting solution to 200 mL and add 15 mL of HCl. Cool the solution to 25°C and add 10 to 35 mL of the 0.2 *N* $KBrO_3$-KBr solution (Note 88) from a pipet or buret. Stir the solution and allow to stand for about 30 seconds to ensure complete bromination. Add 10 mL of KI (250 g/L). Stir the resulting solution well and then titrate with the 0.1 *N* $Na_2S_2O_3$ solution until the color of the iodine becomes faintly yellow. At this point add 2 mL of the starch solution and titrate the solution to the disappearance of the blue color.

Note 86—An excess of the 8-hydroxyquinoline reagent is needed to avoid a low result for MgO, but too great an excess will yield high results. The following guide should be used to determine the amount of reagent added.

Appropriate Content of MgO, percent	Appropriate Amount of Reagent Required, mL
0 to 1.5	10
1.5 to 3.0	15
3.0 to 4.5	20
4.5 to 6.0	25

Note 87—The precipitate should be filtered within an hour. Prolonged standing may cause high results.

Note 88—The amount of the standard $KBrO_3$-KBr solution used should be as follows:

Appropriate Content of MgO, Percent	Amount of Standard $KBrO_3$-KBr Solution, mL
0 to 1	10
1 to 2	15
2 to 3	20
3 to 4	25
4 to 5	30
5 to 6	35

23.4.4. *Blank*—Make a blank determination following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

23.5. *Calculation*—Calculate the percentage of MgO as follows (Note 89):

$$\text{MgO, \%} = E\left(V_1 R - V_2\right) \times 200 \qquad (14)$$

where:

E = MgO equivalent of the $Na_2S_2O_3$ solution, g/mL;
V_1 = milliliters of $KBrO_3$-KBr solution used;
R = ratio in strength of the $KBrO_3$-KBr solution, to the $Na_2S_2O_3$;
V_2 = milliliters of $Na_2S_2O_3$ solution used; and
200 = 100 divided by the mass of sample used (0.5 g).

Report the result rounded in accordance with Table 3.

Note 89—V_1R represents the volume of $Na_2S_2O_3$ solution equivalent to the volume of $KBrO_3$-KBr solution used. V_2 represents the amount of $Na_2S_2O_3$ required by the excess $KBrO_3$-KBr which is not reduced by magnesium oxyquinolate.

24. LOSS ON IGNITION ALTERNATIVE TEST METHOD

24.1. *Portland Blast Furnace Slag Cement and Slag Cement*:

24.1.1. *Summary of Test Method*—This test method covers a correction for the gain in mass due to oxidation of sulfides usually present in such cement by determining the decrease in the sulfide sulfur content during ignition. It gives essentially the same result as the reference test method (Sections 16.2.1 through 16.2.3) which provides for applying a correction based on the increase in SO_3 content.

24.1.2. *Procedure*:

24.1.2.1. Weigh 1 g of cement in a tared platinum crucible, cover, and ignite in a muffle furnace at a temperature of 950° ± 50°C for 15 minutes. Cool to room temperature in a desiccator and determine the mass. After determining the mass, carefully transfer the ignited material to a 500-mL boiling flask. Break up any lumps in the ignited cement with the flattened end of a glass rod.

24.1.2.2. Determine the sulfide sulfur content of the ignited sample using the procedure described in Sections 15.2.1 through 15.2.5. Using the same procedure also determines the sulfide sulfur content of a portion of the cement that has not been ignited.

24.1.3. Calculate the percentage loss of mass occurring during ignition (Section 24.1.2.1) and add twice the difference between the percentages of sulfide sulfur in the original sample and ignited sample as determined in Section 24.1.2.2. Report this value as the loss on ignition, rounded in accordance with Table 3 (Note 90).

Note 90—If a gain in mass is obtained during the ignition, subtract the percentage of gain from the correction for sulfide oxidation.

25. TITANIUM DIOXIDE (ALTERNATIVE TEST METHOD)

25.1. *Summary of Test Method*—In this test method, titanium dioxide (TiO_2) is determined colorimetrically by comparing the color intensity of the peroxidized solution of the titanium in the sample with the color intensity of a peroxidized standard solution of titanic sulfate.

25.2. *Interferences*—Interfering elements in the peroxide test method for TiO_2 are vanadium, molybdenum, and chromium. In very small quantities the interference of the last two is negligible. However, vanadium in very small quantities causes interference and, as some cements contain this element, the Na_2CO_3 fusion (Section 25.5.4) and extraction with water are necessary.

25.3. *Apparatus*:

25.3.1. *Colorimeter*—The apparatus shall consist of a colorimeter of the Kennicott or Duboscq type, or other colorimeter or spectrophotometer designed to measure light transmittancy, and suitable for measurements at wavelengths between 400 and 450 nm.

25.4. *Reagents*:

25.4.1. *Ammonium Chloride* (NH_4Cl).

25.4.2. *Ammonium Nitrate* (20 g NH_4NO_3/L).

25.4.3. *Ferrous Sulfate Solution* (1 mL = 5 mg Fe_2O_3)—Dissolve 17.4 g of ferrous sulfate ($FeSO_47H_2O$) in water containing 50 mL of H_2SO_4 and dilute to 1 L. One milliliter is equivalent to 1 percent of Fe_2O_3 in 0.5 g of sample.

25.4.4. *Hydrogen Peroxide* (30 percent)—Concentrated hydrogen peroxide (H_2O_2).

25.4.5. *Sodium Carbonate* (20 g Na_2CO_3/L).

25.4.6. *Sodium or Potassium Pyrosulfate* ($Na_2S_2O_7$ or $K_2S_2O_7$).

25.4.7. *Titanic Sulfate, Standard Solution* (1 mL = 0.2 mg TiO_2)—Use standard TiO_2 furnished by NIST (Standard Sample 154 or its replacements). Dry for two hours at 105° to 110°C. Transfer a weighed amount, from 0.20 to 0.21 g of the TiO_2 to a 125-mL Phillips beaker. Add 5 g of ammonium sulfate ($(NH_4)_2SO_4$) and 10 mL of H_2SO_4 to the beaker and insert a short-stem glass funnel in the mouth of the beaker. Heat the mixture cautiously to incipient boiling while rotating the flask over a free flame. Continue the heating until complete solution has been effected and no unattached material remains on the wall of the flask (Note 91). Cool and rapidly pour the solution into 200 mL of cold water while stirring vigorously. Rinse the flask and funnel with H_2SO_4 (1 + 19), stir, and let the solution and washings stand for at least 24 hours. Filter into a 1-L volumetric flask, wash the filter thoroughly with H_2SO_4 (1 + 19), dilute to the mark with H_2SO_4 (1 + 19), and mix.

Note 91—There may be a small residue, but it should not contain more than a trace of TiO_2 if the operations have been properly performed.

25.4.8. Calculate the TiO_2 equivalent of the titanic sulfate solution, g/mL, as follows:

$$E = AB/1000 \qquad (15)$$

where:

E = TiO_2 equivalent of the $Ti(SO_4)_2$ solution, g/mL;

A = grams of standard TiO_2 used (corrected for loss on drying);

B = percentage of TiO_2 in the standard TiO_2 as certified by the National Institute of Standards and Technology, divided by 100; and

1000 = number of milliliters in the volumetric flask.

25.5. *Procedure*:

25.5.1. Mix thoroughly 0.5 g of the sample of cement and about 0.5 g of NH_4Cl in a 50-mL beaker, cover the beaker with a watch glass, and add cautiously 5 mL of HCl, allowing the acid to run down the lip of the covered beaker. After the chemical action has subsided, lift the cover, stir the mixture with a glass rod, replace the cover, and set the beaker on a steam bath for 30 minutes (Note 92). During this time of digestion, stir the contents occasionally and break up any remaining lumps to facilitate the complete decomposition of the cement. Fit a medium-textured filter paper to a funnel and transfer the precipitate to the filter. Scrub the beaker with a rubber policeman and rinse the beaker and policeman. Wash the filter two or three times with hot HCl (1 + 99) and then with 10 or 12 small portions of hot water, allowing each portion to drain through completely.

Note 92—A hot plate may be used instead of a steam bath if the heat is so regulated as to approximate that of a steam bath.

25.5.2. Transfer the filter and residue to a platinum crucible (Note 93), dry, and ignite slowly until the carbon of the paper is completely consumed without inflaming. Treat the SiO_2 thus obtained with 0.5 to 1 mL of water, about 10 mL of HF, and 1 drop of H_2SO_4, and evaporate cautiously to dryness (Note 94).

Note 93—When it is desired to shorten the procedure for purposes other than referee analysis, usually with little sacrifice of accuracy, the procedure given in Section 24.5.2 may be omitted.

Note 94—When a determination of SiO_2 is desired in addition to one of TiO_2, the SiO_2 may be obtained and treated with HF as directed in Sections 6.2.3.1 through 6.2.4.

25.5.3. Heat the filtrate to boiling and add NH_4OH until the solution becomes distinctly alkaline as indicated by an ammoniacal odor. Add a small amount of filter paper pulp to the solution and boil for 50 to 60 seconds. Allow the precipitate to settle, filter through a medium-textured paper, and wash twice with hot NH_4NO_3 solution (20 g/L). Place the precipitate in the platinum crucible in which the SiO_2 has been treated with HF and ignite slowly until the carbon of the paper is consumed.

Note 95—When a determination of ammonium hydroxide group is desired in addition to one of TiO_2, the precipitation and ignition may be made as described in Sections 7.2.1 through 7.2.4. However, the crucible must contain the residue from the treatment of the SiO_2 with HF unless circumstances permit its omission as indicated in Note 94.

25.5.4. Add 5 g of Na_2CO_3 to the crucible and fuse for 10 to 15 minutes. (See Section 24.2.1) Cool, separate the melt from the crucible, and transfer to a small beaker. Wash the crucible with hot water, using a policeman. Digest the melt and washings until the metal is completely disintegrated, then filter through a 90-mm medium-textured filter paper and wash a few times with Na_2CO_3

(20 g/L). Discard the filtrate. Place the precipitate in the platinum crucible and ignite slowly until the carbon of the paper is consumed.

25.5.5. Add 3 g of $Na_2S_2O_7$ or $K_2S_2O_7$ to the crucible and heat below red heat until the residue is dissolved in the melt (Note 96). Cool and dissolve the fused mass in water containing 2.5 mL of H_2SO_4. If necessary, reduce the volume of the solution (Note 97), filter into a 100-mL volumetric flask through a 7-cm medium-textured filter paper, and wash with hot water. Add 5 mL of H_3PO_4, and cool the solution to room temperature. Add H_2O_2 (1.0 mL of 30 percent strength or its equivalent) (Note 98), dilute to the mark with water, and mix thoroughly.

Note 96—Start the heating with caution because pyrosulfates (also known as fused bisulfates) as received often foam and spatter in the beginning due to an excess of H_2SO_4. Avoid an unnecessarily high temperature or unnecessarily prolonged heating, as fused pyrosulfates may attack platinum. A supply of nonspattering pyrosulfates may be prepared by heating some pyrosulfate in a platinum vessel to eliminate the excess H_2SO_4 and crushing the cool fused mass.

Note 97—If the solution is evaporated to too small a volume and allowed to cool, there may be a precipitate of sulfates difficult to redissolve. In case of over-evaporation, do not permit the contents to cool, but add hot water and digest on a steam bath or hot plate until the precipitate is redissolved, with the possible exception of a small amount of SiO_2.

Note 98—Hydrogen peroxide deteriorates on standing. Its strength may be determined by adding a measured volume of the solution to 200 mL of cold water and 10 mL of H_2SO_4 (1 + 1) and titrating with a standard solution of potassium permanganate ($KMnO_4$) prepared in accordance with Section 13.2.2. If the standard solution contains 5.6357 mg of $KMnO_4$/mL, 49.5 mL of it will be required by 0.50 mL of H_2O_2 (30 percent).

25.5.6. Prepare from the standard $Ti(SO_4)_2$ solution a suitable reference standard solution or a series of reference standard solutions in 100-mL volumetric flasks, depending upon the type of colorimeter to be used. To each solution add 3 g of $Na_2S_2O_7$ or $K_2S_2O_7$ dissolved in water, an amount of $FeSO_4$ solution equivalent to the Fe_2O_3 content in 0.5 g of the cement under test, 2.5 mL of H_2SO_4, and 5 mL of H_3PO_4 (Note 99). When the solution is at room temperature, add H_2O_2 (1.0 mL of 30 percent strength or its equivalent), dilute to the mark with water, and mix thoroughly (Note 100).

Note 99—The color imparted to the solution by $Fe_2(SO_4)_2$ is partly offset by the bleaching effect of H_2SO_4, H_3PO_4, and alkali salts on ferric and peritanic ions. The directions should be followed closely for the highest degree of precision. However, when it is desired to shorten this procedure for purposes other than referee analysis, the addition of pyrosulfate, $FeSO_4$ solution and H_3PO_4 to the color comparison solutions may be omitted provided the Fe_2O_3 of the sample cement is less than 5 percent. This usually leads to little sacrifice to accuracy.

Note 100—The color develops rapidly and is stable for a sufficient period of time, but if the peroxidized solution is allowed to stand a long time, bubbles of oxygen may appear and interfere with color comparison. When the contents of a tube are first mixed, there may be fine bubbles which should be allowed to clear up before the comparison is made. Comparison between the standard and unknown solution should be made not less than 30 minutes after addition of H_2O_2.

25.5.7. Compare the color, light transmittancy, or absorbance of the unknown solution with the reference standard solution. The technique of comparing colored solutions or measuring transmittancy or absorbance depends on the type of apparatus (see Sections 25.5.8 through 25.5.10) and should be in accordance with standard practice appropriate to the particular type used or with instructions supplied by the manufacturer of the equipment. If the peroxidized solution of cement is compared with a single standard peroxidized solution, bear in mind that a single peroxidized solution cannot be used for the whole range in TiO_2 content that may be encountered. The difference in volume or depth for the two liquids should not exceed 50 percent of the smaller value. All solutions should contain the prescribed concentrations of H_2SO_4, H_3PO_4, $Fe_2(SO_4)_3$, and persulfate except under the circumstances indicated in Note 100.

25.5.8. *Colorimeter of the Kennicott Type*—By means of a plunger in a reservoir of standard peroxidized solution, adjust the amount of solution through which light passes until it gives the same color intensity as the peroxidized solution of the sample.

25.5.9. *Colorimeter of the Duboscq Type*—Lower or raise the plungers in the cups until the two solutions give the same color intensity when viewed vertically. The color matching may be done either visually or photoelectrically.

25.5.10. *Colorimeter Designed to Measure Light Transmittancy*—The measurement should be made between 400 to 450 nm and may be made either visually or photoelectrically. In most colorimeters of this type, the instrument is calibrated with standard solutions and a calibration curve showing the relation of light transmittancy or absorbance to TiO_2 content is prepared in advance of the analysis of the sample for TiO_2.

25.5.11. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagent, and correct the results obtained in the analysis accordingly.

25.6. *Calculation*—Calculate the percentage of TiO_2, rounded in accordance with Table 3. When a colorimeter designed to measure light transmittancy is used, read the percentage of TiO_2 from a calibration curve showing the relation of light intensity to TiO_2 content. When the peroxidized solution of the sample is compared with a single reference standard solution, calculate the percentage of TiO_2 as follows (Note 101):

25.6.1. *For Colorimeters of the* Kennicott *Type*:

$$\mathrm{TiO_2}, \% = \left(100\,VE/S\right) \times \left(D/C\right) \qquad (16)$$

25.6.2. *For* Colorimeters *of the Duboscq Type*:

$$\mathrm{TiO_2}, \% = \left(100\,VE/S\right) \times \left(F/G\right) \qquad (17)$$

where:

V = milliliters of standard $Ti(SO_4)_2$ solution in the peroxidized standard solution;

E = TiO_2 equivalent of the standard $Ti(SO_4)_2$ solution, g/mL;

S = grams of sample used;

C = total volume of the peroxidized reference standard solution, mL;

D = volume of peroxidized reference standard solution that matches the peroxidized solution of the sample, mL;

F = depth of peroxidized reference standard solution through which light passes; and

G = depth of peroxidized solution of the sample through which light passes.

Note 101—The difference between D and C or between F and G should not exceed 50 percent of the smaller value.

26. PHOSPHORUS PENTOXIDE (ALTERNATIVE TEST METHOD)

26.1. *Summary of Test Method*—In this test method, phosphorus is determined volumetrically by precipitation of the phosphorus as ammonium phosphomolybdate and titration with NaOH and H_2SO_4.

26.2. *Reagents*:

26.2.1. *Ammonium Molybdate Solution*—Prepare the solution in accordance with Section 9.3.1.

26.2.2. *Ammonium Nitrate* (NH_4NO_3).

26.2.3. *Potassium Nitrate Solution* (10 g/L)—Dissolve 10 g of potassium nitrate (KNO_3) in water freshly boiled to expel CO_2 and cooled, and dilute to 1 L.

26.2.4. *Sodium Hydroxide, Standard Solution* (0.3 *N*)—Dissolve 12 g of sodium hydroxide (NaOH) in 1 L of water that has been freshly boiled to expel CO_2, and cooled. Add 10 mL of a freshly filtered, saturated solution of barium hydroxide ($Ba(OH)_2$). Shake the solution frequently for several hours, and filter it. Protect it from contamination by CO_2 in the air. Standardize the solution against standard acid potassium phthalate (Standard Sample No. 84) or benzoic acid (Standard Sample No. 39) furnished by the National Institute of Standards and Technology, according to the directions furnished with the standard. Calculate the phosphorus pentoxide (P_2O_5) equivalent (Note 102) of the solution, g/mL, as follows:

$$E = N \times 0.003086 \tag{18}$$

where:

E = P_2O_5 equivalent of the NaOH solution, g/mL;

N = normality of the NaOH solution; and

0.003086 = P_2O_5 equivalent of 1 N NaOH solution, g/mL.

Note 102—The value of the solution is based on the assumption that the phosphorus in cement is precipitated as ammonium phosphomolybdate $2(NH_4)_3PO_4 \cdot 12MoO_3$) and that the precipitate reacts with the NaOH solution thus:

$$\begin{aligned} &2(NH_4)_3PO_4 \cdot 12MoO_3 + 46NaOH = \\ &\qquad 2(NH_4)_2HPO_4 + (NH_4)_2MoO_4 + 23Na_2MoO_4 + 22H_2O \end{aligned} \tag{19}$$

The number of 0.003086 is obtained by dividing the molecular weight of P_2O_5 (141.96) by 46 (for 46 NaOH in the equation) and by 1000 (number of milliliters in 1 L).

As the actual composition of the precipitate is influenced by the conditions under which the precipitation is made, it is essential that all the details of the procedure are followed closely as prescribed.

26.2.5. *Sodium Nitrite* (50 g $NaNO_2$/L).

26.2.6. *Sulfuric Acid, Standard Solution* (0.15 *N*)—Dilute 4.0 mL of H_2SO_4 to 1 L with water that has been freshly boiled and cooled. Standardize against the standard NaOH solution. Determine the ratio in strength of the standard H_2SO_4 solution to the standard NaOH solution by dividing the volume of NaOH solution by the volume of H_2SO_4 solution used in the titration.

26.3. *Procedure*:

26.3.1. Weigh 1 to 3 g of the sample (Note 103) and 10 g of NH_4NO_3 into a 150-mL beaker. Mix the contents, add 10 mL of HNO_3, and stir quickly, using the flattened end of a glass rod to crush lumps of cement, until the cement is completely decomposed and the thick gel of silica (SiO_2) is broken up. Cover the beaker with a watch glass, place it on a water bath or a hot plate at approximately 100°C for 15 to 20 minutes, and stir the contents occasionally during the heating.

Add 20 mL of hot water to the beaker and stir the contents. If the cement contains an appreciable amount of manganese as shown by the presence of a red or brown residue, add a few milliliters of $NaNO_2$ (50 g/L) to dissolve this residue. Boil the contents of the beaker until all nitrous fumes are completely expelled. This procedure should not take more than five minutes, and water should be added to replace any lost by evaporation. Filter, using medium-textured paper, into a 400-mL beaker under suction and with a platinum cone to support the filter paper. Wash the residue of SiO_2 with hot water until the volume of filtrate and washings is about 150 mL.

Note 103—The amounts of sample and reagents used depend on the content of phosphorus in the cement. The minimum requirements are sufficient if the cement contains 0.5 percent P_2O_5 or more. The maximum amounts are required if the content of P_2O_5 is 0.1 percent or less.

26.3.2. Heat the solution to 69° to 71°C, remove it from the heat source, and immediately add 50 to 100 mL of the ammonium molybdate solution. Stir the solution vigorously for five minutes, wash down the sides of the beaker with cool KNO_3 solution (10 g/L), cover the beaker with a watch glass, and allow to stand two hours. Using suction, filter the precipitate (Note 104), decanting the solution with as little disturbance to the precipitate as possible. Stir the precipitate in the beaker with a stream of the cool KNO_3 solution, decant the liquid, then wash the precipitate onto the filter. Scrub the stirring rod and beaker with a policeman and wash the contents onto the filter. Wash and precipitate until it is acid-free (Note 105), allowing each portion of wash solution to be sucked completely through before adding the next.

Note 104—The filter may be a small medium-textured filter paper supported by a platinum cone, or a small Hirsch funnel may be used with filter paper cut to fit and a thin mat of paper pulp or acid-washed asbestos pulp. The filtration should be carried out with care to avoid any loss of the precipitate. The filter should fit well, and the suction should be started before filtration and maintained until the end of the washing.

Note 105—About 10 washings are usually required. Test the 10th washing with one drop of neutral phenolphthalein indicator and half a drop of the standard NaOH solution. If a definite pink color lasts at least five minutes, the precipitate is considered to be acid-free; otherwise, continue the washing.

26.3.3. Transfer the filter and precipitate to the beaker in which the precipitation took place, using small damp pieces of paper to wipe out the funnel and to pick up portions of the precipitate that may remain on it. Add 20 mL of cool CO_2-free water to the beaker, and break up the filter by stirring rapidly with the policeman that was used to scrub the beaker. Add an excess of the 0.3 normal NaOH solution, stir the contents until all trace of yellow has disappeared, wash down the policeman and sides of the beaker with 50 mL of cool, CO_2-free water, and add two drops of neutral phenolphthalein indicator solution. Treat the solution with a measured quantity of the 0.15 N H_2SO_4 solution, sufficient to destroy completely the pink color. Complete the titration with the NaOH solution until there is a definite faint pink color that lasts at least five minutes.

26.3.4. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

26.4. *Calculation*—Calculate the percentage of P_2O_5 as follows:

$$P_2O_5,\ \% = \left[E\left(V_1 - V_2R\right)/S\right] \times 100 \qquad (20)$$

where:

E = P_2O_5 equivalent of the NaOH solution, g/mL;

V_1 = milliliters of NaOH solution used;

V_2 = milliliters of H_2SO_4 solution used;

R = ratio in strength of the H_2SO_4 solution to the NaOH solution; and

S = grams of sample used.

Report the result rounded in accordance with Table 3.

27. MANGANIC OXIDE (ALTERNATIVE TEST METHOD)

27.1. *Summary of Test Method*—In this test method manganic oxide is determined volumetrically by titration with potassium permanganate solution.

27.2. *Reagents*:

27.2.1. *Potassium Permanganate, Standard Solution* (0.18 *normal*)—Prepare a solution of potassium permanganate ($KMnO_4$) and standardize as described in Section 13.2.2, except that the manganic oxide (Mn_2O_3) equivalent of the solution is calculated instead of the calcium oxide (CaO) equivalent. Calculate the Mn_2O_3 equivalent of the solution as follows:

$$E = \left(B \times 0.3534\right)/A \tag{21}$$

where:

E = Mn_2O_3 equivalent of the $KMnO_4$ solution, g/mL;

B = grams of $Na_2C_2O_4$ used,

A = milliliters of $KMnO_4$ solution required by the $Na_2C_2O_4$; and

0.3534 = mole ratio of 3 Mn_2O_3 to 10 $Na_2C_2O_4$.

27.2.2. *Zinc Oxide* (ZnO), powder.

27.3. *Procedure*:

27.3.1. Place 2 g of the sample in a 250-mL beaker and add about 50 mL of water to the cement. Stir the mixture until it is in suspension and then add about 15 mL of HCl. Heat the mixture gently until the solution is as complete as possible. Add 5 mL of HNO_3 and 50 mL of water to the solution and boil it until most of the chlorine has been expelled. If necessary, add hot water to maintain the solution at a volume of about 100 mL. Stop the boiling and add ZnO powder to the solution until the acid is neutralized. Add an excess of 3 to 5 g of ZnO powder to the solution and boil it for a few minutes.

27.3.2. Without filtering, and while keeping the solution hot (90° to 100°C) by intermittent or continuous heating, titrate the solution with the 0.18 *N* $KMnO_4$ solution until a drop of it gives a permanent pink color (Note 106). When the end point is approached, add the standard solution dropwise. After each drop, stir the solution, allow the precipitate to settle a little, and observe the color of the stratum of the solution by looking through the side of the beaker.

Note 106—In the case of a cement in which the approximate content of Mn_2O_3 is unknown, a preliminary determination may be made with rapid titration, 0.5 to 1 mL of the standard solution being added at a time, and without an attempt to keep the solution close to the boiling point.

27.3.3. *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

27.4. *Calculation*—Calculate the percentage of Mn_2O_3 as follows:

$$\mathrm{Mn_2O_3}, \% = EV \times 50 \tag{22}$$

where:

E = Mn_2O_3 equivalent of the $KMnO_4$ solution, g/mL;

V = milliliters of $KMnO_4$ solution used; and

50 = 100 divided by the mass of sample used (2 g).

Report the result rounded in accordance with Table 3.

28. FREE CALCIUM OXIDE (ALTERNATIVE TEST METHOD)

28.1. *Summary of Test Methods*—These are rapid test methods for the determination of free calcium oxide in fresh clinker. When applied to cement or aged clinker, the possibility of the presence of calcium hydroxide should be kept in mind since these test methods do not distinguish before free CaO and free $Ca(OH)_2$. Two test methods are provided. Alternate Test Method A is a modified Franke procedure in which uncombined lime is titrated with dilute perchloric acid after solution in an ethylacetoacetate-isobutyl alcohol solvent. Alternate Test Method B is an ammonium acetate titration of the alcohol-glycerin solution of uncombined lime with $Sr(NO_3)_2$ as an accelerator.

28.2. *Modified Franke Test Method (Alternative Method A)*:

28.2.1. *Apparatus*:

28.2.1.1. *Refluxing Assembly*—consisting of a flask with flat-bottom short neck Erlenmeyer flask with 250-mL capacity. The water-cooled refluxing condenser should have a minimum length of 300 mm. The flask and reflux condenser shall be connected with standard tapered ground glass joints. The reflux condenser shall be fitted with an absorption tube containing a desiccant such as indicating silica gel and a material for the removal of CO_2 such as Ascarite. The absorption tube shall be inserted with a rubber stopper in the upper end of the reflux column.

28.2.1.2. *Buret*—having a 10-mL capacity and graduated in units not more than 0.05 mL.

28.2.1.3. *Vacuum Filtration Assembly*—consisting of a Gooch crucible size No. 3, 25-mL capacity in which is placed a suitable filter paper, 21-mm size, a Walter crucible holder, a 500-mL vacuum flask, and vacuum source. The crucible is half filled with compressed filter pulp.

28.2.1.4. *Glass Boiling Beads*:

28.2.2. *Solutions Required*:

28.2.2.1. *Ethyl Acetoacetate-Isobutyl Alcohol Solvent*—three parts of volume of ethyl acetoacetate and 20 parts by volume of isobutyl alcohol.

28.2.2.2. *Thymol Blue Indicator*—Dissolve 0.1 g of thymol blue indicator powder in 100 mL of isobutyl alcohol.

28.2.2.3. *Perchloric Acid, Standard Solution* (0.2 *normal*)—Dilute 22 mL of 70 to 72 percent perchloric acid to 1 L with isobutyl alcohol. Standardize this solution as follows: Ignite 0.1000 g of primary standard calcium carbonate in a platinum crucible at 900° to 1000°C. Cool the crucible and contents in a desiccator and determine the mass to the nearest 0.0001 g to constant mass. Perform the mass determinations quickly to prevent absorption of water and CO_2. Immediately transfer the CaO without grinding to a clean, dry Erlenmeyer flask and again determine the mass of the empty crucible to the nearest 0.0001 g to determine the amount of CaO added. Then follow procedure beginning with "Add 70 mL of the prepared ethyl acetoacetate isobutyl alcohol . . ." in Section 28.2.3.1. Calculate the CaO equivalents of the standard perchloric acid solution in grams per milliliter by dividing the mass of CaO used by the volume of perchloric acid required for the titration.

28.2.3. *Procedure*:

28.2.3.1. Transfer 1.0000 g of ground sample (Note 107) into a clean, dry 250-mL Erlenmeyer flask. Add four to five glass boiling beads. Add 70 mL of the prepared ethyl acetoacetate-isobutyl alcohol solvent. Agitate the flask to disperse the sample.

Note 107—Thorough grinding of the sample is essential for proper exposure of the free lime grains that often are occluded in crystals of tricalcium silicate in the cement. However, exposure of the sample to the air must be kept at a minimum to prevent carbonation of the free lime. In particular, direct breathing into the sample must be avoided. The sample should be sufficiently fine to easily pass a No. 200 (75-µm) sieve but actual sieving is not recommended. If the sample is not to be immediately tested, it must be kept in an airtight container to avoid unnecessary exposure to the atmosphere.

28.2.3.2. Attach the flask to a reflux condenser and bring the material to a boil. Reflux for 15 minutes.

28.2.3.3. Remove flask from condenser, stopper, and cool rapidly to room temperature.

28.2.3.4. Filter the sample and solution using the vacuum assembly. Wash the flask and residue with small increments (10 to 15 mL) of isobutyl alcohol until a total of 50 mL has been used for wash solution.

28.2.3.5. Add 12 drops of the thymol blue indicator to the filtrate and immediately titrate with 0.2 normal perchloride acid to the first distinct color change.

28.2.4. *Calculations*—Calculate the percent free calcium oxide as follows:

$$\text{free CaO, \%} = \frac{EV \times 100}{W} \qquad (23)$$

where:

E = CaO equivalent of the perchloric acid, g/mL;

V = milliliters of perchloric acid solution required by sample; and

W = mass of the sample, g.

Report the result rounded in accordance with Table 3.

28.3. *Rapid $Sr(NO_3)_2$ Test Method (Alternative Test Method B)*:

28.3.1. *Reagents*:

28.3.1.1. *Ammonium Acetate, Standard Solution* (1 mL = 5 mg CaO)—Prepare a standard solution of ammonium acetate ($NH_4C_2H_3O_2$) by dissolving 16 g of desiccated ammonium acetate in 1 L of ethanol in a dry, clean, stoppered bottle. Standardize this solution by the same procedure as described in Section 28.3.2.1, except use the following in place of the sample: ignite to constant mass approximately 0.1 g of calcium carbonate ($CaCO_3$) in a platinum crucible at 900 to 1000°C, cool the contents in a desiccator, and determine the mass to the nearest 0.0001 g. Perform the mass determinations quickly to prevent absorption of water and CO_2. Immediately transfer the CaO without grinding to a 250-mL boiling flask (containing glycerin-ethanol solvent and $Sr(NO_3)_2$), and again determine the mass of the empty crucible to determine the mass of CaO to the nearest

0.1 mg. Continue as described in Sections 28.3.2.1 and 28.3.2.2. Calculate the CaO equivalent of the ammonium acetate in grams per milliliter by dividing the mass of CaO used by the volume of solution required.

28.3.1.2. *Phenolphthalein Indicator*—Dissolve 1.0 g of phenolphthalein in 100 mL of ethanol (Formula 2B) (Note 108).

28.3.1.3. *Glycerin-Ethanol Solvent* (1 + 2)—Mix 1 volume of glycerin with two volumes of ethanol (Formula 2B). To each liter of this solution, add 2.0 mL of phenolphthalein indicator solution.

Note 108—Ethanol denatured in accordance with Formula 2B (99.5 percent ethanol and 0.5 percent benzol) is preferred but may be replaced by isopropyl alcohol, A.R.

28.3.1.4. *Strontium Nitrate* ($Sr(NO_3)_2$), reagent grade.

28.3.2. *Procedure*:

28.3.2.1. Transfer 60 mL of the glycerin-ethanol solvent into a clean, dry, 250-mL standard-taper flat-bottom boiling flask. Add 2 g of anhydrous strontium nitrate ($Sr(NO_3)_2$), and adjust the solvent to slightly alkaline with a dropwise addition of a freshly prepared dilute solution of NaOH in ethanol until a faint pink color is formed. Weigh 1.000 g of the finely ground sample (Note 108) into the flask, add encapsulated stirring bar, and immediately attach a water-cooled condenser (with a standard 24/40 glass joint). Boil the solution in the flask on a magnetic stirrer hot plate for 20 minutes with mild stirring.

28.3.2.2. Remove the condenser and filter the contents of the flask on a small polypropylene Büchner funnel under vacuum, using a 250-mL filtering flask with side tube. Bring the filtrate to a boil and immediately titrate with standard ammonium acetate solution to a colorless end point.

28.3.3. *Calculation*—Calculate the percent free CaO as follows:

$$\text{free CaO, \%} = EV \times 100 \qquad (24)$$

where:

E = CaO equivalent of the ammonium acetate solution, g/mL; and

V = milliliters of ammonium acetate solution required by the sample.

Report the result rounded in accordance with Table 3.

29. KEYWORDS

29.1. Chemical analysis; compositional analysis; hydraulic cements.

30. REFERENCES

30.1. Crow, R. F. and J. D. Connolly. Atomic Absorption Analysis of Portland Cement and Raw Mix Using Lithium Metaborate Fusion. *Journal of Testing and Evaluation*, Vol. 1, No. 5, September 1973, *pp*. 382–393.

30.2. Moore, C. W. Suggested Method for Spectrochemical Analysis of Portland Cement by Fusion with Lithium Tetraborite Using an X-Ray Spectrometer. E-2 SM 10–26 in *Test Methods for Emission Spectrochemical Analysis*, ASTM, 1971.

30.3. Jugovic, Z. T. Applications of Spectrophotometric and EDTA Methods for Rapid Analysis of Cement and Raw Materials. *Analytical Techniques for Hydraulic Cement and Concrete*, ASTM STP 395. ASTM, 1966, *pp*. 65–93.

30.4. Bean, B. L. and T. H. Arni. *A New Rapid Test Method for Cement Analysis (Atomic Absorption Spectrophotometry)*, Report No. FHWA-RD-72-41. Department of Transportation, Federal Highway Administration, September 1972. (Order copies from National Technical Information Service, Springfield, VA 22151, by Order No. PB 243622.)

30.5. Bean, B. L. *Improvements in the Rapid Analysis of Portland Cement by Atomic Absorption Spectrophotometry*. Report No. FHWA RD-73-4. Department of Transportation, Federal Highway Administration, March 1973. (Order copies from National Technical Information Service, Springfield, VA 22151, by Order No. PB-220-549.)

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF DETERMINATION OF EQUIVALENCE POINT FOR THE CHLORIDE DETERMINATION

(Column 1) $AgNO_3$, mL	(Column 2) Potential, mV	(Column 3) ΔmV [a]	(Column 4) Δ^2mV [b]
1.60	125.3		
		5.8	
1.80	119.5		1.4
		7.2	
2.00	112.3		1.3
		8.5	
2.20	103.8		1.3
		9.8	
2.40	94.0		0.6
		9.2	
2.60	84.8		2.3
		6.9	
2.80	77.9		0.8
		6.1	
3.00	71.8		1.3
		4.8	
3.20	67.0		

The equivalence point is in the maximum ΔmV interval (Column 3) and thus between 2.20 and 2.40 mL. The exact equivalence point in this 0.20 increment is calculated from the Δ^2mV (Column 4) data as follows:

$$E = 2.20 + (1.3/(1.3 + 0.6)) \times 0.20 = 2.337 \text{ mL. Round to } 2.34.$$

[a] Differences between successive readings in Column 2.

[b] Differences between successive Δ readings in Column 3 "second differentials."

X2. CO_2 DETERMINATIONS IN HYDRAULIC CEMENTS

X2.1. *Scope*:

X2.1.1. This appendix contains information about methods for determination of carbon dioxide (CO_2) in hydraulic cement. The methods listed received a favorable evaluation by ASTM Task Group C01.23.04.

X2.1.2. Section X2.2 lists the analytical methods that received a favorable evaluation, briefly describes each method, suggests analytical techniques or cautions that may be useful, and indicates limitations to some of the methods.

X2.1.3. The methods listed in Sections X2.2.1, X2.2.4, X2.2.5, and X2.2.6 determine total carbon calculated as CO_2. For that reason, they are not appropriate for determination of carbon dioxide in fly ash, limestones containing carbon in the form of graphite or kerogen, in other carbon-bearing materials, or in blended cements produced from these materials.

X2.1.4. The methods listed in Sections X2.2.2 and X2.2.3 can determine actual CO_2 directly rather than by calculation from total carbon. They are suggested for analysis of blended cement ingredients that are likely to contain non-carbonate carbon.

X2.1.5. The split loss on ignition method in Section X2.2.1 can give misleading results when used with materials containing $CaOH_2$ (calcium hydroxide). This can occur with aged cement, cement made from aged clinker, or high free lime clinker, in addition to cements with a lime or hydrated lime ingredient.

X2.2. *Analytical Methods*:

X2.2.1. *Split Loss on Ignition*—This procedure is comparable to the analytical method described in ASTM C 114, Section 16.1.2, with the following modifications:

1. A crucible of known mass and containing a sample of known mass is initially heated at 550°C for two hours.
2. After being cooled to room temperature in a desiccator, and its mass determined, the crucible with sample is then heated at 950°C for two hours.
3. Finally, the crucible with sample is cooled and its mass is determined as per step No. 2.
4. The difference in residue masses after the respective heat treatments is assumed to be carbon dioxide.

TGA results indicated that $Ca(OH)_2$ can lose a significant portion of its mass above 500°C. Thus the Split on Loss of Ignition procedure should not be used when situations described in Section X2.1.5 exist.

X2.2.2. *Thermogravimetric Analysis (TGA)*—This method involves the determination of sample mass at various temperatures. The heating of a sample through a temperature range allows for mass loss differentiation based on mineral form (for example, $CaCO_3$, $MgCO_3$, $CaOH_2$, etc.). Specific operational information is provided by the equipment manufacturers. If free carbon is present, an inert atmosphere (for example, nitrogen) should be used for sample analysis.

X2.2.3. *ASTM C 25, Section 22*—"Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime." This method involves decomposition of the sample with HCl. The liberated CO_2 is then passed through a series of scrubbers to remove water and sulfides. The CO_2 is absorbed with special Sodium Hydroxide Absorbent (Ascarite). The gain in mass of the absorption tube is determined and calculated as percent CO_2. Calcium carbonate, for instance, can be calculated by multiplying the determined CO_2 content by a conversion factor (for example, $CO_2 \times 2.2742 = CaCO_3$).

X2.2.4. *X-ray Fluorescence Spectroscopy*—In this method the sample is ground to a fine particle size, pressed into a flat pellet and irradiated with the chosen instrument. Carbon content is determined by comparing the collected carbon emissions to calibration standards.

X2.2.5. *Combustion by Induction Furnace/IR*—This method involves volatilization by induction furnace and detection by infrared absorption. Suitable calibration standards (for example, calcium carbonate and synthetic carbon) are available from some instrument manufacturers. NIST cement CRMs with known additions of NIST argillaceous limestone (or other suitable standards) should also be considered to check instrument calibration.

X2.2.6. *ASTM E 350*—This method, "Total Carbon by the Combustion Gravimetric" from "Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron," is suitable for the determination of carbon in concentrations from 0.05 to 1.80 percent (as carbon dioxide 0.18 to 6.60 percent). The test method involves burning the sample in a stream of oxygen; the carbon dioxide in the evolved gases is then collected in a suitable absorbent and its mass determined. Time of analysis is less than 10 minutes.

X2.3. *Cooperative Test Results:*

X2.3.1. Tables X2.1 and X2.2 list results from two series of cooperative tests using several of the analytical methods evaluated by the Task Force Group. In all, five of the six methods receiving favorable ratings were included. The sixth method, ASTM C 25, was specifically not tested in these cooperative series, but was rated favorably because of long history of use with related materials.

X2.3.2. Table X2.1 includes results of single determinations using three of the different analytical methods. The methods used were Split Loss on Ignition, ASTM E 350, and Combustion by Induction Furnace with Infrared Detection.

Table X2.1—Cooperative Test Series No. 1

	Single Determinations			
	Carbon Dioxide Unknown[a]	Determinations Base Cement[b]	Added CO_2, c% Determined[c]	Added CO_2, % Known[d]
Split LOI	2.40	0.45	1.97	2.00
	2.52	0.56	1.99	
	2.41	0.36	2.07	
	2.39	0.32	2.09	
	2.41	0.36	2.07	
	2.28	0.27	2.02	
ASTM E 350	2.00	0.02	1.98	
	2.00	0.02	1.98	
Induction Furnace/IR	2.46	0.40	2.07	
	2.53	0.48	2.08	
	2.38	0.40	2.00	
	2.42	0.48	1.97	
			2.02	
Average Standard Deviation			0.05	

[a] The Unknown was prepared by blending/grinding a mixture of 5.00% NIST CRM 1C Argillaceous Limestone and 95.00% CCRL Portland Cement Reference Sample No. 85. According to the Certificate of Analysis, CRM 1C had a loss on ignition of 39.9%. For the purpose of the cooperative test series, the loss on ignition was assumed to be CO_2 only.

[b] The Base Cement was CCRL Portland Cement Reference Sample No. 85.

[c] The Determined % Added CO_2 was obtained by subtracting the Base Cement % CO_2 from the Unknown % CO_2.

[d] The addition of 5.00% NIST CRM 1C (with a loss on ignition value of 39.9%) would provide 2.00% Added CO_2. (Again, it was assumed that the CRM 1C loss on ignition was only carbon dioxide.)

X2.3.3. Table X2.2 includes results based on average of three determinations. Results from four of the different analytical methods are included. Methods used were Split Loss on Ignition, X-Ray Fluorescence Analysis, Induction Furnace with Infrared Detection, and Thermo-Gravimetric Analysis. ASTM E 350 was not used in this series of tests.

Table X2.2—Cooperative Test Series No. 2

	Average from Three Determinations			
	Carbon Dioxide Unknown[a]	Determinations Base Cement[b]	Added CO_2, c% Determined[c]	Added CO_2, % Known[d]
Split LOI	2.00	0.41	1.59	1.60
	1.65	0.32	1.33	
	2.02	0.46	1.56	
	1.91	0.35	1.56	
	2.10	0.43	1.67	
	1.91	0.41	1.50	
	1.98	0.46	1.52	
XRFA	1.68[e]	0.00[e]	1.68[e]	
Induction Furnace/IR	2.23	0.28	1.95	
	1.96	0.28	1.68	
	1.95	0.40	1.55	
TGA	1.77	0.20	1.57	
	1.87	0.25	1.62	
			1.60	
Average Standard Deviation			0.14	

[a] The Unknown was prepared by blending/grinding a mixture of 4.00% NIST CRM 1C Argillaceous Limestone and 96.00% CCRL Portland Cement Reference Sample No. 85. According to the Certificate of Analysis, CRM 1C had a loss on ignition of 39.9%. For the purpose of the cooperative test series, the loss of ignition was assumed to be CO_2 only.

[b] The Base Cement was CCRL Portland Cement Reference Sample No. 85.

[c] The Determined % Added CO_2 was obtained by subtracting the Base Cement % CO_2 from the Unknown % CO_2.

[d] The addition of 4.00% NIST CRM 1C (with a loss on ignition value of 39.9%) would provide 1.60% Added CO_2. (Again, it was assumed that the CRM 1C loss on ignition was only carbon dioxide.)

[e] The XRF instrument was calibrated using standards composed of the Base Cement (that is, CCRL No. 85) and NIST CRM 1C. It was assumed that the Base Cement contained 0% CO_2.

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[1] Similar to ASTM C 114-07 except for terminology related to mass and weights.

[2] Gebhardt, R. F. Rapid Methods for Chemical Analysis of Hydraulic Cement. ASTM STP 985, 1988.

[3] Reagent Chemicals, American Chemical Society Specifications, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Reagent Chemicals and Standards*, by Joseph Rosin, D. Van Nostrand Co., Inc., New York, N.Y., and the *United States Pharmacopeia*.

[4] See also the ASTM *Manual on Presentation of Data and Control Chart Analysis STP 15D*, 1976.

[5] The 1988 revision of these test methods deleted the colorimetric method for determination of ZnO using an extraction with CCl_4. Those interested in this test method should refer to the 1987 *Annual Book of ASTM Standards*, Volume 4.01.

[6] The 1963 revision of these test methods deleted the classical (J. L. Smith) gravimetric method for the determination of Na_2O and K_2O in cements. Those interested in this method should refer to the 1961 *Annual Book of ASTM Standards*, Part 4. The 1983 revision of these test methods deleted the details of the flame photometric procedure for the determination of Na_2O and K_2O. Those interested in this method should refer to the 1987 *Annual Book of ASTM Standards*, Part 13.

[7] The 1965 revision of these test methods deleted the methoxyl test method for determining vinsol resin. Those interested in this test method should refer to the 1966 *Annual Book of ASTM Standards*, Part 9.

Standard Method of Test for

Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)

AASHTO Designation: T 106M/T 106-09
ASTM Designation: C 109/C 109M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)

AASHTO Designation: T 106M/T 106-09
ASTM Designation: C 109/C 109M-07

1. SCOPE

1.1. This test method covers determination of the compressive strength of hydraulic cement mortar using 50-mm (or 2-in.) cube specimens.

Note 1—ASTM C 349 provides an alternative procedure for this determination (not to be used for acceptance tests).

1.2. This test method covers the application of the test using either inch-pound or SI units. The values stated in either system shall be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.3. Values in SI units shall be obtained by measurement in SI units or by appropriate conversion, using the Rules for Conversion and Rebounding given in Standard IEEE/ASTM SI 10, of measurements made in other units.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.)

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 152M/M 152, Flow Table for Use in Tests of Hydraulic Cement
- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 240, Blended Hydraulic Cements
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- T 105, Chemical Analysis of Hydraulic Cement
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 91, Standard Specification for Masonry Cement
- C 349, Standard Test Method for Compressive Strength of Hydraulic-Cement Mortars (Using Portions of Prisms Broken in Flexure)
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 778, Standard Specification for Standard Sand
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- C 1157, Standard Performance Specification for Hydraulic Cement
- C 1328, Standard Specification for Plastic (Stucco) Cement
- C 1329, Standard Specification for Mortar Cement
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. SUMMARY OF TEST METHOD

3.1. The mortar used consists of one part cement and 2.75 parts of sand proportioned by mass. Portland or air-entraining portland cements are mixed at specified water/cement ratios. Water content for other cements is that sufficient to obtain a flow of 110 ± 5 in 25 drops of the flow table. Fifty-millimeter [or 2-in.] test cubes are compacted by tamping in two layers. The cubes are cured 24 hours in the molds and stripped and immersed in lime water until tested.

4. SIGNIFICANCE AND USE

4.1. This test method provides a means of determining the compressive strength of hydraulic cement and other mortars and results may be used to determine compliance with specifications. Further, this test method is referenced by numerous other specifications and test methods. Caution must be exercised in using the results of this test method to predict the strength of concretes.

5. APPARATUS

5.1. *Weights and Weighing Devices*—Shall conform to the requirements of ASTM C 1005. The weighing device shall be evaluated for precision and bias at a total load of 2000 g.

5.2. *Glass Graduates*—Of suitable capacities (preferably large enough to measure the mixing water in a single operation) to deliver the indicated volume at 20ºC. The permissible variation shall be ±2 mL. These graduates shall be subdivided to at least 5 mL, except that the graduation lines may be omitted for the lowest 10 mL for a 250-mL graduate and for the lowest 25 mL for a 500-mL graduate. The main graduation lines shall be circles and shall be numbered. The least graduations shall extend at least one-seventh of the way around, and intermediate graduations shall extend at least one-fifth of the way around.

5.3. *Specimen Molds*—For the 50-mm [or 2-in.] cube specimens shall be tight fitting. The molds shall have no more than three cube compartments and shall be separable into no more than two parts. The parts of the molds when assembled shall be positively held together. The molds shall be made of hard metal not attacked by the cement mortar. For new molds the Rockwell hardness number of the metal shall be not less than 55 HRB. The sides of the molds shall be sufficiently rigid to prevent spreading or warping. The interior faces of the molds shall be plane surfaces and shall conform to the tolerances of Table 1.

Table 1—Permissible Variations of Specimen Molds

Parameter	50-mm Cube Molds		2-in. Cube Molds	
	New	In Use	New	In Use
Planeness of sides	<0.025 mm	<0.05 mm	<0.001 in.	<0.002 in.
Distance between opposite sides	50 mm ± 0.13 mm	50 mm ± 0.50 mm	2 in. ± 0.005	2 in. ± 0.02
Height of each compartment	50 mm + 0.25 mm to – 0. 13 mm	50 mm + 0.25 mm to – 0.38 mm	2 in. + 0.01 in. to – 0.005 in.	2 in. + 0.01 in. to – 0.015 in.
Angle between adjacent faces[a]	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°

[a] Measured at points slightly removed from the intersection. Measured separately for each compartment between all the interior faces and the adjacent face and between interior faces and top and bottom planes of the mold.

5.4. *Mixer, Bowl, and Paddle*—An electrically driven mechanical mixer of the type equipped with paddle and mixing bowl, as specified in T 162.

5.5. *Flow Table and Flow Mold*—Conforming to the requirements of M 152M/M 152.

5.6. *Tamper*—A nonabsorptive, nonabrasive, nonbrittle material such as a rubber compound having a Shore A durometer hardness of 80 ± 10 or seasoned oak wood rendered nonabsorptive by immersion for 15 minutes in paraffin at approximately 200ºC [392ºF], shall have a cross section of 13 by 25 mm [$^1/_2$ by 1 in.] and a convenient length of about 120 to 150 mm [5 to 6 in.]. The tamping face shall be flat and at right angles to the length of the tamper.

5.7. *Trowel*—Having a steel blade 100 to 150 mm [4 to 6 in.] in length, with straight edges.

5.8. *Moist Cabinet or Room*—Conforming to the requirements of M 201.

5.9. *Testing Machine*—Either the hydraulic or the screw type, with sufficient opening between the upper bearing surface and the lower bearing surface of the machine to permit the use of verifying apparatus. The load applied to the test specimen shall be indicated with an accuracy of ±1.0 percent. If the load applied by the compression machine is registered on a dial, the dial shall be provided with a graduated scale that can be read to at least the nearest 0.1 percent of the full scale load (Note 2). The dial shall be readable within one percent of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment that is easily accessible from the outside of the dial case, and with a suitable device that at all times until reset will indicate to within 1 percent accuracy the maximum load applied to the specimen.

5.9.1. If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 percent of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 percent for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1 percent system accuracy the maximum load applied to the specimen.

Note 2—As close as can be read is considered 0.5 mm [$^1/_{50}$ in.] along the arc described by the end of the pointer. Also, one-half of the scale interval is about as close as can reasonably be read when the spacing on the load indicating mechanism is between 1 mm [$^1/_{25}$ in.] and 1.6 mm [$^1/_{16}$ in.]. When the spacing is between 1.6 mm [$^1/_{16}$ in.] and 3.2 mm [$^1/_8$ in.], one-third of the scale interval can be read with reasonable certainty. When the spacing is 3.2 mm [$^1/_8$ in.] or more, one-fourth of the scale interval can be read with reasonable certainty.

5.9.2. The upper bearing shall be a spherically seated, hardened metal block firmly attached at the center of the upper head of the machine. The center of the sphere shall lie at the center of the surface of the block in contact with the specimen. The block shall be closely held in its spherical seat, but shall be free to tilt in any direction. A hardened metal bearing block shall be used beneath the specimen to minimize wear of the lower platen of the machine. To facilitate accurate centering of the test specimen in the compression machine, one of the two surfaces of the bearing blocks shall have a diameter or diagonal of between 70.7 mm [2.83 in.] (see Note 3) and 73.7 mm [2.9 in.]. When the upper block bearing surface meets this requirement, the lower block bearing surface shall be greater than 70.7 mm [2.83 in]. When the lower block bearing surface meets this requirement, the diameter or diagonal of upper block bearing surface shall be between 70.7 and 79.4 mm [2.83 and $3^1/_8$ in.]. When the lower block is the only block with a diameter or diagonal between 70.7 and 73.7 mm [2.83 and 2.9 in.], the lower block shall be used to center the test specimen. In that case, the lower block shall be centered with respect to the upper bearing block and held in position by suitable means. The bearing block surfaces intended for contact with the specimen shall have a Rockwell hardness number not less than 60 HRC. These surfaces shall not depart from plane surfaces by more than 0.013 mm [0.0005 in.] when the blocks are new and shall be maintained within a permissible variation of 0.025 mm [0.001 in.].

Note 3—The diagonal of the 50-mm [2-in.] cube is 70.7 mm [2.83 in.].

6. MATERIALS

6.1. *Graded Standard Sand*:

6.1.1. The sand (Note 4) used for making test specimens shall be natural silica sand conforming to the requirements for graded standard sand in ASTM C 778.

Note 4—*Segregation of Graded Sand*—The graded standard sand should be handled in such a manner as to prevent segregation, because variations in the grading of the sand cause variation in the consistency of the mortar. In emptying bins or sacks, care should be exercised to prevent the formation of mounds of sand or craters in the sand, down the slopes of which the coarser particles will roll. Bins should be of sufficient size to permit these precautions. Devices for drawing the sand from bins by gravity should not be used.

7. TEMPERATURE AND HUMIDITY

7.1. *Temperature*—The temperature of the air in the vicinity of the mixing slab, the dry materials, molds, base plates, and mixing bowl shall be maintained between 23.0 ± 3.0°C [73.5 ± 5.5°F]. The temperature of the mixing water, moist closet, or moist room and water in the storage tank shall be set at 23 ± 2ºC [73.5 ± 3.5ºF].

7.2. *Humidity*—The relative humidity of the laboratory shall be not less than 50 percent. The moist closet or moist room shall conform to the requirements of M 201.

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8. TEST SPECIMENS

8.1. Make two or three specimens from a batch of mortar for each period of test or test age.

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9. PREPARATION OF SPECIMEN MOLDS

9.1. Apply a thin coating of release agent to the interior faces of the mold and non-absorptive base plates. Apply oils and greases using an impregnated cloth or other suitable means. Wipe the mold faces and the base plate with a cloth as necessary to remove any excess release agent and to achieve a thin, even coating on the interior surfaces. When using an aerosol lubricant, spray the release agent directly onto the mold faces and base plate from a distance of 150 to 200 mm [6 to 8 in.] to achieve complete coverage. After spraying, wipe the surface with a cloth as necessary to remove any excess aerosol lubricant. The residue coating should be just sufficient to allow a distinct fingerprint to remain following light finger pressure (Note 5).

9.2. Seal the surfaces where the halves of the mold join by applying a coating of light cup grease such as petrolatum. The amount should be sufficient to extrude slightly when the two halves are tightened together. Remove any excess grease with a cloth.

9.3. After placing the mold on its base plate (and attaching, if clamp-type) carefully remove with a dry cloth any excess oil or grease from the surface of the mold and the base plate to which watertight sealant is to be applied. As a sealant, use paraffin, microcrystalline wax, or a mixture of three parts paraffin to five parts rosin by mass. Liquefy the sealant by heating between 110 and 120ºC [230 and 248ºF]. Effect a watertight seal by applying the liquefied sealant at the outside contact lines between the mold and its base plate.

Note 5—Because aerosol lubricants evaporate, molds should be checked for a sufficient coating of lubricant immediately prior to use. If an extended period of time has elapsed since treatment, retreatment may be necessary.

Note 6—*Watertight Molds*—The mixture of paraffin and rosin specified for sealing the joints between molds and base plates may be found difficult to remove when molds are being cleaned. Use of straight paraffin is permissible if a watertight joint is secured; but due to the low strength of paraffin, it should be used only when the mold is not held to the base plate by paraffin alone. A watertight joint may be secured with paraffin alone by slightly warming the mold and base plate before brushing the joint. Molds so treated should be allowed to return to the specified temperature before use.

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10. PROCEDURE

10.1. *Composition of Mortars*:

10.1.1. The proportions of materials for the standard mortar shall be one part of cement to 2.75 parts of graded standard sand by mass. Use a water-cement ratio of 0.485 for all portland cements and 0.460 for all air-entraining portland cements. The amount of mixing water for other than portland and air-entraining portland cements shall be such as to produce a flow of 110 ± 5 as determined in accordance with Section 10.3 and shall be expressed as mass percent of cement.

10.1.2. The quantities of materials to be mixed at one time in the batch of mortar for making six and nine test specimens shall be as follows in Table 2:

Table 2—Mixing Proportions for 2-in. Cubes

	No. of Specimens	
	6	9
Cement, g	500	740
Sand, g	1375	2035
Water, mL: portland (0.485)	242	359
Air-entraining portland (0.460)	230	340
Other (to flow of 110 ± 5)	—	—

10.2. *Preparation of Mortar*:

10.2.1. Mechanically mix in accordance with the procedure given in T 162.

10.3. *Determination of Flow*:

10.3.1. Carefully wipe the flow-table top clean and dry, and place the flow mold at the center. Place a layer of mortar about 25 mm [1 in.] in thickness in the mold and tamp 20 times with the tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Then fill the mold with mortar and tamp as specified for the first layer. Cut off the mortar to a plane surface, flush with the top of the mold, by drawing the straight edge of a trowel (held nearly perpendicular to the mold) with a sawing motion across the top of the mold. Wipe the table top clean and dry, being especially careful to remove any water from around the edge of the flow mold. Lift the mold away from the mortar 60 seconds after completing the mixing operation. Immediately, drop the table through a height of 13 mm [$^1/_2$ in.], 25 times in 15 seconds. Using the calipers, determine the flow by measuring the diameters of the mortar along the four lines scribed in the table top, recording each diameter as the number of caliper divisions, estimated to one tenth of a division. If some other caliper is being used, measure the diameter of the mortar along the four lines scribed in the table top, recording each diameter to the nearest millimeter.

10.3.2. For portland and air-entraining portland cements, merely record the flow.

10.3.3. In the case of cements other than portland or air-entraining portland cements, make trial mortars with varying percentages of water until the specified flow is obtained. Make each trial with fresh mortar.

10.3.4. Immediately following completion of the flow test, return the mortar from the flow table to the mixing bowl. Quickly scrape the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl and then remix the entire batch 15 seconds at medium speed. Upon completion of mixing, the mixing paddle shall be shaken to remove excess mortar into the mixing bowl.

10.3.5. When a duplicate batch is to be made immediately for additional specimens, the flow test may be omitted and the mortar allowed to stand in the mixing bowl 90 seconds without covering. During the last 15 seconds of this interval, quickly scrape the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl. Then remix for 15 seconds at medium speed.

10.4. *Molding Test Specimens*:

10.4.1. Complete the consolidation of the mortar in the molds either by hand tamping or by a qualified alternative method. Alternative methods include but are not limited to the use of a vibrating table or mechanical devices.

10.4.2. *Hand Tamping*—Start molding the specimens within a total elapsed time of not more than 2 minutes and 30 seconds after completion of the original mixing of the mortar batch. Place a layer of mortar about 25 mm [1 in.] (approximately one-half of the depth of the mold) in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 seconds in four rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen, as illustrated in Figure 1. The tamping pressure shall be just sufficient to ensure uniform filling of the molds. The four rounds of tamping (32 strokes) of the mortar shall be completed in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first layer. During tamping of the second layer, bring in the mortar forced out onto the tops of the molds after each round of tamping by means of the gloved fingers and the tamper upon completion of each round and before starting the next round of tamping. On completion of the tamping the tops of all cubes should extend slightly above the tops of the molds. Bring in the mortar that has been forced out onto the tops of the molds with a trowel and smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mold. Then, for the purpose of leveling the mortar and making the mortar that protrudes above the top of the mold of more uniform thickness, draw the flat side of the trowel (with the leading edge slightly raised) lightly once along the length of the mold. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straightedge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the length of the mold.

10.4.3. *Alternative Methods*—Any consolidation method may be used that meets the qualification requirements of this section. The consolidation method consists of a specific procedure, equipment and consolidation device, as selected and used in a consistent manner by a specific laboratory. The mortar batch size of the method may be modified to accommodate the apparatus, provided the proportions maintain the same ratios as given in Section 10.1.2.

10.4.3.1. Separate qualifications are required for the following classifications:

10.4.3.2. *Class A, Non-Air Entrained Cements*—For use in concrete. Refer to M 85, M 240, and ASTM C 1157.

10.4.3.3. *Class B, Air-Entrained Cements*—For use in concrete. Refer to M 85, M 240, and ASTM C 1157.

10.4.3.4. *Class C, Masonry, Mortar, and Stucco Cements*—Refer to ASTM C 91, ASTM C 1328, and ASTM C 1329.

10.4.3.5. An alternative method may only be used to test the cement types as given in Section 10.4.3.1 above, for which it has been qualified.

10.4.3.6. It can also be used for Strength Activity Index determinations for fly ash and slag, refer to M 295 and M 302, provided the alternative method has qualified for both Class A and Class C cements.

10.4.4. *Qualification Procedure*—Contact Cement and Concrete Reference Laboratory (CCRL) to purchase cement samples that have been used in the Proficiency Sample Program (PSP). Four samples (5 kg each) of the class to be qualified will be required to complete a single qualification (see Note 7).

10.4.4.1. In one day, prepare replicate six-cube or nine-cube batches using one of the cements and cast a minimum of 36 cubes. Complete one round of tests on each cement on different days. Store and test all specimens as prescribed in the sections below. Test all cubes at the age of 7 days.

10.4.4.2. Tabulate the compressive strength data and complete the mathematical analyses as instructed in Annex A1.

10.4.5. *Re-qualification of the Alternate Compaction Method*:

10.4.5.1. Re-qualification of the method shall be required if any of the following occur:

- Evidence that the method may not be providing data in accordance with the requirements of Table 2.
- Results that differ from the reported final average of a CCRL-PSP sample with a rating of three or less.
- Results that differ from the accepted value of a known reference sample with established strength values by more than twice the multi-laboratory 1s percent values of Table 2. Before starting the re-qualification procedure, evaluate all aspects of cube fabrication and testing process to determine if the offending result is due to some systematic error or just an occasional random event.

10.4.5.2. If the compaction equipment is replaced, significantly modified, repaired, or has been recalibrated, re-qualify the equipment in accordance with Section 10.4.4.

Note 7—It is recommended that a large homogenous sample of cement be prepared at the time of qualification for use as a secondary standard and for method evaluation. Frequent testing of this sample will give early warning of any changes in the performance of the apparatus.

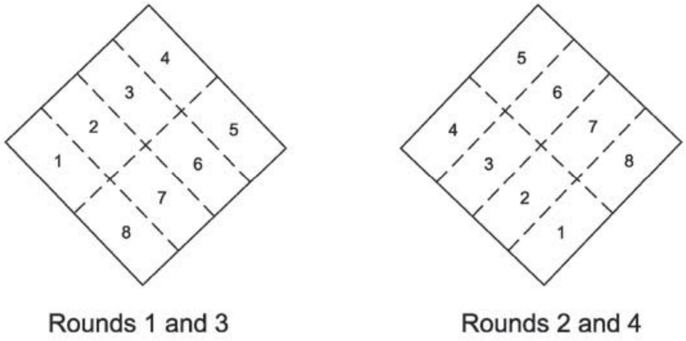

Figure 1—Order of Tamping in Molding of Test Specimens

10.5. *Storage of Test Specimens*—Immediately upon completion of molding, place the test specimens in the moist closet or moist room. Keep all test specimens, immediately after molding, in the molds on the base plates in the moist closet or moist room from 20 to 72 hours with their upper surfaces exposed to the moist air but protected from dripping water. If the specimens are removed from the molds before 24 hours, keep them on the shelves of the moist closet or moist room until they are 24 hours old. Then immerse the specimens, except those for the 24-hour test, in saturated lime water in storage tanks constructed of non-corroding materials. Keep the storage water clean by changing as required.

10.6. *Determination of Compressive Strength*:

10.6.1. Test the specimens immediately after their removal from the moist closet in the case of 24-hour specimens, and from storage water in the case of all other specimens. All test specimens for a given test age shall be broken within the permissible tolerance prescribed as follows in Table 3:

Table 3—Testing Time Tolerances

Test Age	Permissible Tolerance
24 hours	± $^1/_2$ hour
3 days	± 1 hour
7 days	± 3 hours
28 days	± 12 hours
56 days	± 24 hours

If more than one specimen at a time is removed from the moist closet for the 24-hour tests, keep these specimens covered with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, keep these specimens in water at a temperature of 23 ± 2°C [73.5 ± 3.5°F] and of sufficient depth to completely immerse each specimen until time of testing.

10.6.2. Wipe each specimen to a surface-dry condition, and remove any loose sand grains or incrustations from the faces that will be in contact with the bearing blocks of the testing machine.

Check these faces by applying a straightedge (Note 8). If there is appreciable curvature, grind the face or faces to plane surfaces or discard the specimen. A periodic check of the cross-sectional area of the specimen should be made.

Note 8—*Specimen Faces*: Results much lower than the true strength will be obtained by loading faces of the cube specimen that are not truly plane surfaces. Therefore, it is essential that the specimen molds be kept scrupulously clean, as otherwise large irregularities in the surface will occur. Instruments for cleaning molds should always be softer than the metal in the molds to prevent wear. In case grinding specimen faces is necessary, it can be accomplished best by rubbing the specimen on a sheet of fine emery paper or cloth glued to a plane surface, using only a moderate pressure. Such grinding is tedious for more than a few hundredths of a millimeter (thousandths of an inch); where more than this is found necessary, it is recommended that the specimen be discarded.

10.6.3. Apply the load to specimen faces that were in contact with the true plane surfaces of the mold. Carefully place the specimen in the testing machine below the center of the upper bearing block. Prior to the testing of each cube, it shall be ascertained that the spherically seated block is free to tilt. Use no cushioning or bedding materials. Bring the spherically seated block into uniform contact with the surface of the specimen. Apply the load rate at a relative rate of movement between the upper and lower platens corresponding to a loading on the specimen with the range of 900 to 1800 N/s [200 to 400 lb/s]. Obtain this designated rate of movement of the platen during the first half of the anticipated maximum load and make no adjustment in the rate of movement of the platen in the latter half of the loading, especially while the cube is yielding before failure.

Note 9—It is advisable to apply only a very light coating of a good quality, light mineral oil to the spherical seat of the upper platen.

11. CALCULATION

11.1. Record the total maximum load indicated by the testing machine, and calculate the compressive strength as follows:

$$fm = P/A \qquad (1)$$

where:

fm = compressive strength in MPa [psi],

P = total maximum load in N [lbf], and

A = area of loaded surface in mm^2 [$in.^2$].

Either 50-mm [2-in.] cube specimens may be used for the determination of compressive strength, whether SI or inch-pound units are used. However, consistent units for load and area must be used to calculate strength in the units selected. If the cross-sectional area of the specimen varies more than 1.5 percent from the nominal, use the actual area for the calculation of the compressive strength. The compressive strength of all acceptable test specimens (Section 13) made from the same sample and tested at the same period shall be averaged and reported to the nearest 0.1 MPa [10 psi].

12. REPORT

12.1. Report the flow to the nearest 1 percent and the water used to the nearest 0.1 percent. Average compressive strength of all specimens from the same sample shall be reported to the nearest 0.1 MPa [10 psi].

13. FAULTY SPECIMENS AND RETESTS

13.1. In determining the compressive strength, do not consider specimens that are manifestly faulty.

13.2. The maximum permissible range between specimens from the same mortar batch, at the same test age, is 8.7 percent of the average when three cubes represent a test age and 7.6 percent when two cubes represent a test age (Note 10).

Note 10—The probability of exceeding these ranges is 1 in 100 when the within-batch coefficient of variation is 2.1 percent. The 2.1 percent is an average for laboratories participating in the portland cement and masonry cement reference sample programs of the Cement and Concrete Reference Laboratory (CCRL).

13.3. If the range of three specimens exceeds the maximum in Section 13.2, discard the result that differs most from the average and check the range of the remaining two specimens. Make a retest of the sample if fewer than two specimens remain after discarding faulty specimens or discarding tests that fail to comply with the maximum permissible range of two specimens.

Note 11—Reliable strength results depend upon careful observance of all the specified requirements and procedures. Erratic results at a given test period indicate that some of the requirements and procedures have not been carefully observed; for example, those covering the testing of the specimens as prescribed in Sections 10.6.2 and 10.6.3. Improper centering of specimens resulting in oblique fractures or lateral movement of one of the heads of the testing machine during loading will often cause lower strength results.

14. PRECISION AND BIAS

14.1. *Precision*—The precision statements for this test method are listed in Table 4 and are based on results from the Cement and Concrete Reference Laboratory (CCRL) Reference Sample Program. They are developed from data where a test result is the average of compressive strength tests of three cubes molded from a single batch of mortar and tested at the same age. A significant change in precision will not be noted when a test result is the average of two cubes rather than three.

Table 4—Precision

		Test Age, Days	Coefficient of Variation 1s, Percent[a]	Acceptable Range of Test Results d2s, Percent[a]
Portland cements:				
Constant water-cement ratio:				
Single-laboratory		3	4.0	11.3
		7	3.6	10.2
	Av		3.8	10.7
Multilaboratory		3	6.8	19.2
		7	6.4	18.1
	Av		6.6	18.7
Blended cements:				
Constant flow mortar:				
Single-laboratory		3	4.0	11.3
		7	3.8	10.7
		28	3.4	9.6
	Av		3.8	10.7
Multilaboratory		3	7.8	22.1
		7	7.6	21.5
		28	7.4	20.9
	Av		7.6	21.5
Masonry cements:				
Constant flow mortar:				
Single-laboratory		7	7.9	22.3
		28	7.5	21.2
	Av		7.7	21.8
Multilaboratory		7	11.8	33.4
		28	12.0	33.9
	Av		11.9	33.7

[a] These numbers represent, respectively, the (1s percent) and (ds2 percent) limits as described in ASTM C 670. Precision data for tests at ages of 24 hours and 56 days are not available.

14.2. These precision statements are applicable to mortars made with cements mixed and tested at the ages as noted. The appropriate limits are likely somewhat larger for tests at younger ages and slightly smaller for tests at older ages.

14.3. *Bias*—The procedure in this test method has no bias because the value of compressive strength is defined in terms of the test method.

15. KEYWORDS

15.1. Compressive strength; hydraulic cement mortar; hydraulic cement strength; mortar strength; strength.

16. REFERENCES

16.1. Goodspeed, C. H., S. Vanikar, and R. Cook. High Performance Concrete Defined for Highway Structures. *Concrete International*, Vol. 18, No. 2, February 1996, *pp*. 62–67.

ANNEX

(Mandatory Information)

A1. ANALYSES OF TEST RESULTS FOR QUALIFICATION OF ALTERNATE COMPACTION METHODS

A1.1. *Calculation of Average Within-Batch Standard Deviation and Elimination of Outliers*—Tabulate the results for each cement sample (or round) in separate spreadsheets. In the spreadsheet, list results of each batch in columns and complete the calculations as shown in Table A1.1.

A1.1.1. Eliminate any outliers from the test data and repeat the calculations until none of the values lie outside the normal range.

A1.1.2. Tabulate the cube strengths with all the outliers eliminated and complete the calculations as shown in Table A1.2.

A1.2. *Summary of Results*—Compile the results of the four rounds and complete the calculations as shown in Table A1.3. The number of outliers shall not exceed 5 percent of the total number of test when rounded to the nearest whole number (for example, 4 rounds by 4 batches by 9 cubes = 144 tests by 5% (5/100) = 7.2 or 7.

A1.3. *Precision Qualification*—Calculate the relative within batch error (*RWBE*%) as shown in Table A1.3. This value must be less than 2.1percent to comply with the limit established in Note 10 of this specification.

A1.4. *Bias Qualification*—The test results compiled in Table A1.3 are evaluated against three limits to demonstrate an acceptable qualification. The limits have been established statistically from analyses of historical CCRL data and are given in Table A1.4.

A1.5. *Rationale for the Limits Given in Section A1.4*:

A1.5.1. The multilaboratory precision (1s%) for the average of *n* batches is given by:

Table A1.1—Example Using 9-Cube Batch

Round—2

CCRL Sample #140 Industry Average Strength, $X_i = 32.923$
Cast Date—00/00/00

7-Day Strengths, MPa

A	B	C	D	E
Batch Number	1	2	3	4
Cube 1	33.0	34.3	34.4	33.2
Cube 2	33.9	32.5	34.0	34.0
Cube 3	33.4	34.0	34.1	33.8
Cube 4	33.1	33.8	34.0	33.8
Cube 5	33.0	33.4	34.2	34.0
Cube 6	32.8	33.7	31.8	33.1
Cube 7	33.6	32.6	33.9	32.8
Cube 8	31.5	32.1	33.0	33.3
Cube 9	33.6	34.3	33.4	34.4
Average, X_b	33.10	33.42	33.65	33.60
SD_b	0.70	0.82	0.81	0.52
N_b	9	9	9	9
$(N_b–1)SD_b^2$	3.936	5.432	5.265	2.145
			N_r	36
			X_r	33.44
			SD_r	0.692
			MND	1.703
Normal Range				
Maximum	34.81	35.12	35.35	35.30
Minimum	31.40	31.71	32.95	31.89
Outliers	None	None	Cube 6	None

where:

X_i = industry average strength (CCRL);
X_b = average of test values in a single batch;
SD_b = Standard deviation of a single batch =

$$\sqrt{\frac{\sum_{\text{cube}}\left(x - x_b\right)^2}{N_b - 1}}$$

N_b = number of tests per batch;
$(N_b - 1)SD_b^2$ = an intermediate calculation;
N_r = total number of tests per round;
X_r = grand average of tests values obtained per round, MPa;
SD_r = mean standard deviation of round =

$$\sqrt{\frac{\sum_{\text{Batch}}\left(N_b - 1\right)SD_b^2}{N_r - 1}}$$

MND = Maximum normal deviation: use Excel™ function "=nominv (1–0.25/Nr,0,SDr)" or equivalent, or use statistical tables to find the inverse integrated nominal distribution for an integral value (1–0.25/N_r) in a normal distribution with $\sigma = SD_r$.

Normal Range:
Maximum = $(X_b + MND)$
Minimum = $(X_b - MND)$
Outlier = Any test value falling outside the calculated normal range

$$s\%_{ML,n} = \sqrt{s\%_{ML}^2 - \left(1 - \frac{1}{n}\right) s\%_{SO}^2}$$

A1.5.2. The limit for deviation of the individual rounds (no failures being allowed when four rounds are performed) is 1.2 $s\%_{ML,n}$, as used in T 105.

A1.5.3. The multilaboratory precision (1s%) for the mean of four rounds is 0.5 $s\%_{ML,n}$.

A1.5.4. The limit for deviation of the mean of four rounds (95 percent confidence) is 1.96 times this, or 0.98 $s\%_{ML,n}$.

Table A1.2—Test Data after the Elimination of Outlines (Example Using 9-Cube Batch)

Round—2

CCRL Sample #140 Industry Average Strength, X_i = 32.923
Cast Date—00/00/00

7-Day Strengths, MPa

A	B	C	D	E
Batch Number	1	2	3	4
Cube 1	33.0	34.3	34.4	33.2
Cube 2	33.9	32.5	34.0	34.0
Cube 3	33.4	34.0	34.1	33.8
Cube 4	33.1	33.8	34.0	33.8
Cube 5	33.0	33.4	34.2	34.0
Cube 6	32.8	33.7		33.1
Cube 7	33.6	32.6	33.9	32.8
Cube 8		32.1	33.0	33.3
Cube 9	33.6	34.3	33.4	34.4
Average, X_{bv}	33.29	33.42	33.89	33.60
SD_{bv}	0.39	0.82	0.46	0.52
N_{bv}	8	9	8	9
$(N_{bv} - 1)SD_{bv}^2$	1.092	5.348	1.462	2.159
			N_{rv}	34
			X_{rv}	33.55
			X_i	32.92
			SD_{rv}	0.55
			E_r, MPa	0.63
			RE_r,%	1.91

where:

X_{bv} = average of valid test values obtained per batch, MPa;
X_i = Industry average strength (CCRL), MPa;
SD_{bv} = $\sqrt{\dfrac{\sum_{\text{Valid cube}} \left(x - x_{bv}\right)^2}{N_{bv} - 1}}$

N_{bv} = number of tests per batch;
$(N_{vb} - 1)SD_{bv}^2$ = an intermediate calculation;
N_{rv} = total number of tests per round;
X_{rv} = grand average of tests values obtained per round, MPa;
SD_{rv} = mean standard deviation of round =

$$\sqrt{\frac{\sum_{\text{Batch}} \left(N_{bv} - 1\right) SD_{bv}^2}{N_{rv} - 1}}$$

E_r = error = $(X_i - X_{rv})$, MPa; and
R_{er} = relative error for the round, % = $100(E_r/X_{rv})$.

A1.5.5. The values for $s\%_{ml}$ and $s\%_{xo}$ for Cement Classes A and C (non-air-entrained cements for mortar respectively) are the 7-day values in the current precision statement of T 106M/T 106. There appear to be no data for Cement Class B (air-entrained cements for concrete). Working on the assumption that the value of this quantity is related to the air content, the values adopted for Class B are the mean of the A and C-values.

For the applicable conditions, the equations above give the following:

Deviations of Limits for Table A1.4

Cement Class	A	B	C	A	B	C
Batches per round (*n*)	6	6	6	4	4	4
Single Operator s% (single batch)	3.6	5.75	7.9	3.6	5.75	7.9
Multilaboratory s% (single batch)	6.4	9.1	11.8	6.4	9.1	11.8
Multilaboratory s% (n batches)	5.5	7.4	9.3	5.6	7.6	9.6
Limit for deviation of a single round %	6.6	8.9	11.2	6.7	9.1	11.5
Limit of deviation of mean of four rounds %	5.4	7.3	9.2	5.5	7.5	9.4

Table A1.3—Summary of Results

A	B	C	D	E	F	G	H	I
	CCRL #	Day	X_i MPa	X_{rv}, MPa	RE_r, %	N_{rv}	SD_{rv}	$(N_r - 1)SD_r^2$
Round 1	139	1	28.47	30.42	6.85	36	0.97	32.93
Round 2	140	2	32.92	33.55	1.91	34	0.55	9.98
Round 3	141	3	32.64	33.14	1.53	34	0.47	7.29
Round 4	142	4	32.24	33.01	2.39	36	0.51	9.10
						Max, RE_r,%		6.85
						Mean, RE_r,%		3.17
						GMWBE, MPa		0.65
						RWBE, %		2.01
						Max, *RWBE*, %[a]		2.1
						Precision Test		Pass

[a] = See Note 10.

where:

X_r = industry average strength, MPa;
X_{rv} = grand mean value of the valid tests of a round;
RE_{rv}, % = relative error = $100(X_i - X_{rv})$;
N_{rv} = total number of valid tests of the round;

SD_{rv} = mean standard deviation of a round = $\sqrt{\dfrac{\sum_{\text{Batch}} \left(N_{bv} - 1\right) SD_{rv}^{2}}{N_{rv} - 1}}$

$(N_r - 1)SD_r^2$ = intermediate calculation;
X_g = grand mean value of the valid tests (4 rounds);
N_g = total number of valid tests in 4 rounds;
$GMWBE$ = grand mean within-batch error, MPa = $\sqrt{\dfrac{\sum_{\text{Round}} \left(N_{rv} - 1\right) SD_{rv}^{2}}{N_{g} - 1}}$

$RWBE$ = relative within batch error, % = $100\left(\dfrac{GMWBE}{X_g}\right)$; and

Max, $RWBE$ = maximum allowed $RWBE$ = 2.10% (see Note 10).

Table A1.4—Bias Qualification Requirements

	6-Cube Batches (Minimum 6 Batches per Round)			9-Cube Batches (Minimum 4 Batches per Round)		
Cement classification (see Section 10.4.3.1)	A	B	C	A	B	C
Maximum allowable relative error any 4 or 6 batches, $MARE_r$%	6.6	8.9	11.2	6.7	9.1	11.5
Maximum allowable relative error mean of 4 rounds of 4 batches or 6 batches <5% failures, *GRE*%	5.4	7.3	9.2	5.5	7.5	9.4
Minimum allowable confidence limit, % *MACL* %	95	95	95	95	95	95

Table A1.5—Bias Tests (Example Using 9-Cube Batches, Class A Cement)

MRE_r %, the maximum relative error value of the four rounds	6.85
$MARE_r$ %, max allowable MRE_r from Table A1.4	6.7—Fails
GRE, the average RE_r % of the 4 rounds	3.13
Maximum limit of $MGRE_g$ % from Table A1.4	5.5—Pass
Bias confidence limit, *CL* %	96.99
Minimum allowable confidence limit, *MACL* % (from Table A1.4)	95—Pass

The above results indicate the data fails to show compliance.

where:

MRE_r, % = the maximum relative error, % obtained for any round (from values in column F, Table A1.3),
$MARE_r$, % = the maximum allowable relative error, % of any Round (Table A1.4),
GRE, % = the grand average of the RE_r, % values of the 4 rounds,
$MARE_g$, % = maximum allowed *GRE*, % value (average of column F, Table A1.3), and
CL, % = bias confidence limit, %, the confidence with which it can be stated that the error of the mean of 4 rounds is non-zero. Calculate this by use of ExcelT function "=ttest(<range of industry means>,<range of values obtained>,1,1)" or equivalent, or use statistical tables to find the confidence in a one-tailed, paired-value t-test on the set of round errors.

Note A1—The qualification method fails for bias if (1) the MRE_r exceeds the $MARE_r$, percentage limit; or if (2) the GRE, percentage exceeds the $MGRE_g$ limit and the CL, percentage exceeds 95 percent.

Standard Method of Test for

Autoclave Expansion of Hydraulic Cement

AASHTO Designation: T 107-07
ASTM Designation: C 151-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Autoclave Expansion of Hydraulic Cement

AASHTO Designation: T 107-07
ASTM Designation: C 151-05

1. SCOPE

1.1. This test method covers determination of the autoclave expansion of hydraulic cement by means of a test on a neat cement specimen.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For specific precaution statements, see the section on Safety Precautions.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- T 129, Normal Consistency of Hydraulic Cement
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standard*:

- C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- C 1157, Standard Performance Specification for Hydraulic Cement
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. SIGNIFICANCE AND USE

3.1. The autoclave expansion test provides an index of potential delayed expansion caused by the hydration of CaO or MgO or both, when present in hydraulic cement.[1]

4. INTERFERENCES

4.1. Pozzolans containing fine-grained quartz have been reported to cause excessive expansion under autoclave test conditions due to alkali-silica reaction that will not occur under normal service conditions.[2] When excessive expansion of paste containing pozzolans occurs, it is recommended that the specimens be examined (See ASTM C 856) for evidence of alkali-silica reaction (Note 1).

Note 1—If the excessive expansion has resulted from alkali-silica reaction under autoclave conditions, the pozzolan can be evaluated for alkali reactivity using the procedure described in ASTM C 1157.

5. APPARATUS

5.1. *Weighing Devices and Weights*—for determining the mass of materials conforming to the requirements of ASTM C 1005.

5.2. *Glass Graduates*—200- or 250-mL capacity, and conforming to the requirements of M 210.

5.3. *Molds*—25 by 25-mm or 1 by 1-in. cross section, conforming to the requirements of M 210.

5.4. *Flat Trowel*—having a straightedged steel blade 100 to 150 mm (4 to 6 in.) in length.

5.5. *Autoclave*—consisting of a high-pressure steam vessel provided with a thermometer well. The autoclave shall be equipped with automatic controls and a rupture disk with a bursting pressure of 2.41 MPa (350 psi) ±5 percent. In locations where the use of a rupture disk is not permitted, the autoclave shall be equipped with a safety valve. In addition, the autoclave shall be equipped with a vent valve to allow the escape of air during the early part of the heating period and to release any steam pressure remaining at the end of the cooling period. The pressure gauge shall have a nominal capacity of 4.14 MPa (600 psi), a dial with a nominal diameter of 114 mm ($4^1/_2$ in.) and shall be graduated from 0 to 4.14 MPa (0 to 600 psi) with scale divisions not exceeding 0.03 MPa (5 psi). The error in the gauge shall not exceed ±0.02 MPa (±3 psi) at the operating pressure of 2.03 MPa (295 psi). The capacity of the heating unit shall be such that with maximum load (water plus specimens) the pressure of the saturated steam in the autoclave may be raised to a gauge pressure of 2.03 MPa (295 psi) in 45 to 75 minutes from the time the heat is turned on. The automatic control shall be capable of maintaining the gauge pressure of 2.03 ± 0.07 MPa (295 ± 10 psi) for at least three hours. A gauge pressure of 2.03 ± 0.07 MPa (295 ± 10 psi) corresponds to a temperature of (420 ± 3ºF) 216 ± 2ºC. The autoclave shall be designed to permit the gauge pressure to drop from 2.03 MPa (295 psi) to less than 0.07 MPa (10 psi) in 1.5 hours after the heat supply has been shut off.

5.5.1. *Rupture Disk*—The rupture disk shall be made of a material having a tensile strength that is relatively insensitive to temperature in the range 20 to 216ºC (68 to 420ºF) and that is electrochemically compatible with the pipe leading to it and to its holder.

5.6. *Length Comparator*—The comparator used for measuring length change of specimens shall conform to the requirements of M 210.

6. TEMPERATURE AND HUMIDITY

6.1. *Molding Room*—Maintain the temperature of the molding room, dry materials, and mixing water, and the relative humidity of the molding room within the limits of M 210.

6.2. *Moist Storage Facilities*—Maintain the temperature and humidity of the moist storage facilities to the requirements of M 201.

7. SAFETY PRECAUTIONS

7.1. The pressure gauge should have a maximum capacity of 4.14 MPa (600 psi). A gauge with too small or too large a capacity may be a hazard, since for pressure above the specified maximum working pressure, with a smaller capacity gauge, the pressure may be off scale, and with a larger capacity gauge, the arc of movement may be too small to invite attention. The operator shall be sure the gauge hand has not passed the maximum graduation on the scale.

7.2. Test the pressure gauge for proper operation. Always use a thermometer together with the pressure gauge, so as to provide a means of detecting any failure of the pressure gauge to operate properly, and to indicate any unusual condition.

7.3. Maintain the automatic control in proper working order at all times.

7.4. Set the safety valve to relieve the pressure at about 6 to 10 percent above the maximum of 2.10 MPa (305 psi) specified in this test method, that is, at about 2.28 MPa (330 psi). Unless the manufacturer has given specific instructions as to maintenance of the safety valve, test the valve twice each year. Test with a gauge testing device, or by adjusting the automatic controls to allow the autoclave to reach a pressure of about 2.28 MPa (330 psi), at which pressure the safety valve will either open or be adjusted to open. Direct the safety valve discharge away from the operator.

Note 2—Unexpected combinations of conditions may occur. For example, in one case the automatic control had failed, the safety valve had become stuck, and the gauge hand, which at first glance appeared to be at about zero, had passed the maximum graduation and had come to stop on the wrong side of the pin. This condition of the gauge was finally detected and the pressure, then of an unknown magnitude, was released before failure could occur in the apparatus.

7.5. Wear heavy leather work gloves to prevent burning of the hands when removing the top of the autoclave at the end of the test. Direct the vent valve away from the operator. When removing the autoclave lid, tilt it so that any steam escaping from beneath the lid may be discharged away from the operator. Care shall be taken to avoid scalding by any liquid that may have been used in the autoclave well.

7.6. The operator shall be made aware that for many autoclave pressure gages the return of the gauge hand to the initial rest or starting point does not necessarily indicate zero pressure within the autoclave; there may then still remain an appreciable dangerous pressure.

8. NUMBER OF TEST SPECIMENS

8.1. Make at least one test specimen.

9. PREPARATION OF SPECIMEN MOLDS

9.1. Prepare the specimen molds in accordance with the requirements of M 210 except that molds need not be sealed.

10. PREPARATION OF TEST SPECIMENS

10.1. *Mixing Cement Paste*—Prepare the standard batch consisting of 650 g of cement and sufficient water to give a paste of normal consistency in accordance with the procedure described in T 129. Mix this batch in accordance with the procedure described in T 162. Both a time of setting specimen and an autoclave bar may be made from the same batch. If the paste to be used for time of setting is the paste sample already used to determine normal consistency, then the autoclave bar may be prepared immediately from the remainder of the batch.

10.2. *Molding Specimens*—Immediately following preparation of the time of setting specimen or completion of mixing, mold the test specimen in two approximately equal layers, each layer being compacted with the thumbs or forefingers by pressing the paste into the corners, around the gauge studs, and along the surface of the mold until a homogeneous specimen is obtained. Compact the top layer, cut off the paste flush with the top of the mold with a thin-edged trowel, and smooth the surface with a few strokes of the flat trowel. During the operations of mixing and molding, protect the hands with rubber gloves.

10.3. *Storage of Test Specimens*—After filling the mold, place it in the moist closet or moist room. Store the specimens in the molds in the moist enclosure for at least 20 hours; if removed from the molds before 24 hours, they shall be kept in the moist closet or moist room until time of test.

11. PROCEDURE

11.1. At 24 hours ± 30 minutes after molding, remove the specimens from the moist atmosphere, immediately obtain a length comparator reading for each specimen, and place in the autoclave at room temperature in a rack so that all sides of the specimen will be exposed to saturated steam. The autoclave shall contain enough water, at an initial temperature of 68 to 82ºF (20 to 28ºC), to maintain an atmosphere of saturated steam vapor during the entire test. Ordinarily 7 to 10 percent of the volume of the autoclave should be occupied by the water.

11.2. To permit air to escape from the autoclave during the early portion of the heating period, leave the vent valve open until steam begins to escape. (**Warning**—See Section 7 on Safety Precautions.) Close the valve and raise the temperature of the autoclave at a rate that will bring the gauge pressure of the steam to 2.03 MPa (295 psi) in 45 to 75 minutes from the time the heat is turned on. Maintain 2.03 ± 0.07 MPa (295 ± 10 psi) pressure for three hours. At the end of the three-hour period, shut off the heat supply and cool the autoclave at such a rate that the pressure will be less than 0.07 MPa (10 psi) at the end of the 1.5-hour period, and slowly release any remaining pressure by partially opening the vent valve until atmospheric pressure is attained. Then open the autoclave and place the test specimen in water at a temperature above 90ºC (194ºF). Cool the water surrounding the bars at a uniform rate by adding cold water so that the temperature of the water will be lowered to 23ºC (74ºF) in 15 minutes. Maintain the water surrounding the specimens at 23ºC for an additional 15 minutes; then, remove one specimen at a time from the water, blot the pins, but not the specimen, and obtain a length comparator reading for each specimen.

12. CALCULATION

12.1. Calculate the change in length of the test specimen by subtracting the length comparator reading before autoclaving from that after autoclaving, and report as percent of the effective gauge length to the nearest 0.01 percent. Report the percentage of increase in length as the autoclave expansion. Indicate a decrease in length by a minus sign prefixed to the percent value.

13. PRECISION AND BIAS

13.1. *Precision*—The single-operator (within-laboratory) standard deviation has been found to be 0.024 percent throughout the range of 0.11 percent to 0.94 percent expansions. Therefore, results of two properly conducted tests by the same operator for expansions of similar batches should not differ from each other by more than 0.07 percent expansion. The multilaboratory (between laboratory) standard deviation has been found to be 0.030 percent throughout the range of 0.11 percent to 0.94 percent expansions. Therefore, results of two properly conducted tests from two different laboratories for expansions of similar batches should not differ from each other by more than 0.09 percent expansion.

13.2. *Bias*—Because there is no accepted reference material suitable for determining bias, bias has not been determined.

For additional useful information on details of cement test methods, reference may be made to the "Manual of Cement Testing," which appears in the *Annual Book of ASTM Standards*, Volume 04.01.

14. KEYWORDS

14.1. Autoclave; autoclave expansion; expansion; hydraulic cement; soundness.

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[1] Gonnerman, H.F., W. Lerch, and T.M. Whitside. Investigations of the Hydration Expansion Characteristics of Portland Cements. *Portland Cement Association Research Department Bulletin 45*, 1953, *pp*. 1–168.

[2] Wang, H., "Autoclave Soundness Test Mischaracterizes Cement-Fly Ash Blends by Introducing Alkali-Quartz Reaction," Cement, Concrete, and Aggregates, Vol. 24, No. 2, 2002, *pp*. 68–72.

Standard Method of Test for

Sampling and Amount of Testing of Hydraulic Cement

AASHTO Designation: T 127-04 (2008)
ASTM Designation: C 183-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling and Amount of Testing of Hydraulic Cement

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1. SCOPE

1.1. This practice covers procedures for sampling and for the amount of testing of hydraulic cement after it has been manufactured and is ready to be offered for sale.

1.2. The values stated in SI units are to be regarded as the standard. The inch–pound units in parentheses are for information purposes only.

1.2.1. A ton as used in this practice is 907 kg (2000 lb).

1.2.2. Values in SI units shall be obtained by measurement in SI units or by appropriate conversion using the rules for conversion and rounding given in standard IEEE/ASTM SI 10, of measurements made in other units.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 85, Portland Cement
- M 240, Blended Hydraulic Cement
- T 98, Fineness of Portland Cement by the Turbidimeter
- T 105, Chemical Analysis of Hydraulic Cement
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 107, Autoclave Expansion of Hydraulic Cement
- T 131, Time of Setting of Hydraulic Cement by Vicat Needle
- T 137, Air Content of Hydraulic Cement Mortar
- T 153, Fineness of Hydraulic Cement by Air Permeability Apparatus
- T 154, Time of Setting of Hydraulic Cement Paste by Gillmore Needles
- T 160, Length Change of Hardened Hydraulic Cement Mortar and Concrete
- T 186, Early Stiffening of Hydraulic Cement (Paste Method)

2.2. *ASTM Standards*:

- C 91, Standard Specification for Masonry Cement
- C 157, Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
- C 186, Standard Test Method for Heat of Hydration of Hydraulic Cement
- C 227, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
- C 265, Standard Test Method for Water-Extractable Sulfate in Hydrated Hydraulic Cement Mortar
- C 452, Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate
- C 563, Standard Test Method for Approximation of Optimum SO3 in Hydraulic Cement Using Compressive Strength
- C 845, Standard Specification for Expansive Hydraulic Cement
- C 1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution
- C 1157, Standard Performance Specification for Hydraulic Cement
- C 1328, Standard Specification for Plastic (Stucco) Cement
- C 1329, Standard Specification for Mortar Cement
- E 11, Standard Specification for Woven Wire Test Sieve Cloth Standard Test Sieves

2.3. *ACI Standard*:

- ACI 225.1R, Guide to the Selection and Use of Hydraulic Cements

2.4. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *lot (of cement)*—specific quantity of cement offered for inspection at any one time. A lot may be one or more storage bins filled consecutively. A lot may also be the contents of one or more transport units representing cement drawn from the same storage bin.

3.1.2. *reduced testing rate*—test program that provides for the testing of only two samples from any given lot of samples obtained and prepared for testing at the normal rate as described herein. The program utilizes probability factors and is so designed that when results from the two samples fulfill the requirements of the program, it may be said with 95 percent confidence that fewer than 5 percent of the samples would be outside the specification limits.

4. SIGNIFICANCE AND USE

4.1. The sampling procedures described are intended for use in the procurement of samples of hydraulic cement after it has been manufactured and is ready to be offered for sale. They are not intended as sampling procedures for quality control purposes during manufacturing. The testing procedures outlined cover the amount of testing to be done and provide guidance for reporting on conformance or non-conformance of cements with requirements of purchase specifications.

4.2. This practice is referenced as the procedure for sampling masonry cement (ASTM C 91), portland cement (M 85), blended hydraulic cement (M 240), expansive hydraulic cement (ASTM C 845), plastic stucco cement (ASTM C 1328), mortar cement (ASTM C 1329), and hydraulic cement based on a performance specification (ASTM C 1157).

4.3. Most building codes and construction specifications require that hydraulic cement to be used in the work meet the applicable requirements of the relevant purchase specifications, such as Specifications M 85, M 240, ASTM C 91, ASTM C 845, ASTM C 1157, ASTM C 1328 and ASTM C 1329. If the code or specification requires sampling of the manufactured cement, the provisions given in Section 4.4 are applicable. Not much cement is sold on the basis of such sampling and testing. A useful discussion of sampling and testing cement is contained in ACI 225.1R.

4.4. The procedures covered in this practice should be done by or for purchasers of hydraulic cement who are using a code or specification that requires sampling and testing to determine if the samples conform to the relevant acceptance specifications. The testing is done using specified methods to determine whether the samples yield test results that conform to the specification, and the tests serve as a basis for acceptance or rejection of the lot of material sampled.

4.5. It is neither intended nor required that all cements be tested using all the test methods referenced in Section 2.

5. KINDS AND SIZE OF SAMPLES AND BY WHOM TAKEN

5.1. A cement sample secured from a conveyor, from bulk storage, or from a bulk shipment in one operation shall be termed a “grab sample.” A sample obtained during a 10-minute interval using an automatic sampling device that continuously samples a cement stream may also be termed a grab sample. Grab samples taken at prescribed intervals over a period of time may be combined to form a “composite sample” representative of the cement produced during that period of time.

5.2. All samples, whether grab or composite, shall have a mass of at least 5 kg (10 lb).

5.3. The purchaser may designate a representative to supervise the sampling, packing, and shipping of samples when it is so specified in the purchase contract.

5.4. Package the samples in moisture-proof, airtight containers numbered consecutively in the order in which the samples are taken. The purchase contract shall state who will pay for the costs of sampling, packaging, shipping, and testing the samples.

Note 1—Polyvinyl chloride sample containers, upon occasion, have been found to affect the air-entraining potential of a cement sample. The same problem might be experienced with containers made from other plastics.

6. TESTING-TIME REQUIREMENTS FOR THE COMPLETION OF TESTS

6.1. When tests of hydraulic cement are made at a laboratory other than that of the cement manufacturer, the cement sampling schedule, sample transportation time, and sample testing schedule must be coordinated among the purchaser, the manufacturer, and the testing laboratory so that the tests results will be available when required.

6.2. The manufacturer of the cement shall make the cement available to be sampled for testing early enough before the time the test results are needed so that at least the applicable time intervals listed in Section 6.3 exist.

6.3. When this has been done, the testing laboratory shall provide test results not later than the indicated number of days after sampling:

Tests	Time Interval, Days
T 106 (1-day results), T 98,T 105, T 107, T 131, T 137, T 153, T 154, T 186; ASTM C 265, C 563	8
T 106 (3-day results)	10
T 106 (7-day results); ASTM C 186	14
ASTM C 227, C 452, and C 1012 (14-day results)	21
T 106 (28-day results); ASTM C 186	35
T 160 (34-day results); ASTM C 157	41
ASTM C 227 (56-day results)	63
ASTM C 227 (91-day results)	98

7. SAMPLING

7.1. The cement may be sampled by any of the applicable methods described in this section.

7.1.1. *From the Conveyor Delivering to Bulk Storage*—Take one grab sample, having a mass of at least 5 kg (10 lb), at approximately six-hour intervals.

7.1.2. *Transfer Sampling*—Sample cement in storage while the cement is being transferred from one bin to another. Take one grab sample from the transfer stream for each 360 Mg (400 tons) of cement, or fraction thereof, but take no less than two grab samples and combine them to produce a composite sample.

7.1.3. *Other Sampling Methods*—When neither of the above sampling methods is applicable, samples may, when authorized by the purchaser, be taken by one of the following methods:

7.1.3.1. *From Bulk Storage at Points of Discharge*—Withdraw cement from the discharge openings in a steady stream until sampling is completed. Estimate the quantity of cement in Mg to be withdrawn from one discharge opening as $0.055\ d^3 \times 0.2$, where d is the depth in meters of cement above the discharge opening. If a high circular silo is being sampled, take all samples from one opening. If the quantity of the cement in the bin exceeds 1100 Mg (1200 tons) when low rectangular bins are being sampled, discharge openings employed in the sampling shall be such that for no opening shall the number of samples represent more than one-half the contents of the bin or more than 1800 Mg (2000 tons). In sampling bulk storage at points of discharge, while the cement is flowing through the openings, take samples at such intervals so that at least two grab samples shall be secured for each 360 Mg (400 tons) in the bin or silo.

7.1.3.2. *From Bulk Storage and Bulk Shipment by Means of a Slotted Tube Sampler*—When the depth of the cement to be sampled does not exceed 2.1 m (7 ft), obtain samples using a slotted tube sampler similar to that shown in Figure 1. It shall be between 1.5 and 1.8 m (5 and 6 ft) long and approximately 35 mm ($1^3/_8$ in.) in outside diameter and consist of two polished brass telescopic tubes with registering slots that are opened or closed by rotation of the inner tube, the outer tube being provided with a sharp point to facilitate penetration. Take samples from well-distributed points and various depths of the cement so that the samples taken will represent the cement involved.

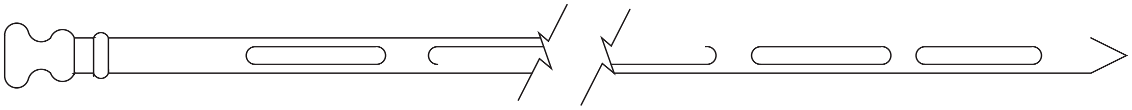

Figure 1—Slotted Tube Sampler for Bulk Cement

7.1.3.3. *From Packaged Cement by Means of Tube Sampler*—Insert the sampler, shown in Figure 2, diagonally into the valve of the bag and place the thumb over the air hole. Then withdraw the sampler. Take one sample from a bag in each 4.5 Mg (5 tons) or fraction thereof.

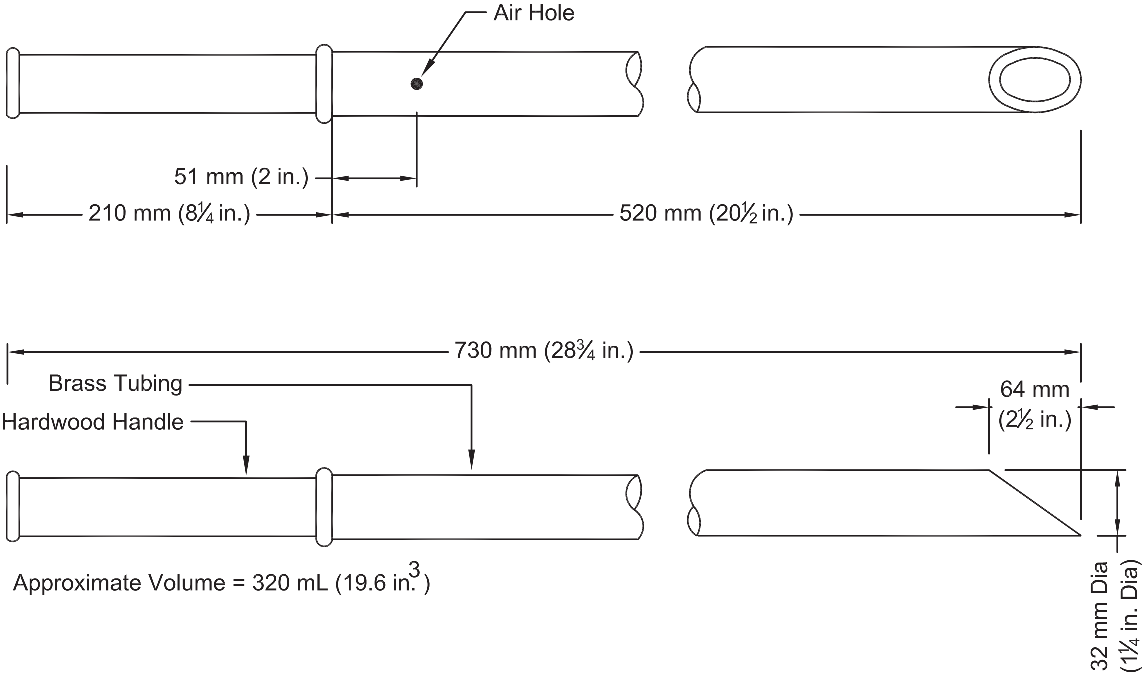

Figure 2—Tube Sampler for Packaged Cement

7.1.3.4. *From Bulk Shipment of Car or Truck*:

1. *Single Shipment*—If only one car or truck is being loaded and the loading is continuous and all from the same source, take a 5-kg (10-lb) sample. If not continuous or unknown, combine five or more portions from different points in the load to form the test sample.
2. *Multiple Shipments*—When the shipment consists of several cars or trucks loaded from the same source and on the same day, sample the shipment at the rate of one sample for each 90 Mg (100 tons) of cement or fraction thereof, but take not less than two samples. Consider cement represented by such samples as a lot, and test the samples in accordance with the procedure outlined in Section 9, Amount of Testing.

7.2. *Protection of Samples*—As samples are taken, place them directly in moisture-proof airtight containers to avoid moisture absorption and aeration of the sample. If the samples are placed in cans, fill the can completely and immediately seal. Use moisture-proof, multiple-wall paper bags or plastic bags if they are strong enough to avoid breakage, and if they can be sealed immediately after filling in such a manner as to eliminate excess air in the sample and avoid moisture absorption and aeration of the sample. Samples shall be treated as described in Section 8, Preparation of Sample.

8. PREPARATION OF SAMPLE

8.1. Before testing, pass each sample through an 850-µm (No. 20) sieve, or any other sieve having approximately the same size openings, in order to mix the sample, break up lumps, and remove foreign material. Discard the foreign materials and hardened lumps that do not break up on sieving or brushing. Store the cement in airtight moisture-proof containers to prevent aeration or absorption of moisture prior to test.

9. AMOUNT OF TESTING

9.1. *General*—When required, the purchaser shall specify the amount of testing for heat of hydration (ASTM C 186), alkali reactivity (ASTM C 227), and sulfate resistance (ASTM C 1012). Make all other tests on individual grab or composite samples chosen as specified herein under Section 9.2.6, Selection of Samples for Testing. Do only those tests required by the applicable specification.

9.2. *Normal Testing*—Determine the number of samples to be tested in accordance with Table 1. The normal testing rate shall be used under the following conditions:

9.2.1. Before the quality history has been established,

9.2.2. When no samples from a particular mill have been tested within a year,

9.2.3. When the quality history is based entirely on data more than two years old, and

9.2.4. When it is deemed necessary to recalculate the critical limit because of indicated lack of control as shown by the control chart of the range.

Table 1—Number of Samples for Test

Lot Size—Number of Samples	Number of Tests	
	Normal Rate	Reduced Rate
2	2	2
3	3	2
4 to 10	4	2
11 to 20	6	2
Over 20	8	2

Note 2—Random grab samples taken at inappropriate times, such as immediately following the repair or adjustment of manufacturing equipment, or from inappropriate places, such as from the top surface of the material in a car, will not suitably reflect the properties of a cement, and therefore should not be used as the basis for acceptance or rejection of a lot of cement.

9.2.5. *Reduced Testing*—After the quality history has been established, test at the reduced testing rate. If the results of these tests are within the critical range, make additional tests (total equal to the number of tests at the normal rate as shown in Table 1).

Note 3—When the quality history indicates that the results for a given requirement will probably be within the critical range, and substantial delay in completion of the tests would result from making additional tests (for example, compressive strength), it may be desirable to make the tests at the normal rate, rather than the reduced testing rate.

9.2.6. *Selection of Samples for Testing*—Take samples to be tested from each lot by some random method. The following method is suggested: Place a group of consecutively numbered markers equal to the number of samples in a container and mix, then draw one marker at a time from the container until the number drawn is equal to the number of samples to be tested at the normal rate. If the testing is to be done at the reduced rate, mix the drawn markers and draw two to select the numbers of the samples to be tested.

9.3. *Establishing a Quality History and Control Charts*:

9.3.1. *Quality History*—The quality history shall represent cement from the same source as the cement to be tested, and shall be based on data not more than two years old. There shall be available test results for not less than 40 test samples representing not less than seven lots of cement. The test samples shall conform to the applicable provisions of this practice. A pair shall be two test samples from the same lot, in numerical sequence. Several pairs from the same lot may be used where available. The number of paired samples representing a large lot may be reduced as follows: From the consecutively numbered group of tested samples representing the entire lot, select a subgroup by some random method. List the numbers identifying the subgroup in numerical sequence, and pair in the order of listing. Compute the range (difference between the test results of a pair) for each pair of test results. Total the ranges and divide their sum by the total number of ranges used to obtain the average range, $\bar{r}$. Compute the average range, $\bar{r}$, for each included physical and chemical property limited by specification requirements.

9.3.2. *Critical Limit*—Calculate the critical limit, *C*, for each included physical and chemical property limited by a specification requirement. First, multiply the average range, $\bar{r}$, by the probability factor, 2.49; this will yield a number that for convenience is called *d*. If the requirement has a maximum specification limit, obtain *C* by subtracting *d* from the specification limit and, if a minimum, add *d* to the specification limit. Maintain quality history charts.

Note 4—Improved estimates of the range $\bar{r}$, and consequently of *C*, will result if the test results are not rounded. For example, the test result of 21.78 percent for SiO_2 is preferred to the rounded value of 21.8 percent. For the fineness, the calculated value of 3,243 is preferred to the rounded value of 3,240.

9.3.3. *Control Chart of the Range*—Maintain a control chart of the range to indicate when the critical limit needs to be recomputed. Multiply the average range, $\bar{r}$, as obtained in Section 9.5.2, by the probability factor 3.267 to obtain the upper control limit for the range between each consecutive pair of test results. The horizontal scale of the chart will be successive groups of two, and the vertical scale will be the range. Where the range chart indicates lack of control (points beyond the upper control limit), the critical limit, *C*, may need to be recalculated. Consider the occurrence of two consecutive points beyond the upper control limit for the range, or the occurrence of three points beyond the upper control limit in any series of five consecutive points cause to recalculate the critical limit. Where it becomes necessary to recalculate the critical limit, discontinue reduced testing until a new quality history has been established.

Note 5—Examples of the calculation of $\bar{r}$, *d*, and quality history and control charts are shown in Table 2 and Figures 3 and 4. The specification limits used in these examples are hypothetical.

Table 2—Test Data, Type I Low-Alkali Cement

Lot No.	Sample No.	Alkalies, %	Range, %	Seven-Day Strength (Average of Three Specimens) MPa	(psi)	Range MPa	(psi)
88	1	0.58		35.5	(5150)		
	13	0.61	0.03	37.0	(5358)	1.44	(208)
	17	0.57		32.2	(4675)		
	21	0.55	0.02	33.1	(4800)	0.86	(125)
91	1	0.55		32.0	(4633)		
	5	0.55	0.00	33.9	(4917)	1.95	(283)
	13	0.57		34.3	(4975)		
	21	0.54	0.03	35.2	(5108)	0.92	(133)
98	5	0.55		33.8	(4896)		
	13	0.56	0.01	34.2	(4957)	0.42	(61)
	17	0.56		35.4	(5133)		
	21	0.56	0.00	36.3	(5267)	0.92	(133)
106	5	0.42		35.6	(5158)		
	13	0.45	0.03	34.1	(4950)	1.44	(208)
	17	0.47		33.3	(4832)		
	21	0.39	0.08	32.6	(4728)	0.72	(104)
107	4	0.47		34.1	(4938)		
	8	0.46	0.01	34.8	(5042)	0.72	(104)
	12	0.40		32.3	(4683)		
	20	0.41	0.01	33.7	(4892)	1.44	(208)
111	4	0.45		36.1	(5233)		
	8	0.44	0.01	36.9	(5350)	0.80	(117)
	12	0.41		35.6	(5163)		
	20	0.40	0.01	36.2	(5246)	0.57	(83)
112	3	0.45		36.8	(5333)		
	7	0.48	0.03	34.2	(4958)	2.59	(375)
	15	0.48		34.5	(4996)		
	19	0.49	0.01	35.3	(5113)	0.80	(117)
113	2	0.49		34.0	(4937)		
	15	0.46	0.03	33.1	(4803)	0.92	(133)
	20	0.47		34.4	(4994)		
	24	0.49	0.02	34.0	(4925)	0.48	(69)
120	1	0.46		32.5	(4717)		
	6	0.46	0.00	33.2	(4814)	0.67	(98)
	11	0.46		32.2	(4675)		
	21	0.46	0.00	33.2	(4808)	0.92	(133)
123	6	0.46		36.6	(5304)		
	11	0.45	0.01	36.3	(5267)	0.26	(38)
	21	0.44		35.3	(5117)		
	26	0.44	0.00	35.8	(5196)	0.55	(79)
Total	40		0.34			19.39	2811

Calculation of Critical Limit and Control Limit

	Alkalies	Strength, MPa	Strength, psi
Specification limit	0.60	30.0	4350
$\bar{r}$	0.017	0.969	141
$d = 2.49\ \bar{r}$	0.042	2.413	350
Critical limit	(0.60 – 0.042)	(30 + 2.4)	(4350 + 350)
	0.558	32.4	4700
$3.267\ \bar{r}$	0.0555	3.17	459
Control limit	0.056	3.2	459

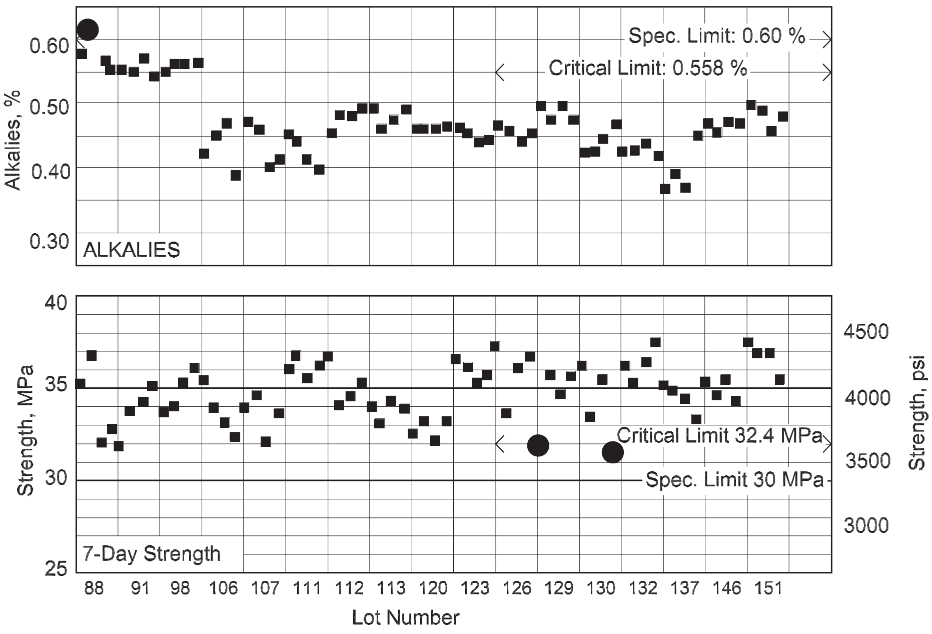

Figure 3—Quality History Chart

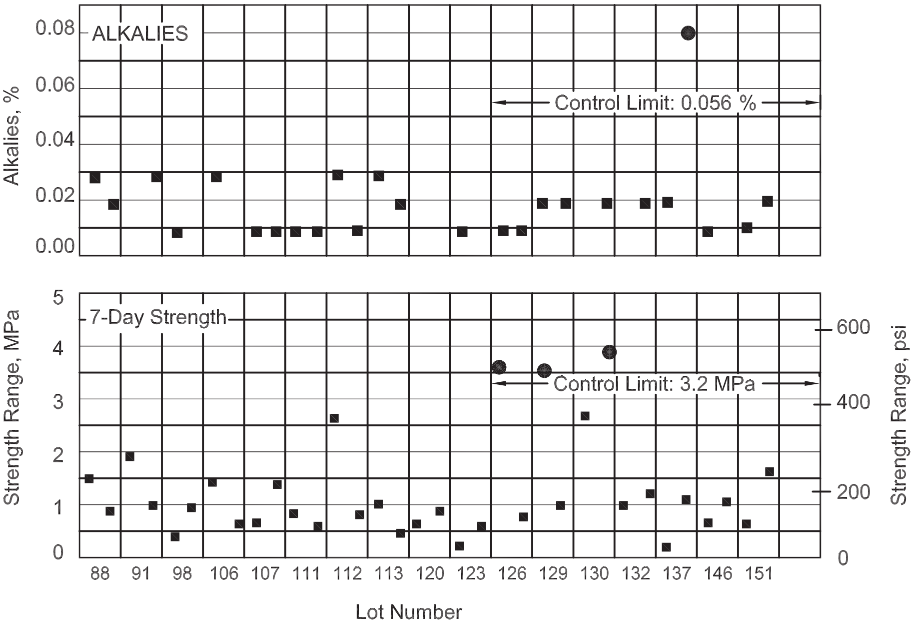

Figure 4—Control Chart for Range

9.4. *Reporting for Normal Testing*—When the testing is done at the normal testing rate, report the cement as complying with the specification if it meets the specification requirements, and report it as failing to meet the specification requirements if it does not meet each of the requirements as specified.

9.5. *Reporting for Reduced Testing*—When the testing is done at the reduced testing rate, report the cement as complying with the specification if the average of the test results is further from the specified limit than the critical limit. If the average of the results for one or more requirements is between the critical limit and the specification limit, test additional samples (total equal to the number of tests at the normal rate) for that requirement, and if on completion of the additional tests, all of the results meet the specified requirements, report the cement as complying with the specification. Report the cement as failing to meet the specification requirements if any test result does not conform to the respective requirements.

9.6. When a cement is reported as failing to meet the specification requirements, state in the report which requirement the cement failed and the applicable limit.

10. NONCOMPLIANCE AND RETEST

10.1. If any test result fails to meet the specification requirement, the lot of cement shall not be reported as not complying with the specification unless noncompliance is confirmed by retest as described in Section 10.2.

10.2. A retest is considered to be an additional test of a certain property that is made when the initial test of that property produces a result not complying with the specification requirements. A retest may consist of either a single determination or a set of replicate determinations.

10.3. Retests shall be conducted in accordance with the provisions, if given, of the applicable specification. If no provisions are given, the following procedure shall be used:

10.3.1. Make the retest on a portion of the same sample as was used for the initial test. Use referee methods whenever they are provided for determination of the property requiring retest and in such case use only the results obtained by referee methods. The retest shall consist of the same number of determinations required for the initial test, or, if a within-laboratory precision statement is given which is based on a specified number of replicates (that is, duplicate or triplicate determinations), the number of replicates used as the basis of such precision statement. If two or more determinations are required, the value reported shall be the average of all results that are within the limits of precision of the method at the 95 percent confidence level, as stated in the applicable specification or as generally recognized.

11. KEYWORDS

11.1. Hydraulic cement; sampling; testing.

Standard Method of Test for

Normal Consistency of Hydraulic Cement

AASHTO Designation: T 129-06
ASTM Designation: C 187-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Normal Consistency of Hydraulic Cement

AASHTO Designation: T 129-06
ASTM Designation: C 187-04

1. SCOPE

1.1. This method covers determination of the normal consistency of hydraulic cement.

1.2. The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. See Section 1.4 for a specific warning statement.

1.4. **Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure. The use of gloves, protective clothing, and eye protection is recommended. Wash contact area with copious amounts of water after contact. Wash eyes for a minimum of 15 min. Avoid exposure of the body to clothing saturated with the liquid phase of the unhardened material. Remove contaminated clothing immediately after exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- D 1193, Standard Guide for Use of Joint Sealants
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods

3. SIGNIFICANCE AND USE

3.1. This method is intended to be used to determine the amount of water required to prepare hydraulic cement pastes for testing.

4. APPARATUS

4.1. *Reference Masses and Devices for Determining Mass* conforming to the requirements of ASTM C 1005. The devices for determining mass shall be evaluated for precision and bias at a total load of 1000 g.

4.2. *Glass Graduates*—200- or 250-mL capacity and conforming to the requirements of M 210.

4.3. *Vicat Apparatus*—shall consist of a frame (A) bearing a movable rod (B), weighing 300 g, with one end (C), the plunger end, being 10 mm in diameter for a distance of at least 50 mm, and the other end having a removable needle (D), 1 mm in diameter and 50 mm in length. The rod (B) is reversible, and can be held in any desired position by a set screw (E), and has an adjustable indicator (F) that moves over a scale (graduated in millimeters) attached to the frame (A). The paste is held in a rigid conical ring (G), resting on a plane non-absorptive square base plate (H) about 100 mm on each side. The rod (B) shall be made of stainless steel having a hardness of not less than 35 HRC (see Note 1) and shall be straight with the plunger end, which is perpendicular to the rod axis. The ring shall be made of a noncorroding, nonabsorbent material; shall have an inside diameter of 70 mm at the base and 60 mm at the top; and shall have a height of 40 mm. (See Figure 1.) In addition to the above, the Vicat apparatus shall conform to the requirements as indicated in Table 1.

4.4. *Flat Trowel*, having a sharpened straightedged steel blade 100 to 150 mm in length.

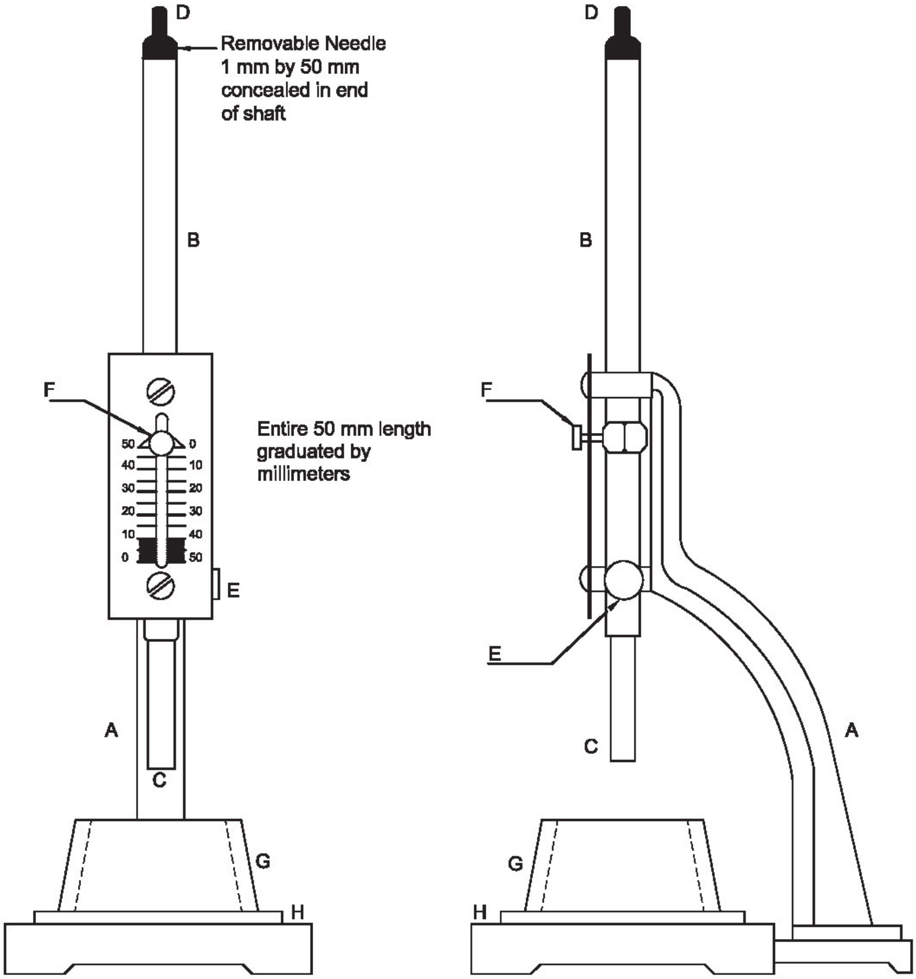

Figure 1—Vicat Apparatus

Table 1—Vicat Apparatus

Vicat Apparatus	
Weight of movable rod	300 ± 0.5 g (0.661 lb ± 8 grains)
Diameter of plunger end of rod	10 ± 0.05 mm (0.394 ± 0.002 in.)
Diameter of needle	1 ± 0.05 mm (0.039 ± 0.002 in.)
Inside diameter of ring at bottom	70 ± 3 mm (2.75 ± 0.12 in.)
Inside diameter of ring at top	60 ± 3 mm (2.36 ± 0.12 in.)
Height of ring	40 ± 1 mm (1.57 ± 0.04 in.)
Graduated scale	The graduated scale, when compared with a standard scale accurate to within 0.1 mm at all points, shall not show a deviation at any point greater than 0.25 mm.

Note 1—The requirement that the rod be made of stainless steel shall apply only to new Vicat apparatus or replacement rods and not to equipment in use that meets the other requirements of T 129.

5. TEMPERATURE AND HUMIDITY

5.1. The temperature of the air in the vicinity of the mixing slab, the dry cement, molds, and base plates shall be maintained between 20 and 27.5ºC (68 and 81.5ºF). The temperature of the mixing water shall not vary from 23ºC (73.4ºF) by more than ±1.7ºC (3ºF).

5.2. The relative humidity of the laboratory shall be not less than 50 percent.

6. PROCEDURE

6.1. *Preparation of Cement Paste*—Mix 650 g of cement with a measured quantity of clean water following the procedure prescribed in Section 6 of T 162. The water shall conform to the numerical limits of ASTM D 1193 for Type III or Type II grade of reagent water.

6.2. *Molding Test Specimen*—Quickly form the cement paste, prepared as described in Section 6.1, into the approximate shape of a ball with gloved hands. Then toss six times through a free path of about 150 mm (6 in.) from one hand to another so as to produce a nearly spherical mass that may be easily inserted into the Vicat ring with a minimum amount of additional manipulation. Press the ball, resting in the palm of one hand, into the larger end of the conical ring (G), held in the other hand, completely filling the ring with paste. (See Figure 1.) Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on the base plate (H), and slice off the excess paste at the smaller end at the top of the ring by a single oblique stroke of a sharp-edged trowel held at a slight angle with the top of the ring; smooth the top, if necessary, with a few light touches of the pointed end of the trowel. During these operations of cutting and smoothing, take care not to compress the paste.

6.3. *Consistency Determination*—Center the paste confined in the ring, resting on the plate, under the rod (B) (see Figure 1), the plunger end C of which shall be brought in contact with the surface of the paste, and tighten the setscrew (E). Then set the movable indicator (F) to the upper zero mark of the scale, or take an initial reading and release the rod immediately. This must not exceed 30 seconds after completion of mixing. The apparatus shall be free of all vibrations during the test. The paste shall be of normal consistency when the rod settles to a point 10 ± 1 mm below the original surface in 30 seconds after being released. Make trial pastes with varying percentages of water until the normal consistency is obtained. Make each trial with fresh cement.

7. CALCULATION

7.1. Calculate the amount of water required for normal consistency to the nearest 0.1 percent and report it to the nearest 0.5 percent of the weight of the dry cement.

8. PRECISION AND BIAS

8.1. The single operator-instrument precision has been found to be 0.25(1s), and the multilaboratory precision has been found to be 0.35(1s) as defined in ASTM E 177; therefore, the results of two properly conducted tests by the same operator in a laboratory should agree within 0.7 percentage point, and test results between two laboratories should agree within 1.0 percentage point 95 percent of the time.

9. KEYWORDS

9.1. Consistency; normal consistency; Vicat needles.

Standard Method of Test for

Time of Setting of Hydraulic Cement by Vicat Needle

AASHTO Designation: T 131-10
ASTM Designation: C 191-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Time of Setting of Hydraulic Cement by Vicat Needle

AASHTO Designation: T 131-10
ASTM Designation: C 191-08

1. SCOPE

1.1. These test methods determine the time of setting of hydraulic cement by means of the Vicat needle. Two test methods are given; Method A is the Reference Test Method using the manually operated standard Vicat apparatus, while Method B permits the use of an automatic Vicat machine that has, in accordance with the qualification requirements of this method, demonstrated acceptable performance.

1.2. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. See Section 1.4 for a specific warning statement.

1.4. **Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure. The use of gloves, protective clothing, and eye protection is recommended. Wash contact area with copious amounts of water after contact. Wash eyes for a minimum of 15 minutes. Avoid exposure of the body to clothing saturated with the liquid phase of the unhardened material. Remove contaminated clothing immediately after exposure.

Note 1—For the method for determining the time of setting by Gillmore needles, see T 154.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- M 240, Blended Hydraulic Cements
- T 129, Normal Consistency of Hydraulic Cement
- T 154, Time of Setting of Hydraulic Cement Paste by Gillmore Needles
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 151, Standard Test Method for Autoclave Expansion of Hydraulic Cement
- C 183, Standard Practice for Sampling and the Amount of Testing of Hydraulic Cement
- C 219, Standard Terminology Relating to Hydraulic Cement
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- C 1157, Standard Performance Specification for Hydraulic Cement
- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1. *Definitions*—The terms used in this test method are defined in accordance with ASTM C 219.

4. SUMMARY OF TEST METHOD

4.1. A paste that is proportioned and mixed to normal consistency, as described in the test method T 129, is molded and placed in a moist cabinet and allowed to start setting. Periodic penetration tests are performed on this paste by allowing a 1-mm Vicat needle to settle into this paste. The Vicat initial time of setting is calculated as the time elapsed between the initial contact of cement and water and the time when the penetration is at 25 mm. The Vicat final time of setting is calculated as the time when the needle does not sink visibly into the paste.

5. SIGNIFICANCE AND USE

5.1. This test method provides a means of determining compliance with a specification limit for Vicat time of setting. Refer to the appropriate specification for the cement to determine if this test method is used for specification compliance.

5.2. The measured time of setting is affected by the percentage and temperature of the water used, the amount of kneading the paste received, and by the temperature and humidity of the mixing room air and the moist cabinet or moist room air.

5.3. The measured time of setting of hydraulic cement is test-method specific. Time of setting as measured by this method will not necessarily be similar to other methods used for determining the time of setting of hydraulic cements.

6. APPARATUS

6.1. *Vicat Apparatus*—See Annex A1.1 and Figure A1.1. The Vicat apparatus for this test method shall have a movable rod, B, of mass 300 ± 0.5 g.

6.1.1. The end of the rod used for measuring penetration shall have a removable needle, D, with a diameter of 1.00 ± 0.05 mm and length no less than 50 mm.

6.1.2. The needle end that contacts the specimen shall be flat, plane, and at right angles to the axis of the rod.

6.2. *Reference Masses and Devices for Determining Mass,* conforming to the requirements of ASTM C 1005. The devices for determining mass shall be evaluated for precision and accuracy at a total load of 1 kg.

6.3. *Glass Graduates*, 200- or 250-mL capacity, and conforming to the requirements of ASTM C 1005.

6.4. Plane non-adsorptive plate, 100 ± 5 mm square of similar planeness, corrosivity, and absorptivity to that of glass (see Annex A1.1, Figure A1.1, H).

6.5. *Flat trowel*, having a sharpened straightedged steel blade 100 to 150 mm in length. The edges, when placed on a plane surface, shall not depart from straightness by more than 1 mm.

6.6. Conical ring, made of a rigid non-corroding, nonabsorbent material that shall have a height of 40 ± 1 mm, an inside diameter at the bottom of 70 ± 3 mm, and an inside diameter at the top of 60 ± 3 mm (see Annex A1.1, Figure A1.1, G).

6.7. *Mixer, bowl, and paddle*, conforming to T 162.

6.8. *Automatic Vicat Needle Apparatus for Method B*—The apparatus shall be equipped essentially with a standard Vicat needle. The needle shall have a 1.0 ± 0.05 mm diameter and have a length of at least 50 mm. The total mass supported by the needle tip at the time of measurement shall be 300 ± 0.5 g. The instrument shall be capable of automatically completing and recording penetration measurements of a test specimen at predetermined time intervals not exceeding 10 minutes and make each penetration test at least 5 mm away from any previous penetration and at least 10 mm away from the inner side of the mold.

6.9. *Specimen Mold for Method B*—The cement paste is held in a conical ring with a height of 40 ± 1 mm and a removable base plate. The test surface shall have a minimum diameter of 60 ± 3 mm as described in Section 6.6.

6.10. Inspect and document Section 6 apparatus for conformance to the requirements of this test method at least every $2^1/_2$ years.

7. REAGENTS AND MATERIALS

7.1. *Mixing Water*—Potable water is satisfactory for routine tests. Use water conforming to the requirements of ASTM D 1193 for Type III or Type IV grade reagent water for all referee and cooperative tests.

8. SAMPLING

8.1. When the test is required for acceptance testing, sample cement in accordance with ASTM C 183.

9. CONDITIONING

9.1. Maintain the temperature of the air in the vicinity of the mixing slab, the dry cement, molds, and base plates at 23.0 ± 3.0°C.

9.2. Maintain the temperature of the mixing water at 23.0 ± 3.0°C.

9.3. The relative humidity of the mixing room shall not be less than 50 percent.

9.4. The moist closet or moist room shall be in accordance with M 201.

10. PREPARATION OF CEMENT PASTE

10.1. The cement paste used for the determination of the time of setting is obtained from one of the following methods:

10.1.1. Prepare a new batch of paste by mixing 650 g of cement with the percentage of mixing water required for normal consistency (T 129), following the procedure described in T 162.

10.1.2. For Method A, at the option of the tester, use the test specimen used for determining normal consistency (Note 2).

10.1.3. At the option of the tester, use the paste remaining from the batch used for the autoclave specimen (ASTM C 151) or from the normal consistency determination (T 129).

Note 2—The specimen used for the determination of the normal consistency will have an irregular surface, making it unsuitable for Method B.

11. METHOD A—MANUAL VICAT NEEDLE

11.1. *Apparatus*—Refer to Sections 6.1, 6.4, 6.6, and 11.1.1, and Annex A1 for a description of the Vicat apparatus.

12. METHOD A—PROCEDURE

12.1. *Molding Test Specimen*—With gloved hands, quickly form the cement paste, prepared as described in Section 10, into a ball and toss six times from one hand to the other, maintaining the hands about 150 mm (6 in.) apart. Press the ball, resting in the palm of the hand, into the larger end of the conical ring (G), held in the other hand, completely filling the ring with paste. (See Figure A1.1.) Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end onto a non-absorptive plate (H), and slice off the excess paste at the smaller end at the top of the ring by a single oblique stroke of the trowel held at a slight angle with the top of the ring. Smooth the top of the specimen, if necessary, with one or two light touches of the pointed end of the trowel. During the operation of cutting and smoothing, take care not to compress the paste. Immediately after molding, place the test specimen in the moist closet or moist room and allow it to remain there except when penetration measurements are being made. The specimen shall remain in the conical mold, supported by the non-absorptive plate throughout the test period.

12.2. *Time of Setting Determination*—Allow the time of setting specimen to remain in the moist cabinet for 30 minutes after molding without being disturbed. Determine the penetration of the 1-mm needle at this time and every 15 minutes thereafter (every 10 minutes for Type III cements) until a penetration of 25 mm or less is obtained. Perform the penetration test by lowering the needle (D), of the rod (B) until it rests on the surface of the cement paste. Tighten the set screw, E, and set the indicator (F), at the upper end of the scale, or take an initial reading. Release the rod quickly by releasing the set screw (E), and allow the needle to settle for 30 seconds; then take the reading to determine the penetration. At the option of the tester, if the paste is obviously quite soft on the early readings, retard the fall of the rod to avoid bending the 1-mm needle, but when actual penetration measurements to determine the time of setting are made, release the rod only by the set screw. Make each penetration test at least 5 mm away from any previous penetration and at least 10 mm away from the inner side of the mold. Record the results of all penetration tests and, by interpolation, determine the time when a penetration of 25 mm is obtained. The elapsed time between the initial contact of cement and water and the penetration of 25 mm is the Vicat time of setting or Vicat initial time of setting.

12.3. Determine the Vicat final time of setting end point to be the first penetration measure that does not mark the specimen surface with a complete circular impression. Verify final set by performing two additional penetration measurements on different areas of the specimen surface. Obtain verification measurements within 90 s of the first "final set" measurement. The elapsed time between the initial contact of cement and water and the end point determination above is the Vicat final time of setting.

12.4. *Precautions*—Keep all the apparatus free from vibration during the penetration test. Keep the 1-mm needle straight and clean. The needle must be kept clean to prevent cement from adhering to the sides of the needle and decreasing penetration, and to prevent cement from adhering to the point and increasing penetration.

13. METHOD A—PRECISION AND BIAS

13.1. *Precision*:

13.1.1. The single-operator (within-laboratory) standard deviation has been found to be 12 minutes for the initial time of setting, throughout the range of 49 to 202 minutes, and 20 minutes for the final time of settings throughout the range of 185 to 312 minutes. Therefore, results of two properly conducted tests by the same operator on Vicat initial time of setting of similar paste should not differ from each other by more than 34 minutes and on Vicat final time of setting of similar pastes should not differ from each other by more than 56 minutes.

13.1.2. The multilaboratory (between-laboratory) standard deviation has been found to be 16 minutes for the initial time of setting throughout the range of 49 to 207 minutes, and 43 minutes for the final time of setting throughout the range of 185 to 312 minutes. Therefore, results of two properly conducted tests from two different laboratories on Vicat initial time of setting of similar pastes should not differ from each other by more than 45 minutes, and on Vicat final time of setting of similar pastes should not differ from each other by more than 122 minutes.

13.2. *Bias*—Since there are no accepted reference materials suitable for determining the bias for the procedure in this test method, no statement on bias is presented.

14. METHOD B—AUTOMATIC VICAT APPARATUS

14.1.1. *Automatic Vicat Needle Apparatus*—Refer to Sections 6.8 and 6.9 for a description of the Automatic Vicat needle apparatus.

15. METHOD B—PROCEDURE

15.1. *Molding Test Specimen*—With gloved hands, quickly form the cement paste, prepared as described in Section 10, into a ball and toss six times from one hand to the other, maintaining the hands about 150 mm (6 in.) apart. Press the ball, resting in the palm of the hand, into the larger end of the conical ring, held in the other hand, completely filling the ring with paste. Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on to the base plate. Use a trowel to remove the excess paste at the top of the mold. Holding the trowel at about a 30 degrees incline with the leading edge raised and starting near the center of the mold, level the paste by drawing the trowel across the top of the mold using a sawing motion; repeat the procedure for the other half of the surface. Then smooth the surface level to the top of the mold making steady and complete strokes across the entire surface with the trailing edge of the trowel. Repeat the cutting and smoothing steps but at 90 degrees from the previous cut. Repeat the steps as required to produce a surface level with the top of the mold. Usually the paste is level within two cycles, but occasionally three will be required. Avoid excessive strokes and compaction. Since the automatic Vicat device references to the top edge of the mold, it is imperative that the top surface of the paste be uniform and level with the top of the mold.

15.2. *Time of Setting Determination*—Follow the manufacturer's instructions and complete the required instrument calibration and zero procedures. Set the instrument to measure no less frequently than every 10 minutes (Note 3). Position the molded specimen in the automatic Vicat apparatus and initiate measurements (Note 4).

Note 3—Automatic devices are usually capable of measurement more frequently than once every 10 minutes and more frequent measurement minimizes interpolation.

Note 4—The initial time of setting according to Method A is determined as the elapsed time required to achieve a penetration of 25 mm and the final time of setting as the total time elapsed until the needle does not sink visibly into the paste. The end points established by a qualified automatic Vicat test method may deviate significantly from end points specified in Method A, and require standardization to correct bias.

15.3. Determine the range of applicability of the method from the range of the average time of setting of the cements used for qualification and standardization, and limit that range to 30 minutes greater than the maximum, and 30 minutes less than the minimum.

15.4. *Performance Requirement (Qualification) for Automatic Vicat Instrument*:

15.4.1. When time of setting results from automatic Vicat apparatus are to be used for acceptance or rejection of cement, the method used shall comply with the qualification requirements covered in Annex A2.

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16. METHOD B—PERFORMANCE REQUIREMENT (QUALIFICATION) FOR AUTOMATIC VICAT INSTRUMENT

16.1. *Scope*—When time of setting results from the automatic Vicat apparatus are to be used for acceptance or rejection of cement, the method used shall comply with the qualification requirements of this section. A method is considered to consist of the specific instrument and the molding procedure meeting the requirements of this standard, and used in a consistent manner by a given laboratory.

16.2. *Hydraulic Cement Samples Required*—Select three cements that comply with requirements of M 85, M 240, or ASTM C 1157, and that when tested in accordance with Method A, shall include the following:

16.2.1. One cement that has an initial time of setting of less than 110 minutes,

16.2.2. One cement with an initial time of setting of greater than 150 minutes,

16.2.3. One cement with a final time of setting of less than 180 minutes, and

16.2.4. One cement with a final time of setting of greater than 210 minutes (Note 5).

Note 5—Laboratories are advised to reserve sufficient cement for future qualification and standardization.

16.3. *Tests*—Using the method to be qualified and including the standardization formula described in the section on standardization, make single determinations of the times of initial and final setting on each of the three cements. On the same day, conduct companion time of setting determinations according to Method A. Make single determinations of the normal consistency on each cement, and use that amount of water for all replicate batches. Complete three rounds of tests on different days, repeating all the steps of the methods. Conduct the qualification tests on specimens prepared separately from the standardization testing.

16.4. *Calculations*—Calculate the three-round averages for initial and final time of setting for each cement and method. A method complies with the initial time of setting qualification requirements if the difference between the initial time of setting average values for Method A and the corresponding average values of Method B is not greater than 25 minutes for any sample, and the range for any three replicate tests by Method B does not exceed 30 minutes. Likewise, a method complies with the final time of setting qualification requirements if the difference between the final time of setting average values for Method B is not greater than 45 minutes for any sample, and the range for any three replicate tests by Method B does not exceed 30 minutes. Example qualification data are given in Annex A1.

16.5. *Standardization*—When standardization is required in order to achieve agreement between Method A and Method B, it can be applied to either the initial time of setting, final time of setting, or both. A standardization formula shall be based on a comparison of test results obtained using Method A and the chosen method using the automatic instrument (Method B). Results of tests from at least five different hydraulic cements shall be required for standardization. The cements shall have a minimum range of 60 minutes initial time of setting, and a minimum range of 90 minutes final time of setting when tested in accordance with Method A. If desired, the three cements used for instrument qualification may be used, but make new determinations. Use the same method as used for instrument qualification, including all the same steps. Valid standardization formulas shall be mathematically derived and applied to all samples (Note 6).

Note 6—Generally, the automatic instruments are computer operated and easily adapted to standardization calculations.

17. METHOD B—PRECISION AND BIAS

17.1. *Precision*—No precision data are available at this time. A laboratory is advised to develop its own precision data for the method and instrument used. Based on qualification requirements, the precision of the method should not be greater than that of Method A.

17.2. *Bias*—Since there are no accepted reference materials suitable for determining the bias for the procedure in this test method, no statement on bias is presented.

18. CALCULATION

18.1. Calculate the Vicat time of setting to the nearest one minute as follows:

$$\left(\left(\frac{(H-E)}{(C-D)}\right)\times(C-25)\right)+E \qquad (1)$$

where:

H = time in minutes of first penetration less than 25 mm,
E = time in minutes of last penetration greater than 25 mm,
C = penetration reading at time E, and
D = penetration reading time at time H.

18.2. Calculate the Vicat final time of setting by determining the elapsed time between the time of the initial contact between cement and water and the time when the needle does not sink visibly into the paste, rounded to the nearest 5 minutes.

19. REPORT

19.1. Report the time of setting and the method used as follows:

Vicat time of setting (A or B) ______ minutes
Vicat final time of setting (A or B) ______ minutes

20. KEYWORDS

20.1. Automatic Vicat; hydraulic-cement paste; time of setting; Vicat; Vicat needle.

ANNEX

(Mandatory Information)

A1. VICAT APPARATUS

A1.1. The Vicat apparatus shall consist of a frame (A), bearing a movable rod (B), having a mass as specified by the method referencing this apparatus, with one end (C), the plunger end, with a diameter as specified by the method referencing this apparatus, and the other end having a mass or removable steel needle (D), as specified by the method referencing this apparatus. The rod (B) is reversible, and can be held in any desired position by a set screw (E), and has an adjustable indicator (F), which moves over a scale graduated in millimeters and attached to the frame (A). The gradations on the graduated scale, when compared to a scale accurate to within 0.1 mm at all points, shall not show a variance from the reference scale greater than 0.25 mm. (See Figure A1.1.)

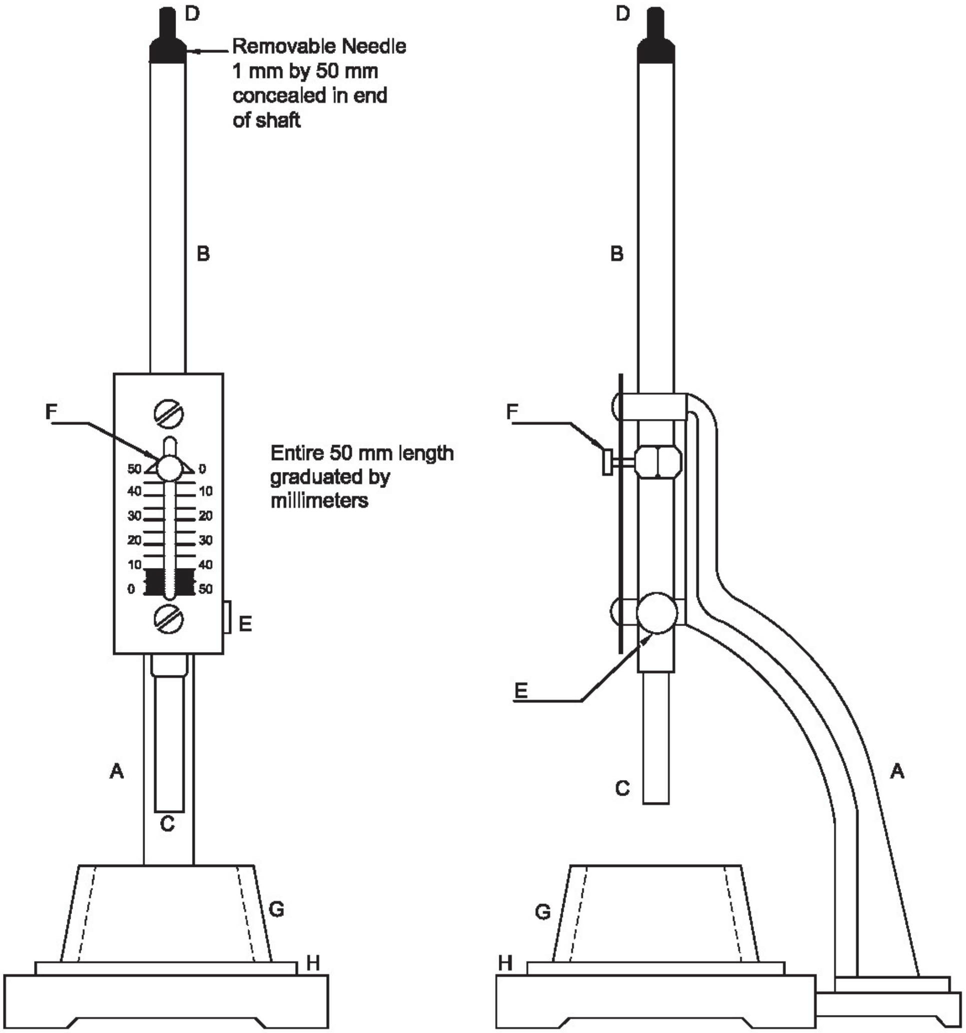


Figure A1.1—Vicat Apparatus

A2. PERFORMANCE REQUIREMENT (QUALIFICATION) FOR AUTOMATIC VICAT INSTRUMENT

A2.1. When time of setting results from the automatic Vicat apparatus are to be used for acceptance or rejection of cement, the method used shall comply with the qualification requirements covered in this section. A method is considered to consist of the specific instrument and the molding procedure meeting the requirements of this test method, and used in a consistent manner by a given laboratory.

A2.2. *Hydraulic Cement Samples Required*—Select three cements that comply with requirements of M 85 or M 240, and that when tested in accordance with Method A, shall include the following:

A2.2.1. One cement that has an initial time of setting of less than 110 min,

A2.2.2. One cement with an initial time of setting of greater than 150 min,

A2.2.3. One cement with a final time of setting of less than 180 min, and

A2.2.4. One cement with a final time of setting of greater than 210 min (see Note A1).

Note A1—Laboratories are advised to reserve sufficient cement for future qualification and standardization.

A2.3. *Tests*—Using the method to be qualified and including the standardization formula described in the section of standardization, make single determinations of the times of initial and final setting on each of the three cements. On the same day, conduct companion time of setting determinations according to Method A. Make single determinations of the normal consistency on each cement, and use that amount of water for replicate batches. Complete three rounds of tests on different days, repeating all the steps of the methods. Conduct the qualification tests on specimens prepared separately from the standardization testing.

A2.4. *Calculations*—Calculate the three-round averages for initial and final time of setting for each cement and method. A method complies with the initial time of setting qualifications requirements if the difference between the initial time of setting average values for Method A and the corresponding average values of Method B is not greater then 25 min for any sample, and the range for any three replicate tests by Method B does not exceed 30 min. Likewise, a method complies with the final time of setting averages values for Method A and corresponding average values for Method B is not greater than 45 min for any sample, and the range for any three replicate tests by Method B does not exceed 30 min. Example qualification data are given in Appendix X1.

A2.5. *Standardization*—When standardization is required in order to achieve agreement between Method A and Method B, it can be applied to either the initial time of setting, final time of setting, or both. A standardization formula shall be based on a comparison of test results obtained using Method A and chosen method using the automatic instrument (Method B). Results of tests from at least five different hydraulic cements shall be required for standardization. The cements shall have a minimum range of 60 min initial time of setting, and a minimum range of 90 min final time of setting when tested in accordance with Method A. If desired, the three cements used for instrument qualification may be used, but make new determinations. Use the same method as used for instrument qualification, including all the same steps. Valid standardization formulas shall be mathematically derived and applied to all samples (see Note A2).

Note A2—Generally, the automatic instruments are computer operated and easily adapted to standardization calculations.

A3. REQUALIFICATION OF A METHOD

A3.1. Requalify the method at least once per year and when any of the following conditions occur:

A3.1.1. The instrument has been significantly modified.

A3.1.2. The instrument has been substantially repaired.

A3.1.3. Substantial evidence indicates that the method is not providing data meeting the performance requirements.

A3.1.4. The average of a Cement and Concrete Reference Laboratory (CCRL) sample differs from the value obtained by the method by more than 45 min for either the initial of final time of setting.

APPENDIX

(Nonmandatory Information)

X1. SAMPLE QUALIFICATION RESULTS

Table X1.1—Time of Initial Setting, Minutes

Cement	Round No.	Initial T 131 Method A	Initial Auto Method B	Diff. Avg. (Spec. 25 Max.)
A	1	95	105	—
A	2	90	105	—
A	3	95	90	—
Range (Spec. 30 Max)		5	15	—
Average		93.3	100.0	6.7
B	1	100	120	—
B	2	105	95	—
B	3	85	95	—
Range (Spec. 30 Max)		20	25	—
Average		96.7	103.3	6.7
C	1	155	170	—
C	2	155	160	—
C	3	145	155	—
Range (Spec. 30 Max)		10	15	—
Average		151.7	161.7	10.0

Table X1.2—Time of Final Setting, Minutes

Cement	Round No.	Final T 131 Method A	Final Auto Method B	Diff. Avg. (Spec. 45 Max.)
A	1	150	150	—
A	2	145	150	—
A	3	170	125	—
Range (Spec. 30 Max)		25	25	—
Average		155.0	141.7	13.3
B	1	185	180	—
B	2	200	180	—
B	3	185	155	—
Range (Spec. 30 Max)		15	25	—
Average		190.0	171.7	18.3
C	1	235	225	—
C	2	240	220	—
C	3	240	215	—
Range (Spec. 30 Max)		5	10	—
Average		238.3	220.0	18.3

Standard Method of Test for

Tensile Strength of Hydraulic Cement Mortars

AASHTO Designation: T 132-87 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Tensile Strength of Hydraulic Cement Mortars

AASHTO Designation: T 132-87 (2009)

1. SCOPE

1.1. This method covers determination of the tensile strength of hydraulic cement mortars employing the briquet specimen. It is primarily for use by those interested in research on methods for determining tensile strength of hydraulic cement.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 92, Wire-Cloth Sieves for Testing Purposes
- T 129, Normal Consistency of Hydraulic Cement

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 778, Standard Specification for Standard Sand
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- *Manual of Cement Testing*

3. SIGNIFICANCE AND USE

3.1. Researchers in the field of hydraulic cement have recognized the need for improved tensile strength. This method allows for the determination of tensile strength of a hydraulic cement mortar by casting and testing briquet specimens. It is recommended that the tester be familiar with this method in order to obtain the best possible accuracy and precision.

3.2. Table 1 contains minimum tensile strength values, which are stated limits in M 85 for portland cement. The user of this method may be interested in comparing research results with these values when briquets composed of one part cement to three parts standard sand have been made. These values may not be appropriate for comparison when different proportions or proportions involving other than standard sand have been used.

Table 1—Tensile Strength[a]

	Cement Type				
	I	II	III	IV	V
1 day in moist air, psi (kPa)	—	—	275 (1,896)	—	—
1 day in moist air, 2 days in water, psi (kPa)	150 (1,034)	125 (862)	375 (2,586)	—	—
1 day in moist air, 6 days in water, psi (kPa)	275 (1,896)	250 (1,724)	—	175 (1,207)	250 (1,724)
1 day in moist air, 27 days in water, psi (kPa)	350 (2,413)	325 (2,241)	—	300 (2,068)	325 (2,241)

[a] Taken from M 85-70 without change.

4. APPARATUS

4.1. *Weights and Weighing Devices*—The weights and weighing devices shall conform to the requirements of ASTM C 1005. The weighing devices shall be evaluated for precision and accuracy at a total load of 1,000 g or at 2,000 g, as applicable.

4.2. *Sieves*—Square-hole, woven wire cloth, No. 20 (850-µm) and No. 30 (600-µm) sieves conforming to M 92.

4.3. *Glass Graduates*—Glass graduates of suitable capacities (preferably large enough to measure the mixing water in a single operation) shall be made to deliver the indicated volume at 68°F (20°C). The permissible variation shall be ±1.0 mL. These graduates shall be subdivided to at least 1 mL, except that the graduation lines may be omitted for the lowest 5 mL for 100- and 150-mL graduates and for the lowest 10 mL for a 200-mL graduate. The main graduation lines shall be circles and shall be numbered. The least graduations shall extend at least one-seventh of the way around the cylinder, and intermediate graduations shall extend at least one-fifth of the way around.

4.4. *Briquet Molds*—The molds for making test specimens shall be made of metal not attacked by the cement mortar, and shall have sufficient material in the sides to prevent spreading during molding. Gang molds, when used, shall be of the type shown in Figure 1. The dimensions of the briquet molds shall conform to the following requirements: width of mold, between inside faces, at waist line of briquet, 25 mm (1 in.) with permissible variations of ±0.25 mm (0.01 in.) for molds in use and ±0.13 mm (0.005 in.) for new molds; thickness of molds measured at the point of greatest thickness on either side of the mold at the waist line, 25 mm (1 in.) with permissible variations of +0.10 mm (0.004 in.) and –0.05 mm (0.002 in.) for new molds and –0.5 mm (0.02 in.) for molds in use. The briquet test specimens shall conform to the dimensional requirements shown in Figure 2.

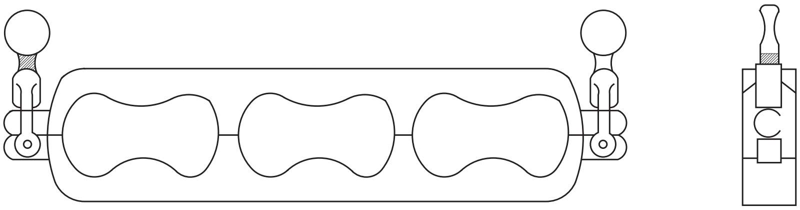
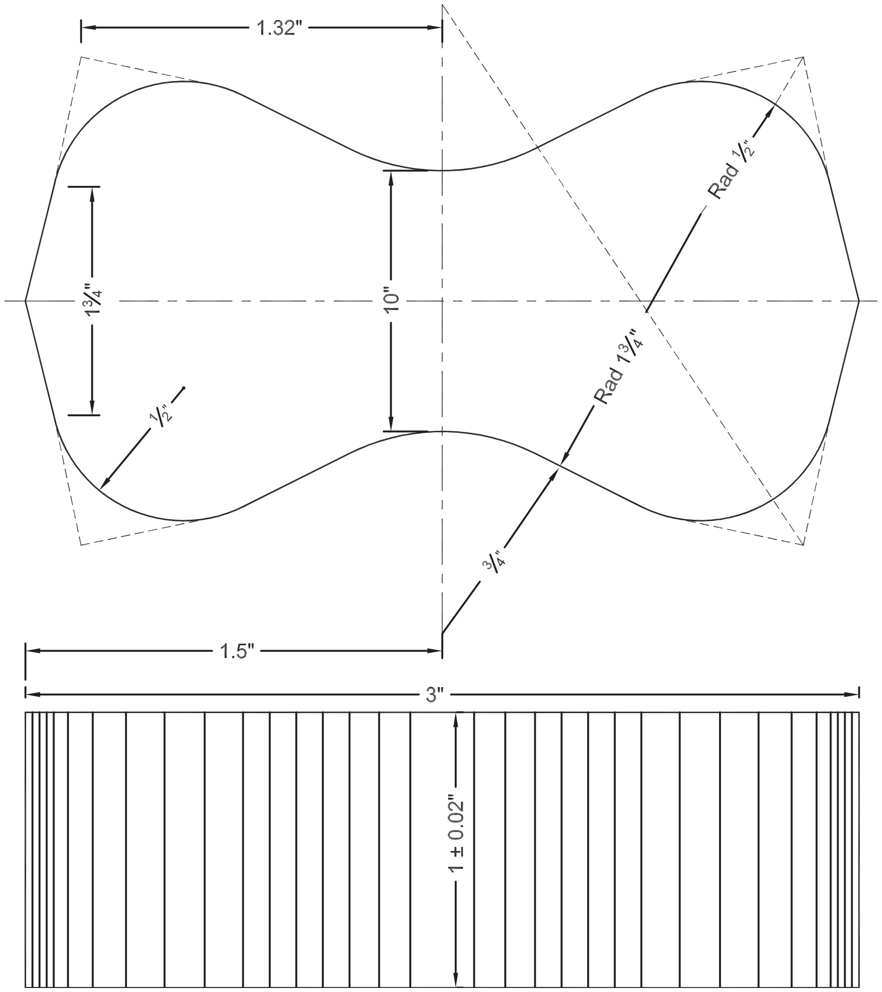


Figure 1—Briquet Gang Mold



Note: 1 in. = 25.4 mm

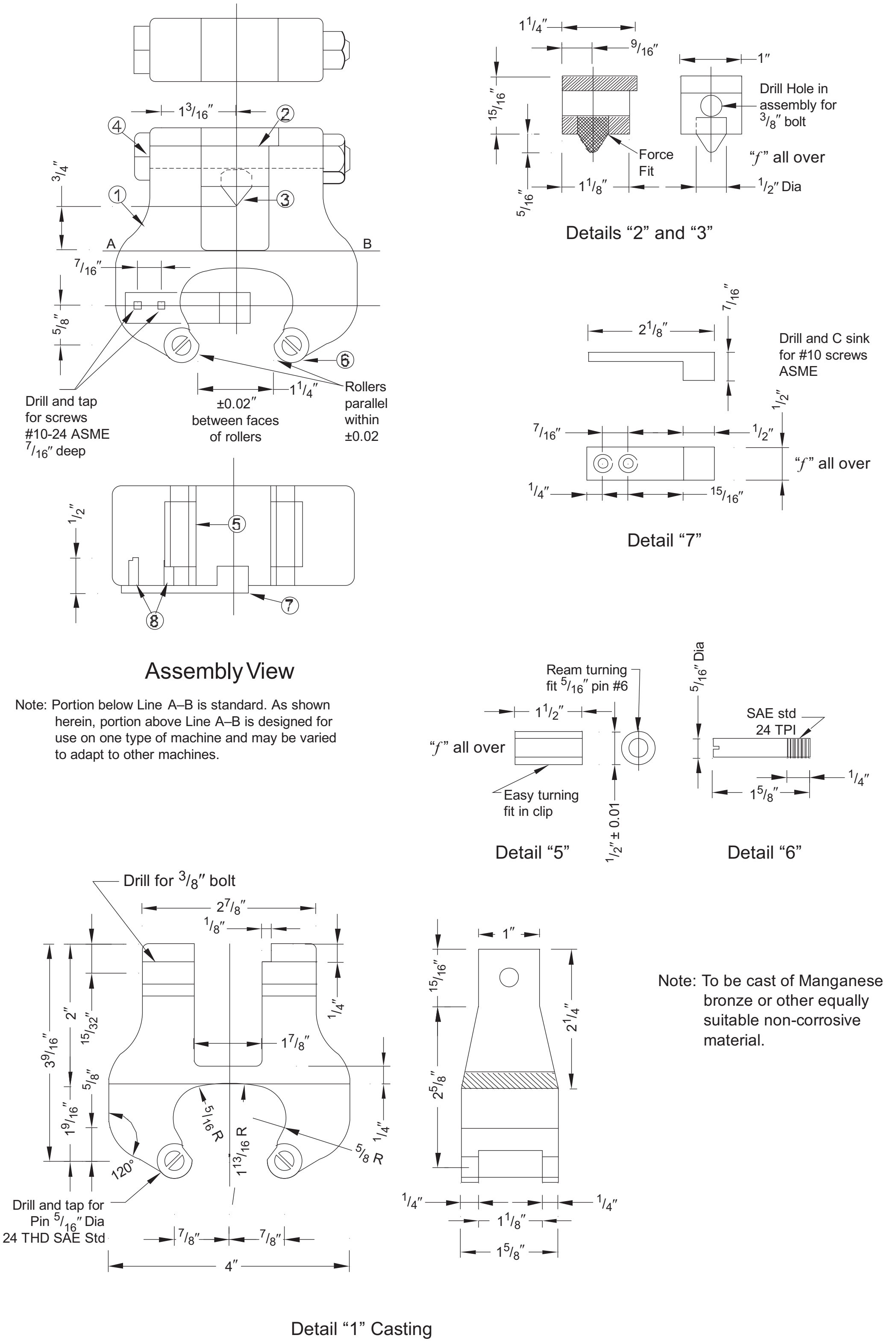
Figure 2—Briquet Specimen for Tensile Strength Test

4.5. *Trowel*—The trowel shall be of a convenient size and have a steel blade 100 to 150 mm (4 to 6 in.) long.

4.6. *Testing Machine*—The testing machine shall be capable of applying the load continuously at a rate of 600 ± 25 lbf (2.67 ± 0.11 kN) min, with provision for adjustments of the rate of loading. The requirements for accuracy of the testing machine shall be as follows: The error for loads of not less than 100 lbf (445 N) shall not exceed ± 1.0 percent for a new machine, or ± 1.5 percent for a used machine. The testing machine shall be calibrated frequently in order to determine its accuracy.

Note 1—For instructions relating to the manner and frequency of calibration of the testing machine, see Section 40 of the *Manual of Cement Testing*.

4.7. *Clips*—The clips for holding the tension test specimens shall be in accordance with Figure 3 and Table 2.



Note: Portion below Line A–B is standard. As shown herein, portion above Line A–B is designed for use on one type of machine and may be varied to adapt to other machines.

Note: To be cast of Manganese bronze or other equally suitable non-corrosive material.

Note: 1 in. = 25.4 mm

Figure 3—Clips for Briquet Testing Machine

Table 2—Clip for Briquet Testing Machine

No.	Name	Req'd	Mat'l	Remarks
1	Clip	2	*	* See Detail
2	Pivot Block	2	*	* Manganese Bronze
3	Pivot	2	Steel	Case-Hardened
4	Sq. H'd. Bolt, Hex. Nut	2	M.S.	$^3/_8$ in. St'd. – $3^1/_2$ in. long
5	Roller	4	**	** Stainless Steel
6	Pin	4	**	**Stainless Steel
7	Guide	2	**	**Stainless Steel
8	Flat Head Mach. Scr.	4	Brass	#10-24 TH'D ASME

5. STANDARD SAND

5.1. The sand used for making test specimens (see Section 8.1) shall be natural silica sand conforming to the requirements for 20–30 standard sand as described in ASTM C 778.

6. TEMPERATURE AND HUMIDITY

6.1. The temperature of the air in the vicinity of the mixing slab, the dry materials, molds, and base plates shall be maintained between 68 and 81.5°F (20 and 27.5°C). The temperature of the mixing water, moist closet or moist room, and water in the briquet storage tank shall not vary from 73.4°F (23°C) by more than ± 3°F (1.7°C).

6.2. The relative humidity of the laboratory shall be not less than 50 percent. The moist closet or moist room shall be so constructed as to provide storage facilities for test specimens at a relative humidity of not less than 95 percent.

7. NUMBER OF BRIQUETS

7.1. Three or more briquets shall be made for each period of test specified.

8. PROCEDURE

8.1. *Proportioning, Consistency, and Mixing of Mortars*:

8.1.1. The proportions of the standard mortar shall be one part cement to three parts standard sand by weight. The quantities of dry materials to be mixed at one time in the batch of mortar shall be no less than 1,000 nor more than 1,200 g for making six briquets and no less than 1,500 nor more than 1,800 g for making nine briquets. The percentage of water used in the standard mortar shall depend upon the percentage of water required to produce a neat cement paste of normal consistency from the same sample of cement and shall be as indicated in Table 3, the values being in percentage of the combined dry weights of the cement and standard sand. Determine the percentage of water required to produce a neat cement paste of normal consistency in accordance with T 129.

Table 3—Percentage of Water for Standard Mortars

Water for Neat Cement Paste of Normal Consistency, Percent	Water for Mortar of One Part Cement to Three Parts Standard Sand, Percent[a]
15	9.0
16	9.2
17	9.3
18	9.5
19	9.7
20	9.8
21	10.0
22	10.2
23	10.3
24	10.5
25	10.7
26	10.8
27	11.0
28	11.2
29	11.3
30	11.5

[a] When the proportions of cement to sand are other than one to three by weight, the amount of mixing water shall be calculated from the following formula upon which Table 3 is based:

$$y = \frac{2}{3}\left(\frac{P}{n+1}\right) + K$$

where:

y = water required for the sand mortar, percent;

P = water required for neat cement paste of normal consistency, percent;

n = number of parts of sand to one of cement by weight; and

K = a constant which for the standard sand has the value 6.5.

Note 2—Other proportions involving the use of graded sand, silica flour, or other similar materials may also be used to develop meaningful research information.

8.1.2. Weigh the dry materials, place them upon a smooth nonabsorbent surface, thoroughly mix dry, and form a crater in the center. Pour the proper percentage of clean water into the crater, and turn the material on the outer edge into the crater within 30 seconds by the aid of a trowel. After an additional interval of 30 seconds for the absorption of the water, during which interval lightly trowel the dry mortar around the outside of the cone over the remaining mortar to reduce the evaporation losses and to promote absorption, complete the operation by continuous, vigorous mixing, squeezing, and kneading with the hands for $1^1/_2$ minutes. During the operation of mixing, protect the hands with snug-fitting rubber gloves.

8.2. *Molding Test Specimens*:

8.2.1. Before being filled, thinly cover the molds with a film of mineral oil. Immediately following completion of mixing the mortar, and with the molds resting on unoiled glass or metal plates, fill the molds heaping full without compacting. Then press the mortar in firmly with the thumbs, applying the force 12 times to each briquet, at points to include the entire surface. The force shall be such that the simultaneous application of both thumbs will register a force of 15 to 20 lbf (67 to 89 N). Maintain each application of the thumbs not longer than sufficient to attain the specified force. Heap the mortar above the mold and smooth it off with a trowel. Draw the trowel over the mold in such a manner as to exert a force of not more than 4 lbf (17.8 N). Cover the mold with a plane glass or metal plate oiled with mineral oil, and turn over the mold and plates (held together with the hands) rotating the mold about its longitudinal axis. Remove the top plate and repeat the operation of heaping, thumbing, and smoothing off. Use no ramming or tamping, nor any troweling in excess of that required to smooth off the specimen.

8.3. *Storage of Test Specimens*:

8.3.1. Keep all test specimens, immediately after molding, in the molds on the base plates in the moist closet or moist room for from 20 to 24 hours with their upper surfaces exposed to the moist air but protected from dripping water. If removed from the molds before 24 hours, keep them on the shelves of the moist closet or moist room until they are 24 hours old, then immerse the specimens, except for those for the 24-hour test, in saturated lime water in storage tanks constructed of noncorroding materials. Keep the storage water clean by changing as required.

8.4. *Determination of Tensile Strength*:

8.4.1. Test the briquet specimens immediately after their removal from the moist closet for 24-hour specimens, and from storage water for all other specimens. Break all test specimens for a given test age within the permissible tolerance prescribed in the following table:

Test Age	Permissible Tolerance
24 h	± $^1/_2$ h
3 days	± 1 h
7 days	± 3 h
28 days	± 12 h

If more than one specimen at a time is removed from the moist closet for the 24-hour tests, cover these briquets with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, place these briquets in a pan of water at a temperature of 73.4 ± 3°F (23 ± 1.7°C) and of sufficient depth to completely immerse each briquet until time of testing.

8.4.2. Wipe each briquet to a surface-dry condition, and remove any loose sand grains or incrustations from the surfaces that will be in contact with the clips of the testing machine. The bearing surfaces of the clips shall be clean and free of sand, and the roller bearings shall be well oiled and maintained so as to ensure freedom of turning. Keep the stirrups supporting the clips free of accumulations, and keep the pivots in proper adjustment so that the clips may swing freely on the pivots without binding in the stirrups. Carefully center the briquets in the clips and apply the load continuously at the rate of 600 ± 25 lbf (2.67 ± 0.11 kN)/min.

9. FAULTY BRIQUETS AND RETESTS

9.1. Briquets that are manifestly faulty, or that give strengths differing by more than 15 percent from the average value of all test briquets made from the same sample and tested at the same period, shall not be considered in determining the tensile strength (Note 3). After discarding briquets or strength values, if less than two strength values are left for determining the tensile strength at any given period, a retest shall be performed.

Note 3—Reliable strength results depend upon careful observance of all of the specified requirements and procedures. Erratic results at a given test period indicate that some of the requirements and procedures have not been carefully observed; for example, those covering the testing of the briquets, as prescribed in Section 8.4.2.

10. CALCULATION

10.1. Record the total maximum load indicated by the testing machine and calculate the tensile strength in pounds-force per square inch or kilopascals. If the cross-sectional area of a briquet varies more than 2.0 percent from the nominal, use the actual area for the calculation of the tensile strength. The tensile strength of all acceptable test briquets (see Section 9) made from the same sample and tested at the same period shall be averaged and reported to the nearest 5 psi (34.5 kPa).

11. PRECISION AND BIAS

11.1. The following precision statements are applicable when a test result is the average of tensile strength tests of three briquets molded from a single batch of mortar tested at the same age. It is applicable to mortar made with Type I, IA, II, or III cement tested at 3 or 7 days (1 and 3 days for Type III cement) (Note 4).

Note 4—The appropriate limits are likely somewhat smaller at 1 day and larger at ages greater than 7 days.

11.1.1. *Multilaboratory Precision*—The multilaboratory standard deviation has been found to be 32 psi. Therefore, the results of properly conducted tests of a single batch by two different laboratories should not differ from each other by more than 90 psi (Note 5).

Note 5—These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

11.1.2. *Single-Laboratory Precision*—The single-laboratory standard deviation has been found to be 21 psi. Therefore, the results of two properly conducted tests of single batches of mortar made with the same materials either on the same day or within the same week should not differ from each other by more than 59 psi (Note 4).

Standard Method of Test for

Density of Hydraulic Cement

AASHTO Designation: T 133-98 (2006)
ASTM Designation: C 188-95e

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density of Hydraulic Cement

AASHTO Designation: T 133-98 (2006)
ASTM Designation: C 188-95e

1. SCOPE

1.1. This method covers determination of the density of hydraulic cement. Its particular usefulness is in connection with the design and control of concrete mixtures.

1.2. The density of hydraulic cement is defined as the mass of a unit volume of the solids.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

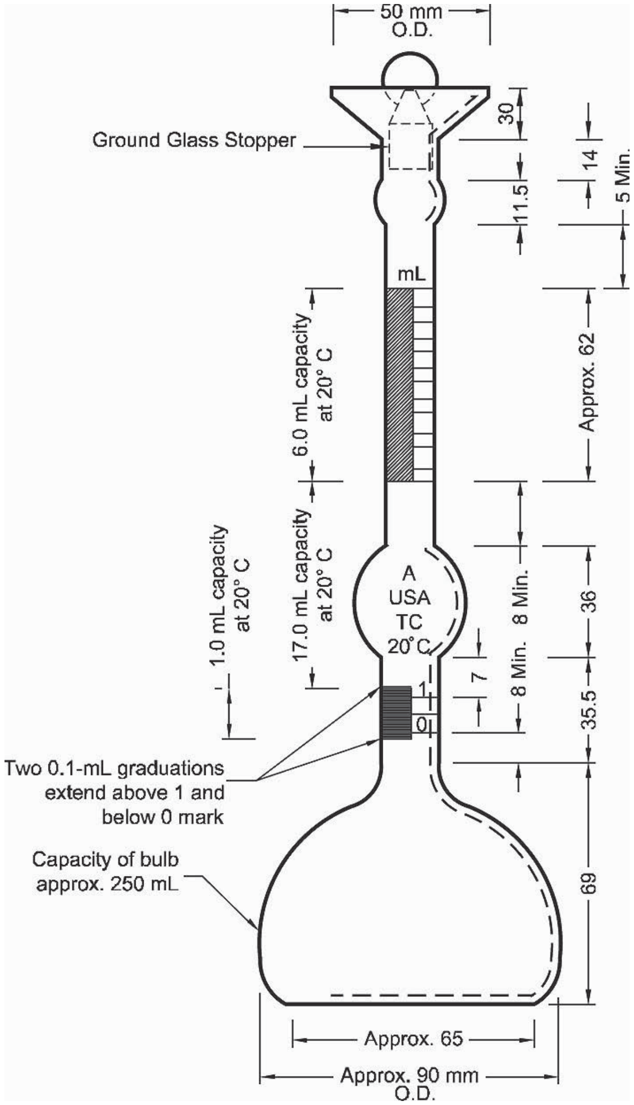
- T 105, Chemical Analysis of Hydraulic Cement

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *Le Chatelier Flask*—the standard flask—is circular in cross section with shape and dimensions conforming essentially to Figure 1 (Note 1). The requirements in regard to tolerance, inscription and length, spacing, and uniformity of graduation will be rigidly observed. There shall be a space of at least 10 mm between the highest graduation mark and the lowest point of grinding for the glass stopper.



Notes: 1. All dimensions shown in millimeters unless otherwise noted.

2. Variations of a few millimeters in such dimensions as total height of flask, diameter of base, etc., are to be expected and will not be considered sufficient cause for rejection. The dimensions of the flask shown in Figure 1 apply only to new flasks and not to flasks in use which meet the other requirements of this test method.

Figure 1—Le Chatelier Flask for Density Test

3.1.1. The material of construction shall be best quality glass, transparent and free of striae. The glass shall be chemically resistant and shall have small thermal hysteresis. The flasks shall be thoroughly annealed before being graduated. They shall be of sufficient thickness to ensure reasonable resistance to breakage.

3.1.2. The neck shall be graduated from 0 to 1 mL and from 18 to 24 mL in 0.1 mL graduations. The error of any indicated capacity shall not be greater than 0.05 mL.

3.1.3. Each flask shall bear a permanent identification number and the stopper, if not interchangeably ground, shall bear the same number. Interchangeable ground-glass parts shall be marked on both members with the standard-taper symbol, $\overline{\$}$, followed by the size designation. The standard temperature shall be indicated, and the unit of capacity shall be shown by the letters “mL” placed above the highest graduation mark.

3.2. Kerosine, free of water, or naphtha, having a density greater than 0.7391 mL at 23 ± 2ºC shall be used in the density determination.

3.3. The use of alternative equipment or methods for determining density is permitted provided that a single operator can obtain results with ±0.03 Mg/m^3 of the results obtained using the flask method.

Note 1—The design is intended to ensure complete drainage of the flask when emptied and stability of standing on a level surface as well as accuracy and precision of reading.

4. PROCEDURE

4.1. Determine the density of cement on the material as received, unless otherwise specified. If the density determination on a loss-free sample is required, first ignite the sample as described in the test for loss on ignition in Section 16.1 of T 105.

4.2. Fill the flask (Note 2) with either of the liquids specified in Section 3.2 to a point on the stem between the 0 and the 1-mL mark. Dry the inside of the flask above the level of the liquid, if necessary, after pouring. Record the first reading after the flask has been immersed in the water bath (Note 3) in accordance with Section 4.4.

Note 2—It is advisable to use a rubber pad on the table top when filling or rolling the flask.

Note 3—Before the cement has been added to the flask, a loose-fitting, lead-ring weight around the stem of the flask will be helpful in holding the flask in an upright position in the water bath, or the flask may be held in the water bath by a buret clamp.

4.3. Introduce a quantity of cement, weighed to the nearest 0.05 g (about 64 g for portland cement) in small increments at the same temperature as the liquid (Note 2). Take care to avoid splashing and see that the cement does not adhere to the inside of the flask above the liquid. A vibrating apparatus may be used to accelerate the introduction of the cement into the flask and to prevent the cement from sticking to the neck. After all the cement has been introduced, place the stopper in the flask and roll the flask in an inclined position (Note 2), or gently whirl it in a horizontal circle, so as to free the cement from air until no further air bubbles rise to the surface of the liquid. If a proper amount of cement has been added, the level of the liquid will be in its final position at some point of the upper series of graduations. Take the final reading after the flask has been immersed in the water bath in accordance with Section 4.4.

4.4. Immerse the flask in a constant-temperature water bath for sufficient periods of time in order to avoid flask-temperature variations greater then 0.2ºC between the initial and the final readings.

5. CALCULATION

5.1. The difference between the first and the final readings represents the volume of liquid displaced by the mass of cement used in the test.

5.2. Calculate the cement density, p, as follows:

$$p(\mathrm{Mg/m^3}) = p(g/\mathrm{cm^3}) = \text{mass of cement, g/displaced volume, cm}^3$$

Note 4—The displaced volume in milliliters is numerically equal to the displaced volume in cubic centimeters.

Note 5—Density in megagrams per cubic meter (Mg/m^3) is numerically equal to grams per cubic centimeter (g/cm^3). Calculate the cement density, *p*, to three decimal places and round to the nearest 0.01 Mg/m^3.

Note 6—In connection with proportioning and control of concrete mixtures, density may be more usefully expressed as specific gravity, the latter being a dimensionless number. Calculate the specific gravity as follows: Sp gr = cement density/water density at 4ºC (at 4ºC the density of water is 1 Mg/m^3(1 g/cm^3)).

6. PRECISION AND BIAS

6.1. The single-operator standard deviation for portland cements has been found to be 0.012.[1] Therefore, the results of two properly conducted tests by the same operator on the same material should not differ by more than 0.03.[1]

6.2. The multilaboratory standard deviation for portland cements has been found to be 0.037.[1] Therefore, the results of two properly conducted tests from two different laboratories on samples of the same cement should not differ by more than 0.10.[1]

6.3. Since there is no accepted reference material suitable for determining any bias that may be associated with T 133, no statement on bias is being made.

7. KEYWORDS

7.1. Density; hydraulic cement; specific gravity.

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[1] These numbers represent 1s and d2s limits described in ASTM C 670.

Standard Method of Test for

Air Content of Hydraulic Cement Mortar

AASHTO Designation: T 137-04 (2008)
ASTM Designation: C 185-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Air Content of Hydraulic Cement Mortar

AASHTO Designation: T 137-04 (2008)
ASTM Designation: C 185-02

1. SCOPE

1.1. This test method covers the determination of the air content of hydraulic cement mortar under the conditions hereinafter specified.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. Values in SI shall be obtained by measurement in SI units or by appropriate conversion, using the Rules for Conversion and Rounding in IEEE/ASTM SI 10, of measurements made in other units.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 152M/M 152, Flow Table for Use in Tests of Hydraulic Cement
- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 91, Standard Specification for Masonry Cement
- C 778, Standard Specification for Standard Sand
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 438, Standard Specification for Glasses in Laboratory Apparatus
- E 694, Standard Specification for Laboratory Glass Volumetric Apparatus

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

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3. SUMMARY OF TEST METHOD

3.1. Prepare a mortar with standard sand and the cement to be tested, using a water content sufficient to give a required flow. Compact the mortar into a measure of known volume and determine mass. Calculate the air content from the measured density of the mortar, the known densities of the constituents, and the mixture proportions.

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4. SIGNIFICANCE AND USE

4.1. The purpose of this test method is to determine whether or not the hydraulic cement under test meets the air-entraining or non-air-entraining requirements of the applicable hydraulic cement specification for which the test is being made. The air content of concrete is influenced by many factors other than the potential of the cement for air entrainment.

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5. APPARATUS

5.1. *Flow Table, Flow Mold, and Caliper*—conforming to the requirements of M 152M/M 152.

5.2. *Measure*—A cylindrical measure having an inside diameter of 76 ± 2 mm and a depth (approximately 88 mm) adjusted by standardization with water to contain 400 ± 1 mL at 23.0 ± 2.0ºC (Note 2). For the purposes of this test, the capacity of the measure in milliliters is the mass of the water content of the measure, in grams, divided by 0.9976, no correction in mass being made for the buoyant effect of air. The measure shall have a uniform wall thickness. The thickness of the wall and bottom shall not be less than 2.9 mm. The total mass of the empty measure shall not be more than 900 g. The measure shall be made of a metal not attacked by the cement mortar.

Note 1—The 400-mL measure can be calibrated readily by filling with distilled water at 23.0 ± 2.0ºC to a point where the meniscus extends appreciably above the top of the measure, placing a clean piece of plate glass on the top of the measure, and allowing the excess water to be squeezed out. The absence of air bubbles as seen through the glass ensures that the measure is completely full. Care shall be taken that the excess water is wiped from the sides of the container before determining the mass.

5.3. *Mixer, Bowl, and Paddle*—conforming to the apparatus section of T 162.

5.4. *Straightedge*—A steel straightedge not less than 200 mm long and not less than 1.5 mm nor more than 3.5 mm in thickness.

5.5. *Standard Masses and Balances*—conforming to the requirements of ASTM C 1005. The balance device shall be evaluated for precision and accuracy at a total load of 2 kg.

5.6. *Glass Graduates*—Glass graduates of 250-mL capacity, conforming to the requirements of ASTM E 438 and E 694.

5.7. *Tamper*—in accordance with T 106. The tamping face of the tamper shall be flat and at right angles to the length of the tamper.

5.8. *Tapping Stick*—a piece of hard wood having a diameter of approximately 16 mm and a length of approximately 152 mm.

5.9. *Spoon*—A metal restaurant-type serving spoon not less than 230 mm in length and with a bowl approximately 100 mm in length.

6. TEMPERATURE AND HUMIDITY

6.1. Maintain the temperature of the room and dry materials at 23.0 ± 4.0ºC.

6.2. Condition the mixing water and the measure, if it is being calibrated at 23.0 ± 2.0ºC.

6.3. The relative humidity of the laboratory shall not be less than 50 percent.

7. STANDARD SAND

7.1. Use sand conforming to the requirements of ASTM C 778 for 20–30 sand.

8. SAMPLING

8.1. Sample the cement in accordance with T 127.

9. PROCEDURE

9.1. *Batch*—Proportion the standard mortar using 350 g of cement to 1400 g of 20–30 standard sand and sufficient water to give a flow of 87.5 ± 7.5 percent when determined in accordance with Section 9.3.

Note 2—Masonry cements require different sand, sample mass, and flow. Refer to ASTM C 91.

9.2. *Mixing of Mortar*—Mix the mortar in accordance with T 162.

9.3. *Flow Determination*—Carefully wipe dry the flow-table top and place the flow mold at the center of it. Using the spoon, place a layer of mortar about 25 mm in thickness in the mold and tamp 20 times with the tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Over fill the mold approximately 20 mm with mortar and tamp as specified for the first layer. Then cut off the mortar to a plane surface, flush with the top of the mold, by drawing the straightedge with a sawing motion across the top of the mold. Wipe the flow-table top clean and dry, being especially careful to remove any water from around the edge of the mold. Lift the mold away from the mortar 60 seconds after completing the mixing operation. Immediately drop the table 10 times in accordance with M 152. The flow is the resulting increase in average diameter of the mortar mass, as determined with the calipers, measured on at least four diameters at approximately equispaced intervals, expressed as a percentage of the original diameter. Make trial mortars with varying percentages of water until the specified flow is obtained. Make each trial with fresh mortar.

9.4. *Mass per 400 mL of Mortar*—When the quantity of mixing water has been found that produces a flow of 87.5 ± 7.5 percent, immediately determine the mass per 400 mL of mortar, using the mortar remaining in the mixing bowl after the flow has been determined. In the determination of the mass per 400 mL, do not use the portion of the mortar used in the flow determination.

Using the spoon, place the mortar gently into the 400-mL measure in three equal layers, tamping each layer 20 times with the tamper around the inner surface of the measure. The position of the tamper shall be that: the broad side of the tamper is parallel to the radius and is perpendicular to the inner surface of the measure. Each layer is tamped in on complete revolution (rotation) with only sufficient pressure to adequately fill the measure and eliminate voids within the mortar. After the measure has been filled and tamped in the above prescribed manner, tap the sides of the measure lightly with the side of the tapping stick, one each at five different points at approximately equal spacing around the outside of the measure, in order to preclude entrapment of extraneous air (Note 3).

No obvious space shall be left between the mortar and the inner surface of the measure as a result of the tamping operation. Then cut the mortar off to a plane surface, flush with the top of the measure, by drawing the straightedge with a sawing motion across the top of the measure, making two passes over the entire surface, the second pass being made at right angles to the first. If, in the striking-off operation, loose sand grains cause the straightedge to ride above the top surface of the measure, these grains shall be removed, and the operation repeated. Complete the entire operation of filling and striking off the measure within 90 seconds. Wipe off all mortar and water adhering to the outside of the measure. Determine the mass of the measure and its contents. Subtract the mass of the container, and record the mass of the mortar in grams.

Note 3—This operation may be facilitated by placing the measure on a steady flat-surfaced support of lesser diameter than the measure while filling and wiping.

10. CALCULATION

10.1. Calculate the air content of the mortar from the following formula, which is based on batch proportions given in Section 9.1, taking the specific gravity of portland cement as 3.15 and of 20–30 standard sand as 2.65. When the hydraulic cement is other than portland, the appropriate value for its specific gravity shall be substituted for the value of 3.15 and the formula rederived accordingly:

$$\text{Air Content, Volume, Percent} = 100 - W\,[(182.7 + P)/(2000 + 4P)] \qquad (1)$$

where:

W = mass of 400 mL of mortar, g; and

P = percentage of mixing water, based on mass of cement used.

Note 4—This formula can be derived as follows:

$$\text{Air Content, Volume, Percent} = 100[1 - (W_a/W_c)] \qquad (2)$$

where:

W_a = actual mass per unit of volume as determined by this test method;

= W/400 g/mL, where W is the mass in grams of the specified 400 mL of mortar (Section 9.4);

W_c = theoretical mass per unit of volume, calculated on an air-free basis as follows and using the values for quantities of materials and specific gravities as given in Sections 9.1 and 10.1:

$$= \frac{350 + 1400 + 350 \times P \times 0.01}{\frac{350}{3.15} + \frac{1400}{2.65} + \frac{350 \times P \times 0.01}{1}}$$

$$= \frac{(5 + 0.01P)}{(1.827 + 0.01P)}$$

P = percentage of mixing water, based on mass of cement.

Substituting for W_a and W_c, we have:

Air Content, Volume, Percent:

$$= 100\left(1 - \frac{W}{400} \times \frac{1.827 + 0.01P}{5 + 0.01P}\right)$$

$$= 100 - \frac{W}{4} \times \frac{(1.827 + 0.01P)}{(5 + 0.01P)}$$

$$= 100 - 2.5W\,\frac{(182.7 + P)}{(5000 + 10P)}$$

$$= 100 - W\,\frac{(182.7 + P)}{(2000 + 4P)}$$

10.2. Make only one determination of air content on a batch.

Note 5—Difficulty has occasionally been experienced with this test by some persons. These difficulties usually have taken the form of values for air content that are abnormally high and that may be greater than the specified maxima in specifications for hydraulic cement. The air-entraining potential of the sand may be reduced by washing in the laboratory with potable water by decantation until a clear, colorless supernatant liquid is obtained. In case of dispute, such freshly washed sand shall be used.

11. REPORT

11.1. When this test method is used for specific action in compliance testing, the value for air content shall be reported to the nearest 1 percent.

12. PRECISION AND BIAS

12.1. The single operator, within-laboratory, standard deviation has been found to be 0.56 percent air content throughout the range of 8 to 19 percent air. Therefore, results of two properly conducted tests by the same operator on similar batches should not differ by more than 1.6 percent air.

12.2. The multilaboratory standard deviation has been found to be 1.0 percent air content throughout the range from 8 to 19 percent air. Therefore, results of two different laboratories on similar batches should not differ from each other by more than 2.8 percent air.

13. KEYWORDS

13.1. Air content; hydraulic cement; mortar.

Standard Method of Test for

Fineness of Hydraulic Cement by Air Permeability Apparatus

AASHTO Designation: T 153-09
ASTM Designation: C 204-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Fineness of Hydraulic Cement by Air Permeability Apparatus

AASHTO Designation: T 153-09
ASTM Designation: C 204-07

1. SCOPE

1.1. This test method covers determination of the fineness of hydraulic cement, using the Blaine air permeability apparatus, in terms of the specific surface expressed as total surface area in square centimeters per gram, or square meters per kilogram of cement. Two test methods are given: Test Method A is the Reference Test Method using the manually operated standard Blaine apparatus, while Test Method B permits the use of an automated apparatus that is in accordance with the qualification requirements of this test method's demonstrated acceptable performance. Although the test method may be, and has been, used for the determination of the measures of fineness of various other materials, it should be understood that, in general, relative rather than absolute fineness values are obtained.

1.1.1. This test method is known to work well for portland cements. However, the user should exercise judgment in determining its suitability with regard to fineness measurements of cements with densities or porosities that differ from those assigned to Standard Reference Material No. 114.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- A 582/A 582M, Standard Specification for Free-Machining Stainless Steel Bars
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 832, Standard Specification for Laboratory Filter Papers

2.2. *Other Documents*:

- No. 114, National Institute of Standards and Technology Standard Reference Material[1]
- BS 4359: 1971 British Standard Method for the Determination of Specific Surface of Powders: Part 2: Air Permeability Methods[2]

TEST METHOD A: REFERENCE METHOD

3. APPARATUS

3.1. *Nature of Apparatus*—The Blaine air permeability apparatus consists essentially of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The number and size of the pores in a prepared bed of definite porosity is a function of the size of the particles and determines the rate of airflow through the bed. The apparatus, illustrated in Figure 1, shall consist specifically of the parts described in Sections 3.2 to 3.8.

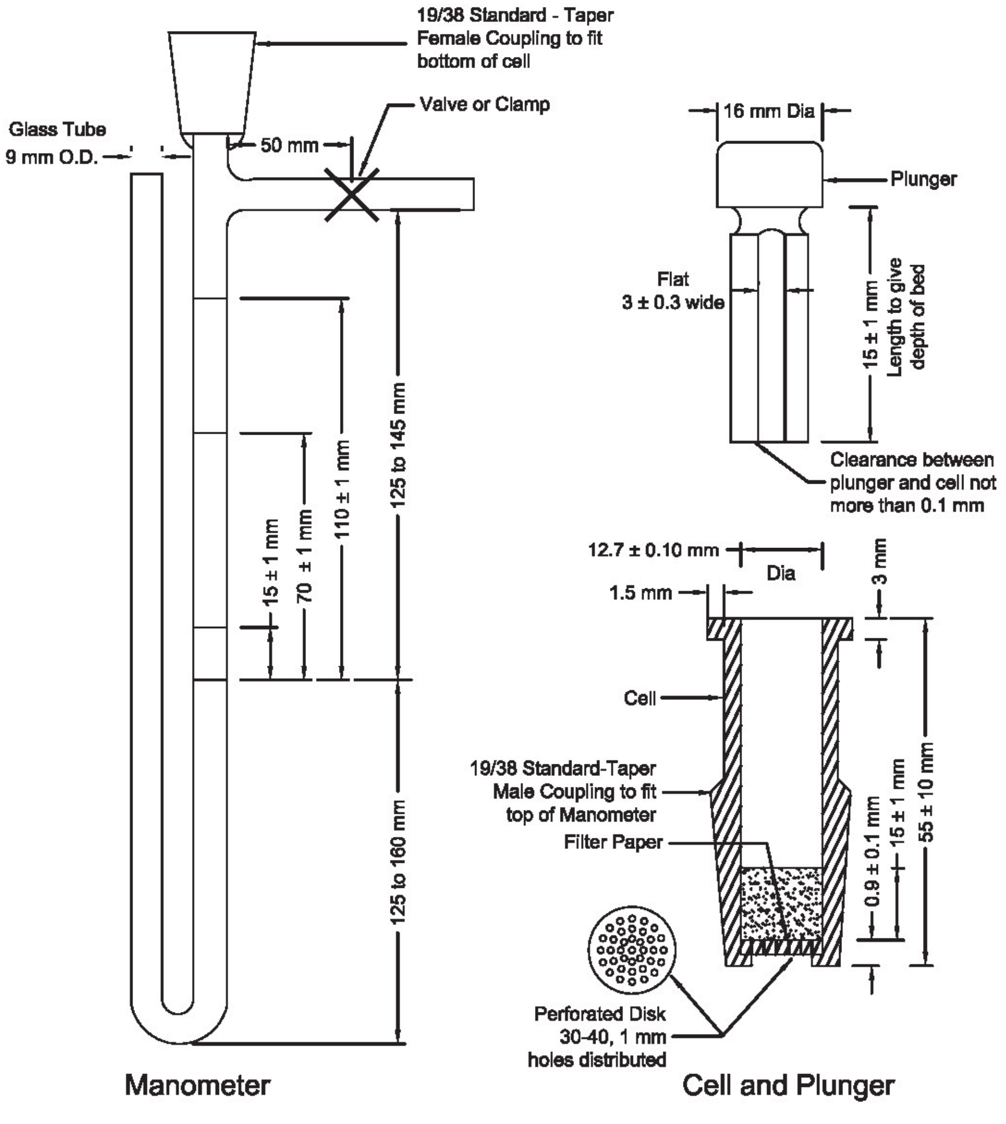


Figure 1—Blaine Air Permeability Apparatus

3.2. *Permeability Cell*—The permeability cell shall consist of a rigid cylinder 12.70 ± 0.10 mm in inside diameter, constructed of austenitic stainless steel. The interior of the cell shall have a finish of 0.81 µm (32 µin.). The top of the cell shall be at right angles to the principal axis of the cell. The lower portion of the cell must be able to form an airtight fit with the upper end of the manometer, so there is no air leakage between the contacting surfaces. A ledge 0.5 to 1 mm in width shall be an integral part of the cell or be firmly fixed in the cell 55 ± 10 mm from the top of the cell for support of the perforated metal disk. The top of the permeability cell shall be fitted with a protruding collar to facilitate the removal of the cell from the manometer.

Note 1—ASTM A 582/A 582M Type 303 stainless steel (UNS designation S30300) has been found to be suitable for the construction of the permeability cell and the plunger.

3.3. *Disk*—The disk shall be constructed of noncorroding metal and shall be 0.9 ± 0.1 mm in thickness, perforated with 30 to 40 holes 1 mm in diameter equally distributed over its area. The disk shall fit the inside of the cell snugly. The center portion of one side of the disk shall be marked or inscribed in a legible manner so as to permit the operator always to place that side downwards when inserting it into the cell. The marking or inscription shall not extend into any of the holes, nor touch their peripheries, nor extend into that area of the disk that rests on the cell ledge.

3.4. *Plunger*—The plunger shall be constructed of austenitic stainless steel and shall fit into the cell with a clearance of not more than 0.1 mm. The bottom of the plunger shall sharply meet the lateral surfaces and shall be at right angles to the principal axis. An air vent shall be provided by means of a flat 3.0 ± 0.3 mm wide on one side of the plunger. The top of the plunger shall be provided with a collar such that when the plunger is placed in the cell and the collar brought in contact with the top of the cell, the distance between the bottom of the plunger and the top of the perforated disk shall be 15 ± 1 mm.

3.5. *Filter Paper*—The filter paper shall be medium retentive, corresponding to Type 1, Grade B, in accordance with ASTM E 832. The filter paper disks shall be circular, with smooth edges, and shall have the same diameter (Note 2) as the inside of the cell.

Note 2—Filter paper disks that are too small may leave part of the sample adhering to the inner wall of the cell above the top disk. When too large in diameter, the disks have a tendency to buckle and cause erratic results.

3.6. *Manometer*—The U-tube manometer shall be constructed according to the design indicated in Figure 1, using nominal 9-mm outside diameter, standard-wall, glass tubing. The top of one arm of the manometer shall form an airtight connection with the permeability cell. The manometer arm connected to the permeability cell shall have a midpoint line etched around the tube at 125 to 145 mm below the top side outlet and also others at distances of 15 ± 1 mm, 70 ± 1 mm, and 110 ± 1 mm above that line. A side outlet shall be provided at 250 to 305 mm above the bottom of the manometer for use in the evacuation of the manometer arm connected to the permeability cell. A positive airtight valve or clamp shall be provided on the side outlet not more than 50 mm from the manometer arm. The manometer shall be mounted firmly and in such a manner that the arms are vertical.

3.7. *Manometer Liquid*—The manometer shall be filled to the midpoint line with a nonvolatile, nonhygroscopic liquid of low viscosity and density, such as dibutyl phthalate (dibutyl 1,2-benzenedicarboxylate) or a light grade of mineral oil. The fluid shall be free of debris.

3.8. *Timer*—The timer shall have a positive starting and stopping mechanism and shall be capable of being read to the nearest 0.5 seconds or less. The timer shall be accurate to 0.5 seconds or less for time intervals up to 60 seconds, and to 1 percent or less for time intervals of 60 to 300 seconds.

4. CALIBRATION OF APPARATUS

4.1. *Sample*—The calibration of the air permeability apparatus shall be made using the current lot of NIST Standard Reference Material No. 114. The sample shall be at room temperature when tested.

4.2. *Bulk Volume of Compacted Bed of Powder*—Determine the bulk volume of the compacted bed of powder by the mercury displacement method as follows:

4.2.1. Place two filter paper disks in the permeability cell, pressing down the edges, using a rod having a diameter slightly smaller than that of the cell, until the filter disks are flat on the perforated metal disk; then fill the cell with mercury, ACS reagent grade or better, removing any air bubbles adhering to the wall of the cell. Use tongs when handling the cell. If the cell is made of material that will amalgamate with mercury, the interior of the cell shall be protected by a very thin film of oil just prior to adding the mercury. Level the mercury with the top of the cell by lightly pressing a small glass plate against the mercury surface until the glass is flush to the surface of the mercury and rim of the cell, being sure that no bubble or void exists between the mercury surface and the glass plate. Remove the mercury from the cell, determine the mass, and record the mass of the mercury. Remove one of the filter disks from the cell. Using a trial quantity of 2.80 g of cement (Note 3) compress the cement (Note 4) in accordance with Section 4.5 with one filter disk above and one below the sample. Into the unfilled space at the top of the cell, add mercury, remove entrapped air, and level off the top as before. Remove the mercury from the cell, determine the mass, and record the mass of the mercury.

4.2.2. Calculate the bulk volume occupied by the cement to the nearest 0.005 cm^3 as follows:

$$V = \frac{W_A - W_B}{D} \tag{1}$$

where:

V = bulk volume of cement, cm^3;

W_A = grams of mercury required to fill the cell, no cement being in the cell;

W_B = grams of mercury required to fill the portion of the cell not occupied by the prepared bed of cement in the cell; and

D = density of mercury at the temperature of test, Mg/m^3. (See Table 1.)

Table 1—Density of Mercury, Viscosity of Air (η), and $\sqrt{n}$ at Given Temperatures

Room Temperature, °C	Density of Mercury, Mg/m^3	Viscosity of Air, η μ Pa·s	$\sqrt{\eta}$
16	13.56	17.88	4.23
18	13.55	17.98	4.24
20	13.55	18.08	4.25
22	13.54	18.18	4.26
24	13.54	18.28	4.28
26	13.53	18.37	4.29
28	13.53	18.47	4.30
30	13.52	18.57	4.31
32	13.52	18.67	4.32
34	13.51	18.76	4.33

4.2.3. Make at least two determinations of bulk volume of cement, using separate compactions for each determination. The bulk volume value used for subsequent calculations shall be the average of two values agreeing within ±0.005 cm^3. Note the temperature in the vicinity of the cell and record at the beginning and end of the determination.

Note 3—It is not necessary to use the standard sample for the bulk volume determination.

Note 4—The prepared bed of cement shall be firm. If too loose or if the cement cannot be compressed to the desired volume, adjust the trial quantity of cement used.

4.3. *Preparation of Sample*—Enclose the contents of a vial of the standard cement sample in a jar, approximately 120 cm^3 (4 oz) and shake vigorously for 2 minutes to fluff the cement and break up lumps or agglomerates. Allow the jar to stand unopened for a further 2 minutes, then remove the lid and stir gently to distribute throughout the sample the fine fraction that has settled on the surface after fluffing.

4.4. *Mass of Sample*—The mass of the standard sample used for the calibration test shall be that required to produce a bed of cement having a porosity of 0.500 ± 0.005, and shall be calculated as follows:

$$W = \rho V \left(1 - \in\right) \tag{2}$$

where:

W = grams of sample required;

ρ = density of test sample (for portland cement a value of 3.15 Mg/m^3 or 3.15 g/cm^3 shall be used);

V = bulk volume of bed cement, cm^3, as determined in accordance with Section 4.2; and

$\in$ = desired porosity of bed of cement (0.500 ± 0.005) (Note 5).

Note 5—The porosity is the ratio of volume of voids in a bed of cement to the total or bulk volume of the bed, *V*.

4.5. *Preparation of Bed of Cement*—Seat the perforated disk on the ledge in the permeability cell, inscribed or marked face down. Place a filter paper disk on the metal disk and press the edges down with a rod having a diameter slightly smaller than that of the cell. Determine the mass to the nearest 0.001 g the quantity of cement determined in accordance with Section 4.4 and place in the cell. Tap the side of the cell lightly in order to level the bed of cement. Place a filter paper disk on top of the cement and compress the cement with the plunger until the plunger collar is in contact with the top of the cell. Slowly withdraw the plunger a short distance, rotate about 90 degrees, repress, and then slowly withdraw. Use of fresh disks is required for each determination.

4.6. *Permeability Test*:

4.6.1. Attach the permeability cell to the manometer tube, making certain that an airtight connection is obtained (Note 6) and taking care not to jar or disturb the prepared bed of cement.

4.6.2. Slowly evacuate the air in the one arm of the manometer U-tube until the liquid reaches the top mark, and then close the valve tightly. Start the timer when the bottom of the meniscus of the manometer liquid reaches the second (next to the top) mark and stop when the bottom of the meniscus of liquid reaches the third (next to the bottom) mark. Note the time interval measured and record in seconds. Note the temperature of test and record in degrees Celsius.

4.6.3. In the calibration of the instrument, make at least three determinations of the time of flow on each of three separately prepared beds of the standard sample (Note 7). The calibration shall be made by the same operator who makes the fineness determination.

Note 6—A little stopcock grease should be applied to the standard taper connection. The efficiency of the connection can be determined by attaching the cell to the manometer, stoppering it, partially evacuating the one arm of the manometer, then closing the valve. Any continuous drop in pressure indicates a leak in the system.

Note 7—The sample may be refluffed and reused for preparation of the test bed, provided that it is kept dry and all tests are made within 4 hours of the opening of the sample.

4.7. *Recalibration*—The apparatus shall be recalibrated (Note 8):

4.7.1. At periodic intervals, the duration of which shall not exceed $2^1/_2$ years to correct for possible wear on the plunger or permeability cell, or upon receipt of evidence that the test is not providing data in accordance with the precision and bias statement in Section 8.

4.7.2. If any loss in the manometer fluid occurs, recalibrate starting with Section 4.5, or

4.7.3. If a change is made in the type or quality of the filter paper used for the tests.

Note 8—It is suggested that a secondary sample be prepared and used as a fineness standard for the check determinations of the instrument between regular calibrations with the standard cement sample.

5. PROCEDURE

5.1. *Temperature of Cement*—The cement sample shall be at room temperature when tested.

5.2. *Size of Test Sample*—The mass of the sample used for the test shall be the same as that used in the calibration test on the standard sample, with these exceptions: When determining the fineness of Type III or other types of fine-ground portland cement whose bulk for this mass is so great that ordinary thumb pressure will not cause the plunger collar to contact the top of the cell, the mass of the sample shall be that required to produce a test bed having a porosity of 0.530 ± 0.005. When determining the fineness of materials other than portland cement, or if for a portland cement sample one of the required porosities cannot be attained, the mass of the sample shall be adjusted so that a firm, hard bed is produced by the compacting process. In no case, however, shall more than thumb pressure be used to secure the proper bed, nor shall such thumb pressure be used that the plunger "rebounds" from the cell top when pressure is removed.

5.3. *Preparation of Bed of Cement*—Prepare the test bed of cement in accordance with the method described in Section 4.5.

5.4. *Permeability Tests*—Make the permeability tests in accordance with the method described in Section 4.6, except that only one time-of-flow determination need be made on each bed.

6. CALCULATION

6.1. Calculate the specific surface values in accordance with the following equations:

$$S = \frac{S_s \sqrt{T}}{\sqrt{T_s}} \tag{3}$$

$$S = \frac{S_S \sqrt{\eta_S} \sqrt{T}}{\sqrt{T_S} \sqrt{\eta}} \tag{4}$$

$$S = \frac{S_s(b - \in_s)\sqrt{\in^3}\sqrt{T}}{\sqrt{\in_s^3}\sqrt{T_s}(b - \in)} \tag{5}$$

$$S = \frac{S_s(b - \in_s)\sqrt{\in^3}\sqrt{\eta_s}\sqrt{T}}{\sqrt{\in_s^3}\sqrt{T_s}\sqrt{\eta}(b - \in)} \tag{6}$$

$$S = \frac{S_s\rho_s(b_s - \in_s)\sqrt{\in^3}\sqrt{T}}{\rho(b - \in)\sqrt{\in_s^3}\sqrt{T_s}} \tag{7}$$

$$S = \frac{S_s\rho_s(b_s - \in_s)\sqrt{\eta_s}\sqrt{\in^3}\sqrt{T}}{\rho(b - \in)\sqrt{\in_s^3}\sqrt{\eta}\sqrt{T_s}} \tag{8}$$

where:

S = specific surface of the test sample, m^2/kg;

S_s = specific surface of the standard sample used in calibration of the apparatus, m^2/kg (Note 9);

T = measured time interval, *s*, of manometer drop for test sample (Note 10);

T_s = measured time interval, *s*, of manometer drop for standard sample used in calibration of the apparatus (Note 10);

η = viscosity of air, micro pascal seconds (μ Pa·s), at the temperature of test of the test sample (Note 10);

η_s = viscosity of air, micro pascal seconds (μ Pa·s), at the temperature of test of the standard sample used in calibration of the apparatus (Note 10);

$\in$ = porosity of prepared bed of test sample (Note 10);

$\in_s$ = porosity of prepared bed of standard sample used in calibration of apparatus (Note 10);

ρ = density of test sample (for portland cement a value of 3.15 Mg/m^3 or 3.15 g/cm^3 shall be used);

ρ_s = density of standard sample used in calibration of apparatus (assumed to be 3.15 Mg/m^3 or 3.15 g/cm^3);

b = a constant specifically appropriate for the test sample (for hydraulic cement a value of 0.9 shall be used); and

b_s = 0.9, the appropriate constant for the standard sample.

Note 9—The proper specific surface value is indicated on the certificate that accompanies the SRM 114 series samples at the time of purchase.

Note 10—Values for $\sqrt{\eta}$, $\sqrt{\in^3}$, and $\sqrt{T}$ may be taken from Tables 1, 2, and 3, respectively.

6.1.1. Equations 3 and 4 shall be used in calculations of fineness of portland cements compacted to the same porosity as the standard fineness sample. Equation 3 is used if the temperature of test of the test sample is within ±3°C of the temperature of calibration test, and Equation 4 is used if the temperature of test of the test sample is outside of this range.

6.1.2. Equations 5 and 6 shall be used in calculation of fineness of portland cements compacted to some porosity other than that of the standard fineness sample used in the calibration test. Equation 5 is used if the temperature of test of the test sample is within ±3ºC of the temperature of calibration test of the standard fineness sample, and Equation 6 is used if the temperature of test of the test sample is outside of this range.

6.1.3. Equations 7 and 8 shall be used in calculation of fineness of materials other than portland cement. Equation 7 shall be used when the temperature of test of the test sample is within ±3°C of the temperature of calibration test, and Equation 8 is used if the temperature of test of the test sample is outside of this range.

6.1.4. It is recommended that values of *b* be determined on no less than three samples of the material in question. Test each sample at a minimum of four different porosities over a porosity range of at least 0.06. Correlation coefficients should exceed 0.9970 for the correlation of

$$\sqrt{\in^3}\,T$$

versus $\in$ on each sample tested. (See Appendix.)

6.2. To calculate the specific surface values in square meters per kilogram, multiply the surface area in cm^2/g by the factor of 0.1.

6.3. Round values in cm^2/g to the nearest 10 units (in m^2/kg to the nearest unit). Example: 3447 cm^2/g is rounded to 3450 cm^2/g or 345 m^2/kg.

Table 2—Values for Porosity of Cement Bed

Porosity of Bed, $\in$	$\sqrt{\in^3}$	Porosity of Bed, $\in$	$\sqrt{\in^3}$
0.495	0.348	0.525	0.380
0.496	0.349	0.526	0.381
0.497	0.350	0.527	0.383
0.498	0.351	0.528	0.384
0.499	0.352	0.529	0.385
0.500	0.354	0.530	0.386
0.501	0.355	0.531	0.387
0.502	0.356	0.532	0.388
0.503	0.357	0.533	0.389
0.504	0.358	0.534	0.390
		0.535	0.391
0.505	0.359		
0.506	0.360		
0.507	0.361		
0.508	0.362		
0.509	0.363		
0.510	0.364		

Table 3—Time of Airflow

T	$\sqrt{T}$	T	$\sqrt{T}$	$\sqrt{T}$	T	$\sqrt{T}$	T	$\sqrt{T}$	T	$\sqrt{T}$	T
26	5.10	51	7.14	76	8.72	101	10.05	151	12.29	201	14.18
$26^{1}/_{2}$	5.15	$51^{1}/_{2}$	7.18	$76^{1}/_{2}$	8.75	102	10.10	152	12.33	202	14.21
27	5.20	52	7.21	77	8.77	103	10.15	153	12.37	203	14.25
$27^{1}/_{2}$	5.24	$52^{1}/_{2}$	7.25	$77^{1}/_{2}$	8.80	104	10.20	154	12.41	204	14.28
28	5.29	53	7.28	78	8.83	105	10.25	155	12.45	205	14.32
$28^{1}/_{2}$	5.34	$53^{1}/_{2}$	7.31	$78^{1}/_{2}$	8.86	106	10.30	156	12.49	206	14.35
29	5.39	54	7.35	79	8.89	107	10.34	157	12.53	207	14.39
$29^{1}/_{2}$	5.43	$54^{1}/_{2}$	7.38	$79^{1}/_{2}$	8.92	108	10.39	158	12.57	208	14.42
30	5.48	55	7.42	80	8.94	109	10.44	159	12.61	209	14.46
$30^{1}/_{2}$	5.52	$55^{1}/_{2}$	7.45	$80^{1}/_{2}$	8.97	110	10.49	160	12.65	210	14.49
31	5.57	56	7.48	81	9.00	111	10.54	161	12.69	211	14.53
$31^{1}/_{2}$	5.61	$56^{1}/_{2}$	7.52	$81^{1}/_{2}$	9.03	112	10.58	162	12.73	212	14.56
32	5.66	57	7.55	82	9.06	113	10.63	163	12.77	213	14.59
$32^{1}/_{2}$	5.70	$57^{1}/_{2}$	7.58	$82^{1}/_{2}$	9.08	114	10.68	164	12.81	214	14.63
33	5.74	58	7.62	83	9.11	115	10.72	165	12.85	215	14.66
$33^{1}/_{2}$	5.79	$58^{1}/_{2}$	7.65	$83^{1}/_{2}$	9.14	116	10.77	166	12.88	216	14.70
34	5.83	59	7.68	84	9.17	117	10.82	167	12.92	217	14.73
$34^{1}/_{2}$	5.87	$59^{1}/_{2}$	7.71	$84^{1}/_{2}$	9.19	118	10.86	168	12.96	218	14.76
35	5.92	60	7.75	85	9.22	119	10.91	169	13.00	219	14.80
$35^{1}/_{2}$	5.96	$60^{1}/_{2}$	7.78	$85^{1}/_{2}$	9.25	120	10.95	170	13.04	220	14.83
36	6.00	61	7.81	86	9.27	121	11.00	171	13.08	222	14.90
$36^{1}/_{2}$	6.04	$61^{1}/_{2}$	7.84	$86^{1}/_{2}$	9.30	122	11.05	172	13.11	224	14.97
37	6.08	62	7.87	87	9.33	123	11.09	173	13.15	226	15.03
$37^{1}/_{2}$	6.12	$62^{1}/_{2}$	7.91	$87^{1}/_{2}$	9.35	124	11.14	174	13.19	228	15.10
38	6.16	63	7.94	88	9.38	125	11.18	175	13.23	230	15.17
$38^{1}/_{2}$	6.20	$63^{1}/_{2}$	7.97	$88^{1}/_{2}$	9.41	126	11.22	176	13.27	232	15.23
39	6.24	64	8.00	89	9.43	127	11.27	177	13.30	234	15.30
$39^{1}/_{2}$	6.28	$64^{1}/_{2}$	8.03	$89^{1}/_{2}$	9.46	128	11.31	178	13.34	236	15.36
40	6.32	65	8.06	90	9.49	129	11.36	179	13.38	238	15.43
40½	6.36	65½	8.09	90½	9.51	130	11.40	180	13.42	240	15.49
41	6.40	66	8.12	91	9.54	131	11.45	181	13.45	242	15.56
41½	6.44	66½	8.15	91½	9.57	132	11.49	182	13.49	244	15.62
42	6.48	67	8.19	92	9.59	133	11.53	183	13.53	246	15.68
$42^{1}/_{2}$	6.52	$67^{1}/_{2}$	8.22	$92^{1}/_{2}$	9.62	134	11.58	184	13.56	248	15.75
43	6.56	68	8.25	93	9.64	135	11.62	185	13.60	250	15.81
$43^{1}/_{2}$	6.60	$68^{1}/_{2}$	8.28	$93^{1}/_{2}$	9.67	136	11.66	186	13.64	252	15.87
44	6.63	69	8.31	94	9.70	137	11.70	187	13.67	254	15.94
$44^{1}/_{2}$	6.67	$69^{1}/_{2}$	8.34	$94^{1}/_{2}$	9.72	138	11.75	188	13.71	256	16.00
45	6.71	70	8.37	95	9.75	139	11.79	189	13.75	258	16.06
$45^{1}/_{2}$	6.75	$70^{1}/_{2}$	8.40	$95^{1}/_{2}$	9.77	140	11.83	190	13.78	260	16.12
46	6.78	71	8.43	96	9.80	141	11.87	191	13.82	262	16.19
$46^{1}/_{2}$	6.82	$71^{1}/_{2}$	8.46	$96^{1}/_{2}$	9.82	142	11.92	192	13.86	264	16.25
47	6.86	72	8.49	97	9.85	143	11.96	193	13.89	266	16.31
$47^{1}/_{2}$	6.89	$72^{1}/_{2}$	8.51	$97^{1}/_{2}$	9.87	144	12.00	194	13.93	268	16.37
48	6.93	73	8.54	98	9.90	145	12.04	195	13.96	270	16.43
$48^{1}/_{2}$	6.96	$73^{1}/_{2}$	8.57	$98^{1}/_{2}$	9.92	146	12.08	196	14.00	272	16.49
49	7.00	74	8.60	99	9.95	147	12.12	197	14.04	274	16.55
$49^{1}/_{2}$	7.04	$74^{1}/_{2}$	8.63	$99^{1}/_{2}$	9.97	148	12.17	198	14.07	276	16.61
50	7.07	75	8.66	100	10.00	149	12.21	199	14.11	278	16.67
$50^{1}/_{2}$	7.11	$75^{1}/_{2}$	8.69	$100^{1}/_{2}$	10.02	150	12.25	200	14.14	280	16.73

T = Time of airflow in seconds; $\sqrt{T}$ = The factor for use in the equations.

7. REPORT

7.1. For portland cements and portland cement-based materials, report results on a single determination on a single bed.

7.2. For very high fineness materials with longtime intervals, report the average fineness value of two permeability tests, provided that the two agree within 2 percent of each other. If they do not agree, discard the values and repeat the test (Note 11) until two values so agreeing are obtained.

Note 11—Lack of agreement indicates a need for checks of procedure and apparatus. See also the ASTM *Manual of Cement Testing*.

8. PRECISION AND BIAS

8.1. *Single-Operator Precision*—The single-operator coefficient of variation for portland cements has been found to be 1.2 percent (Note 12). Therefore, results of two properly conducted tests, by the same operator, on the same sample, should not differ by more than 3.4 percent (Note 12) of their average.

8.2. *Multilaboratory Precision*—The multilaboratory coefficient of variation for portland cements has been found to be 2.1 percent (Note 12). Therefore, results of two different laboratories on identical samples of a material should not differ from each other by more than 6.0 percent (Note 12) of their average.

Note 12—These numbers represent, respectively, the 1s percent and d2s percent limits as described in ASTM C 670.

8.3. Since there is no accepted reference material suitable for determining any bias that may be associated with T 153, no statement is being made.

TEST METHOD B: AUTOMATED APPARATUS

9. APPARATUS

9.1. The automated test method shall employ apparatus designed either on the principles of the Blaine air-permeability method (see Note 13) or apparatus based on the air permeability principles of the Lea and Nurse method (see Note 14).

Note 13—Automated apparatus is generally equipped with a microprocessor capable of operating the measuring devices, and calculating and displaying the test results. Commercially available units may have significantly different dimensions for manometer and cement bed than those specified by standard methods.

Note 14—The Lea and Nurse constant flow rate air permeability method is described in BS 4359: 1971.

10. CALIBRATION OF APPARATUS

10.1. Follow the manufacturer's directions for calibrating the apparatus (see Note 15). If the apparatus is equipped with more than one cell, each cell will require a separate calibration. The manufacturer's procedure shall detail the method for bed preparation and the steps required to initiate the automated measurement. It is essential that the procedure be followed precisely and consistently for all tests.

Note 15—The manufacturer of the apparatus will generally provide standard samples that can be used for calibration.

11. PROCEDURE

11.1. *Temperature of Cement*—The cement sample shall be at room temperature when tested.

11.2. *Size of the Test Sample*—The mass of the sample used for the test shall be the same as used in the calibration test unless cements of different density or porosity are to be tested; then follow the manufacturer's guidelines for adjusting mass.

11.3. *Permeability Tests*—Make permeability tests using the same procedure used for the calibration tests. Only one determination need be made for each bed preparation.

12. PERFORMANCE REQUIREMENT (QUALIFICATION) FOR THE AUTOMATED APPARATUS

12.1. *Scope*—When the specific surface values determined by an automated apparatus are to be used for acceptance or rejection of cement, the method used shall comply with the qualification requirements of this section. A method is considered to consist of the specific instrument and testing procedure meeting the requirements of this standard and used in a consistent manner by a given laboratory.

12.2. *Samples*—Select two cement samples that have surface area and density that bracket the desired test range. The range of the surface area shall not exceed 2000 cm^2/g (200 m^2/kg) and shall have densities that differ no more than 0.06 g/cm^3 (60 Mg/m^3).

12.3. *Tests*—Make triplicate determinations on each cement sample following Test Method A (Reference Method). On the same day, complete a second round of triplicate tests using the method to be qualified (Test Method B) and including the standardization formula described in this section. Prepare a new cell bed and repeat all the steps of the test procedures for each determination. Report values to the nearest 10 cm^2/g (1 m^2/kg).

12.4. *Calculations*—Calculate the range and the mean of the three replicate tests for each method and each cement. A method complies with the qualification requirements if the absolute difference between the average value of Test Method A and the corresponding average value for Test Method B (each with three replicates) is not greater than 2.7 percent of the Test Method A average (see Note 16) and the range for any three replicate tests does not exceed 4.0 percent of the average (see Note 17). The method is qualified only if both cement samples shall meet the above requirements. Example qualification data are given in the Appendix.

Note 16—This value represents the least-significant-difference (*lsd*) for 95 percent confidence as applied to the coefficient of variation of 1.2 percent (Single-Operator-Precision) for Test Method A, given in Section 8.1. The equation is:

$$lsd\left(95\%\right) = t_{0.05,df}\left[\left(2CV^2/n\right)\right]^{1/2} \tag{9}$$

where:

df = 4, degree of freedom, two from each of the two sets of results;

n = 3, the number of replicates;

CV = 1.2 percent, the Single-Operator-Precision; and

$t_{0.05,4}$ = 2.776, Students-*t* statistic for a 5 percent probability with a $df = 4$.

Note 17—This value represents the d2s percentage calculation for 3 replicates in accordance with Table 1 of ASTM C 670 and applied to the coefficient of variation of 1.2 percent (Single-Operator-Precision) for Test Method A, given in Section 8.1.

12.5. *Standardization*:

12.5.1. When standardization is required in order to achieve agreement between Test Method A and Test Method B, standardize the apparatus as follows:

12.5.1.1. Prepare a separate standardization for each type of cement to be tested, using reference samples of density within 0.06 g/cm^3(60 Mg/m^3) of the cement to be tested, and packed to the same bed porosity.

12.5.1.2. For each standardization, obtain five reference samples with a minimum air permeability fineness range of 800 cm^2/g (80 m^2/kg) and a minimum difference between samples of 50 cm^2/g (5 m^2/kg). If cement samples used for qualification are used, make new determinations. Use the same method as used for the instrument qualification and follow all the steps. Valid standardization formulas shall be mathematically derived and applied to all samples.

13. REQUALIFICATION OF A METHOD

13.1. Requalify the method at least once per year and when any of the following conditions occur:

13.1.1. The instrument has been significantly modified.

13.1.2. The instrument has been substantially repaired.

13.1.3. Substantial evidence indicates that the method is not providing data meeting the performance requirements.

13.1.4. The average of a Cement and Concrete Reference Laboratory (CCRL) proficiency test sample differs from the value obtained by the method by more than 6 percent.

14. PRECISION AND BIAS

14.1. *Precision*—No precision data are available at this time. Based on qualification requirements, the precision of the method should not be greater than that of Test Method A.

14.2. *Bias*—Since there are no acceptable reference materials suitable for determining any bias that may be associated with T 153, no statement on bias is presented.

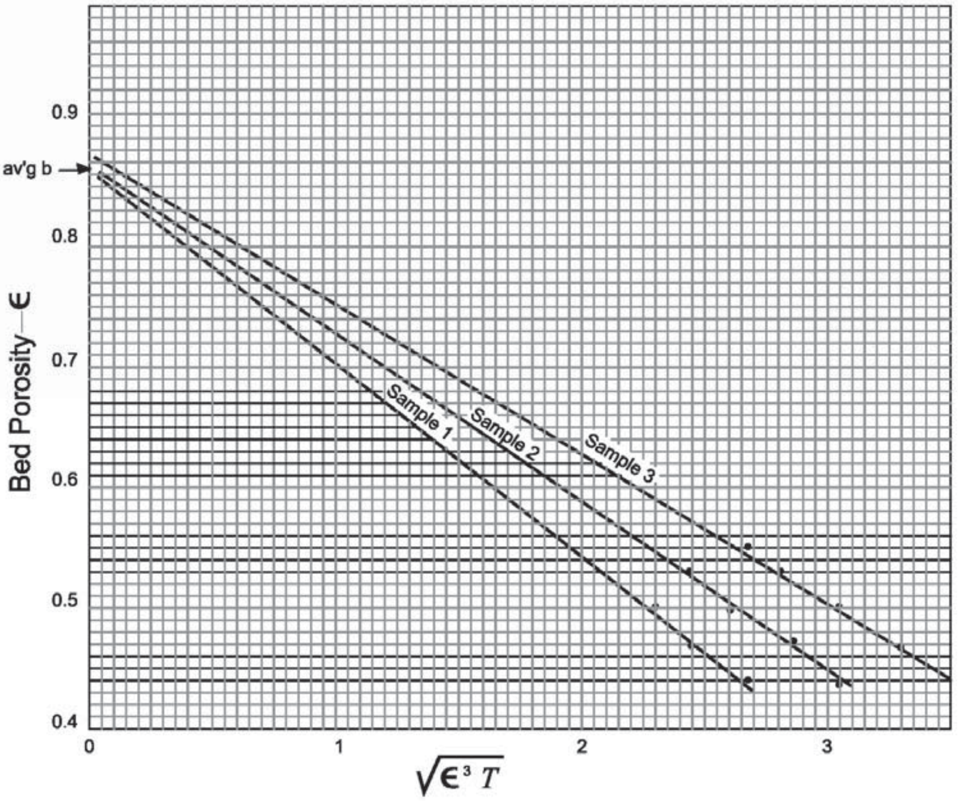
15. KEYWORDS

15.1. Air permeability; apparatus; fineness.

APPENDIX

(Nonmandatory Information)

X1. ILLUSTRATIVE METHOD FOR THE DETERMINATION OF THE VALUE FOR THE CONSTANT *B* (FOR USE IN FINENESS CALCULATIONS OF MATERIALS OTHER THAN PORTLAND CEMENT)



Material: Silica flour:

ρ = density of test sample = 2.65 Mg/m^3;

V = bulk volume of sample bed = 1.887 cm^3;

∈ = desired porosity of test;

W = grams of sample required = ρ*V* (1 – ∈); and

T = measured test time interval, seconds.

Computed values of *b* by linear regression:

Sample 1 *b* = 0.863 (correlation coefficient = 0.9980)

Sample 2 *b* = 0.869 (correlation coefficient = 0.9993)

Sample 3 *b* = 0.879 (correlation coefficient = 0.9973)

Average *b* = 0.870

Figure X1.1—Illustrative Method for the Determination of the Value for the Constant *b* (for use in fineness calculations of materials other than portland cement) (See Table X1.1.)

Table X1.1—Illustrative Method for the Determination of the Value for the Constant *b* (See Figure X1.1.)

$\in$	W	T	$\sqrt{\in^{3} T}$
Sample 1			
0.530	2.350	29.0	2.078
0.500	2.500	42.0	2.291
0.470	2.650	57.5	2.443
0.440	2.800	82.5	2.651
Sample 2			
0.530	2.350	39.0	2.410
0.500	2.500	55.5	2.634
0.470	2.650	79.0	2.864
0.440	2.800	108.5	3.040
Sample 3			
0.530	2.350	51.5	2.769
0.500	2.500	73.0	3.021
0.470	2.650	104.0	3.286
0.440	2.800	141.5	3.472

Table X1.2—Sample Qualification Results

Cement	Tests	Test Method A cm^2/g (m^2/kg)	Test Method B cm^2/g (m^2/kg)	Difference
A	1	3120 (312)	3130 (313)	
A	2	3130 (313)	3160 (316)	
A	3	3090 (309)	3140 (314)	
	Avg	3113 (311.3)	3143 (314.3)	30
	Range Max	40 (4)	30 (3)	
	4.0 % of Avg	1.3 % (Pass)	1.0 % (Pass)	
	Max Difference		(30 × 100)/3113 = or	
	2.7% of Test Method A Average		(30 × 100)/3113 =	0.9% (Pass)

Cement	Tests	Test Method A cm^2/g (m^2/kg)	Test Method B cm^2/g (m^2/kg)	Difference
B	1	4180 (418)	4160 (416)	
B	2	4030 (403)	4150 (415)	
B	3	4060 (406)	4210 (421)	
	Avg	4090 (409.0)	4173 (417.3)	83
	Range Max	150	60	
	4.0 % of Avg	3.7 % (Pass)	1.4 % (Pass)	
	Max Difference		(83 × 100)/4090 = or	2.0% (Pass)
	2.7% of Test Method A Average		(8.3 × 100)/409 =	

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[1] Available from National Institute of Standards and Technology (NIST), 1040 Bureau Dr., Stop 3460, Gaithersburg, MD 20899-3460.

[2] Available from British Standards Institute (BSI), 389 Chiswick High Road, London W4 4AL, U.K.

Standard Method of Test for

Time of Setting of Hydraulic Cement Paste by Gillmore Needles

AASHTO Designation: T 154-10
ASTM Designation: C 266-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Time of Setting of Hydraulic Cement Paste by Gillmore Needles

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1. SCOPE

1.1 This test method covers the determination of the time of setting of hydraulic-cement paste by means of the Gillmore needles.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

1.4 **Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure. The use of gloves, protective clothing, and eye protection is recommended. Wash contact area with copious amounts of water after contact. Wash eyes for a minimum of 15 minutes. Avoid exposure of the body to clothing saturated with the liquid phase of the unhardened material. Remove contaminated clothing immediately after exposure.

1.5 The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 201, Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- T 107, Autoclave Expansion of Hydraulic Cement
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 129, Normal Consistency of Hydraulic Cement
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2 *ASTM Standards*:

- C 219, Standard Terminology Relating to Hydraulic Cement
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- D 1193, Standard Specification for Reagent Water

3. TERMINOLOGY

3.1 Refer to ASTM C 219 for definitions of terms.

4. SUMMARY OF TEST METHOD

4.1 Sufficient water is added to the cement that is being tested to produce a paste of normal consistency. A specimen is molded from this paste and is tested for time of setting by means of the Gillmore initial and final needles. The initial time of setting is the time elapsed between initial contact of cement and water and the time when the Gillmore Initial needle does not leave a complete circular impression in the paste surface. The final time of setting is the time elapsed between initial contact of cement and water and the time when the Gillmore Final needle does not leave a complete circular impression in the paste surface.

5. SIGNIFICANCE AND USE

5.1 The purpose of this test method is to establish whether a cement complies with a specification limit on Gillmore time of setting.

6. APPARATUS

6.1 *Flat Trowel,* having a sharpened straightedged steel blade 100 to 150 mm in length. The edges, when placed on a plane surface, shall not depart from straightness by more than 1 mm.

6.2 *Mixer, Bowl, Paddle, and Scraper*—conforming to the requirements of T 162.

6.3 *Glass Graduates,* 200 or 250 mL capacity, conforming to the requirements of M 210.

6.4 *Mass Determining Devices,* conforming to the requirements of ASTM C 1005. The devices for determining mass shall be evaluated for precision and accuracy at a total load of 1000 g.

6.5 *Plane Non-Absorptive Plates,* 100 mm ± 5 mm (4 ± 0.197 in.) square, of similar planeness, corrosivity, and absorptivity to that of glass (see T 129, Figure 1, item H).

6.6 *Gillmore Needles,* conforming to the following requirements:

6.6.1 The initial time of setting needle shall have a mass of 0.250 ± 0.001 lb (113.4 ± 0.5 g) and a tip diameter of 0.084 ± 0.002 in. (2.12 ± 0.05 mm).

6.6.2 The final time of setting needle shall have a mass of 1.000 ± 0.001 lb (453.6 ± 0.5 g) and a tip diameter of 0.042 ± 0.002 in. (1.06 ± 0.05 mm).

6.6.3 The needle tips shall be cylindrical for a distance of 0.189 ± 0.020 in. (4.8 ± 0.5 mm). The needle ends shall be plane and at right angles to the axis of the rod and shall be maintained in a clean condition. (See Note 1.)

Note 1—The Gillmore needles should preferably be mounted as shown in Figure 1(b).

6.7 Inspect and document Section 6 apparatus for conformance to the requirements of this test method at least every $2^1/_2$ years.

7. REAGENTS

7.1 *Mixing Water*—Potable water is satisfactory for routine tests. For all referee and cooperative tests, reagent water conforming to the requirements of ASTM D 1193 for Type III or Type IV grade of reagent water shall be used.

8. SAMPLING

8.1 When the test is part of acceptance testing, sample the cement in accordance with T 127.

9. CONDITIONING

9.1 Maintain the temperature of the room, dry materials, paddle, bowl, and plane non-absorptive plates at 23.0 ± 3.0 ºC (73.4 ± 5.4ºF). Maintain the temperature of the mixing water at 23.0 ± 2.0ºC (73.4 ± 3.5ºF).

9.2 Maintain the relative humidity of the mixing room at not less than 50 percent.

9.3 The moist cabinet or moist room shall conform to the requirements of M 201.

10. PROCEDURE

10.1 *Preparation of Cement Paste*:

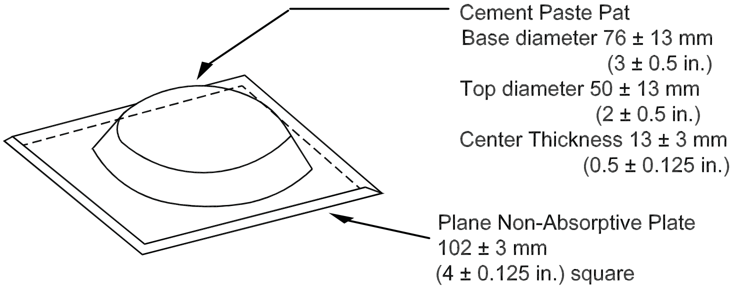
10.1.1 Obtain the cement paste used for determination of the time of setting from one of the following methods:

10.1.2 Prepare a new batch of paste by mixing 650 g of cement with the percentage of mixing water required for normal consistency (T 129), following the procedure described in T 162.

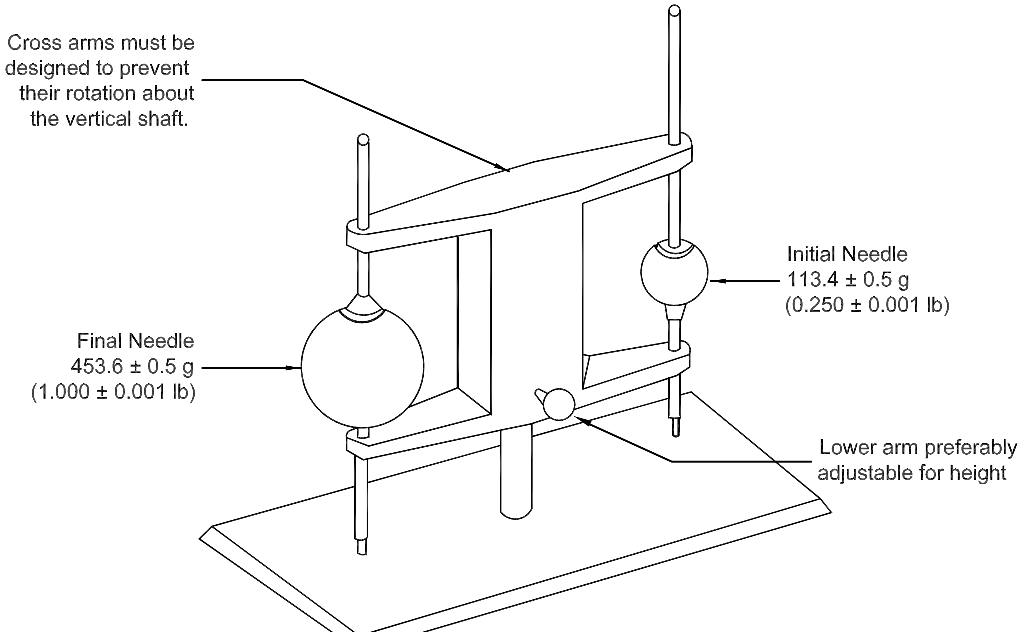
10.1.3 At the option of the tester, use the paste remaining from the batch used for the autoclave expansion specimen (T 107) or from the normal consistency determination (T 129).

10.2 *Molding Test Specimen*—From the cement paste prepared as described in Section 10.1, make a pat approximately 76 mm (3 in.) in diameter and approximately 13 mm (0.5 in.) in thickness at the center with a flat top and tapering to a thin edge (Figure 1(a)) on a clean *plane nonabsorptive plate*. In molding the pat, flatten the cement paste first on the glass and then form the pat by drawing the trowel from the outer edge toward the center, then flattening the top. After making, place the pat in the moist cabinet or moist room and allow it to remain there except when the determinations of time of setting are being made.

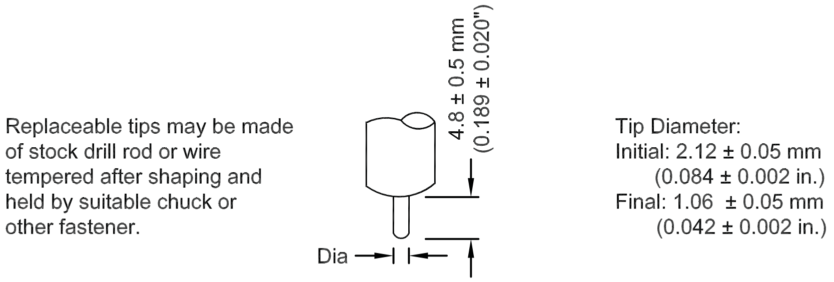
10.3 *Time of Setting Determination*—Determine the time of setting by holding the needle in a vertical position and lightly applying it to the surface of the pat.



(a) Pat with top surface flattened for determining time of setting by Gillmore Method



(b) Gillmore Apparatus



(c) Detail of Gillmore Apparatus Needle Tips

Figure 1—Gillmore Apparatus and Test Specimen

10.3.1 Using the Initial Gillmore needle, determine the Gillmore Initial time of setting end point to be the first penetration measurement that does not mark the specimen surface with a complete circular impression. Verify Initial set by obtaining two additional penetration measurements on different areas of the specimen surface. Verification measurements must be obtained within 90 s of the first "initial set" measurement. The elapsed time, in minutes, between the time of contact of cement and mixing water and the end point determined above is the Gillmore initial time of setting.

10.3.2 Using the Final Gillmore needle, determine the Gillmore Final time of setting end point to be the first penetration measurement that does not mark the specimen surface with a complete circular impression. Verify Final set by obtaining two additional penetration measurements on different areas of the specimen surface. Verification measurements must be obtained within 90 s of the first "final set" measurement. The elapsed time, in minutes, between the time of contact of cement and mixing water and the end point determined above is the Gillmore final time of setting.

11. REPORT

11.1 Report the time of setting, to the nearest 5 minutes, as follows:

- Initial Time of Setting, Gillmore—minutes.
- Final Time of Setting, Gillmore—minutes.

12. PRECISION AND BIAS

12.1 *Precision*—Gillmore Initial Time of Setting on samples testing is between 100 and 341minutes. (See Note 2.)

12.1.1 The single-operator (within laboratory) standard deviation has been found to be 16 minutes (1s); therefore, results of two properly conducted tests by the same operator on samples of the same cement should not differ from each other by more than 44 minutes (d2s) (1s and d2s are defined in ASTM C 670).

12.1.2 The multilaboratory standard deviation has been found to be 28 minutes (1s); therefore, results of two properly conducted tests from two different laboratories should not differ from each other by more than 78 minutes (d2s).

12.2 *Precision*—Gillmore Final Time of Setting on samples testing is between 239 and 561 minutes. (See Note 2.)

12.2.1 The single-operator (within laboratory) standard deviation has been found to be 22 minutes (1s); therefore, results of two properly conducted tests by the same operator on samples of the same cement should not differ from each other by more than 62 minutes (d2s).

12.2.2 The multilaboratory standard deviation has been found to be 46 minutes (1s); therefore, results of two properly conducted tests from two different laboratories on samples of the same cement should not differ by more than 129 minutes (d2s).

12.3 *Bias*:

12.3.1 Since an accepted reference material suitable for determining any bias of this method does not exist, no statement on bias is being made.

Note 2—These data are based upon CCRL Portland Cement round-robin test samples 47 to 138 and CCRL Masonry cement round-robin test samples 1 to 46.

13. KEYWORDS

13.1 Gillmore needles; hydraulic cement paste; time of setting.

Standard Method of Test for

Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

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AASHTO Designation: T 162-09
ASTM Designation: C 305-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

AASHTO Designation: T 162-09
ASTM Designation: C 305-06

1. SCOPE

1.1. This method covers the mechanical mixing of hydraulic cement pastes and mortars of plastic consistency.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standard*:

- C 778, Standard Specification for Standard Sand

3. SIGNIFICANCE AND USE

3.1. This method is intended for use in the mechanical mixing of pastes and mortars for the testing of hydraulic cements.

4. APPARATUS

4.1. *Mixer*—The mixer shall be an electrically driven mechanical mixer of the epicyclic type, which imparts both a planetary and a revolving motion to the mixer paddle. The mixer shall have a minimum of two speeds, controlled by definite mechanical means. (Rheostat adjustment of speed will not be acceptable.) The first, or slow, speed shall revolve the paddle at a rate of 140 ± 5 r/min, with a planetary motion of approximately 62 r/min. The second speed shall revolve the paddle at a rate of 285 ± 10 r/min, with a planetary motion of approximately 125 r/min. The electric motor shall be at least 124 W ($^1/_6$ hp). The mixer shall be equipped with a screw which is an integral part of the mixer or a clearance adjustment bracket as shown in Figure 1 (Note 1), which shall be used to maintain the clearance between the lower end of the paddle and the bottom of the bowl not greater than 2.5 mm but not less than 0.8 mm (the approximate diameter of a grain of 20 to 30 Ottawa sand) when the bowl is in the mixing position.

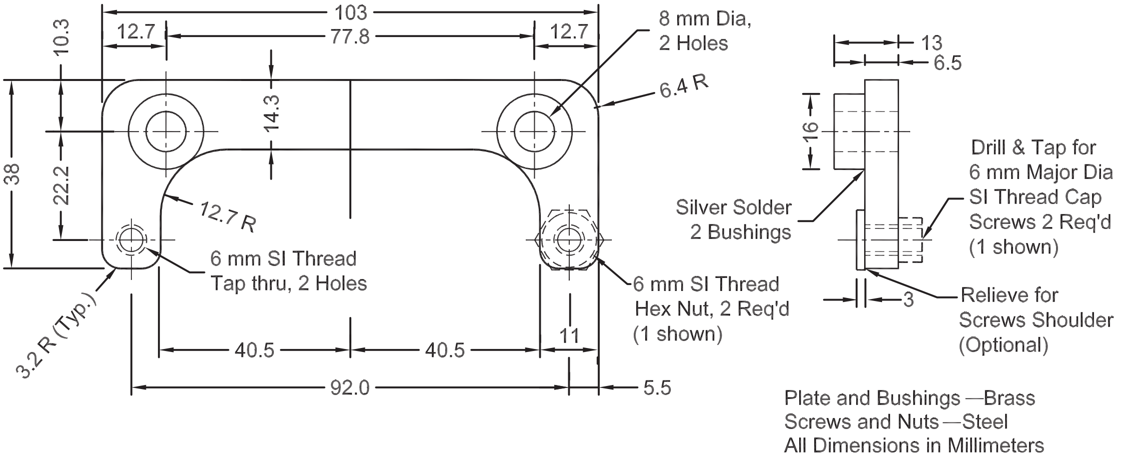
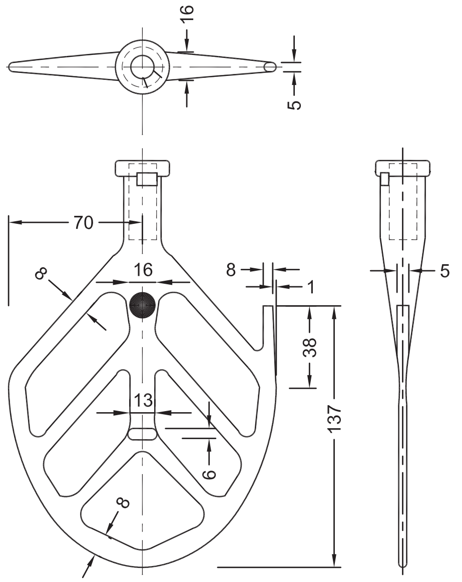


Figure 1—Clearance Adjustment Bracket

Note 1—When the bracket is in the proper position beneath the motor housing, the lugs are to the front and facing upward and the heads of the adjustment screws are to the rear and facing downward in the path of the sliding frame that holds the bowl. It is intended that the bracket be fastened at the front housing connection by inserting replacement screws of an appropriate size upward through the opening in each lug and into the existing threaded holes in the bottom of the motor housing. The original stops for the sliding frame are to be filed down if they prevent the frame from coming in contact with the adjustment screws.

Note 2—This is the approximate diameter of a grain of 20 to 30 sand as described in ASTM C 778.

4.2. *Paddle*—The paddle shall be readily removable, made of stainless steel, and shall conform to the basic design shown in Figure 2. The dimensions of the paddle shall be such that when in the mixing position, the paddle outline conforms to the contour of the bowl used with the mixer, and the clearance between corresponding points on the edge of the paddle and the side of the bowl in the position of closest approach shall be approximately 4.0 mm, but not less than 0.8 mm.



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 2—Paddle

4.3. *Mixing Bowl*—The removable mixing bowl shall have a nominal capacity of 4.73 L, shall be of the general shape and comply with the limiting dimensions shown in Figure 3, and shall be made of stainless steel. The bowl shall be so equipped that it will be positively held in the mixing apparatus in a fixed position during the mixing procedure. There shall be provided a lid, made of a nonabsorbing material not attacked by cement.

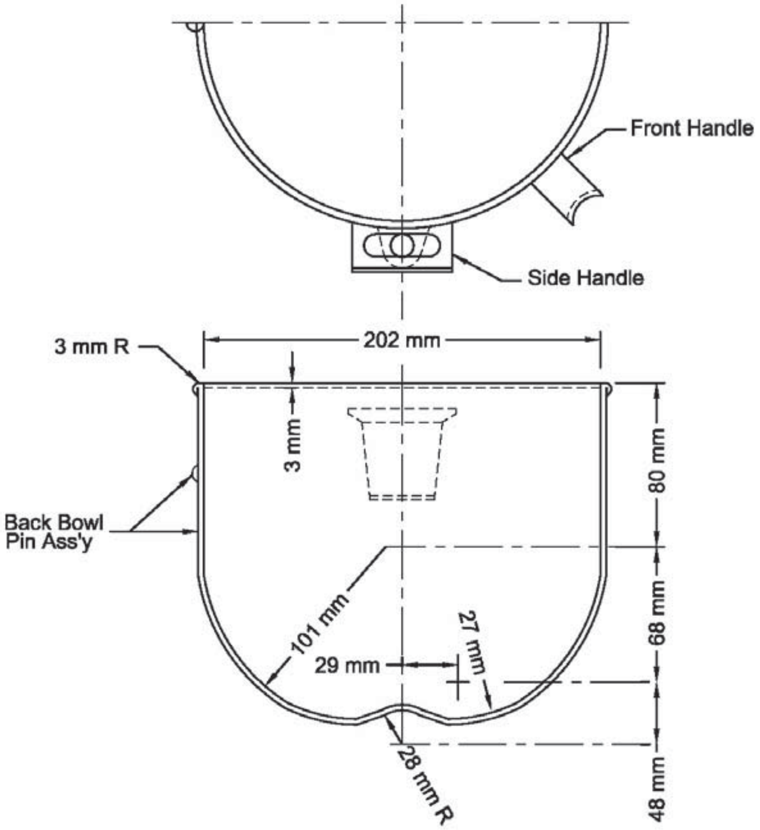


Figure 3—Mixing Bowl

4.4. *Scraper*—The scraper shall consist of a semirigid rubber blade attached to a handle about 150 mm long. The blade shall be about 75 mm long, 50 mm wide, and tapered to a thin edge about 2 mm thick.

Note 3—A kitchen tool known as a plate and bowl scraper conforms to these requirements.

4.5. *Supplementary Apparatus*—The balances, weights, glass graduates, and any other supplementary apparatus used in measuring and preparing the mortar materials prior to mixing shall conform to the respective requirements for such apparatus as specified in the method for the particular test for which the mortar is being prepared.

5. TEMPERATURE AND HUMIDITY

5.1. The temperature of the room shall be maintained between 20.0 and 27.5ºC (68.0 and 81.5ºF), and the temperature of the dry materials, paddle, and bowl shall be within the above range at the time of test. The temperature of the mixing water shall not vary from 23.0ºC (73.4ºF) by more than ±1.7ºC (3ºF).

5.2. The relative humidity of the laboratory shall not be less than 50 percent.

6. MATERIALS, PROPORTIONING, CONSISTENCY

6.1. The materials and their proportions and quantities shall conform to the requirements contained in the particular method for which the paste or mortar is being prepared.

7. PROCEDURE FOR MIXING PASTES

7.1. Place the dry paddle and the dry bowl in the mixing position in the mixer. Then introduce the materials for a batch into the bowl and mix in the following manner:

7.1.1. Place all the mixing water in the bowl.

7.1.2. Add the cement to the water and allow 30 seconds for the absorption of the water.

7.1.3. Start the mixer and mix at slow speed (140 ± 5 r/min) for 30 seconds.

7.1.4. Stop the mixer for 15 seconds and during this time scrape down into the batch any paste that may have collected on the side of the bowl.

7.1.5. Start the mixer at medium speed (285 ± 10 r/min) and mix for 60 seconds.

8. PROCEDURE FOR MIXING MORTARS

8.1. Place the dry paddle and the dry bowl in the mixing position in the mixer. Then introduce the materials for a batch into the bowl and mix in the following manner:

8.1.1. Place all the mixing water in the bowl.

8.1.2. Add the cement to the water; then start the mixer and mix at the slow speed (140 ± 5 r/min) for 30 seconds.

8.1.3. Add the entire quantity of sand slowly over a 30-second period, while mixing at slow speed.

8.1.4. Stop the mixer, change to medium speed (285 ± 10 r/min), and mix for 30 seconds.

8.1.5. Stop the mixer and let the mortar stand for 90 seconds. During the first 15 seconds of this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl; then for the remainder of this interval, close the mixer enclosure or cover the bowl with the lid.

8.1.6. Finish by mixing for 60 seconds at medium speed (285 ± 10 r/min).

8.1.7. In any case requiring a remixing interval, any mortar adhering to the side of the bowl shall be quickly scraped down into the batch with the scraper prior to remixing.

Note 4—Warning—The clearances between paddle and bowl specified in this method are suitable when using the standard mortar made with standard sand as described in ASTM C 778. To permit the mixer to operate freely and to avoid serious damage to the paddle and bowl when coarser aggregates are used, it may be necessary to set the clearance adjustment bracket to provide greater clearances than those specified in Section 4.1.

Standard Method of Test for

Early Stiffening of Hydraulic Cement (Mortar Method)

AASHTO Designation: T 185-09[1]
ASTM Designation: C 359-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Early Stiffening of Hydraulic Cement (Mortar Method)

AASHTO Designation: T 185-09[1]
ASTM Designation: C 359-08

1. SCOPE

1.1. This method covers the determination of early stiffening in hydraulic cement mortar.

1.2. The values stated in SI units are the standard. The values in parentheses are for information only.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4. **Warning**—Fresh hydraulic-cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure. The use of gloves, protective clothing, and eye protection is recommended. Wash contact area with copious amounts of water after contact. Wash eyes for a minimum of 15 minutes. Avoid exposure of the body to clothing saturated with the liquid phase of the unhardened material. Remove contaminated clothing immediately after exposure.

1.5. The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 129, Normal Consistency of Hydraulic Cement
- T 137, Air Content of Hydraulic Cement Mortar
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 778, Standard Specification for Standard Sand

- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements
- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 2251, Standard Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *early stiffening, n*—the early development of stiffness in the working characteristics of a hydraulic-cement paste, mortar, or concrete. Varieties include false set and flash set.

3.1.2. *false set, n*—the early development of stiffness in the working characteristics of a portland-cement paste, mortar, or concrete without the evolution of much heat, which stiffness can be dispelled and plasticity regained by further mixing without addition of water; also known as "grab set," "premature stiffening," "hesitation set," and "rubber set."

3.1.3. *flash set, n*—the early development of stiffness in the working characteristics of a hydraulic-cement paste, mortar, or concrete, usually with the evolution of considerable heat, which stiffness cannot be dispelled nor can the plasticity be regained by further mixing without addition of water; also known as "quick set."

4. SUMMARY OF TEST METHOD

4.1. A mortar is prepared with the cement to be tested, using specified quantities of cement, standard sand, and an amount of water that will produce a mortar with an initial penetration of 46 ± 3 mm, using the modified Vicat apparatus. Measurements of penetration are made at stipulated intervals after the beginning of the mixing procedure. Upon completion of the first series of penetration measurements, the mortar is returned to the mixer to be remixed. Following the remix procedure, an additional penetration, termed the remix penetration, is determined. The report is a tabulation of the penetration measurements and the amount of mixing water used.

5. SIGNIFICANCE AND USE

5.1. The purpose of this test method is to determine the degree to which a cement mortar develops early stiffening. It is intended for use by those interested in methods for determining the potential early stiffening of hydraulic cement.

5.2. When used for estimating the relative tendency of a cement to manifest early stiffening, a judgment may be made by comparing the behavior in the penetration series (Sections 10.4.1 and 10.4.2) and the remix procedure (Section 10.4.3) to differentiate a relatively less serious and less persistent tendency to early stiffening from one that is more persistent and, consequently, more serious (flash set).

5.3. Severe false setting in a cement may cause difficulty from a placing and handling standpoint, but it is not likely to cause difficulties where concrete is mixed for a longer time than usual, as usually occurs in transit mixing, or where it is remixed prior to placing or transporting, in concrete pumping operations. It is most likely noticed where concrete is mixed for a short period of time in stationary mixers and transported to the forms in nonagitating equipment, as on some paving jobs, and when concrete is made in an on-site batch plant.

5.4. Cements with severe false setting usually require slightly more mixing water to produce the same consistency, which may result in slightly lower strengths and increased drying shrinkage.

5.5. Early stiffening resulting from false set is not likely to cause a cement to fail the applicable time of setting requirement.

5.6. Early stiffening resulting from flash set, depending on severity, can cause a cement to fail the applicable time of setting requirement.

6. APPARATUS

6.1. *Vicat Apparatus,* conforming to the requirements of Figure 1 in T 129, with the following modifications:

6.1.1. The 1-mm needle shall be replaced by a mass, such that the total mass of the 10-mm plunger, indicator, and added mass shall be 400 ± 0.5 g.

6.2. *Spoon,* conforming to the requirement of T 137.

6.3. *Mixer, Bowl, Paddle, and Scraper,* conforming to the requirements of T 162.

6.4. *Glass Graduates,* 200- or 250-mL capacity, conforming to the requirements of ASTM C 1005.

6.5. *Masses and Mass Determining Devices,* conforming to the requirements of ASTM C 1005. The devices for determining mass shall be evaluated for precision and accuracy at a total load of 1000 g.

6.6. *Thermometer,* ASTM No. S12C or S12F, conforming to the requirements of ASTM E 2251.

6.7. *Flat Trowel,* having a sharpened straightedged steel blade 100 to 150 mm (4 to 6 in.) in length. The edges, when placed on a plane surface, shall not depart from straightness by more than 1 mm.

6.8. *Clock Timer*, having readability to the nearest second.

6.9. *Containers,* approximately 50 by 50 by 150 mm (2 by 2 by 6 in.) inside dimensions (Figure 1). These containers, which may be made of any suitable materials such as sheet metal or plastic, shall be rigid, watertight, and at least 50 mm (2 in.) deep.

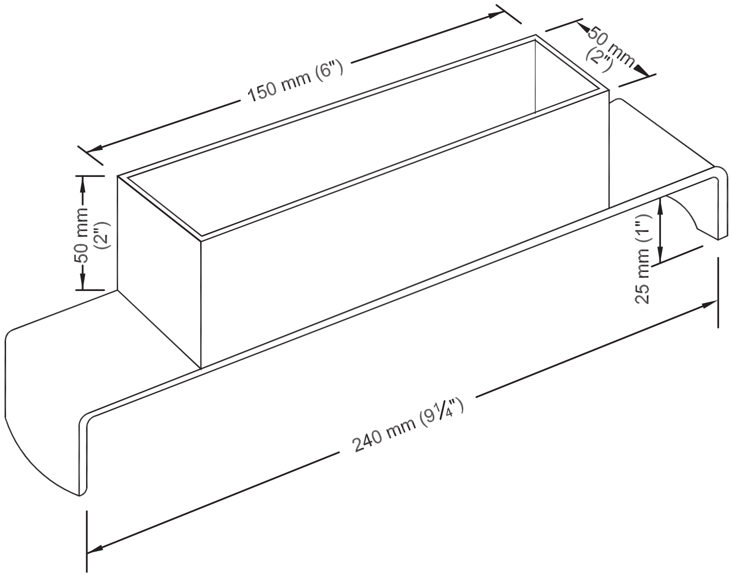


Figure 1—Container for Early Stiffening Test

7. REAGENTS AND MATERIALS

7.1. *Standard Sand*, *20-30 and Graded,* conforming to the requirements of ASTM C 778.

7.2. *Mixing Water*—Potable water is satisfactory for routine tests. For all referee and cooperative tests, reagent water conforming to the requirements of ASTM D 1193 for Type III or Type IV grades of reagent water shall be used.

8. SAMPLING

8.1. When the test is part of acceptance testing, sample the cement in accordance with T 129.

9. CONDITIONING

9.1. The temperature of the room, dry materials, paddle, bowl, and containers shall be maintained between 23.0 ± 3.0ºC (73.4 + 5.4ºF).

9.2. The relative humidity of the mixing room shall not be less than 50 percent.

10. PROCEDURE

10.1. *Batch*—Mix at one time 600 g of cement, 300 g of graded standard sand, 300 g of 20-30 standard sand, and an amount of water that produces a mortar with an initial penetration of 46 ± 3 mm.

10.2. *Mixing of Mortar*—Mix in the mechanical mixer as follows:

10.2.1. Place the sand and cement in the dry bowl, and mix the dry materials for a few seconds with the spoon.

10.2.2. Place the bowl in the mixer, set the paddle in place and mix the dry materials for 10 seconds at slow speed (140 ± 5 r/min).

10.2.3. With the mixer operating at slow speed (140 ± 5 r/min), add the entire quantity of mixing water within 5 seconds. Stop the mixer, quickly change to medium speed (285 ± 10 r/min), and continue the mixing for 1 minute, timing from the first addition of water.

10.2.4. Stop the mixer, scrape the sides of the mixing bowl with the rubber scraper, and quickly place the thermometer in the mortar. Allow it to stand undisturbed for the remainder of a 45-second interval from the time of stopping the mixer.

10.2.5. Read the temperature, remove the thermometer, start the mixer, and mix for 15 seconds at medium speed (285 ± 10 r/min). If the mortar temperature is not in the range from 23 ± 2.0ºC (73.4 ± 3.6ºF), discard the batch and adjust the temperature of the water or sand, or both, to give the required temperature.

10.3. *Filling Container*:

10.3.1. Immediately after completion of the mixing, remove the bowl from the mixer and with a spoon, uniformly distribute a portion of the mortar into the container until the container is heaping full. Quickly and gently place each spoonful of mortar in the container. When removing the mortar from the bowl, do not remove the material pushed up on the side of the bowl by the paddle. After the container has been filled, reassemble the mixer, cover the bowl with a lid, and retain the remaining mortar for a remix test to be performed later. To compact the mortar in the container, lift the container approximately 80 mm (3 in.) from the table with both hands and rap it twice against the surface of the table.

10.3.2. With the leading edge slightly raised, strike off the mortar with one stroke of the trowel along the length of the container. Then remove the excess mortar by means of a sawing motion with the straight edge of the trowel along the length of the container in a direction opposite to that used in striking off. Then, smooth the surface of the mortar with a single stroke of the trowel.

10.4. *Penetration Tests*:

10.4.1. After filling the container, immediately place the 10-mm plunger of the Vicat apparatus in contact with the surface of the mortar at the midpoint of the container on the longitudinal center line. Set the movable indicator at zero. Release the plunger 3 minutes after the beginning of the wet mixing and record, as the initial penetration, the depth in millimeters to which the plunger has settled below the surface 10 seconds after being released. If the plunger does not settle to a depth of 46 ± 3 mm, discard the batch and adjust the quantity of water to produce the required consistency.

10.4.2. Immediately withdraw and clean the plunger. In a similar manner, determine, after moving the Vicat apparatus to the desired location, the penetrations at intervals of 5, 8, and 11 minutes after the beginning of mixing. Do not move the filled container until these measurements are completed. Make all penetrations along the longitudinal center line of the container. Obtain 5- and 8-minute penetrations at a distance of approximately 40 mm ($1^1/_2$ in.) from each end of the container, respectively, and determine the 11-minute penetration at a point approximately midway between the points at which the initial and 5-minute penetrations were determined.

10.4.3. At the completion of the measurement of the 11-minute penetration, immediately return the mortar in the container to the bowl. Start the mixer, raise the bowl into mixing position, and remix the contents of the bowl at medium speed (285 ± 10 r/min) for one minute. Fill a clean container as outlined in Sections 10.3.1 and 10.3.2, and determine the penetration 45 seconds after completion of mixing.

11. CALCULATION

11.1. *Early Stiffening Amount*—The change in penetration from the initial penetration to the 11-min penetration.

11.1.1. Calculate as follows:

$$A - D$$

where:

A = Initial Penetration,
B = Penetration at 5 min,
C = Penetration at 8 min,
D = Penetration at 11 min, and
E = Penetration after Remix.

11.1.2. Report to the nearest mm.

11.2. *Average Early Stiffening Rate*—An average of the rate penetration change between each set of measurements.

11.2.1. Calculate as follows:

$$\frac{\frac{A-B}{2}+\frac{B-C}{3}+\frac{C-D}{3}}{3}$$

where:

A = Initial Penetration,
B = Penetration at 5 min,
C = Penetration at 8 min, and
D = Penetration at 11 min.

11.2.2. Report to the nearest 0.1 mm/mm.

11.3. *Early Stiffening Recovery*—The percent penetration recovery accomplished with the REMIX procedure.

11.3.1. Calculate as follows:

$$100 \times \frac{E}{A}$$

where:

E = Penetration after Remix, and
A = Initial Penetration.
(See Note 1.)

Note 1—Since it is possible for the remix penetration to exceed the initial penetration, this number may exceed 100 percent.

11.3.2. Report to the nearest percent.

12. REPORT

12.1. The report shall show the depths of the penetration as follows in Table 1:

Table 1—Penetration Report

Mixing Water	_________	mL
Initial penetration	_________	mm
5-minute penetration	_________	mm
8-minute penetration	_________	mm
11-minute penetration	_________	mm
Remix penetration	_________	mm
Early Stiffening Amount	_________	mm
Average Early Stiffening Rate	_________	mm/min
Early Stiffening Recovery	_________	percent

13. PRECISION AND BIAS

13.1. Interlaboratory test data for the determination of statements of precision and bias in accordance with ASTM C 670 are being evaluated by ASTM subcommittee C01.30. Statements of precision and bias will be included in a later revision of this test method.

14. KEYWORDS

14.1. Early stiffening; false set; flash set; hydraulic cement mortar.

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[1] Except for the section on Precision and Bias, this method agrees with ASTM C 359-08.

Standard Method of Test for

Early Stiffening of Hydraulic Cement (Paste Method)

AASHTO Designation: T 186-09[1]
ASTM Designation: C 451-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Early Stiffening of Hydraulic Cement (Paste Method)

AASHTO Designation: T 186-09[1]
ASTM Designation: C 451-08

1. SCOPE

1.1. This test method covers the determination of early stiffening in hydraulic cement paste.

1.2. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3. *This standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic-cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure. The use of gloves, protective clothing, and eye protection is recommended. Wash contact area with copious amounts of water after contact. Wash eyes for a minimum of 15 minutes. Avoid exposure of the body to clothing saturated with the liquid phase of the unhardened material. Remove contaminated clothing immediately after exposure.

1.4. The text of this standard references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 210, Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
- T 127, Sampling and Amount of Testing of Hydraulic Cement
- T 129, Normal Consistency of Hydraulic Cement
- T 162, Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.2. *ASTM Standards*:

- C 219, Standard Terminology Relating to Hydraulic Cement
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- C 1005, Standard Specification for Reference Masses and Devices for Determining Mass and Volume for Use in the Physical Testing of Hydraulic Cements

- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *early stiffening, n*—the early development of stiffness in the working characteristics of a hydraulic cement paste, mortar, or concrete; varieties include false set and flash set.

3.1.2. *false set, n*—the early development of stiffness in the working characteristics of a hydraulic cement paste, mortar, or concrete without the evolution of much heat, which stiffness can be dispelled and plasticity regained by further mixing without addition of water; also known as "grab set," "premature stiffening," "hesitation set," and "rubber set."

3.1.3. *flash set, n*—the early development of stiffness in the working characteristics of a hydraulic cement paste, mortar, or concrete, usually with the evolution of considerable heat, which stiffness cannot be dispelled nor can the plasticity be regained by further mixing without addition of water; also known as "quick set."

3.1.4. Refer to ASTM C 219 for definitions of other terms.

4. SUMMARY OF TEST METHOD

4.1. A paste is prepared with the cement to be tested, using sufficient water to give a required initial penetration as measured by the Vicat apparatus at a stipulated time after completion of mixing. A second penetration, termed the final penetration, is measured at a later stipulated time. The ratio of final penetration to initial penetration is calculated as a percentage.

5. SIGNIFICANCE AND USE

5.1. The purpose of this test method is to determine the degree to which a cement paste develops early stiffening or to establish whether or not a cement complies with a specification limit on early stiffening.

5.2. When used for establishing compliance with a specification limit, the specification requirement is customarily stated in terms of the minimum allowable final penetration, in percent, calculated in accordance with Section 11, Calculation. When used for estimating the relative tendency of a cement to manifest early stiffening, additional information of value may be obtained if the remix procedure described in the Section 10, Procedure, is employed. Under some conditions, a judgment may be made by comparing the behavior in the initial test and in the remix procedure to differentiate a relatively less serious and less persistent tendency to early stiffening (false set) from one that is more persistent and, consequently, more serious (flash set).

5.3. Severe false setting in a cement may cause difficulty from a placing and handling standpoint, but it is not likely to cause difficulties where concrete is mixed for a longer time than usual, as usually occurs in transit mixing, or where it is remixed prior to placing or transporting, as occurs in concrete-pumping operations. It is most likely to be noticeable where concrete is mixed for a short period of time in stationary mixers and transported to the forms in nonagitating equipment, such as on some paving jobs, and when concrete is made in an on-site batch plant.

5.4. Cements with severe false setting usually require slightly more water to produce the same consistency, which may be expected to result in slightly lower strengths and increased drying shrinkage.

5.5. Early stiffening resulting from false set is not likely to cause a cement to fail the applicable time of setting requirement.

5.6. Early stiffening resulting from flash set, depending on severity, can cause a cement to fail the applicable time of setting requirement.

6. APPARATUS

6.1. *Vicat Apparatus,* conforming to the requirements of T 129.

6.2. *Flat Trowel,* having a sharpened straightedge steel blade 100 to 150 mm (4 to 6 in.) in length. The edges when placed on plane surface shall not depart from straightness by more than 1 mm.

6.3. *Mixer, Bowl, Paddle, and Scraper,* conforming to the requirements of T 162.

6.4. *Glass Graduates,* 200- or 250-mL capacity, conforming to the requirements of ASTM C 1005.

6.5. *Masses and Mass Determining Devices,* conforming to the requirements of ASTM C 1005. The devices for determining mass shall be evaluated for precision and accuracy at a total load of 1000 g.

6.6. *Conical Ring*, made of rigid, non-corroding, nonabsorbent material, having a height of 40 ± 1 mm, an inside diameter at the bottom of 70 ± 3 mm, and an inside diameter at the top of 60 ± 3 mm (see T 129, Figure 1, item G).

6.7. *Plane Non-Absorptive Plate*, 100 ± 5 mm square, of similar planeness, corrosivity, and absorptivity to that of glass (see T 129, Figure 1, item H).

6.8. Inspect and document Section 6 apparatus for conformance to the requirements of this test method at least every 2 ½ years.

7. REAGENTS

7.1. *Mixing Water*—Potable water is satisfactory for routine tests. For all referee and cooperative tests, use reagent water conforming to the requirements of ASTM D 1193 for Type III or Type IV grades of reagent water.

8. SAMPLING

8.1. When the test is part of acceptance testing, sample the cement in accordance with T 127.

9. CONDITIONING

9.1. Maintain the temperature of the room, dry materials, paddle, bowl, conical ring, and base plate at 23.0 ± 3.0°C. Maintain the temperature of the mixing water at 23.0 ± 2.0°C.

9.2. Maintain the relative humidity of the mixing room at no less than 50 percent.

10. PROCEDURE

10.1. *Preparation of Cement Paste*—Mix 500 g of cement with sufficient water to produce a paste with an initial penetration of 32 ± 4 mm using the following procedure:

10.1.1. Place the dry paddle and the dry bowl in the mixing position in the mixer.

10.1.2. Introduce the materials for a batch into the bowl and mix in the following manner:

10.1.2.1. Place all the mixing water in the bowl.

10.1.2.2. Add the cement to the water and allow 30 seconds for the water to absorb.

10.1.2.3. Start the mixer and mix at a slow speed (140 ± 5 r/min) for 30 seconds.

10.1.2.4. Stop the mixer for 15 seconds and during this time scrape down into the batch any paste that may have collected on the sides of the bowl.

10.1.2.5. Start the mixer at a medium speed (285 ± 10 r/min) and mix for $2^1/_2$ minutes.

10.2. *Molding Test Specimens*—Quickly form the cement paste into a ball with gloved hands. Press the ball, resting in the palm of one hand, into the larger end of the conical ring held in the other hand, completely filling the ring with paste. Remove the excess at the larger end by a single movement of the palm of the hand. Place the ring on its larger end on the non-absorptive plate, *H*, and slice off the excess paste at the smaller end at the top of the ring by a single oblique stroke of a sharp-edged trowel held at a slight angle with the top of the ring. Smooth the top of the specimen, if necessary, with one or two light touches of the pointed end of the trowel. During the operation of cutting and smoothing, take care not to compress the paste.

10.3. *Determination of Initial Penetration*—Set the paste confined in the ring resting on the plate, *H*, under the rod, *B*, Figure 1 of T 129, about one-third of the diameter from the edge, and bring the plunger end, *C,* in contact with the surface of the paste and the tightened setscrew, *E*. Then set the movable indicator, *F*, to the upper zero mark of the scale, and release the rod exactly 20 seconds after completion of the mixing. Keep the apparatus free of all vibrations during the penetration test. Consider the paste to have proper consistency when the rod settles to a point 32 ± 4 mm below the original surface in 30 seconds after being released. Make trial pastes with varying percentages of water until this consistency is obtained. This consistency is the initial penetration. During the 30-second interval for the initial penetration, return the excess paste to the bowl and cover the bowl and mixing paddle with a lid.

10.4. *Determination of Final Penetration*—After completion of the initial reading, remove the plunger from the paste, clean it, and reset the ring and plate in a new position. Perform this operation with as little disturbance as possible to the paste confined in the Vicat ring. Then bring the plunger again in contact with the surface of the paste, tighten the set screw, and set the movable indicator to the upper zero mark of the scale. Release the plunger a second time 5 minutes (± 10s) after completion of the mixing period; determine the final penetration 30 seconds after the plunger is released.

10.5. *Determination of Remix Penetration*—If the penetrations determined by the foregoing procedure show the cement to be stiffening rapidly, at the option of the tester, obtain information as to the nature of the stiffening by testing as follows:

10.5.1. After completing the measurement of the 5-minute penetration, immediately return the paste in the ring to the bowl.

10.5.2. Start the mixer, raise the bowl into mixing position, and remix the contents of the bowl at a medium speed (285 ± 10 r/min) for 60 seconds.

10.5.3. Fill the ring and determine the penetration following the procedures specified in Sections 10.2 and 10.3.

11. CALCULATION

11.1. Calculate the percent final penetration, based on the ratio of final penetration to initial penetration, as follows:

$$P, \% = \frac{B}{A} \times 100 \qquad (1)$$

where:

P = percent final penetration;

B = final penetration, mm; and

A = initial penetration, mm.

12. REPORT

12.1. Report the results of the test as follows in Table 1:

Table 1—Early Stiffening Report

Initial penetration	_________ mm
Final penetration	_________ mm
Percent final penetration	_________ %
Remix penetration	_________ mm

13. PRECISION AND BIAS

13.1. *Precision*:

13.1.1. On samples testing between 8 percent and 89 percent Paste False Set, the single-operator (within laboratory) standard deviation has been found to be 10 percent (1s), therefore, results of two properly conducted tests by the same operator on samples of the same cement should not differ from each other by more than 28 percent (1s and d2s are defined in ASTM C 670).

13.1.2. On samples testing between 8 percent and 89 percent Paste False Set, the multilaboratory standard deviation has been found to be 12 percent (1s); therefore, results of two properly conducted tests from two different laboratories on samples of the same cement should not differ by more than 34 percent (1s and d2s are defined in ASTM C 670). (See Note 1.)

13.2. *Bias*:

13.2.1. Since an acceptable reference material suitable for determining any bias of this method does not exist, no statement on bias is being made.

Note 1—These data are based upon CCRL portland cement round robin test samples 47 to 138. The data indicate that precision decreases as the false set values fall below approximately 60 percent. These decreases are not clearly statistically significant; however, they do indicate the duplication difficulties on cements that exhibit false set tendencies severe enough to fail or possibly fail specification M 85 optional limits.

14. KEYWORDS

14.1. Early stiffening; false set; flash set; hydraulic cement paste; Vicat.

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[1] Except for the use of SI units, this method agrees with ASTM C 451-08.

Standard Method of Test for

Evaluation by Freezing and Thawing of Air-Entraining Additions to Hydraulic Cement

AASHTO Designation: T 188-05 (2009)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Evaluation by Freezing and Thawing of Air-Entraining Additions to Hydraulic Cement

AASHTO Designation: T 188-05 (2009)

1. SCOPE

1.1. This method is intended for use in determining the ability of cement containing an air-entraining agent to produce frost-resistant concrete when tested in accordance with the procedures described below.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 240, Blended Hydraulic Cement
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 161, Resistance of Concrete to Rapid Freezing and Thawing

2.2. *ASTM Standard*:

- C 215, Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens

3. APPARATUS

3.1. *Molds and Tamping Rod*—The molds and tamping rods shall be as specified in R 39.

3.2. *Freezing and Thawing Apparatus*—The freezing and thawing apparatus shall be as specified in T 161, Procedure A or B.

3.3. *Dynamic Testing Apparatus*—The dynamic testing apparatus shall be as specified in ASTM C 215.

4. AGGREGATES

4.1. The fine and coarse aggregates used in making the concrete specimens shall conform to the requirements of M 6 and M 80, respectively, and shall be the laboratory standards for the intended use (concrete) of the department or agency that will use the cement under test. These aggregates shall be of such a quality that they will not cause concrete (as described in this method) containing them to show a durability factor of less than 80 after 200 cycles of freezing and thawing, if the concrete is made with a paste that is protected against frost damage by an adequate system of air voids.

4.1.1. *Fine Aggregate*—The fine aggregates shall be graded as follows:

Sieve Designation		Mass Percent Passing
mm	No.	
4.75	4	100
2.36	8	85 plus or minus 3
1.18	16	65 plus or minus 5
0.600	30	45 plus or minus 5
0.300	50	21 plus or minus 2
0.150	100	7 plus or minus 5

4.1.2. *Coarse Aggregate*—The coarse aggregates shall be graded as follows:

Sieve Designation		Mass Percent Passing
mm	in.	
19.0	$^3/_4$	100
12.5	$^1/_2$	66 plus or minus 3
9.5	$^3/_8$	33 plus or minus 3
4.75	No. 4	0–3

5. CONCRETE MIXTURE

5.1. A concrete mixture, using cement containing the air-entraining agent in an amount such that the cement meets the requirements of M 85 or M 240 for air-entraining cements. shall be proportioned to have an actual cement content of 335 ± 2.8 kg/m^3 (564 ± 5 lb/yd^3). The water content of the mixtures shall be adjusted to provide a slump of 63.5 ± 12.7 mm ($2^1/_2 \pm {}^1/_2$ in.). The ratio of fine aggregate to total aggregate shall be adjusted to the optimum for concrete to be consolidated by hand rodding. Recommended values for the percentage of fine aggregate in the total aggregate by absolute volume are: for angular coarse aggregate, 41; for rounded coarse aggregate, 36. If other admixtures are to be used in the intended concrete application, they shall be included in the concrete mixture.

5.1.1. The concrete shall be machine mixed according to the applicable provisions of R 39.

6. SPECIMENS AND PROCEDURE

6.1. The specimens and testing procedure shall be as described in T 161, Procedure A or B. For this test the dimensions of the specimens shall be either 75 × 105 × 405 mm (3 × 4 × 16 in.) or 90 × 115 × 405 mm ($3^1/_2 \times 4^1/_2 \times 16$ in.). The testing shall be continued until the specimens have been subjected to 200 cycles or until the relative modulus of each specimen reaches 80 percent of the initial modulus, whichever occurs first.

Standard Method of Test for

Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve

AASHTO Designation: T 192-99 (2007)
ASTM Designation: C 430-96

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve

AASHTO Designation: T 192-99 (2007)
ASTM Designation: C 430-96

1. SCOPE

1.1. This test method covers the determination of the fineness of hydraulic cement by means of the 45-µm (No. 325) sieve.

1.2. The values stated in SI units are to be regarded as the standard. The inch-pound equivalents of SI units may be approximate.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:
- M 92, Wire-Cloth Sieves for Testing Purposes

2.2. *ASTM Standards*:
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 161, Standard Specification for Precision Electroformed Sieves
- E 177, Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods

3. APPARATUS

3.1. *Sieve*:

3.1.1. *Sieve Frame*—The sieve frame shall be of metal not subject to corrosion by water and shall be circular either 51 ± 6 mm (2.0 in. ± 0.25 in.) when woven-wire cloth is mounted in the frame or to 76 ± 6 mm (3.0 ± 0.25 in.) in diameter when an electroformed sheet is mounted in the frame. The depth of the sieve from the top of the frame to the cloth or sheet shall be 76 ± 6 mm (3.0 in. ± 0.25 in.). The frame shall have either side walls of 89 ± 6 mm (3.5 ± 0.25 in.) in total height, or legs at least to 12.0 mm (0.5 in.) in length, sufficient to allow air circulation beneath the sieve cloth or electroformed sheet.

3.1.2. *Sieve Cloth or Electroformed Sheet*—The sieve frame shall be fitted with either a 45-µm (No. 325) stainless steel AISI Type 304 woven-wire sieve cloth, conforming to the requirements of M 92 or a 45-µm electroformed reinforced nickel sieve sheet conforming to the requirements of ASTM E 161 with the exception that the number of openings shall be 71 ± 2 per linear centimeter (180 ± 5 per linear in.).

3.1.3. *Cloth or Sheet Mounting*:

3.1.3.1. *Woven-Wire Cloth Mounting*—Type 304 stainless steel woven-type cloth shall be mounted in the frame without distortion, looseness, or wrinkling. For a sieve fabricated by soldering the cloth to the frame, the joint shall be made smooth to prevent the cement from catching in the joints between the sieve cloth and the frame. Two-piece sieves shall clamp tightly on the cloth to prevent the cement from catching in the joints between the sieve cloth and the frame.

3.1.3.2. *Electroformed Sieve Sheet Mounting*—Electroformed reinforced nickel sieve sheet shall be mounted in the frame without distortion, looseness, or wrinkling. The joint between the sieve cloth and the frame shall be made smooth with a material impervious to water.

3.2. *Spray Nozzle*—The spray nozzle (Figure 1) shall be constructed of metal not subject to corrosion by water and shall be to 17.5 mm (0.69 in.) in inside diameter with a central hole drilled in line with the longitudinal axis, an intermediate row of eight holes drilled 6 mm (0.23 in.) center-to-center at an angle of 5 degrees from the longitudinal axis, and an outer row of eight holes drilled center-to-center at an angle of 10 degrees from the longitudinal axis. All holes shall be to 0.5 mm (0.02 in.) in diameter. The spray nozzle shall be checked at least every 6 months to ensure that the flow rate is between 1500 and 3000 g/min at 69 ± 3 kPa (10 ± 0.4 psi).

3.3. *Pressure Gauge*—The pressure gauge shall be 76 mm (3 in.) minimum diameter, and shall be graduated in 7 kPa (1 psi) increments, and shall have a maximum capacity of 207 kPa (30 psi). The accuracy at 69 kPa (10 psi) shall be ± 2 kPa (0.25 psi).

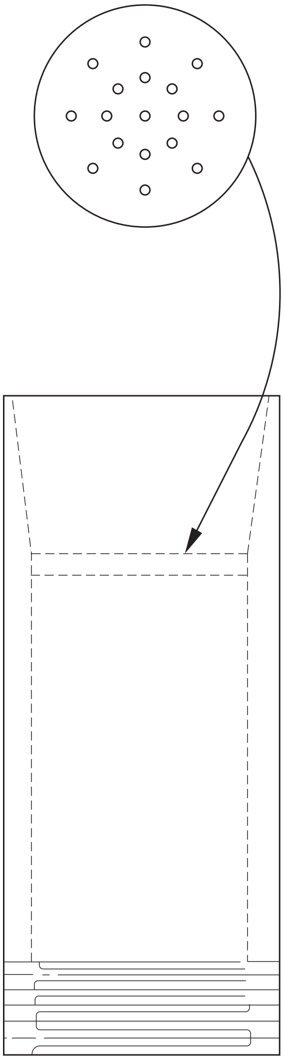

Figure 1—Spray Nozzle with Seventeen 0.5-mm (0.02-in.) Holes

4. CALIBRATION OF 45-μM (NO. 325) SIEVE

4.1. Place 1.000 g of the current lot of National Institute of Standards and Technology standard sample No. 114 on the clean, dry, 45-μm (No. 325) sieve and proceed as in Section 5. The sieve correction factor is the difference between the test residue obtained and the assigned residue value indicated by the electroformed sheet sieve fineness specified for the standard sample, expressed as a percentage of the test residue.

Note 1—It should be observed that the sieve correction as specified is a factor to be multiplied by the residue obtained and that the amount to be added to or subtracted from the residue in any given test is therefore proportional to the amount of residue.

Table 1—Example of Determination of Sieve Correction Factor

Residue on 45-µm (No. 325) Sieve, Sample No. 114	=	12.2%
Residue for a 1-g sample	=	0.122 g
Residue on sieve being calibrated	=	0.093 g
Difference	=	+ 0.029 g
Correction factor = 0.029/0.093 × 100 = +31.18	=	31.2%

5. PROCEDURE

5.1. Place a 1.000 g sample of the cement on the clean, dry 45-µm (No. 325) sieve. Wet the sample thoroughly with a gentle stream of water. Remove the sieve from under the nozzle and adjust the pressure on the spray nozzle to 69 ± 4 kPa (10 ± 0.5 psi). Return the sieve to its position under the nozzle and wash for 1 minute, moving the sieve with a circular motion in a horizontal plane at the rate of one motion per second in the spray. The bottom of the spray nozzle should extend below the top of the sieve frame about 12 mm (0.5 in.). Immediately upon removing the sieve from the spray, rinse once with about 50 cm^3 of distilled or deionized water, using caution not to lose any of the residue, and then blot the lower surface gently upon a damp cloth. Dry the sieve and residue in an oven or over a hot plate (Note 2), supporting the sieve in such a manner that air may pass freely beneath it. Cool the sieve; then brush the residue from the sieve and weigh on an analytical balance capable of reproducing results within 0.0005 g.

Note 2—Care should be taken not to heat the sieve hot enough to soften the solder.

6. CLEANING OF 45-µM (NO. 325) SIEVES

6.1. *Frequency of Cleaning and Calibration*—Sieves fitted with woven wire sieve cloth shall be cleaned after no more than five determinations. Sieves fitted with an electroformed reinforced sieve sheet having 71 openings per linear centimeter shall be cleaned after no more than three determinations. Both types of sieves shall be recalibrated after no more than 100 determinations.

6.2. *Acceptable Cleaning Procedures*—One option for cleaning is to place the sieve in a low-power (150 W maximum power input) ultrasonic bath containing an appropriate laboratory cleaning solution. The bath is to be operated for sufficient time (approximately 10 to 15 minutes at room temperature) to remove particles lodged in the openings. Be apprised that electroformed sieve sheets containing more than 71 openings per linear centimeter may well be damaged by ultrasonic cleaning. An option for cleaning that does not require an ultrasonic bath can also be employed. Immerse the sieve in a bath of appropriate laboratory cleaning solution heated to just below boiling point. Cover with a watch glass to reduce evaporation. Continue this soaking for a time sufficient to loosen lodged particles with a rinse following the bath. Overnight soaking in similar but unheated cleaning solutions is also acceptable, provided a rinse following the bath is able to wash away lodged particles. Cleaning or rinsing with dilute hydrochloric or acetic acid solutions is to be avoided. Appropriate cleaning solutions are restricted to soap or detergent-type solutions.

7. CALCULATION

7.1. Calculate the fineness of the cement to the nearest 0.1 percent as follows:

$$R_c = R_s \times (100 + C) \tag{1}$$

$$F = 100 - R_c \tag{2}$$

where:

F = fineness of the cement expressed as the corrected percentage passing the 45-µm (No. 325) sieve;

R_c = corrected residue, percent;

R_s = residue from the sample retained on the 45-µm (No. 325) sieve, g; and

C = sieve correction factor (determined as prescribed in Section 4) which may be either plus or minus.

Table 2—Example of Determination of Sieve Correction Factor

Sieve correction factor, C	= +31.2%
Residue from sample being tested, R_s	= 0.088 g
Corrected residue, R_c	= 0.088 × (100 + 31.2)
	= 11.5%
Corrected amount passing, F	= 100 – 11.5%
	= 88.5%

8. PRECISION AND BIAS

8.1. *Normal-Fineness Product*—The multilaboratory precision has been found to be ±0.75 percent (1s) as defined in ASTM E 177; therefore, results of properly conducted tests from two different laboratories on identical samples of cement should agree 95 percent of the time within ±2.1 percent.

8.2. *High-Fineness Product*—The multilaboratory precision has been found to be ±0.50 percent (1s) as defined in ASTM E 177; therefore, results of properly conducted tests from two different laboratories on identical samples of cement should agree 95 percent of the time within ±1.4 percent.

Note 3—The use of outside threads instead of inside threads as shown in Figure 1 is permissible.

8.3. Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is being made.

9. KEYWORDS

9.1. Fineness of hydraulic cement.

Standard Method of Test for

Determining the Shear Strength at the Interface of Bonded Layers of Portland Cement Concrete

AASHTO Designation: T 323-03 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Shear Strength at the Interface of Bonded Layers of Portland Cement Concrete

AASHTO Designation: T 323-03 (2007)

1. SCOPE

1.1. This test method covers the determination of the interface shear strength of a drilled concrete core sampled from a bonded concrete overlay pavement or bridge deck.

1.2. This test shall be performed on 100-mm (4-in.) diameter cores of portland cement concrete.

1.3. This test is applicable if, when retrieved by coring, the concrete overlay thickness is at least 25 mm (1 in.) and the thickness of the base concrete is at least 50 mm (2 in.).

1.4. This test procedure is based on the Iowa Department of Transportation Test Method No. Iowa 406-B (1984).

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 22, Compressive Strength of Cylindrical Concrete Specimens

2.2. *Other Documents*:

- Iowa Test Method No. 406-B, Method of Test for Determining the Shearing Strength of Bonded Concrete, Iowa Department of Transportation, 1984.

3. SUMMARY OF METHOD

3.1. This method consists of applying a continuous load to the vertical diametral plane of the test specimen along the bonded interface between the overlay concrete and base concrete (Figure 1).

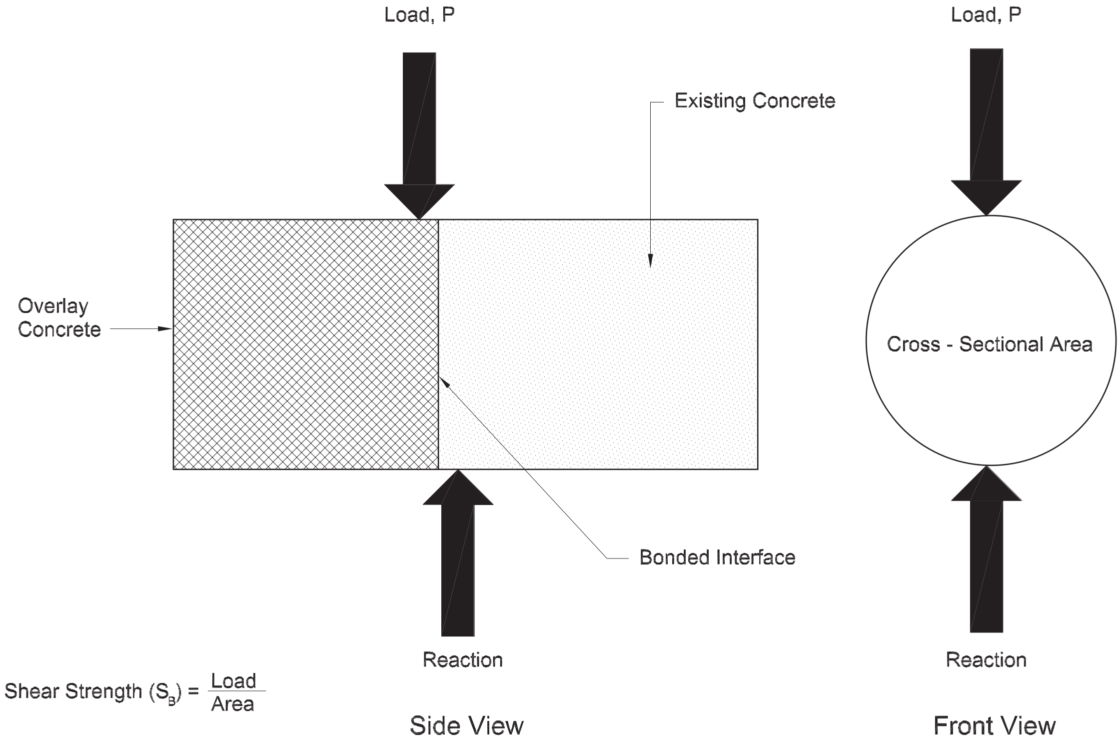

Figure 1—Loading Scheme Used for the Shear Strength Test

3.2. The load is applied until a shear failure occurs at the bonded interface.

3.3. The bond shear strength is calculated by dividing the maximum load attained during the test by the cross-sectional area of the test specimen.

4. SIGNIFICANCE AND USE

4.1. The bond shear strength may be used to assess the integrity of the bond between a bonded concrete overlay and the underlying concrete pavement or bridge deck.

5. APPARATUS

5.1. *Loading Block*—The loading block used for the bond shear test shall be designed to accommodate a 100-mm (4-in.) diameter test specimen. A typical loading block is illustrated in Figure 2.

5.2. *Loading Head*—A metal loading head with a concave surface having a 50-mm (2-in.) radius of curvature is required to apply load to the specimen. The loading head shall be 13 mm (0.5 in.) wide. Edges should be rounded by grinding to remove sharp edges. A typical loading head is illustrated in Figure 2.

5.3. *Testing Machine*—The testing machine shall conform to the requirements of T 22, possessing sufficient capacity and providing the rate of loading described in Section 6.3.

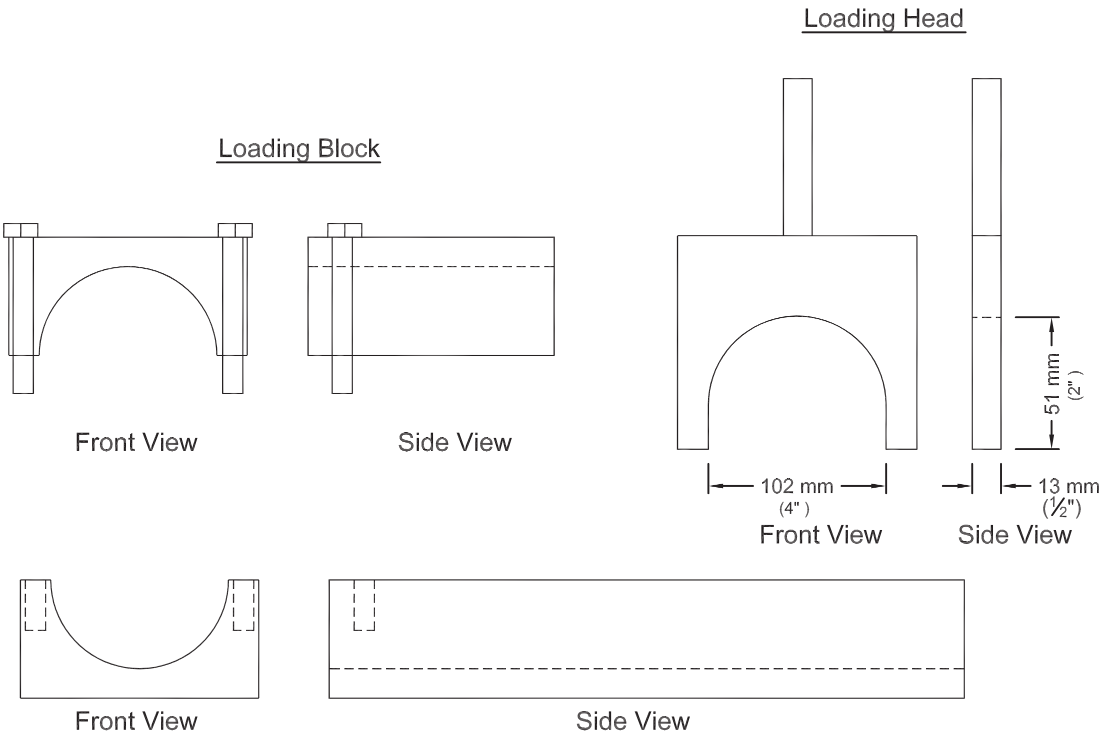

Figure 2—Typical Loading Block and Loading Head

6. PROCEDURE

6.1. *Specimen Preparation*—Measure the diameter of the core, the thickness of the overlay and the thickness of the original concrete to the nearest millimeter (mm) (0.004 in.).

6.2. *Specimen Positioning*—Secure the specimen in the loading block. The bonded interface shall be centered between the edge of the loading block and the edge of the loading head.

6.2.1. Align the loading head adjacent to the bonded interface. The loading head shall rest parallel to the bonded interface on the overlay concrete portion of the specimen. Sample positioning and loading is shown in Figure 3.

6.3. *Rate of Loading*—Apply the load continuously and without shock, at a constant rate within the range of 2760 to 3450 kPa (400 to 500 psi) per minute until failure occurs. Record the maximum applied load, P_{MAX}, carried by the specimen during the test.

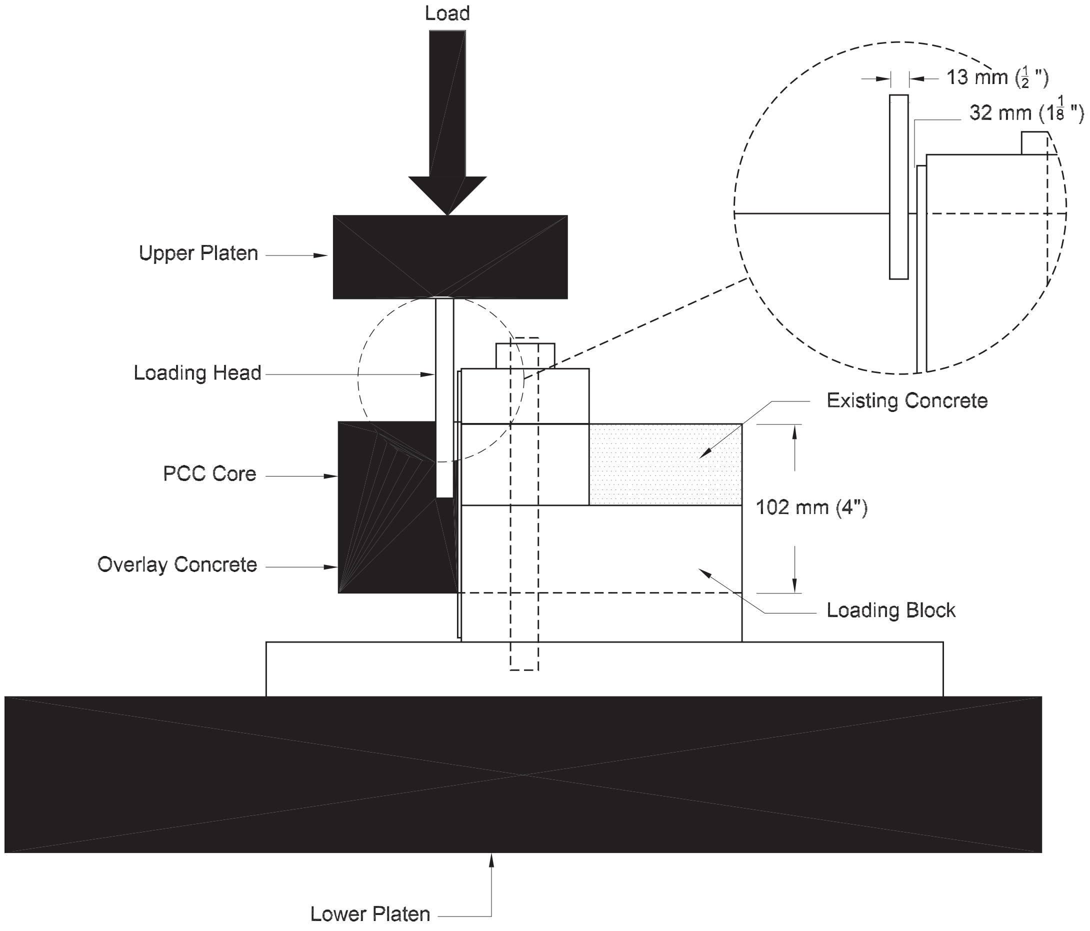

Figure 3—Illustration of Sample Positioning and Loading

7. CALCULATIONS

7.1. Calculate the bond shear strength, S_B, as follows in Equation 1:

SI units:

$$S_B = \frac{P_{MAX} \times 10^3}{A} \tag{1}$$

U.S. units:

$$S_B = \frac{P_{MAX}}{A}$$

where:

S_B = bond shear strength, kPa (psi);

P_{MAX} = maximum load applied to specimen, N (lb); and

A = cross-sectional area of test specimen, mm^2 (in.^{2}).

and in Equation 2:

$$A = \frac{\pi D^2}{4} \quad (2)$$

where:

A = cross-sectional area of test specimen, mm^2 (in.^{2}); and

D = diameter of test specimen, mm (in.).

8. REPORT

8.1. Sampling date and test date.

8.2. *Failure Plane*—Identify if failure occurred at the interface, in the base concrete layer, or in the overlay concrete layer.

8.3. *Test Results*:

8.3.1. *Specimen Dimensions*—including thickness of the overlay concrete, thickness of existing concrete, and the diameter, nearest 1.0 mm (0.05 in.) and the cross-sectional area, nearest 1.0 mm^2 (0.005 in.^{2}).

8.3.2. Maximum load applied, nearest 10 N (2.0 lb).

8.3.3. Bond shear strength, nearest 50 kPa (1.0 psi).

9. PRECISION AND BIAS

9.1. No precision and bias statements are available at this time.

10. KEYWORDS

10.1. Bonded layers; portland cement concrete; shear strength.

Standard Method of Test for

Preformed Expansion Joint Filler for Concrete Construction

AASHTO Designation: T 42-10
ASTM Designation: D 545-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Preformed Expansion Joint Filler for Concrete Construction

AASHTO Designation: T 42-10
ASTM Designation: D 545-08

AASHTO T 42-10 is identical to ASTM D 545-08 except for the following:

1. Change the first and second sentences of Section 1.2 of ASTM D 545-08 to the following:

   1.2 The values stated in SI units are to be regarded as the standard.

2. In Section 2 of ASTM D 545-08, add AASHTO reference documents as follows:

   2.2 *AASHTO Standards*:

   M 231, Weighing Devices Used in the Testing of Materials
   R 16, Regulatory Information for Chemicals Used in AASHTO Tests
   T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)

3. Change the first sentence of Section 4.7 of ASTM D 545-08 to the following:

   One steel template 102 by 102 mm, machined from 6.4-mm steel plate to fit the extrusion mold.

4. Change Section 4.8 of ASTM D 545-08 to the following:

   4.8 Metal Plate, 114 by 114 mm ±2.5 mm with parallel faces machined from 12.7-mm steel plate.

5. Change Section 5.1 of ASTM D 545-08 to the following:

   5.1 One representative sample approximately 0.2 m^2/90 m^2 of joint filler shall be obtained and properly packaged for safe transporting to the testing agency.

6. Change the fourth sentence of Section 7.1.1 of ASTM D 545-08 to the following:

   Measure the final thickness of each specimen to the nearest 0.03 mm.

7. In Section 7.1.1 of ASTM D 545-08, for SI units, change the definition of the numerator and denominator in the formula to the following:

   A = thickness in millimeters after boiling in water, and
   B = thickness in millimeters before boiling in water.

8. In Section 7.3.4 of ASTM D 545-08, change the third sentence to the following:

   Determine the amount of extrusion in millimeters by measuring the maximum movement of the free edge of the test specimen during the 50 percent compression of the specimen.

9. In Section 7.6.1 of ASTM D 545-08, for SI units, change the formula and definitions to the following:

   $$\text{Absorption by Volume, \%} = \frac{W_1 - W}{10.4t} \times 100 \qquad (1)$$

   where:

   W_1 = mass after immersion, g;
   W = mass before immersion, g; and
   t = thickness of specimen, mm.

10. Change Section 7.6.2 of ASTM D 545-08 to the following:

    7.6.2 In the event that the metal template or the test specimen, or both, does not measure to within the tolerances established in Section 4.7, the length and width of the specimen must be measured to within 0.3 mm and percent water absorption by volume calculated as follows:

11. In Section 7.6.2 of ASTM D 545-08, for SI units, change the formula and definitions to the following:

$$\text{Absorption by Volume, \%} = \frac{1000(W_1 - W)}{l \times w \times t} \times 100 \qquad (2)$$

where:

W_1 = mass after immersion, g;

W = mass before immersion, g;

l = length of specimen, mm;

w = width of specimen, mm; and

t = thickness of specimen, mm.

12. Change Section 7.7.3 of ASTM D 545-08, for SI units, to the following:

    7.7.3 Calculate the density in kg/m^3, as follows:

$$\text{Density} = \frac{96.117\ W}{t} \qquad (3)$$

where:

W = mass, g; and

t = thickness, mm.

13. In Section 7.7.4 of ASTM D 545-08, for SI units, change Section 7.7.4 to the following:

    7.7.4 In the event that the metal template or the test specimen, or both, does not measure to within the tolerances established in Section 4.7, the length and width of the specimen must be measured to within 0.3 mm and density calculated in kg/m^3 as follows:

$$\text{Density} = \frac{10^6 W}{l \times w \times t} \qquad (4)$$

where:

W = mass, g;

l = length, mm;

w = width, mm; and

t = thickness, mm.

Standard Method of Test for

Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

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AASHTO Designation: T 65M/T 65-08[1]
ASTM Designation: A 90/A 90M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Mass [Weight] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings

AASHTO Designation: T 65M/T 65-08[1]
ASTM Designation: A 90/A 90M-07

1. SCOPE

1.1. This test method covers procedures for determining the mass [weight] of coating on iron or steel sheet, wire, and other articles in which the coating is zinc or a zinc alloy, such as zinc-5 percent aluminum (including zinc-5 percent aluminum-mischmetal and zinc-5 percent aluminum-0.1 percent magnesium) or 55 percent aluminum-zinc. In the body of this test method, reference to zinc coating shall be interpreted to also include zinc-alloy coating except where specifically stated otherwise.

1.2. The final results determined by this test method shall be expressed in SI units or inch-pound units, depending on the units used in the material specification to which the results are to be compared. Certain portions of the procedure involving determination of specimen mass [weight] traditionally have been performed in SI units, and corresponding inch-pound units are not included.

1.3. For sheet products, the final results are expressed as either coating mass [weight] total both sides, or coating mass [weight] separately on each side, depending on the specified requirements.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For specific hazards statements, see Section 5.1.

1.5. Current regulation codes and hazard classifications for chemicals used in this test method are listed in R 16.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests

2.2. *ASTM Standards*:

- A 653/A 653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
- A 792/A 792M, Standard Specification for Steel Sheet, 55 Percent Aluminum-Zinc Alloy-Coated by the Hot-Dip Process
- A 875/A 875M, Standard Specification for Steel Sheet, Zinc-5 Percent Aluminum Alloy-Coated by the Hot-Dip Process

- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. SIGNIFICANCE AND USE

3.1. This test method provides a standard method for determining the mass [weight] of coating for comparison with specification requirements. A coating of zinc on iron or steel articles provides protection against corrosion. As the protection is provided by sacrificial loss of zinc, the degree of protection is proportional to the mass [weight] of zinc coating. Specifications for zinc-coated articles frequently provide for different classes of coating so that the purchaser can select the coating mass [weight] most suitable to his needs.

4. REAGENTS

4.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[2] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

4.2. *Purity of Water*—Water used to prepare chemical solutions shall be reagent water as defined by Type IV of ASTM D 1193.

4.3. *Antimony Trichloride Solution*—Dissolve 20 g of Sb_2O_3 or 32 g of $SbCl_3$ in 1000 mL of HCl (sp gr 1.18 to 1.19).

4.4. *Hydrochloric Acid (sp gr 1.18 to 1.19)*—Concentrated hydrochloric acid (HCl).

4.5. *Hydrochloric Acid—Antimony Trichloride Solution*—Add 5 mL of antimony trichloride solution to 100 mL of HCl (sp gr 1.18 to 1.19).

4.6. *Hydrochloric Acid (1 + 1)*—Mix 500 mL of HCl (sp gr 1.18 to 1.19) with 500 mL of reagent water and cool to room temperature.

5. HAZARDS

5.1. **Warning**—Small amounts of the poisonous gas stibine (SbH_3) may be evolved during the stripping process using the hydrochloric acid-antimony trichloride method. Hydrochloric acid fumes are present, and hydrogen gas is evolved in the stripping process. Therefore, the test should be performed under conditions of adequate ventilation. A fume hood is recommended for large numbers of samples or where the test is to be carried out frequently over extended periods of time.

6. SAMPLING

6.1. *Zinc-Coated Sheets*—Samples for mass [weight]-of-coating determination shall be secured in accordance with ASTM A 653/A 653M, A 792/A 792M, or A 875/A 875M, depending on the type of coating.

Note 1—For convenience in calculating test results in SI units, the specimen should have an area of 3330 mm^2 of sheet (57.7 ± 0.1 mm square or 65.1 ± 0.1 mm in diameter). For results to be reported in inch-pound units, the specimen should have an area of 5.08 $in.^2$ of sheet (2.25 ± 0.01 in. square or 2.54 ± 0.01 in. in diameter). The mass [weight] of coating in grams on a specimen of that area is numerically equal to the mass [weight] of coating in ounces per square foot of sheet.

6.2. *Zinc-Coated Wire*—Samples shall be secured as designated in the appropriate specification. The specimen of wire may be of any length greater than 305 mm [12 in.], but preferably about 610 mm [24 in.]. Where a continuous length is not available, shorter lengths totaling more than 305 mm [12 in.], but preferably about 610 mm [24 in.], shall be used. Since the density of the steel is known to be 7830 kg/m^3 or [0.283 $lb/in.^3$], it is not necessary to use a specific length of specimen.

6.3. *Zinc-Coated Articles Other Than Sheet or Wire*—Samples for mass [weight] of coating determination shall be secured as designated in the appropriate specification. Except as otherwise provided, the specimens should have a minimum area of 2000 mm^2 [3 $in.^2$] of zinc-coated surface. For very small items, several pieces may have to be stripped to obtain the minimum area.

6.3.1. In the case of threaded articles, such as bolts and screws, the determination shall be made on a portion of the articles that does not include any thread.

7. PROCEDURE

7.1. Stripping of zinc-alloy coatings containing less than 90 percent zinc shall be done using the dilute hydrochloric acid method. Stripping of coatings containing 90 percent or more zinc may be done using either hydrochloric acid-antimony trichloride solution or dilute hydrochloric acid (1 + 1) (alternative standard method).

7.2. Clean the specimens by washing with solvent naphtha or other suitable solvent, then rinse with alcohol, and dry thoroughly.

7.3. Determine the mass [weight] of the specimens individually to the nearest 0.01 g, except for articles other than sheet or wire with a specimen mass [weight] greater than 125 g, determine the mass [weight] to at least the nearest 0.1 g. After determining the mass [weight], immerse each specimen singly in the stripping solution and allow to remain until the violent evolution of hydrogen has ceased and only a few bubbles are being evolved. This requires about 15 to 30 seconds, except in the case of sherardized coatings, which require a somewhat longer time. The same solution may be used repeatedly until the time required for stripping becomes inconveniently long. The temperature of the stripping solution shall at no time exceed 38ºC [100ºF]. After stripping, wash the specimens by scrubbing them under running water, dip in hot water, and wipe or blow dry. Determine the mass [weight] of the specimens again, to the same precision as in the initial determination.

7.4. *Sheet Specimens*—When measuring the total coating mass [weight] on both sides, or the single side coating mass [weight] on each side, determine the area of sheet (one surface) to the nearest 5 mm^2 [0.01 $in.^2$]. If specimens were prepared to the dimensions as provided in Note 1, they shall be presumed to have an area of 3330 mm^2 [5.08 $in.^2$]. When it is not possible to determine the area accurately, as in specimens from corrugated sheets, the thickness of the stripped sheet shall be determined to the nearest 0.01 mm [0.001 in.].

7.4.1. When determining the coating mass [weight] on one side of sheet material, use the procedure described in Section 7.3, except use a "stop-off" to protect one side from the stripping medium. Acid-resistant paints or lacquers, acid-resistant tape, or mechanical devices fastened to the test specimen are examples of commonly used "stop-off" materials. Apply the "stop-off" to the specimen after the initial determination of mass [weight], and remove before the second determination of mass [weight]. Because of the possibility of moisture absorption during the stripping process, the "stop-off" must not be on the specimen during either mass [weight] determination. Determine the coating mass [weight] on the second side subsequently without a "stop-off" on the first side.

7.5. *Wire Specimens*—Determine the diameter of the stripped wire to the nearest 0.01 mm [0.001 in.] by taking the average of two measurements at right angles to each other.

7.6. *Specimens Other Than Sheet or Wire*—Determine the total coated area of the original specimen to the nearest 5 mm^2 [0.01 in.^{2}]. Alternatively, for specimens of uniform thickness of base metal, such as a piece of plate or pipe, determine the average thickness of the stripped specimen to the nearest 0.01 mm [0.001 in.].

---

8. CALCULATION

8.1. *Zinc-Coated Sheet*:

8.1.1. *Results in SI Units*:

8.1.1.1. When the area of sheet is determined, calculate the mass of coating as follows:

$$C = \left[(W_1 - W_2) / A \right] \times K \tag{1}$$

where:

C = mass of coating, g/m^2 of sheet;

W_1 = original mass of specimen, g;

W_2 = mass of stripped specimen, g;

A = area of one surface of the sheet in mm^2 (or in.^{2}); and

K = a constant = 1×10^6 when A is in mm^2, or = 1.55×10^3 when A is in in.^{2}

Note 2—If the specimen was prepared to the dimensions as provided in Note 1, having an area of 3330 mm^2 of sheet, the factor *K/A* is approximately 300, which may be used in the calculation.

8.1.1.2. When it is not possible to obtain a specimen of measurable area, calculate the mass of coating as follows:

$$C = \left[(W_1 - W_2) / W_2 \right] \times T \times K \tag{2}$$

where:

C = mass of coating, g/m^2 of sheet;

W_1 = original mass of the specimen, g;

W_2 = mass of stripped specimen, g;

T = thickness of stripped sheet, mm (or in.); and

K = a constant = 7.83×10^3 when T is in mm, or = 1.99×10^5 when T is in in.

8.1.2. *Results in Inch-Pound Units*:

8.1.2.1. When the area of one surface of the sheet is determined, calculate the weight of coating as follows:

$$C = \left[(W_1 - W_2) / A \right] \times K \tag{3}$$

where:

C = weight of coating, oz/ft^2 of sheet;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

A = area of one surface of the sheet, mm^2 (or in.^{2}); and

K = a constant = 3.28×10^3 when A is in mm^2, or = 5.08 when A is in in.^{2}

Note 3—If the specimen was prepared to the dimensions as provided in Note 1, having an area of 5.08 in.^{2}, the loss of weight in grams is numerically equal to the weight of coating in ounces per square foot of sheet.

8.1.2.2. When it is not possible to secure a specimen of measurable area, calculate the weight of coating as follows:

$$C = \left[\left(W_1 - W_2\right)/W_2\right] \times T \times K \qquad (4)$$

where:

C = weight of coating, oz/ft^2 of sheet;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

T = thickness of stripped sheet, mm (or in.); and

K = a constant = 25.7 when T is in mm, or = 652 when T is in in.

8.2. *Zinc-Coated Wire*:

8.2.1. *Results in SI Units*:

8.2.1.1. Calculate the mass of zinc coating as follows:

$$C = \left[\left(W_1 - W_2\right)/W_2\right] \times D \times M \qquad (5)$$

where:

C = mass of coating, g/m^2 of stripped wire surface;

W_1 = original mass of specimen, g;

W_2 = mass of stripped specimen, g;

D = diameter of stripped wire, mm (or in.); and

M = a constant = 1.96×10^3 when D is in mm, or = 4.97×10^4 when D is in in.

8.2.2. *Results in Inch-Pound Units*:

8.2.2.1. Calculate the weight of zinc coating as follows:

$$C = \left[\left(W_1 - W_2\right)/W_2\right] \times D \times M \qquad (6)$$

where:

C = weight of coating, oz/ft^2 of stripped wire surface;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

D = diameter of stripped wire, mm (or in.); and

M = a constant = 6.42 when D is in mm, or = 163 when D is in in.

8.3. *Zinc-Coated Articles Other Than Sheet or Wire*:

8.3.1. *Results in SI Units*:

8.3.1.1. Calculate the mass of zinc coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / A \right] \times N \qquad (7)$$

where:

C = mass of coating, g/m^2 of surface;

W_1 = original mass of specimen, g;

W_2 = mass of stripped specimen, g;

A = coated area of original specimen, mm^2 (or in.^{2}); and

N = a constant = 1×10^6 when A is in mm^2, or = 1.55×10^3 when A is in in.^{2}

8.3.1.2. If the specimen has a uniform thickness of base metal, calculate the mass of coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times G \times Z \qquad (8)$$

where:

C = mass of coating, g/m^2, of surface;

W_1 = original mass of specimen, g;

W_2 = mass of stripped specimen, g;

G = thickness of stripped specimen, mm (or in.); and

Z = a constant = 3.92×10^3 when G is in mm, or = 9.95×10^4 when G is in in.

8.3.2. *Results in Inch-Pound Units*:

8.3.2.1. Calculate the weight of coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / A \right] \times N \qquad (9)$$

where:

C = weight of coating, oz/ft^2 of surface;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

A = coated area of original specimen, mm^2 (or in.^{2}); and

8.3.2.2. N = a constant = 3.28×10^3 when A is in mm^2, or = 5.08 when A is in in.^{2}

8.3.2.3. If the specimen has a uniform thickness of base metal, calculate the weight of coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times G \times Z \qquad (10)$$

where:

C = weight of coating, oz/ft^2 of surface;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

G = thickness of stripped specimen, mm (or in.); and

Z = a constant = 12.8 when G is in mm, or = 326 when G is in in.

9. REPORT

9.1. Mass [weight] of coating on zinc-coated sheet is expressed in mass [weight] per unit area of sheet, and is either the sum of the masses [weights] of coating on both sides of the sheet or single side mass [weight] on each of two sides. Masses [weights] of coating on each side of the sheet are not necessarily equal, even when both sides are exposed to the molten metal or plating solution simultaneously. Coating masses [weights] on all zinc-coated articles other than sheets are expressed in mass [weight] per unit area of surface. The minimum or range of mass [weight] per unit area for each side of the sheet shall be determined by the purchaser and shall be directly stated in the purchase order.

9.2. Report the mass of zinc coating to the nearest 1 g/m^2 when reporting in metric units.

9.3. Report the weight of zinc coating to the nearest 0.01 oz/ft^2 when reporting in inch-pound units.

9.4. When the mass [weight] of coating of a number of specimens is to be averaged to determine conformance with a specification limit, the average value shall be reported to the precision described in Sections 9.2 and 9.3 in accordance with ASTM E 29.

10. PRECISION AND BIAS

10.1. The precision of this test method is based on an interlaboratory study of ASTM A 90/A 90M conducted in 2006. Each of ten laboratories tested three replicates of two different materials.[3] Data were recorded in inch-pound units only and should not be considered metric equivalents. See Table 1 for a statistical summary of the test results.

Note 4—S_r means the standard deviation of r (repeatability). S_R means the standard deviation for R (reproducibility).

Table 1—Mass Weight Coating (in oz/ft^2)

Material	$\overline{x}$	S_x	S_r	S_R	r	R
Hot-Dipped Zinc-Coated Samples	1.100780	0.021895	0.015333	0.025222	0.042933	0.070621
Electrolytic Zinc-Coated Samples	0.403221	0.008790	0.008378	0.011138	0.023457	0.031187

10.1.1. *Repeatability*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more that the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

10.1.2. *Reproducibility*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that material; "*R*" is the interval representing the difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

10.1.3. Any judgment in accordance with these two statements would have an approximate 95 percent probability of being correct.

10.2. *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

10.3. The precision statement was determined through statistical examination of three results, from ten laboratories, on two materials.

11. KEYWORDS

11.1. Fifty-five (55) percent aluminum-zinc alloy coating; coating mass [weight]; steel sheet; steel wire; zinc-alloy coatings; zinc coating; zinc-5 percent aluminum-alloy coating; zinc-5 percent aluminum-0.1 percent magnesium alloy coating; zinc-5 percent aluminum-mischmetal alloy coating.

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[1] Except for giving preference to SI units, the addition of R 16, and the additional requirement at the end of Section 9.1, this test method agrees with ASTM A 90/A 90M-07.

[2] *Reagent Chemicals*, *American Chemical Society Specifications*. American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory U.K. Chemicals*, BDH Ltd., Poole, Dorset, and the *United States Pharmacopeia and National Formulary,* U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

[3] Supporting data have been filed at ASTM International Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, and may be obtained by requesting Research Report RR: A05-1003.

Standard Method of Test for

Tension Testing of Metallic Materials

AASHTO Designation: T 68M/T 68-09
ASTM Designation: E 8/E 8M-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Tension Testing of Metallic Materials

AASHTO Designation: T 68M/T68-09
ASTM Designation: E 8/E 8M-08

The AASHTO equivalent of this method of test has been discontinued. Please refer to ASTM E 8/E 8M-08 for the information formerly contained in this standard.

Standard Method of Test for

Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles

AASHTO Designation: T 213M/T 213-08[1]
ASTM Designation: A 428/A 428M-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Mass [Weight] of Coating on Aluminum-Coated Iron or Steel Articles

AASHTO Designation: T 213M/T 213-08[1]
ASTM Designation: A 428/A 428M-06

1. SCOPE

1.1. This test method covers procedures for determining the mass [weight] of coating on aluminum-coated iron or steel sheets and wire, and on other aluminum-coated iron and steel articles.

1.2. The final results determined by this test method shall be expressed in SI or inch-pound units, depending on the units used in the material specification to which the results are to be compared. Certain portions of the procedure involving determination of specimen mass [weight] traditionally have been performed in SI units, and corresponding inch-pound units are not included.

1.3. For sheet products, the final results are expressed as either coating mass [weight] total both sides, or coating mass [weight] separately on each side, depending on the specified requirements.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For a specific precautionary statement, see Note 1.

1.5. Current regulation codes and hazard classifications for chemicals used in this test method are listed in R 16.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests

2.2. *ASTM Standards*:

- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 691, Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. SIGNIFICANCE AND USE

3.1. This test method provides a standard method of determining the mass [weight] of coating for comparison with specification requirements. A coating of aluminum on iron or steel articles provides protection against corrosion by forming a relatively inert barrier. Specifications for aluminum-coated articles occasionally provide for different masses [weights] of coating so that the purchaser can select the coating mass [weight] most suited to his needs. The heavier coating will provide greater protection against mechanical damage, which may break the coating.

4. REAGENTS

4.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[2] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

4.2. *Purity of Water*—Water used in preparation of reagent solutions shall conform to ASTM D 1193, Type IV or better.

4.3. *Antimony Trichloride Solution*—Dissolve 200 g of antimony trichloride ($SbCl_3$) in 1000 mL of concentrated hydrochloric acid (HCl, sp gr 1.18 to 1.19) without heating.

4.4. *Hydrochloric Acid (*sp gr 1.18 to 1.19*)*—Concentrated hydrochloric acid (HCl).

4.5. *Sodium Hydroxide Solution*—(20 percent). Dissolve 20 parts by mass [weight] of sodium hydroxide (NaOH) in 80 parts of water.

4.6. *Stannous Chloride Solution*—Dissolve 100 g of stannous chloride ($SnCl_2 \cdot 2H_2O$) in 1000 mL of concentrated hydrochloric acid (HCl, sp gr 1.18 to 1.19) without heating. Add a few granules of reagent-grade tin.

4.7. *Hydrochloric Acid (1+1)*—Mix 500 mL of HCl (sp.gr. 1.18 to 1.19) with 500 mL of reagent water and cool to room temperature.

Note 1—**Warning**: Small amounts of the poisonous gas stibine (SbH_3) may be evolved during the stripping process using the hydrochloric acid-antimony trichloride-stannous chloride method. Hydrochloric acid fumes are present, and hydrogen gas is evolved in the stripping process. Therefore, the test should be performed under conditions of adequate ventilation. A fume hood is recommended for large numbers of samples or where the test is to be carried out frequently over extended periods of time.

5. SAMPLING

5.1. *Aluminum-Coated Sheets*—Samples for mass-of-coating [weight-of-coating] determination shall be secured as designated in the appropriate specification. Test specimens shall have a minimum area of 2000 mm^2 [3 in.^{2}] of sheet, but preferably approximately 3300 mm^2 [5 in.^{2}] of sheet.

Note 2—For results to be reported in SI units, the specimen should have an area of 3300 mm^2 of sheet (57.7 ± 0.1-mm square or 65.1 ± 0.1 mm in diameter). For convenience in calculating test results in inch-pound units, the specimen should have an area of 5.08 in.^{2} of sheet (2.25 ± 0.01 in. square or 2.54 ± 0.01 in. in diameter). The mass [weight] of coating in grams on a specimen of that area is numerically equal to the mass [weight] of coating in ounces per square foot of sheet.

5.2. *Aluminum-Coated Wire*—Samples shall be secured as designated in the appropriate specification. The specimen of aluminum-coated wire may be of any length greater than 300 mm [approximately 12 in.], but preferably about 600 mm [approximately 24 in.]. Where a continuous length is not available, shorter lengths totaling more than 300 mm, but preferably about 600 mm, shall be used. Since the density of the steel is known (7830 kg/m^3 or 0.283 lb/in.^{3}), it is not necessary to use a specific length of specimen.

5.3. *Aluminum-Coated Articles Other Than Sheet or Wire*—Samples for mass [weight] of coating determination shall be secured as designated in the appropriate specification. Except as otherwise provided, the specimens should have a minimum area of 1935 mm^2 [3 in.^{2}] of aluminum-coated surface. For very small items, several pieces may have to be stripped to obtain the minimum area.

5.3.1. In the case of threaded articles, such as bolts and screws, the determination shall be made on a portion of the article that does not include any thread.

6. PROCEDURE

6.1. Strip the aluminum coating from the specimens by using one of the following methods—the sodium hydroxide-hydrochloric acid method (Method A), the hydrochloric acid-antimony trichloride-stannous chloride method (Method B), or the dilute hydrochloric acid method (Method C).

Note 3—Methods A and B are the most common methods used for sheets.

6.2. Clean the specimens immediately before determining the mass [weight] by washing in petroleum ether or other suitable solvent, and dry thoroughly.

6.3. Determine the mass [weight] of the specimens individually to the nearest 0.01 g.

6.4. *Sodium Hydroxide-Hydrochloric Acid Method (Method A)*—Heat the NaOH solution to approximately 90ºC [195°F] (Note 4) and immerse each specimen in the hot solution until the strong reaction ceases. With silicon-free coatings, evolution of gas for considerable time is likely, but do not leave the specimens in the solution for more than a few minutes. Longer immersion inhibits the removal of coating during subsequent dips. Immersion of several specimens simultaneously is permitted provided all surfaces are freely exposed to the solution. Remove specimens from solution and scrub all surfaces under running tap water with a clean cellulose sponge to remove the loose deposit formed in the NaOH solution. Use vigorous scrubbing as necessary for some types of coating, but do not use abrasive materials to remove the deposit. Blot with a towel to remove most of the water (Note 5) and immerse each specimen singly for not more than three seconds in HCl (sp gr 1.18 to 1.19) at room temperature. Remove, scrub again under running tap water with a sponge, and re-immerse in the hot NaOH solution for not more than a few minutes or until action again ceases. Repeat this cycle until immersion in HCl shows no visible reaction (Note 6). Use one to three or more cycles as required, depending on the type and weight of coating. After the final immersion in the NaOH and HCl solutions, scrub as before, dry thoroughly, and determine the mass [weight] of each specimen to the nearest 0.01 g.

Note 4—The temperature is not critical, but the solution should be held several degrees below the boiling point (approximately 105ºC) to prevent excessive foaming during the first immersion. The beaker used for heating the solution and immersing the specimens should be less than half full of solution to avoid the danger of foaming over when the specimens are immersed.

Note 5—Most of the water should be removed to prevent dilution of the HCl, as dilute HCl will attack the base metal to a greater extent than concentrated HCl.

Note 6—It is sometimes difficult to determine the point at which all of the alloy layer has been removed, when stripping silicon-free coatings. If in doubt, determine the mass [weight] of the specimen (after scrubbing and drying) and then put it through one additional stripping cycle. Loss in mass [weight] due to the additional cycle will be on the order of 0.005 g on a 57.2-mm [2.25-in.] square sheet specimen, if all the coating had been removed before the extra cycle.

6.5. *Hydrochloric Acid-Antimony Trichloride-Stannous Chloride Method (Method B)*—After determining the mass [weight], immerse each specimen singly in a solution made by mixing 100 mL of antimony trichloride solution and 100 mL of stannous chloride solution (Note 7). Allow the specimen to remain immersed until the evolution of hydrogen has ceased. Action will stop after 1 to 4 minutes, or somewhat longer, depending on the thickness and silicon content of the coating. Use fresh solution for each test (Note 8). The temperature of the stripping solution shall not exceed 38ºC [100°F]. After stripping, wash the specimen and scrub it with a soft cloth, using a small amount of abrasive cleansing powder if necessary. Rinse the specimens and dry thoroughly with an absorbent cloth or paper and determine the mass [weight] of each specimen to the nearest 0.01 g.

Note 7—Mix the antimony trichloride and stannous chloride solutions together as needed.

Note 8—Very heavy coatings may show residual coating after all action has stopped. If, on examination after stripping, any coating still remains, repeat the immersion step using fresh solution.

6.6. *Dilute Hydrochloric Acid Method (1+1) (Method C)*—After determining the mass [weight], immerse each specimen singly in the stripping solution and allow to remain until the violent evolution of hydrogen has ceased and only a few bubbles are being evolved. Action will stop after 1 to 4 minutes or somewhat longer depending on the thickness and silicon content of the coating. Use of the same solution is permitted until the time for stripping becomes inconveniently long. The temperature of the stripping solution shall at no time exceed 38°C [100°F]. After stripping, wash the specimens by scrubbing them under running water, dip in hot water and wipe or blow dry. Determine the mass [weight] of each specimen to the nearest 0.01 g.

6.7. *Sheet Specimens*—When measuring the total coating mass [weight] on both sides, or the single side coating mass [weight] on each side, determine the area of sheet (one surface) to the nearest 5 mm^2 [0.01 in.^{2}]. If specimens were prepared to the dimensions as provided in Note 2, they shall be presumed to have an area of 3330 mm^2 [5.08 in.^{2}]. When it is not possible to determine the area accurately, as in specimens from corrugated sheets, determine the average thickness of the stripped sheets to the nearest 0.01 mm [0.001 in.].

6.7.1. When determining the single side coating mass [weight] of sheet material, use the procedures described in Sections 6.4, 6.5, or 6.6, except use a "stop-off" to protect the second side from the stripping medium. Acid-resistant paints or lacquers, acid-resistant tape, or mechanical devices fastened to the test specimen are examples of commonly used "stop-off" materials. Apply the "stop-off" to the specimen after the first determination of mass [weight] and remove before the second determination of mass [weight]. Because of the possibility of moisture absorption during the stripping process, the "stop-off" must not be on the specimen during either mass [weight] determination. Determine the coating mass [weight] on the second side subsequently without a "stop-off" on the first side.

6.8. *Wire Specimens*—Determine the diameter of the stripped wire to the nearest 0.01 mm [0.001 in.] by taking the average of two measurements at right angles to each other.

6.9. *Specimens Other Than Sheet or Wire*—Determine the total coated area of the original specimen to the nearest 5 mm^2 [0.01 in.^{2}]. Alternatively, for specimens of uniform thickness of base metal, such as a piece of plate or pipe, determine the average thickness of the stripped specimen to the nearest 0.01 mm [0.001 in.].

7. CALCULATION

7.1. *Aluminum-Coated Sheet*:

7.1.1. *Results in SI Units*:

7.1.1.1. When the area of one surface of the sheet is determined, calculate the mass [weight] of aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / A \right] \times K \tag{1}$$

where:

C = mass of coating, g/m^2 of sheet;
W_1 = original mass of specimen, g;
W_2 = mass of stripped specimen, g;
A = area of one surface of the sheet in mm^2 (or in.^{2}); and
K = a constant = 1×10^6 when A is in mm^2, or = 1.55×10^3 when A is in in.^{2}

Note 9—If the specimen was prepared to the dimensions as provided in Note 2, having an area of 3330 mm^2 of sheet, the factor K/A is approximately 300, which may be used in the calculation.

7.1.1.2. When it is not possible to obtain a specimen of measurable area, calculate the mass of the coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times T \times K \tag{2}$$

where:

C = mass of coating, g/m^2 of sheet;
W_1 = original mass of the specimen, g;
W_2 = mass of the stripped specimen, g;
T = thickness of stripped sheet, mm (or in.); and
K = a constant = 7.83×10^3 when T is in mm, or = 1.99×10^5 when T is in in.

7.1.2. *Results in Inch-Pound Units*:

7.1.2.1. When the area of one surface of the sheet is determined, calculate the weight of aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / A \right] \times K \tag{3}$$

where:

C = weight of coating, oz/ft^2 of sheet;
W_1 = original weight of specimen, g;
W_2 = weight of stripped specimen, g;
A = area of one surface of the sheet, mm^2 (or in.^{2}); and
K = a constant = 3.28×103 when A is in mm^2, or = 5.08 when A is in in.^{2}

Note 10—If the specimen was prepared to the dimensions as provided in Note 2, having an area of 5.08 in.^{2}, the loss of weight in grams is numerically equal to the weight of coating in ounces per square foot of sheet.

7.1.2.2. When it is not possible to secure a specimen of measurable area, calculate the weight of coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times T \times K \qquad (4)$$

where:

C = weight of coating, oz/ft^2 of sheet;
W_1 = original weight of specimen, g;
W_2 = weight of stripped specimen, g;
T = thickness of stripped sheet, mm (or in.); and
K = a constant = 25.7 when T is in mm, or = 652 when T is in in.

7.2. *Aluminum-Coated Wire*:

7.2.1. *Results in SI Units*:

7.2.1.1. Calculate the mass of aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times D \times M \qquad (5)$$

where:

C = mass of coating, g/m^2 of stripped wire surface;
W_1 = original mass of specimen, g;
W_2 = mass of stripped specimen, g;
D = diameter of stripped wire, mm (or in.); and
M = a constant = 1.96×10^3 when D is in mm, or = 4.97×10^4 when D is in in.

7.2.2. *Results in Inch-Pound Units*:

7.2.2.1. Calculate the weight of aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times D \times M \qquad (6)$$

where:

C = weight of coating, oz/ft^2 of stripped wire surface;
W_1 = original weight of specimen, g;
W_2 = weight of stripped specimen, g;
D = diameter of stripped wire, mm (or in.); and
M = a constant = 6.42 when D is in mm, or = 163 when D is in in.

7.3. *Aluminum-Coated Articles Other Than Sheet or Wire*:

7.3.1. *Results in SI Units*:

7.3.1.1. Calculate the mass of aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / A \right] \times N \qquad (7)$$

where:

C = mass of coating, g/m^2 of surface;
W_1 = original mass of specimen, g;
W_2 = mass of stripped specimen, g;

A = coated area of original specimen, mm^2 (or $in.^2$); and

N = a constant = 1×10^6 when A is in mm^2, or = 1.55×10^3 when A is in $in.^2$

7.3.1.2. If the specimen has a uniform thickness of base metal, as an option to the procedure in Section 7.3.1.1, calculate the mass of the aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times G \times Z \qquad (8)$$

where:

C = mass of coating, g/m^2, of surface;

W_1 = original mass of specimen, g;

W_2 = mass of stripped specimen, g;

G = thickness of stripped specimen, mm (or in.); and

Z = a constant = 3.92×10^3 when G is in mm, or = 9.95×10^4 when G is in in.

7.3.2. *Results in Inch-Pound Units*:

7.3.3. Calculate the weight of aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / A \right] \times N \qquad (9)$$

where:

C = weight of coating, oz/ft^2 of surface;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

A = coated area of original specimen, mm^2 (or $in.^2$); and

N = a constant = 3.28×10^3 when A is in mm^2, or = 5.08 when A is in $in.^2$

7.3.3.1. If the specimen has a uniform thickness of base metal, as an option to the procedure in Section 7.3.2.1, calculate the weight of the aluminum coating as follows:

$$C = \left[\left(W_1 - W_2 \right) / W_2 \right] \times G \times Z \qquad (10)$$

where:

C = weight of coating, oz/ft^2 of surface;

W_1 = original weight of specimen, g;

W_2 = weight of stripped specimen, g;

G = thickness of stripped specimen, mm (or in.); and

Z = a constant = 12.8 when G is in mm, or = 326 when G is in in.

8. REPORT

8.1. Mass [weight] of coating on aluminum-coated sheet is expressed in mass [weight] per unit area of sheet, and is either the sum of the masses [weights] of coating on both sides of the sheet, or single side mass [weight] on each of the two sides. Masses [weights] of coating on each side of the sheet are not necessarily equal, even when both sides are exposed to the molten metal simultaneously. Coating masses [weights] on all aluminum-coated articles other than sheets are expressed in mass [weight] per unit area of surface. The minimum or range of mass [weight] per unit area for each side of the sheet shall be determined by the purchaser and shall be directly stated in the purchase order.

8.2. Report the mass [weight] of aluminum coating to the nearest 1 g/m^2 when reporting in metric (SI) units.

8.3. Report the mass [weight] of aluminum coating to the nearest 0.01 oz/ft^2 when reporting in inch-pound units.

8.4. When the mass [weight] of coating of a number of specimens is to be averaged to determine conformance with a specification limit, the average value shall be reported to the precision of Sections 8.2 and 8.3 in accordance with the rounding method of E 29.

9. PRECISION AND BIAS[3]

9.1. *Precision*—The precision of this test method for sheet products has been determined in accordance with ASTM E 691.

9.1.1. The repeatability of the test method was found to be 9.5 g/m^2 [0.031 oz/ft^2] of sheet and the reproducibility was found to be 10.4 g/m^2 [0.034 oz/ft^2].

Note 11—These precision results are based on testing specimens having an area of 3280 mm^2 (5.08 $in.^2$) of sheet. Other test specimen sizes may yield different precision results.

9.1.2. The precision of this test method for products other than sheet steel has not been determined.

Note 12—Repeatability and reproducibility, based on test error alone, are defined as the difference, in absolute value, of two test results obtained in the same laboratory, or between laboratories on the same material (the difference will be expected to exceed the repeatability or reproducibility only about 5 percent of the time).

9.2. *Bias*—Since there is no accepted reference material suitable for determining bias for the procedures in this test method, no statement on bias is being made.

10. KEYWORDS

10.1. Aluminum coating; coating mass [weight]; steel sheets; steel wire.

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[1] This test is identical to ASTM A 428/A 428 M-06 except for inch-pound units, rather than SI units, shown in brackets; the addition of Section 1.5; and the additional requirement at the end of Section 8.1.

[2] *Reagent Chemicals*, American Chemical Society Specifications. American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

[3] Research report available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, and may be obtained by requesting Research Report RR: A05-1000.

Standard Method of Test for

Sampling Procedure for Impact Testing of Structural Steel

AASHTO Designation: T 243M/T 243-08[1]
ASTM Designation: A 673/A 673M-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling Procedure for Impact Testing of Structural Steel

AASHTO Designation: T 243M/T 243-08[1]
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1. SCOPE

1.1. This specification establishes the procedure for longitudinal Charpy V-notch testing of structural steel and contains two frequencies of testing. The impact properties of steel can vary within the same heat and piece, be it as-rolled, control-rolled or heat-treated. The purchaser should, therefore, be aware that testing of one plate, bar, or shape does not provide assurance that all plates, bars, or shapes of the same heat as processed will be identical in toughness with the product tested. Normalizing or quenching and tempering the product will reduce the degree of variation.

1.2. This specification is intended to supplement specifications for structural steel when so specified.

1.3. This specification does not necessarily apply to all product specifications; therefore, the manufacturer or processor should be consulted for energy absorption levels and minimum testing temperatures that can be expected or supplied.

1.4. Two frequencies of testing (P and H) are prescribed.

1.5. The values stated in either SI units or inch-pound units are to be regarded as standard. Within the text, the English units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 160M/M 160, General Requirements for Steel, Plates, Shapes, Sheet Piling, and Bars for Structural Use (Discontinued)
- T 244, Mechanical Testing of Steel Products

3. ORDERING INFORMATION

3.1. The inquiry and order shall indicate the following:

3.1.1. The frequency of testing, (P) or (H);

3.1.2. The test temperature to be used (Sections 4.5 and 4.6);

3.1.3. Minimum average absorbed energy value (see Sections 4.1 and 4.6);

3.1.4. Transverse impact test orientation for plate widths greater than 24 in. [600 mm], if desired (see Section 4.2.2);

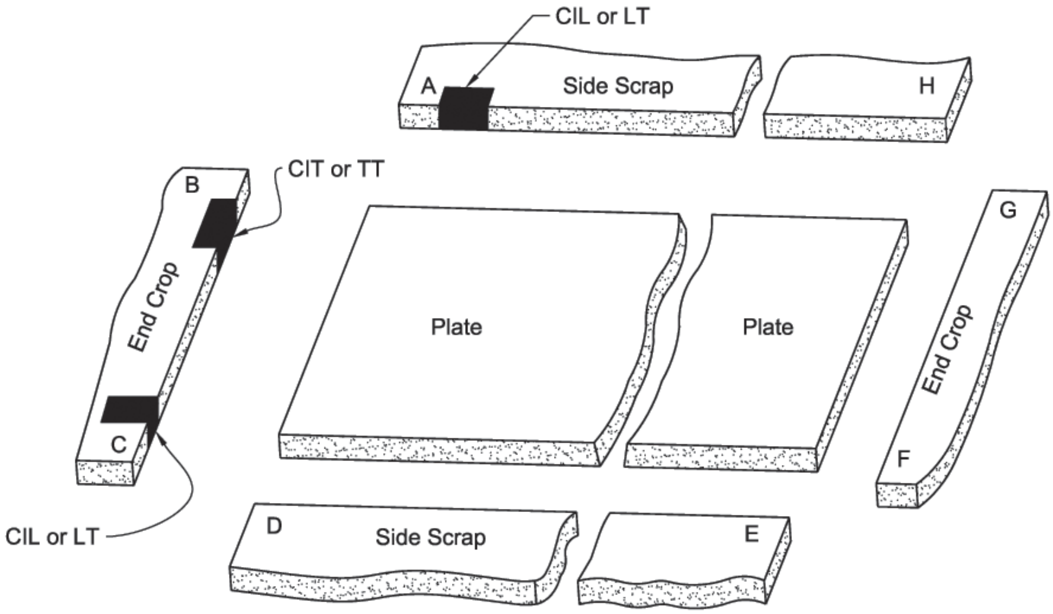
3.1.5. Alternate core location (see Section 4.3), if applicable; and

3.1.6. Condition (as-rolled, stress relieved normalized, normalized and stress relieved, or quenched and tempered).

4. TESTS

4.1. Impact testing shall be in accordance with Test Methods and Definitions in T 244. An impact test shall consist of testing three specimens taken from a single test coupon or test location, the average result of which is to be not less than the minimum average absorbed energy specified in the purchase order, which in no case shall be less than 10 J (7 ft-lbf) for full size specimens.

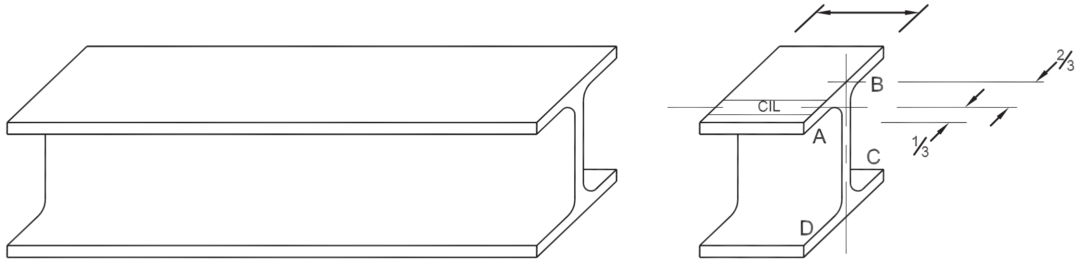
4.2. Except as allowed by Section 4.3, specimen for plates and bars shall be taken from a location adjacent to the location specified for the tension test specimen and the specimen for shapes shall be taken from a location at an end of a shape at a point one-third the distance from the outer edge of the flange or leg to the web or heel of the shape. (See Figures 1 and 2.) For plates produced from coils, three impact tests shall be taken from the product of each coil or qualifying coil (see Section 5). One test coupon shall be obtained from a location adjacent to the location specified for each of the two required tension tests (see M 160M/M 160), and a third test coupon shall be obtained immediately after the last plate produced to the qualifying specification.



Notes:

1. LT (Longitudinal tensile test). For widths through 600 mm [24 in.], may be taken at any location, A through H.
2. TT (Transverse tensile test). For widths more than 600 mm [24 in.], may be taken at locations B, C, F, or G.
3. CIL (Charpy impact longitudinal). May be taken at any location, A through H.
4. CIT (Charpy impact transverse). For widths more than 600 mm [24 in.], may be taken at location B, C, F, or G.

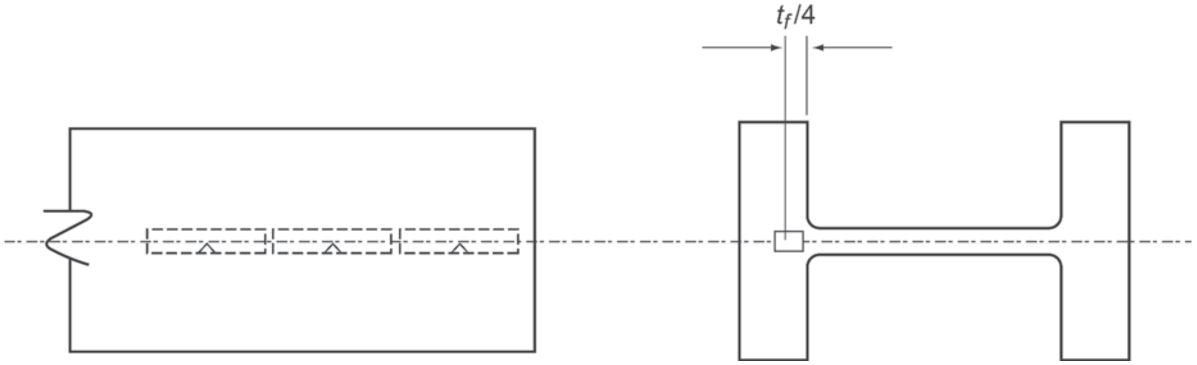
Figure 1—Plate Test Location



Notes:

1. CIL = Charpy impact longitudinal.
2. Test coupon for impact specimens may be taken from locations A, B, C, or D as shown laid out at location A.

Figure 2—Shape Test Location



Note—The notch for any of the specimens can be on either side of the beam centerline.

Figure 3—Alternate Core Location for Charpy V-Notch Specimens

4.2.1. Except as allowed by Section 4.2.2, the longitudinal axis of each specimen shall be parallel to the final direction of rolling of the plate or parallel to the major axis of the shape.

4.2.2. If specified in the purchase order, for plate widths greater than 600 mm [24 in.], the longitudinal axis of each specimen shall be transverse to the final direction of rolling of the plate.

4.2.3. The longitudinal axis of each specimen shall be located, as near as practicable, midway between the surface and the center of the product thickness and the length of the notch shall be perpendicular to the rolled surface of the material.

4.3. For shapes with a flange thickness equal to or greater than 38.1 mm ($1^1/_2$ in.), where alternate core location resting is specified in the purchase order, the longitudinal axis of each specimen shall be located midway between the inner flange surface and the center of the flange thickness at the intersection with the web mid-thickness. (See Figure 3.)

4.4. The absorbed energy values obtained for sub-size specimens shall not be less than the applicable values given in Table 1, which are proportional to the absorbed energy values required for full size specimens.

Table 1—Equivalent Absorbed Energy for Various Specimen Sizes

Full Size, 10 × 10 mm		$^3/_4$ Size, 10 × 7.5 mm		$^2/_3$ Size, 10 × 6.7 mm		$^1/_2$ Size, 10 × 5 mm		$^1/_3$ Size, 10 × 3.3 mm		$^1/_4$ Size, 10 × 2.5 mm	
J	[ft/lbf]	J	[ft/lbf]	J	[ft/lbf]	J	[ft/lbf]	J	[ft/lbf]	J	[ft/lbf]
54	[40]	41	[30]	37	[27]	27	[20]	18	[13]	14	[10]
48	[35]	35	[26]	31	[23]	24	[18]	16	[12]	12	[9]
41	[30]	30	[22]	27	[20]	20	[15]	14	[10]	11	[8]
34	[25]	26	[19]	23	[17]	16	[12]	11	[8]	8	[6]
27	[20]	20	[15]	18	[13]	14	[10]	10	[7]	7	[5]
22	[16]	16	[12]	15	[11]	11	[8]	7	[5]	5	[4]
20	[15]	15	[11]	14	[10]	11	[8]	7	[5]	5	[4]
18	[13]	14	[10]	12	[9]	8	[6]	5	[4]	4	[3]
16	[12]	12	[9]	11	[8]	8	[6]	5	[4]	4	[3]
14	[10]	11	[8]	10	[7]	7	[5]	4	[3]	3	[2]
10	[7]	7	[5]	7	[5]	5	[4]	3	[2]	3	[2]

4.5. Except as allowed by Section 4.6, the test temperature shall be as specified in the purchase order.

4.6. The manufacturer shall have the option of using a lower test temperature than is specified in the purchase order, provided that the absorbed energy values specified in the purchase order are met.

4.7. The actual test temperature used shall be reported with the test results.

5. FREQUENCY OF TESTING

5.1. *Frequency (H) Heat Testing for Plates, Shapes, and Bars*—One impact test (a set of three specimens) shall be made for each 45 Mg [50 tons] of the same type of product subject to the requirements of this specification produced on the same mill from the same heat of steel. The impact test(s) shall be taken from different as-rolled or heat-treated pieces. Impact specimens shall be selected from the thickest material rolled subject to the following modifications: When material rolled up to 50 mm [2 in.] inclusive in thickness differs 10 mm [$^3/_8$ in.] or more in thickness, one impact test shall be made from both the thickest and thinnest material rolled. When material rolled more than 50 mm [2 in.] in thickness differs by more than 25 mm [1 in.] in thickness, one impact test or more shall be made from both the thickest and thinnest material rolled that is more than 50 mm [2 in.] in thickness. If insufficient pieces of the thickest or thinnest material are produced to permit compliance with the above, then testing may proceed to the next nearest thickness available. When plates are produced from coils, three impact tests shall be taken from each qualifying coil. (See Section 4.2.) One such coil shall be tested for 45 Mg [50 tons] of the same product produced on the same mill from the same heat of steel. When material from one heat differs 2 mm [$^1/_{16}$ in.] or more in thickness, tests shall be made from both the thickest and thinnest material rolled regardless of the number of coils represented.

5.2. *Frequency (P) Piece Testing*:

5.2.1. *Plates*—One Charpy V-notch impact test (a set of three specimens) shall be made from each plate as-rolled except for material that has been heat treated by quenching and tempering, in which case specimens shall be selected from each heat-treated plate. When plates are produced from coils, three impact tests shall be taken from each coil.

5.2.2. *Shapes*—One Charpy V-notch impact test (a set of three specimens) shall be made from at least each 15 Mg [15 tons] or each single length of 15 Mg [15 tons] or more, of the same nominal shape size, excluding length, from each heat in the as-rolled condition. If the shapes are heat-treated, one test shall be taken from each heat of each furnace lot. For shapes heat-treated in a continuous furnace, a lot shall not exceed 15 Mg [15 tons].

5.2.3. *Bars*—One Charpy V-notch impact test (a set of three specimens) shall be made for each 5 Mg [5 tons] of the same heat and same diameter or thickness if the material is furnished as-rolled or is heat-treated in a continuous-type furnace. For material heat-treated in a noncontinuous furnace, one test shall be taken from each heat of the same bar diameter or thickness for each furnace charge.

6. HEAT TREATMENT

6.1. The material shall be heat-treated when specified on the purchase order.

6.2. When the plates are to be supplied in the as-rolled condition, the manufacturer or processor (M 160M/M 160) has the option to heat-treat the plates by normalizing, stress relieving, or normalizing and stress relieving to meet the desired toughness properties.

6.3. When the fabricator elects to perform the required heat-treatment or fabricates by hot forming instead of heat-treating, the plates shall be accepted on the basis of tests made on full thickness specimens heat-treated in accordance with the purchaser's order requirements. If the heat-treatment temperatures are not indicated on the purchase order, the manufacturer or processor shall heat-treat the specimens under conditions considered appropriate for grain refinement and to meet the toughness requirements. The plate manufacturer or processor shall inform the purchaser of the procedure followed in treating the specimens.

7. RETESTS

7.1. If more than one individual test value is below the specified minimum average value, or if one individual test value is below the greater of 7 J [5 ft·lbf] or two-thirds of the specified minimum average value, a retest of three additional specimens shall be made, each of which must have a test value equal to or exceeding the specified minimum average value.

7.2. If the required energy values are not obtained upon retest, the material may, at the option of the manufacturer or processor, be heat-treated in the case of as-rolled material or reheat treated in the case of heat-treated material.

7.3. After heat-treatment or reheat treatment, a set of three specimens shall be tested and qualified in the same manner as for the original material.

7.4. If the impact test fails for the thickest product tested when testing to frequency (H), that material shall be rejected and the next thickest material tested to qualify the heat in accordance with Section 4.1. At the option of the manufacturer or processor, retests may be made on the rejected material, in which case each piece shall be accepted or rejected on the basis of the results of its own test.

8. TEST REPORTS

8.1. Test reports for each heat supplied are required when specified by the purchase order.

8.1.1. Test reports shall show the results of each test required by the specification. However, for (H) frequency, only one test need be reported when the amount of materials from shipment is less than 45 Mg [50 tons], or two tests, when the amount of materials from a shipment is 45 Mg [50 tons] or more.

8.1.2. The thickness of the product tested may not necessarily be the same as an individual ordered thickness when (H) heat-testing is ordered. Tests from materials thicknesses in accordance with Section 5.1 and encompassing the thicknesses in a shipment shall be sufficient for qualifying the material in the shipment. These test thicknesses may or may not be within previously tested and shipped thicknesses from the same heat.

8.1.3. For plates produced from coils, all three test results shall be reported for each qualifying coil. If only half or less of a coil is utilized, then only one test from the outer lap and one from the innermost portion shipped need be reported.

8.1.4. For plates produced from coils, both the manufacturer and processor shall be identified on the test report.

8.1.5. A signature is not required on the test report. However, the document shall clearly identify the organization submitting the report. Notwithstanding the absence of a signature, the organization submitting the report is responsible for the content of the report.

8.1.6. When finished material is supplied to a purchase order specifying T 243M/T 243, the organization supplying that material shall provide the purchaser with a copy of the original manufacturer's test report.

9. KEYWORDS

9.1. Charpy V-notch; impact; sampling procedure; steel; structural steel; testing.

APPENDIX

(Nonmandatory Information)

X1. VARIATION IN CHARPY V-NOTCH TESTS

X1.1. A survey of the variation to be expected in Charpy V-notch test results obtained from three common fine grain plate steels was conducted by the American Iron and Steel Institute (AISI).[2] The results of the survey are contained in a Contributions to the Metallurgy of Steel entitled, “The Variations of Charpy V-notch Impact Test Properties in Steel Plates,” (SU/24), published January 1979. The survey data consist of test values obtained from six locations in addition to the locations shown in Figure 1 of this specification. The plate conditions tested involved as-rolled, normalized, and quench and tempered. Sufficient full sized specimens were taken from each sample so that three longitudinal and three transverse specimens could be broken at three test temperatures defined for each grade. The data are presented in tables of probability that impact properties at other than the official location, which may differ from those of the reported test location. Additional data of the same type, but utilizing samples from thicker plates, were published by AISI as SU/27.[3] Another survey sponsored by the AISI, entitled “Statistical Analysis of Structural Plate Mechanical Properties,” was published in January 2003.[4] That study analyzed the impact properties of more modern, higher strength as-rolled structural plate steels.

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[1] This test method is identical to ASTM A 673/A 673M-07 except for inch-pound units, rather than SI units, shown in brackets.

[2] Originally published by the American Iron and Steel Institute. Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, as PCN: 29-00039002

[3] “The Variations in Charpy V-Notch Impact Properties in Steel Plates” originally published by the American Iron and Steel Institute, July 1989.

[4] Available from AISI directly at http://www.steel.org/infrastructure/bridges/index.html.

Standard Method of Test for

Mechanical Testing of Steel Products

AASHTO Designation: T 244-10[1]
ASTM Designation: A 370-09a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

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1. SCOPE

1.1. These test methods cover procedures and definitions for the mechanical testing of steel, stainless steels, and related alloys. The various mechanical tests herein described are used to determine properties required in the product specifications. Variations in testing methods are to be avoided and standard methods of testing are to be followed to obtain reproducible and comparable results. In those cases in which the testing requirements for certain products are unique or at variance with these general procedures, the product specification testing requirements shall control.

1.2. The following mechanical tests are described:

	Sections
Tension	5 to 13
Bend	14
Hardness	15
Brinell	16
Rockwell	17
Portable	18
Impact	19 to 28
Keywords	29

1.3. Annexes covering details peculiar to certain products are appended to these test methods as follows:

Bar products	Annex A1
Tubular products	Annex A2
Fasteners	Annex A3
Round wire products	Annex A4
Significance of notched-bar impact testing	Annex A5
Converting percentage elongation of round specimens to equivalents for flat specimens	Annex A6
Testing multi-wire strand	Annex A7
Rounding of test data	Annex A8
Methods for testing steel reinforcing bars	Annex A9
Procedure for use and control of heat-cycle simulation	Annex A10

1.4. The values stated in SI (MPa) units are to be regarded as the standard.

1.5. When this document is referenced in a metric product specification, the yield and tensile values may be determined in inch-pound (ksi) units then converted into SI (MPa) units. The elongation determined in inch-pound gauge lengths of 2 or 8 in. may be reported in SI unit gauge lengths of 50 or 200 mm, respectively, as applicable. Conversely, when this document is referenced in an inch-pound product specification, the yield and tensile values may be determined in SI units, then converted into inch-pound units. The elongation determined in SI unit gauge lengths of 50 or 200 mm may be reported in inch-pound gauge lengths of 2 or 8 in., respectively, as applicable.

1.6. Attention is directed to R 18 when there may be a need for information on criteria for evaluation of testing laboratories.

1.7. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- T 266, Notched Bar Impact Testing of Metallic Materials (CVN)

2.2. *ASTM Standards*:

- A 703/A 703M, Standard Specification for Steel Castings, General Requirements, for Pressure-Containing Parts
- A 781/A 781M, Standard Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use
- A 833, Standard Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers
- E 4, Standard Practices for Force Verification of Testing Machines
- E 6, Standard Terminology Relating to Methods of Mechanical Testing
- E 8/E 8M, Standard Test Methods for Tension Testing of Metallic Materials
- E 10, Standard Test Method for Brinell Hardness of Metallic Materials
- E 18, Standard Test Methods for Rockwell Hardness of Metallic Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 83, Standard Practice for Verification and Classification of Extensometer Systems
- E 110, Standard Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers
- E 190, Standard Test Method for Guided Bend Test for Ductility of Welds
- E 290, Standard Test Methods for Bend Testing of Material for Ductility

2.3. *ASME Code*:

- ASME Boiler and Pressure Vessel Code, Section VIII, Division I, Part UG-8.[2]

3. GENERAL PRECAUTIONS

3.1. Certain methods of fabrication, such as bending, forming, and welding, or operations involving heating, may affect the properties of the material under test. Therefore, the product specifications cover the stage of manufacture at which mechanical testing is to be performed. The properties shown by testing prior to fabrication may not necessarily be representative of the product after it has been completely fabricated.

3.2. Improper machining or preparation of test specimens may give erroneous results. Care should be exercised to assure good workmanship in machining. Improperly machined specimens should be discarded and other specimens substituted.

3.3. Flaws in the specimen may also affect results. If any test specimen develops flaws, the retest provision of the applicable product specification shall govern.

3.4. If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

4. ORIENTATION OF TEST SPECIMENS

4.1. The terms "longitudinal test" and "transverse test" are used only in material specifications for wrought products and are not applicable to castings. When such reference is made to a test coupon or test specimen, the following definitions apply:

4.1.1. *Longitudinal Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is parallel to the direction of the greatest extension of the steel during rolling or forging. The stress applied to a longitudinal tension test specimen is in the direction of the greatest extension, and the axis of the fold of a longitudinal bend test specimen is at right angles to the direction of greatest extension (Figures 1, 2(a), and 2(b)).

4.1.2. *Transverse Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is at right angles to the direction of the greatest extension of the steel during rolling or forging. The stress applied to a transverse tension test specimen is at right angles to the greatest extension, and the axis of the fold of a transverse bend test specimen is parallel to the greatest extension (Figure 1).

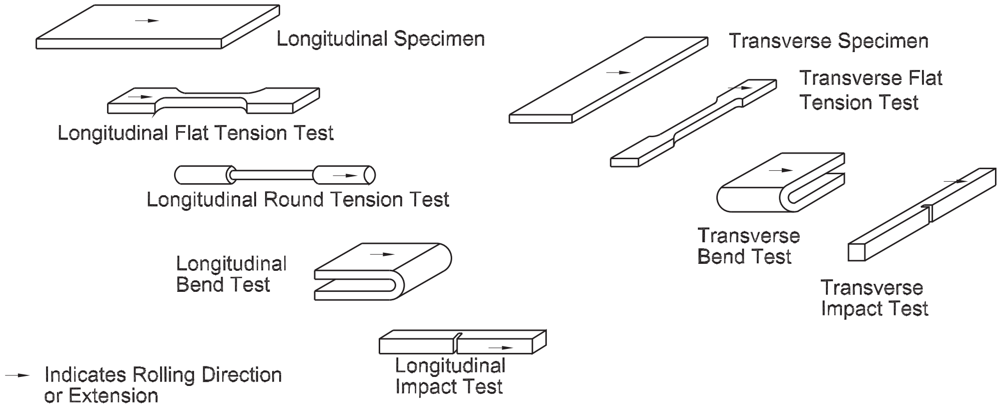
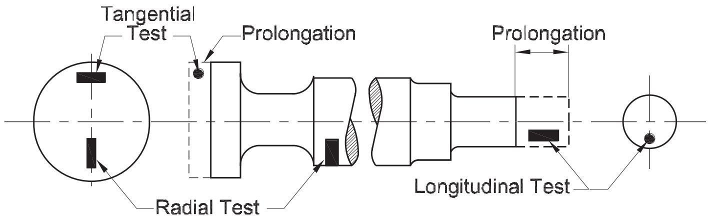
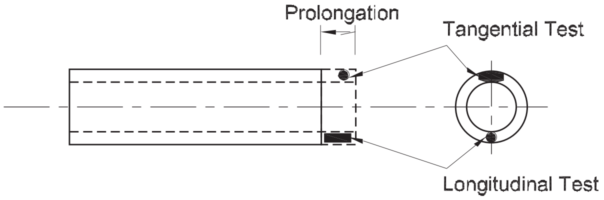


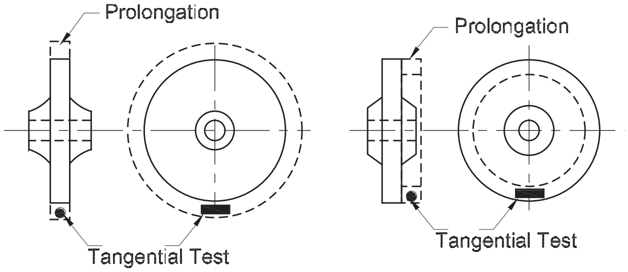
Figure 1—The Relation of Test Coupons and Test Specimens to Rolling Direction or Extension (Applicable to General Wrought Products)



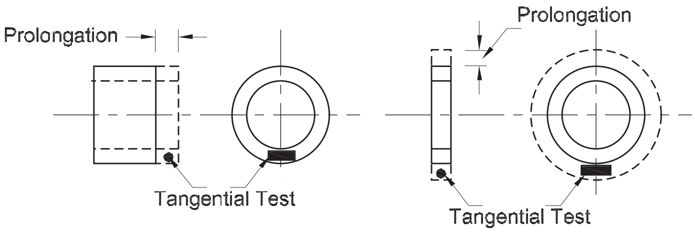
(a) Shafts and Rotors



(b) Hollows Forgings



(c) Disk Forgings



(d) Rings Forgings

Figure 2—Locations of Longitudinal Tension Test Specimens in Rings Cut from Tubular Products

4.2. The terms "radial test" and "tangential test" are used in material specifications for some wrought circular products and are not applicable to castings. When such reference is made to a test coupon or test specimen, the following definitions apply:

4.2.1. *Radial Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is perpendicular to the axis of the product and coincident with one of the radii of a circle drawn with a point on the axis of the product as a center (Figure 2(a)).

4.2.2. *Tangential Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is perpendicular to a plane containing the axis of the product and tangent to a circle drawn with a point on the axis of the product as a center (Figures 2(a), 2(b), 2(c), and 2(d)).

TENSION TEST

5. DESCRIPTION

5.1. The tension test related to the mechanical testing of steel products subjects a machined or full-section specimen of the material under examination to a measured load sufficient to cause rupture. The resulting properties sought are defined in ASTM E 6.

5.2. In general, the testing equipment and methods are given in T 68M. However, there are certain exceptions to T 68M practices in the testing of steel, and they are covered in these test methods.

6. TERMINOLOGY

6.1. For definitions of terms pertaining to tension testing, including tensile strength, yield point, yield strength, elongation, and reduction of area, reference should be made to ASTM E 6.

7. TESTING APPARATUS AND OPERATIONS

7.1. *Loading Systems*—There are two general types of loading systems, mechanical (screw power) and hydraulic. These differ chiefly in the variability of the rate of load application. The older screw power machines are limited to a small number of fixed free-running crosshead speeds. Some modern screw power machines and all hydraulic machines permit stepless variation throughout the range of speeds.

7.2. The tension testing machine shall be maintained in good operating condition, used only in the proper loading range, and calibrated periodically in accordance with the latest revision to T 67.

Note 1—Many machines are equipped with stress-strain recorders for autographic plotting of stress-strain curves. It should be noted that some recorders have a load measuring component entirely separate from the load indicator of the testing machine. Such recorders are calibrated separately.

7.3. *Loading*—It is the function of the gripping or holding device of the testing machine to transmit the load from the heads of the machine to the specimen under test. The essential requirement is that the load shall be transmitted axially. This implies that the centers of the action of the grips shall be in alignment, insofar as practicable, with the axis of the specimen at the beginning and during the test, and that bending or twisting be held to a minimum. For specimens with a reduced section, gripping of the specimen shall be restricted to the grip section. In the case of certain sections tested in full size, nonaxial loading is unavoidable and in such cases shall be permissible.

7.4. *Speed of Testing*—The speed of testing shall not be greater than that at which load and strain readings can be made accurately. In production testing, speed of testing is commonly expressed (1) in terms of free-running crosshead speed (rate of movement of the crosshead of the testing machine when not under load), or (2) in terms of rate of separation of the two heads of the testing machine under load, or (3) in terms of rate of stressing the specimen, or (4) in terms of rate of straining the specimen. The following limitations on the speed of testing are recommended as adequate for most steel products:

Note 2—Tension tests using closed-loop machines (with feedback control of rate) should not be performed using load control, as this mode of testing will result in acceleration of the crosshead upon yielding and elevation of the measured yield strength.

7.4.1. Any convenient speed of testing may be used up to one-half the specified yield point or yield strength. When this point is reached, the free-running rate of separation of the crossheads shall be adjusted so as not to exceed 0.063 millimeters per minute per millimeter ($^1/_{16}$ in. per minute per inch) of reduced section, or the distance between the grips for test specimens not having reduced sections. This speed shall be maintained through the yield point or yield strength. In determining the tensile strength, the free-running rate of separation of the heads shall not exceed 0.5 millimeters per minute per millimeter ($^1/_2$ in. per minute per inch) of reduced section, or the distance between the grips for test specimens not having reduced sections. In any event, the minimum speed of testing shall not be less than $^1/_{10}$ the specified maximum rates for determining yield point or yield strength and tensile strength.

7.4.2. It shall be permissible to set the speed of the testing machine by adjusting the free-running crosshead speed to the above specified values, inasmuch as the rate of separation of heads under load at these machine settings is less than the specified values of free-running crosshead speed.

7.4.3. As an alternative, if the machine is equipped with a device to indicate the rate of loading, the speed of the machine from half the specified yield point or yield strength through the yield point or yield strength may be adjusted so that the rate of stressing does not exceed 690 MPa (100000 psi)/min. However, the minimum rate of stressing shall not be less than 70 MPa (10000 psi)/min.

8. TEST SPECIMEN PARAMETERS

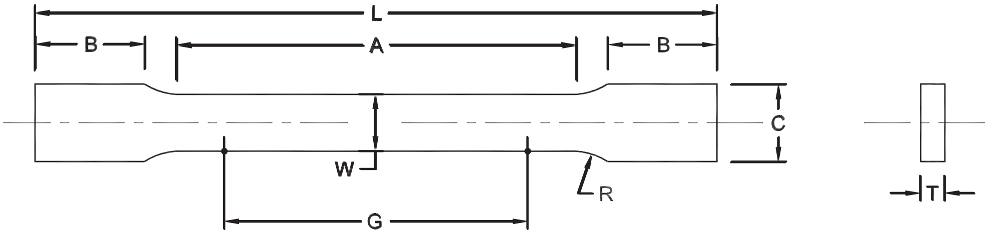
8.1. *Selection*—Test coupons shall be selected in accordance with the applicable product specifications.

8.1.1. *Wrought Steels*—Wrought steel products are usually tested in the longitudinal direction, but in some cases, where size permits and the service justifies it, testing is in the transverse, radial, or tangential direction. (See Figures 1 and 2.)

8.1.2. *Forged Steels*—For open die forgings, the metal for tension testing is usually provided by allowing extensions or prolongations on one or both ends of the forgings, either on all or a representative number as provided by the applicable product specifications. Test specimens are normally taken at mid-radius. Certain product specifications permit the use of a representative bar or the destruction of a production part for test purposes. For ring or disk-like forgings, test metal is provided by increasing the diameter, thickness, or length of the forging. Upset disk or ring forgings, which are worked or extended by forging in a direction perpendicular to the axis of the forging, usually have their principal extension along concentric circles and, for such forgings, tangential tension specimens are obtained from extra metal on the periphery or end of the forging. For some forgings, such as rotors, radial tension tests are required. In such cases, the specimens are cut or trepanned from specified locations.

8.2. *Size and Tolerances*—Test specimens shall be the full thickness or section of material as rolled, or may be machined to the form and dimensions shown in Figures 3 through 6, inclusive. The selection of size and type of specimen is prescribed by the applicable product specification. Full section specimens shall be tested in 200-mm (8-in.) gauge length unless otherwise specified in the product specification.

8.3. *Procurement of Test Specimens*—Specimens shall be sheared, blanked, sawed, trepanned, or oxygen-cut from portions of the material. They are usually machined so as to have a reduced cross section at mid-length in order to obtain uniform distribution of the stress over the cross section and to localize the zone of fracture. When test coupons are sheared, blanked, sawed, or oxygen-cut, care shall be taken to remove by machining all distorted, cold-worked, or heat-affected areas from the edges of the section used in evaluating the test.



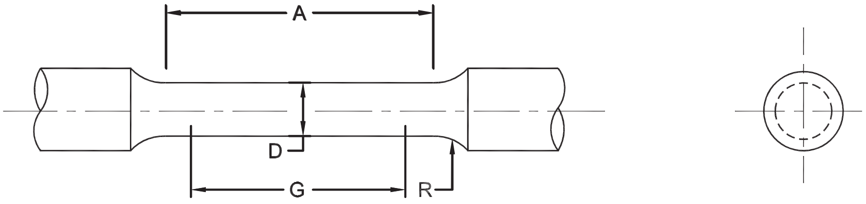
Dimensions

	Standard Specimens						Subsize Specimens	
	Plate-Type, 40-mm ($1^1/_2$ in.) Wide				Sheet Type, 12.5-mm ($^1/_2$ in.) Wide		6-mm ($^1/_4$-in.) Wide	
	200-mm (8-in.) Gauge Length		50-mm (2-in.) Gauge Length					
	mm	in.	mm	in.	mm	in.	mm	in.
G–Gauge length (Notes 1 and 2)	200 ± 0.25	8.00 ± 0.01	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	25.0 ± 0.08	1.000 ± 0.003
W–Width (Notes 3, 5, and 6)	40 + 3 – 6	$1^1/_2 + {}^1/_8 - {}^1/_4$	40 + 3 – 6	$1^1/_2 + {}^1/_8 - {}^1/_4$	12.5 ± 0.25	0.500 ± 0.010	6.25 ± 0.05	0.250 ±0.002
T–Thickness (Note 7)	Thickness of Material							
R–Radius of fillet, min (Note 4)	13	$^1/_2$	13	$^1/_2$	13	$^1/_2$	6	$^1/_4$
L–Overall length, min (Notes 2 and 8)	450	18	200	8	200	8	100	4
A–Length of reduced section, min	225	9	60	$2^1/_4$	60	$2^1/_4$	32	$1^1/_4$
B–Length of grip section, min (Note 9)	75	3	50	2	50	2	32	$1^1/_4$
C–Width of grip section, approximate (Notes 4, 10, and 11)	50	2	50	2	20	$^3/_4$	10	$^3/_8$

Notes:

1. For the 40-mm ($1^1/_2$-in.) wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. For the 200-mm (8-in.) gauge length specimen, a set of nine or more punch marks 25 mm (1 in.) apart, or one or more pairs of punch marks 200 mm (8 in.) apart may be used. For the 50-mm (2-in.) gauge length specimen, a set of three or more punch marks 25 mm (1 in.) apart, or one or more pairs of punch marks 50 mm (2 in.) apart may be used.
2. For the 12.5-mm ($^1/_2$-in.) wide specimen, punch marks for measuring the elongation after fracture shall be made on the flat face or edge of the specimen and within the reduced section. Either a set of three or more punch marks 25 mm (1 in.) apart or one or more pairs of punch marks 50 mm (2 in.) may be used.
3. For the four sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.10, 0.10, 0.05, or 0.025 mm (0.004, 0.004, 0.002, or 0.001 in.), respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at either end shall not be more than 0.40, 0.40, 0.10, or 0.06 mm (0.015, 0.015, 0.005, 0.003 in.), respectively, larger than the width at the center.
4. For each specimen type, the radii of all fillets shall be equal to each other with a tolerance of 1.25 mm (0.05 in.), and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 2.5 mm (0.10 in.).
5. For each of the four sizes of specimens, narrower widths (W or C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.
6. The specimen may be modified by making the sides parallel throughout the length of the specimens, the width and tolerances being the same as those specified above. When necessary, a narrower specimen may be used, in which case the width should be as great as the width of the material being tested permits. If the width is 38 mm ($1^1/_2$ in.) or less, the sides may be parallel throughout the length of the specimen.
7. The dimension T is the thickness of the test specimen as provided for in the applicable product specifications. Minimum nominal thickness of 40-mm ($1^1/_2$-in.) wide specimens shall be 5 mm ($^3/_{16}$ in.), except as permitted by the product specification. Maximum nominal thickness of 12.5-mm ($^1/_2$-in.) and 6.25-mm ($^1/_4$-in.) wide specimens shall be 19 mm ($^3/_4$ in.) and 6 mm ($^1/_4$ in.), respectively.
8. To aid in obtaining axial loading during testing of 6.25-mm ($^1/_4$-in.) wide specimens, the overall length should be as the material will permit.
9. It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips. If the thickness of 12.5-mm ($^1/_2$-in.) wide specimens is greater than 10 mm ($^3/_8$ in.), longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.
10. For standard sheet type specimens and sub-size specimens, the ends of the specimen shall be symmetrical with the centerline of the reduced section within 0.25 and 0.13 mm (0.01 and 0.005 in.), respectively, except that, for steel, if the ends of the 12.5-mm ($^1/_2$-in.) wide specimen are symmetrical within 1.0 mm (0.05 in.), a specimen may be considered satisfactory for all but referee testing.
11. For standard plate-type specimens, the ends of the specimen shall be symmetrical with the centerline of the reduced section within 6.4 mm (0.25 in.) except for referee testing, in which case the ends of the specimen shall be symmetrical with the centerline of the reduced section within 2.5 mm (0.10 in.).

Figure 3—Rectangular Tension Test Specimens



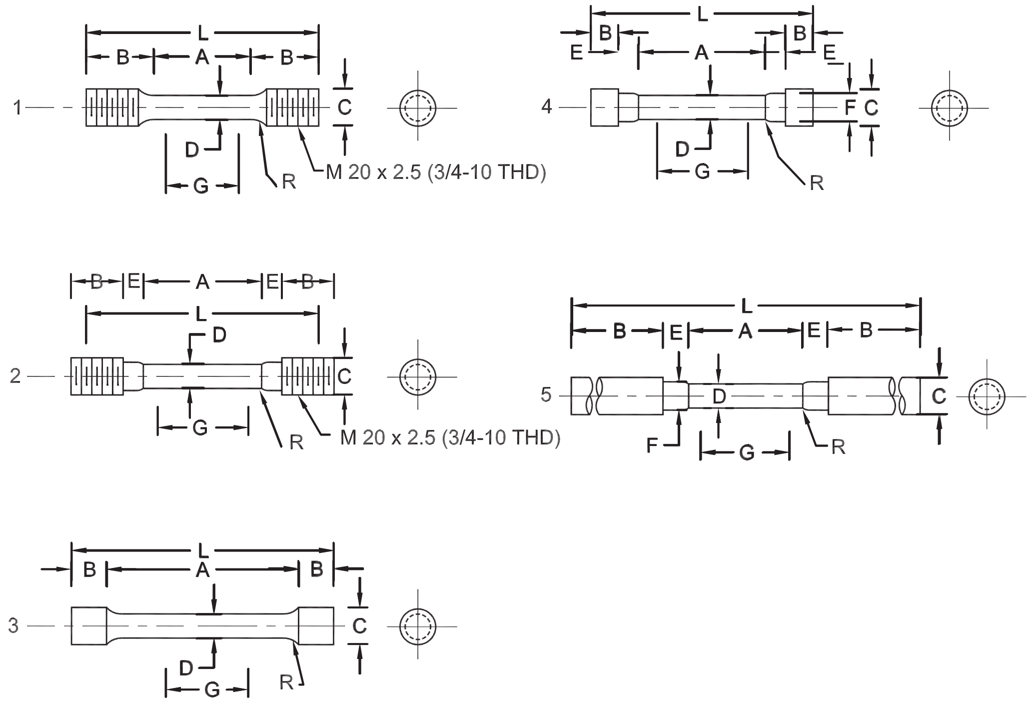
Dimensional Equivalents

	Standard Specimen		Small-Size Specimen Projectional to Standard							
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Nominal Diameter	12.50	0.500	8.75	0.350	6.25	0.250	4.00	0.160	2.50	0.113
G–Gauge length	50.00 ± 0.10	2.000 ± 0.005	35.00 ± 0.10	1.400 ± 0.005	25.00 ± 0.10	1.000 ± 0.005	16.00 ± 0.10	0.640 ± 0.005	10.00 ± 0.10	0.450 ± 0.005
D–Diameter (Note 1)	12.50 ± 0.25	0.500 ± 0.010	8.75 ± 0.18	0.350 ± 0.007	6.25 ± 0.12	0.250 ± 0.005	4.00 ± 0.08	0.160 ± 0.003	2.50 ± 0.05	0.113 ± 0.002
R–Radius of fillet, minimum	10	$^3/_8$	6	$^1/_4$	5	$^3/_{16}$	4	$^5/_{32}$	2	$^3/_{32}$
A–Length of reduced section, minimum (Note 2)	60	$2^1/_4$	45	$1^3/_4$	32	$1^1/_4$	20	$^3/_4$	16	$^5/_8$

Notes:

1. The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 percent larger in diameter than the center (controlling dimension).
2. If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gauge length. Reference marks for the measurement of elongation should, nevertheless, be spaced at the indicated gauge length.
3. The gauge length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. (See Figure 9.) If the ends are to be held in wedge grips, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
4. On the round specimens in Figures 5 and 6, the gauge lengths are equal to four times the nominal diameter. In some product specifications, other specimens may be provided for, but unless the 4-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the standard test specimen.
5. The use of specimens smaller than 6.25-mm (0.250-in.) diameter shall be restricted to cases in which the material to be tested is of sufficient size to obtain larger specimens or when all parties agree to their use for acceptance testing. Smaller specimens require suitable equipment and greater skill in both matching and testing.
6. Five sizes of specimens often used have diameters of approximately 0.505, 0.357, 0.252, 0.160, and 0.113 in., the reason being to permit easy calculations of stresses from loads, since the corresponding cross-sectional areas are equal to 0.200, 0.100, 0.0500, 0.0200, and 0.0100 in.^{2}, respectively. Thus, when the actual diameters agree with these values, the stresses (or strengths) may be computed using the simple multiplying factors 5, 10, 20, 50, and 100, respectively. (The metric equivalents of these fixed diameters do not result in correspondingly convenient cross-sectional area and multiplying factors.)

Figure 4—Standard 12.5-mm (0.500-in.) Round Tension Test Specimen with 50-mm (2-in.) Gauge Length and Examples of Small-Size Specimens Proportional to the Standard Specimen



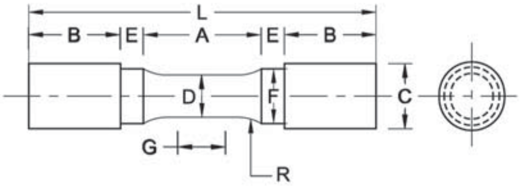
Dimensional Equivalents

	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5	
	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
G–Gauge length	50.00 ± 0.10	2.000 ± 0.005	50.00 ± 0.10	2.000 ± 0.005	50.00 ± 0.10	2.000 ± 0.005	50.00 ± 0.10	2.000 ± 0.005	50.00 ± 0.10	2.000 ± 0.005
D–Diameter (Note 1)	12.50 ± 0.25	0.500 ± 0.010	12.50 ± 0.25	0.500 ± 0.010	12.50 ± 0.25	0.500 ± 0.010	12.50 ± 0.25	0.500 ± 0.010	12.50 ± 0.25	0.500 ± 0.010
R–Radius of fillet, min	10	$^{3}/_{8}$	10	$^{3}/_{8}$	2	$^{1}/_{16}$	10	$^{3}/_{8}$	10	$^{3}/_{8}$
A–Length of reduced section	60, min	$2^{1}/_{4}$, min	60, min	$2^{1}/_{4}$, min	100, approximately	4, approximately	60, min	$2^{1}/_{4}$, min	60, min	$2^{1}/_{4}$, min
L–Overall length, approximate	125	5	140	$5^{1}/_{2}$	140	$5^{1}/_{2}$	120	$4^{3}/_{4}$	240	$9^{1}/_{2}$
B–Length grip section (Note 2)	35, approximately	$1^{3}/_{8}$, approximately	25, approximately	1, approximately	20, approximately	$^{3}/_{4}$, approximately	13, approximately	$^{1}/_{2}$, approximately	75, min	3, min
C–Diameter of end section	20	$^{3}/_{4}$	20	$^{3}/_{4}$	18	$^{23}/_{32}$	22	$^{7}/_{8}$	20	$^{3}/_{4}$
E–Length of shoulder and fillet section, approximate	—	—	16	$^{5}/_{8}$	—	—	20	$^{3}/_{4}$	16	$^{5}/_{8}$
F–Diameter of shoulder	—	—	16	$^{5}/_{8}$	—	—	16	$^{5}/_{8}$	15	$^{19}/_{32}$

Notes:

1. The reduced section may have a gradual taper from the ends towards the center, with the ends not more than 0.10 mm (0.005 in.) larger in diameter than the center.
2. On Specimen 5, it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
3. The types of ends shown are applicable for the standard 0.500-in. round tension test specimen; similar types can be used for sub-size specimens. The use of UNF series of threads ($^{3}/_{4}$ by 16, $^{1}/_{2}$ by 20, $^{3}/_{8}$ by 24, and $^{1}/_{4}$ by 28) is suggested for high-strength brittle materials to avoid fracture in the thread portion.

Figure 5—Suggested Types of Ends for Standard Round Tension Test Specimen



Dimensional Equivalents

	Specimen 1		Specimen 2		Specimen 3	
	mm	in.	mm	in.	mm	in.
G–Length of parallel	Shall be equal to or greater than diameter *D*					
D–Diameter	12.50 ± 0.25	0.500 ± 0.010	20.00 ± 0.40	0.750 ± 0.015	30.00 ± 0.60	1.250 ± 0.025
R–Radius of fillet, min	25	1	25	1	50	2
A–Length of reduced section, min	32	$1^{1}/_{4}$	38	$1^{1}/_{2}$	60	$2^{1}/_{4}$
L–Overall length, min	95	$3^{3}/_{4}$	100	4	160	$6^{3}/_{8}$
B–Length of grip section, approximate	25	1	25	1	45	$1^{3}/_{4}$
C–Diameter of end section, approximate	20	$^{3}/_{4}$	30	$1^{1}/_{8}$	48	$1^{7}/_{8}$
E–Length of shoulder, min	6	$^{1}/_{4}$	6	$^{1}/_{4}$	8	$^{5}/_{16}$
F–Diameter of shoulder	16.00 ± 0.40	$^{5}/_{8} \pm {}^{1}/_{64}$	24.00 ± 0.40	$^{15}/_{16} \pm {}^{1}/_{64}$	36.50 ± 0.40	$1^{7}/_{16} \pm {}^{1}/_{64}$

Note: The reduced section and shoulders (dimensions A, D, E, F, G, and R) shall be shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. Commonly, the ends are threaded and have the dimensions *B* and *C* given above.

Figure 6—Standard Tension Test Specimens for Cast Iron

8.4. *Aging of Test Specimens*—Unless otherwise specified, it shall be permissible to age tension test specimens. The time–temperature cycle employed must be such that the effects of previous processing will not be materially changed. It may be accomplished by aging at room temperature 24 to 48 hours, or in shorter time at moderately elevated temperatures by boiling in water, or heating in oil or in an oven.

8.5. *Measurement of Dimensions of Test Specimens*:

8.5.1. *Standard Rectangular Tension Test Specimens*—These forms of specimens are shown in Figure 3. To determine the cross-sectional area, the center width dimension shall be measured to the nearest 0.13 mm (0.005 in.) for the 200-mm (8-in.) gauge length specimen and 0.025 mm (0.001 in.) for the 50-mm (2-in.) gauge length specimen in Figure 3. The center thickness dimension shall be measured to the nearest 0.025 mm (0.001 in.) for both specimens.

8.5.2. *Standard Round Tension Test Specimens*—These forms of specimens are shown in Figures 4 and 5. To determine the cross-sectional area, the diameter shall be measured at the center of the gauge length to the nearest 0.025 mm (0.001 in.). (See Tables 1 and 2.)

8.6. *General*—Test specimens shall be either substantially full-sized or machined, as prescribed in the product specifications for the material being tested.

8.6.1. Improperly prepared test specimens often cause unsatisfactory test results. It is important, therefore, that care be exercised in the preparation of specimens, particularly in the machining, to assure good workmanship.

8.6.2. It is desirable to have the cross-sectional area of the specimen smallest at the center of the gauge length to ensure fracture within the gauge length. This is provided for by the taper in the gauge length permitted for each of the specimens described in the following sections.

8.6.3. For brittle materials, it is desirable to have fillets of a large radius at the ends of the gauge length.

Table 1—Multiplying Factors to Be Used for Various Diameters of Round Test Specimens

Standard Specimen			Small-Sized Specimens Proportional to Standard					
12.5-mm Round			8.75-mm Round			6.25-mm Round		
Actual Dia, mm	Area, 10^{-6} m^2	Factor, 10^3/m^2	Actual Dia, mm	Area, 10^{-6} m^2	Factor, 10^3/m^2	Actual Dia, mm	Area, 10^{-6} m^2	Factor, 10^3/m^2
12.25	117.9	8.485	8.57	57.68	17.34	6.13	29.51	33.88
12.26	118.1	8.471	8.58	57.82	17.30	6.14	29.61	33.77
12.27	118.2	8.457	8.59	57.95	17.26	6.15	29.71	33.66
12.28	118.4	8.443	8.60	58.09	17.22	6.16	29.80	33.55
12.29	118.6	8.430	8.61	58.22	17.18	6.17	29.90	33.45
12.30	118.8	8.416	8.62	58.36	17.14	6.18	30.00	33.34
12.31	119.0	8.402	8.63	58.49	17.10	6.19	30.09	33.23
12.32	119.2	8.389	8.64	58.63	17.06	6.20	30.19	33.12
12.33	119.4	8.375	8.65	58.77	17.02	6.21	30.29	33.02
12.34	119.6	8.361	8.66	58.90	16.98	6.22	30.39	32.91
12.35	119.8	8.348	8.67	59.04	16.94	6.23	30.48	32.80
12.36	120.0	8.334	8.68	59.17	16.90	6.24	30.58	32.70
12.37	120.2	8.321	6.69	59.31	16.86	6.25	30.68	32.59
12.38	120.4	8.307	8.70	59.45	16.82	6.26	30.78	32.49
12.39	120.6	8.294	8.71	59.58	16.78	6.27	30.88	32.39
12.40	120.8	8.281	8.72	59.72	16.74	6.28	30.97	32.28
12.41	121.0	8.267	8.73	59.86	16.71	6.29	31.07	32.18
12.42	121.2	8.254	8.74	59.99	16.67	6.30	31.17	32.08
12.43	121.3	8.241	8.75	60.13	16.63	6.31	31.27	31.98
12.44	121.5	8.228	8.76	60.27	16.59	6.32	31.37	31.88
12.45	121.7	8.214	8.77	60.41	16.55	6.33	31.47	31.78
12.46	121.9	8.201	8.78	60.55	16.52	6.34	31.57	31.68
12.47	122.1	8.188	8.79	60.68	16.48	6.35	31.67	31.58
12.48	122.3	8.175	8.80	60.82	16.44	6.36	31.77	31.48
12.49	122.5	8.162	8.81	60.96	16.40	6.37	31.87	31.38
12.50	122.7	8.149	8.82	61.10	16.37			
12.51	122.9	8.136	8.83	61.24	16.33			
12.52	123.1	8.123	8.84	61.38	16.29			
12.53	123.3	8.110	8.85	61.51	16.26			
12.54	123.5	8.097	8.86	61.65	16.22			
12.55	123.7	8.084	8.87	61.79	16.18			
12.56	123.9	8.071	8.88	61.93	16.15			
12.57	124.1	8.058	8.89	62.07	16.11			
12.58	124.3	8.045	8.90	62.21	16.07			
12.59	124.5	8.033	8.91	62.35	16.04			
12.60	124.7	8.020	8.92	62.49	16.00			
12.61	124.9	8.007	8.93	62.63	15.97			
12.62	125.1	7.995						
12.63	125.3	7.982						
12.64	125.5	7.969						
12.65	125.7	7.957						
12.66	125.9	7.944						
12.67	126.1	7.932						
12.68	126.3	7.919						
12.69	126.5	7.907						
12.70	126.7	7.894						
12.71	126.9	7.882						
12.72	127.1	7.869						
12.73	127.3	7.857						
12.74	127.5	7.845						
12.75	127.7	7.832						

Table 2—Multiplying Factors to Be Used for Various Diameters of Round Test Specimens

Standard Specimen			Small-Sized Specimens Proportional to Standard					
0.500-in. Round			0.350-in. Round			0.250-in. Round		
Actual Dia, in.	Area, in.^{2}	Multiplying Factor	Actual Dia, in.	Area, in.^{2}	Multiplying Factor	Actual Dia, in.	Area, in.^{2}	Multiplying Factor
0.490	0.1886	5.30	0.343	0.0924	10.82	0.245	0.0471	21.21
0.491	0.1893	5.28	0.344	0.0929	10.76	0.246	0.0475	21.04
0.492	0.1901	5.26	0.345	0.0935	10.70	0.247	0.0479	20.87
0.493	0.1909	5.24	0.346	0.0940	10.64	0.248	0.0483	20.70
0.494	0.1917	5.22	0.347	0.0946	10.57	0.249	0.0487	20.54
0.495	0.1924	5.20	0.348	0.0951	10.51	0.250	0.0491	20.37
							0.0495	20.21
0.496	0.1932	5.18	0.349	0.0957	10.45	0.251	(0.05)[a]	(20.0)[a]
							0.0499	20.05
0.497	0.1940	5.15	0.350	0.0962	10.39	0.252	(0.05)[a]	(20.0)[a]
							0.0503	19.89
0.498	0.1948	5.13	0.351	0.0968	10.33	0.253	(0.05)[a]	(20.0)[a]
0.499	0.1956	5.11	0.352	0.0973	10.28	0.254	0.0507	19.74
0.500	0.1963	5.09	0.353	0.0979	10.22	0.255	0.0511	19.58
0.501	0.1971	5.07	0.354	0.0984	10.16			
0.502	0.1979	5.05	0.355	0.0990	10.10			
				0.0995	10.05			
0.503	0.1987	5.03	0.356	(0.1)[a]	(10.0)[a]			
	0.1995	5.01		0.1001	9.99			
0.504	(0.2)[a]	(5.0)[a]	0.357	(0.1)[a]	(10.0)[a]			
	0.2003	4.99						
0.505	(0.2)[a]	(5.0)[a]						
	0.2011	4.97						
0.506	(0.2)[a]	(5.0)[a]						
0.507	0.2019	4.95						
0.508	0.2027	4.93						
0.509	0.2035	4.91						
0.510	0.2043	4.90						

[a] The values in parentheses may be used for ease in calculation of stresses, in pounds per square inch, as permitted in Note 6 of Figure 4.

9. PLATE-TYPE SPECIMENS

9.1. The standard plate-type test specimens are shown in Figure 3. Such specimens are used for testing metallic materials in the form of plate, structural and bar-sized shapes, and flat material having a nominal thickness of 5 mm ($^3/_{16}$ in.) or more. When product specifications so permit, other types of specimens may be used.

Note 3—When called for in the product specification, the 200-mm (8-in.) gauge length specimen of Figure 3 may be used for sheet and strip material.

10. SHEET-TYPE SPECIMEN

10.1. The standard sheet-type test specimen is shown in Figure 3. This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band, and hoop ranging in nominal thickness from 0.13 to 25 mm (0.005 to 1 in.). When product specifications so permit, other types of specimens may be used, as provided in Section 9. (See Note 3.)

11. ROUND SPECIMENS

11.1. The standard 12.5-mm (0.500-in.) diameter round test specimen shown in Figure 4 is used quite generally for testing metallic materials..

11.2. Figure 4 also shows small-sized specimens proportional to the standard specimen. These may be used when it is necessary to test material from which the standard specimen or specimens shown in Figure 3 cannot be prepared. Other sizes of small round specimens may be used. In any such small-sized specimen, it is important that the gauge length for measurement of elongation be four times the diameter of the specimen. (See Note 4 in Figure 4.)

11.3. The type of specimen ends outside of the gauge length shall accommodate the shape of the product tested, and shall properly fit the holders or grips of the testing machine so that axial loads are applied with a minimum of load eccentricity and slippage. Figure 5 shows specimens with various types of ends that have given satisfactory results.

12. GAUGE MARKS

12.1. The specimens shown in Figures 3 through 6 shall be gauge-marked with a center punch, scribe marks, multiple device, or drawn with ink. The purpose of these gauge marks is to determine the percent elongation. Punch marks shall be light, sharp, and accurately spaced. The localization of stress at the marks makes a hard specimen susceptible to starting fracture at the punch marks. The gauge marks for measuring elongation after fracture shall be made on the flat or on the edge of the flat tension test specimen and within the parallel section; for the 200-mm (8-in.) gauge length specimen, Figure 3; one or more sets of 200-mm (8-in.) gauge marks may be used, intermediate marks within the gauge length being optional. Rectangular 50-mm (2-in.) gauge length specimens, Figure 3, and round specimens, Figure 4, are gauge-marked with a double-pointed center punch or scribe marks. One or more sets of gauge marks may be used; however, one set must be approximately centered in the reduced section. These same precautions shall be so observed when the test specimen is full section.

13. DETERMINATION OF TENSILE PROPERTIES

13.1. *Yield Point*—Yield point is the first stress in a material, less than the maximum obtainable stress, at which an increase in strain occurs without an increase in stress. Yield point is intended for application only for materials that may exhibit the unique characteristic of showing an increase in strain without an increase in stress. The stress–strain diagram is characterized by a sharp knee or discontinuity. Determine yield point by one of the following methods:

13.1.1. *Drop of the Beam or Halt-of-the-Load Method*—In this method, apply an increasing load to the specimen at a uniform rate. When a lever and poise machine is used, keep the beam in balance by running out the poise at approximately a steady rate. When the yield point of the material is reached, the increase of the load will stop, but run the poise a trifle beyond the balance position, and the beam of the machine will drop for a brief but appreciable interval of time. When a machine equipped with a load-indicating dial is used, there is a halt or hesitation of the load-indicating pointer corresponding to the drop of the beam. Note the load at the "drop of the beam" or the "halt of the pointer" and record the corresponding stress as the yield point.

13.1.2. *Autographic Diagram Method*—When a sharp-kneed stress–strain diagram is obtained by an autographic recording device, take the stress corresponding to the top of the knee (Figure 7), or the stress at which the curve drops as the yield point.

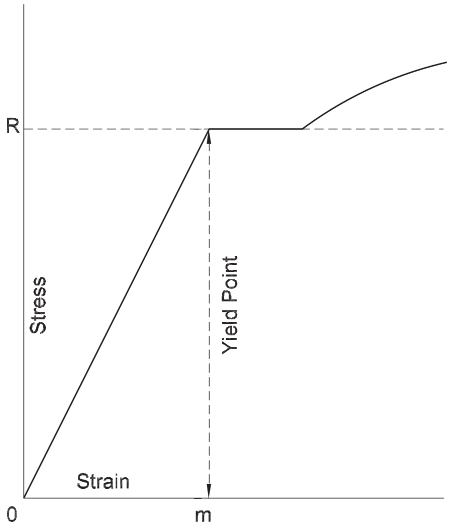


Figure 7—Stress–Strain Diagram Showing Yield Point Corresponding with Top of Knee

13.1.3. *Total Extension-Under-Load Method*—When testing material for yield point and the test specimens may not exhibit a well-defined disproportionate deformation that characterizes a yield point as measured by the drop of the beam, halt-of-the-load, or autographic diagram methods described in Sections 13.1.1 and 13.1.2, a value equivalent to the yield point in its practical significance may be determined by the following method and may be recorded as yield point: Attach a Class C or better extensometer (Notes 4 and 5) to the specimen. When the load producing a specified extension (Note 6) is reached, record the stress corresponding to the load as the yield point (Figure 8).

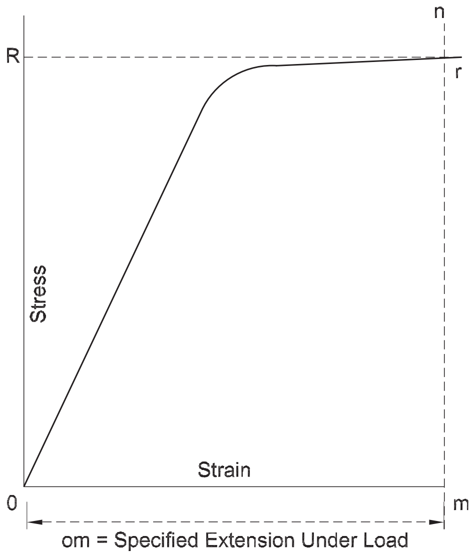


Figure 8—Stress–Strain Diagram Showing Yield Point or Yield Strength by Extension-Under-Load Method

Note 4—Automatic devices are available that determine the load at the specified total extension without plotting a stress–strain curve. Such devices may be used if their accuracy has been demonstrated. Multiplying calipers and other such devices are acceptable for use provided their accuracy has been demonstrated to be equivalent to a Class C extensometer.

Note 5—Reference should be made to ASTM E 83.

Note 6—For steel with a yield point specified not over 550 MPa (80000 psi), an appropriate value is 0.12 mm/mm (0.005 in./in.) of gauge length. For values above 550 MPa (80000 psi), this method is not valid unless the limiting total extension is increased.

Note 7—The shape of the initial portion of an autographically determined stress–strain (or a load-elongation) curve may be influenced by numerous factors, such as the seating of the specimen in the grips, the straightening of a specimen bent due to residual stresses, and the rapid loading permitted in Section 7.4.1. Generally, the aberrations in this portion of the curve should be ignored when fitting a modulus line, such as that used to determine the extension-under-load yield, to the curve.

13.2. *Yield Strength*—Yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain, percent offset, total extension under load, etc. Determine yield strength by one of the following methods:

13.2.1. *Offset Method*—To determine the yield strength by the "offset method," it is necessary to secure data (autographic or numerical) from which a stress–strain diagram with a distinct modulus characteristic of the material being tested may be drawn. Then, on the stress–strain diagram (Figure 9), lay off *Om* equal to the specified value of the offset, draw *mn* parallel to *OA*, and thus locate *r*, the intersection of *mn* with the stress–strain curve corresponding to load *R,* which is the yield strength load. In recording values of yield strength obtained by this method, the value of offset specified or used, or both, shall be stated in parentheses after the term "yield strength"; for example:

Yield strength (0.2% offset) = 360 MPa (52000 psi) *(1)*

When the offset is 0.2 percent or larger, the extensometer used shall qualify as a Class B2 device over a strain range of 0.05 to 1.0 percent. If a smaller offset is specified, it may be necessary to specify a more accurate device (that is, a Class B1 device) or reduce the lower limit of the strain range (for example, to 0.01 percent) or both. See also Note 9 for automatic devices.

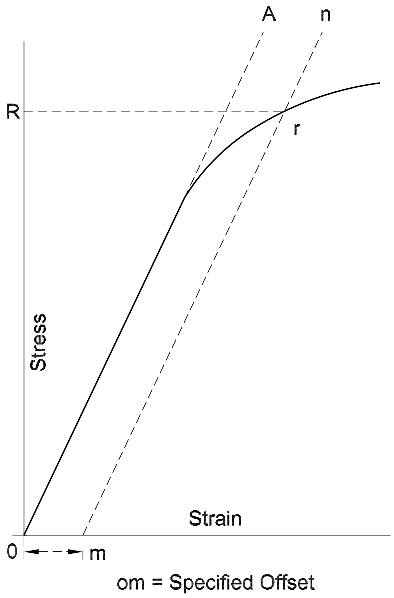


Figure 9—Stress–Strain Diagram for Determination of Yield Strength by the Offset Method

Note 8—For stress–strain diagrams not containing a distinct modulus, such as for some cold-worked materials, it is recommended that the extension-under-load method be utilized. If the offset method is used for materials without a distinct modulus, a modulus value appropriate for the material being tested should be used: 207000 MPa (30000000 psi) for carbon steel; 200000 MPa (29000000 psi) for ferritic stainless steel; 193 000 MPa (28000000 psi) for austenitic stainless steel. For special alloys, the producer should be contacted to discuss appropriate modulus values.

13.2.2. *Extension-Under-Load Method*—For tests to determine the acceptance or rejection of material for which stress–strain characteristics are well known from previous tests of similar material in which stress–strain diagrams were plotted, the total strain corresponding to the stress at which the specified offset (Notes 9 and 10) occurs will be known within satisfactory limits. The stress on the specimen, when this total strain is reached, is the value of the yield strength. In recording values of yield strength obtained by this method, the value of “extension” specified or used, or both, shall be stated in parentheses after the term "yield strength"; for example:

$$\text{Yield strength (0.5\% EUL)} = 360\text{ MPa (52000 psi)} \qquad (2)$$

The total strain can be obtained satisfactorily by use of a Class B1 extensometer (Notes 4, 5, and 7).

Note 9—Automatic devices are available that determine offset yield strength without plotting a stress–strain curve. Such devices may be used if their accuracy has been demonstrated.

Note 10—The appropriate magnitude of the extension under load obviously will vary with the strength range of the particular steel under test. In general, the value of extension under load applicable to steel at any strength level may be determined from the sum of the proportional strain and the plastic strain expected at the specified yield strength. The following equation is used:

$$\text{Extension under load mm/mm (in./in.) of gauge length} = (YS/E) + r \qquad (3)$$

where:

YS = specified yield strength, MPa (psi);

E = modulus of elasticity, MPa (psi); and

r = limiting plastic strain, mm/mm (in./in.).

13.3. *Tensile Strength*—Calculate the tensile strength by dividing the maximum load the specimen sustains during a tension test by the original cross-sectional area of the specimen.

13.4. *Elongation*:

13.4.1. Fit the ends of the fractured specimen together carefully and measure the distance between the gauge marks to the nearest 0.25 mm (0.01 in.) for gauge lengths of 50 mm (2 in.) and less, and to the nearest 0.5 percent of the gauge length for gauge lengths greater than 50 mm (2 in.). A percentage scale reading to 0.5 percent of the gauge length may be used. The elongation is the increase in length of the gauge length, expressed as a percentage of the original gauge length. In recording elongation values, give both the percentage increase and the original gauge length.

13.4.2. If any part of the fracture takes place outside of the middle half of the gauge length or in a punched or scribed mark within the reduced section, the elongation value obtained may not be representative of the material. If the elongation so measured meets the minimum requirements specified, no further testing is indicated, but if the elongation is less than the minimum requirements, discard the test and retest.

13.4.3. Automated tensile testing methods using extensometers allow for the measurement of elongation in a method described below. Elongation may be measured and reported either this way, or as in the method described above, fitting the broken ends together. Either result is valid.

13.4.4. Elongation at fracture is defined as the elongation measured just prior to the sudden decrease in force associated with fracture. For many ductile materials not exhibiting a sudden decrease in force, the elongation at fracture can be taken as the strain measured just prior to when the force falls below 10 percent of the maximum force encountered during the test.

13.4.4.1. Elongation at fracture shall include elastic and plastic elongation and may be determined with autographic or automated methods using extensometers verified over the strain range of interest. Use a Class B2 or better extensometer for materials having less than 5 percent elongation; a Class C or better extensometer for materials having an elongation greater than or equal to 5 percent but less than 50 percent; and a Class D or better extensometer for materials having 50 percent or greater elongation. In all cases, the extensometer gauge length shall be the nominal gauge length required for the specimen being tested. Due to the lack of precision in fitting fractured ends together, the elongation after fracture using the manual methods of the preceding paragraphs may differ from the elongation at fracture determined with extensometers.

13.4.4.2. Percent elongation at fracture may be calculated directly from elongation at fracture data and be reported instead of percent elongation as calculated in Section 13.4.1. However, these two parameters are not interchangeable. Use of the elongation at fracture method generally provides more repeatable results.

13.5. *Reduction of Area*—Fit the ends of the fractured specimen together and measure the mean diameter or the width and thickness at the smallest cross section to the same accuracy as the original dimensions. The difference between the area thus found and the area of the original cross section expressed as a percentage of the original area is the reduction of area.

BEND TEST

14. DESCRIPTION

14.1. The bend test is one method for evaluating ductility, but it cannot be considered as a quantitative means of predicting service performance in bending operations. The severity of the bend test is primarily a function of the angle of bend and the inside diameter to which the specimen is bent, and of the cross section of the specimen. These conditions are varied according to location and orientation of the test specimen and the chemical composition, tensile properties, hardness, type, and quality of the steel specified. ASTM E 190 and ASTM E 290 may be consulted for methods of performing the test.

14.2. Unless otherwise specified, it shall be permissible to age bend-test specimens. The time–temperature cycle employed must be such that the effects of previous processing will not be materially changed. It may be accomplished by aging at room temperature 24 to 48 hours, or in shorter time at moderately elevated temperatures by boiling in water, or heating in oil or an oven.

14.3. Bend the test specimen at room temperature to an inside diameter, as designated by the applicable product specification, to the extent specified without major cracking on the outside of the bent portion. The speed of bending ordinarily is not an important factor.

HARDNESS TEST

15. GENERAL

15.1. A hardness test is a means of determining resistance to penetration and is occasionally employed to obtain a quick approximation of tensile strength. Tables 2, 3, 4, and 5 are for the conversion of hardness measurements from one scale to another or to approximate tensile strength. These conversion values have been obtained from computer-generated curves and are presented to the nearest 0.1 point to permit accurate reproduction of those curves. Since all converted hardness values must be considered approximate, however, all converted Rockwell hardness numbers shall be rounded to the nearest whole number.

15.2. *Hardness Testing*:

15.2.1. If the product specification permits alternative hardness testing to determine conformance to a specified hardness requirement, the conversions listed in Tables 2, 3, 4, and 5 shall be used.

15.2.2. When recording converted hardness numbers, the measured hardness and test scale shall be indicated in parentheses; for example: 353 HBW (38 HRC). This means that a hardness value of 38 was obtained using the Rockwell C scale and converted to a Brinell hardness of 353.

Table 3—Approximate Hardness Conversion Numbers for Nonaustenitic Steels (Rockwell C to Other Hardness Numbers)

Rockwell C Scale, 1471-N (150-kgf) Load, Diamond Penetrator	Vickers Hardness Number	Brinell Hardness, 29.42-kN (3000-kgf) Load, 10-mm Ball	Knoop Hardness, 4.903-N (500-gf) Load and Over	Rockwell A Scale, 588-N (60-kgf) Load, Diamond Penetrator	Rockwell Superficial Hardness			
					15N Scale, 147-N (15-kgf) Load, Diamond Penetrator	30N Scale, 294-N (30-kgf) Load, Diamond Penetrator	45N Scale 441-N (45-kgf) Load, Diamond Penetrator	Approximate Tensile Strength, MPa (ksi)
68	940	—	920	85.6	93.2	84.4	75.4	—
67	900	—	895	85.0	92.9	83.6	74.2	—
66	865	—	870	84.5	92.5	82.8	73.3	—
65	832	739	846	83.9	92.2	81.9	72.0	—
64	800	722	822	83.4	91.8	81.1	71.0	—
63	772	706	799	82.8	91.4	80.1	69.9	—
62	746	688	776	82.3	91.1	79.3	68.8	—
61	720	670	754	81.8	90.7	78.4	67.7	—
60	697	654	732	81.2	90.2	77.5	66.6	—
59	674	634	710	80.7	89.8	76.6	65.5	2420 (351)
58	653	615	690	80.1	89.3	75.7	64.3	2330 (338)
57	633	595	670	79.6	88.9	74.8	63.2	2240 (325)
56	613	577	650	79.0	88.3	73.9	62.0	2160 (313)
55	595	560	630	78.5	87.9	73.0	60.9	2070 (301)
54	577	543	612	78.0	87.4	72.0	59.8	2010 (292)
53	560	525	594	77.4	86.9	71.2	58.6	1950 (283)
52	544	512	576	76.8	86.4	70.2	57.4	1880 (273)
51	528	496	558	76.3	85.9	69.4	56.1	1820 (264)
50	513	482	542	75.9	85.5	68.5	55.0	1760 (255)
49	498	468	526	75.2	85.0	67.6	53.8	1700 (246)
48	484	455	510	74.7	84.5	66.7	52.5	1640 (238)
47	471	442	495	74.1	83.9	65.8	51.4	1580 (229)
46	458	432	480	73.6	83.5	64.8	50.3	1520 (221)
45	446	421	466	73.1	83.0	64.0	49.0	1480 (215)
44	434	409	452	72.5	82.5	63.1	47.8	1430 (208)
43	423	400	438	72.0	82.0	62.2	46.7	1390 (201)
42	412	390	426	71.5	81.5	61.3	45.5	1340 (194)
41	402	381	414	70.9	80.9	60.4	44.3	1300 (188)
40	392	371	402	70.4	80.4	59.5	43.1	1250 (182)
39	382	362	391	69.9	79.9	58.6	41.9	1220 (177)
38	372	353	380	69.4	79.4	57.7	40.8	1180 (171)
37	363	344	370	68.9	78.8	56.8	39.6	1140 (166)
36	354	336	360	68.4	78.3	55.9	38.4	1110 (161)
35	345	327	351	67.9	77.7	55.0	37.2	1080 (156)
34	336	319	342	67.4	77.2	54.2	36.1	1050 (152)
33	327	311	334	66.8	76.6	53.3	34.9	1030 (149)
32	318	301	326	66.3	76.1	52.1	33.7	1010 (146)
31	310	294	318	65.8	75.6	51.3	32.5	970 (141)
30	302	286	311	65.3	75.0	50.4	31.3	950 (138)
29	294	279	304	64.6	74.5	49.5	30.1	930 (135)
28	286	271	297	64.3	73.9	48.6	28.9	900 (131)
27	279	264	290	63.8	73.3	47.7	27.8	880 (128)
26	272	258	284	63.3	72.8	46.8	26.7	860 (125)
25	266	253	278	62.8	72.2	45.9	25.5	850 (123)
24	260	247	272	62.4	71.6	45.0	24.3	820 (119)
23	254	243	266	62.0	71.0	44.0	23.1	810 (117)
22	248	237	261	61.5	70.5	43.2	22.0	790 (115)
21	243	231	256	61.0	69.9	42.3	20.7	770 (112)
20	238	226	251	60.5	69.4	41.5	19.6	760 (110)

[a] This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness–tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. Where more precise conversions are required, they should be developed specially for each steel composition, heat-treatment, and part. Caution should be exercised if conversions from this table are used for the acceptance or rejection of product. The approximate interrelationships may affect acceptance or rejection.

Table 4—Approximate Hardness Conversion Numbers for Nonaustenitic Steels[a] (Rockwell B to Other Hardness Numbers)

						Rockwell Superficial Hardness			
Rockwell B Scale, 981-N (100-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	Vickers Hardness Number	Brinell Hardness, 24.92-kN (3000-kgf) Load, 10-mm Ball	Knoop Hardness, 4.903-N (500-gf) Load and Over	Rockwell A Scale, 588-N (60-kgf) Load, Diamond Penetrator	Rockwell F Scale, 588-N (60-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	15T Scale, 147-N (15-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	30T Scale, 294-N (30-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	45T Scale, 441-N (45-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	Approximate Tensile Strength, MPa (ksi)
100	240	240	251	61.5	—	93.1	83.1	72.9	800 (116)
99	234	234	246	60.9	—	92.8	82.5	71.9	785 (114)
98	228	228	241	60.2	—	92.5	81.8	70.9	750 (109)
97	222	222	236	59.5	—	92.1	81.1	69.9	715 (104)
96	216	216	231	58.9	—	91.8	80.4	68.9	705 (102)
95	210	210	226	58.3	—	91.5	79.8	67.9	690 (100)
94	205	205	221	57.6	—	91.2	79.1	66.9	675 (98)
93	200	200	216	57.0	—	90.8	78.4	65.9	650 (94)
92	195	195	211	56.4	—	90.5	77.8	64.8	635 (92)
91	190	190	206	55.8	—	90.2	77.1	63.8	620 (90)
90	185	185	201	55.2	—	89.9	76.4	62.8	615 (89)
89	180	180	196	54.6	—	89.5	75.8	61.8	605 (88)
88	176	176	192	54.0	—	89.2	75.1	60.8	590 (86)
87	172	172	188	53.4	—	88.9	74.4	59.8	580 (84)
86	169	169	184	52.8	—	88.6	73.8	58.8	570 (83)
85	165	165	180	52.3	—	88.2	73.1	57.8	565 (82)
84	162	162	176	51.7	—	87.9	72.4	56.8	560 (81)
83	159	159	173	51.1	—	87.6	71.8	55.8	550 (80)
82	156	156	170	50.6	—	87.3	71.1	54.8	530 (77)
81	153	153	167	50.0	—	86.9	70.4	53.8	505 (73)
80	150	150	164	49.5	—	86.6	69.7	52.8	495 (72)
79	147	147	161	48.9	—	86.3	69.1	51.8	485 (70)
78	144	144	158	48.4	—	86.0	68.4	50.8	475 (69)
77	141	141	155	47.9	—	85.6	67.7	49.8	470 (68)
76	139	139	152	47.3	—	85.3	67.1	48.8	460 (67)
75	137	137	150	46.8	99.6	85.0	66.4	47.8	455 (66)
74	135	135	147	46.3	99.1	84.7	65.7	46.8	450 (65)
73	132	132	145	45.8	98.5	84.3	65.1	45.8	440 964)
72	130	130	143	45.3	98.0	84.0	64.4	44.8	435 (63)
71	127	127	141	44.8	97.4	83.7	63.7	43.8	425 (62)
70	125	125	139	44.3	96.8	83.4	63.1	42.8	420 (61)
69	123	123	137	43.8	96.2	83.0	62.4	41.8	415 (60)
68	121	121	135	43.3	95.6	82.7	61.7	40.8	405 (59)
67	119	119	133	42.8	95.1	82.4	61.0	39.8	400 (58)
66	117	117	131	42.3	94.5	82.1	60.4	38.7	395 (57)
65	116	116	129	41.8	93.9	81.8	59.7	37.7	385 (56)
64	114	114	127	41.4	93.4	81.4	59.0	36.7	—
63	112	112	125	40.9	92.8	81.1	58.4	35.7	—
62	110	110	124	40.4	92.2	80.8	57.7	34.7	—
61	108	108	122	40.0	91.7	80.5	57.0	33.7	—
60	107	107	120	39.5	91.1	80.1	56.4	32.7	—
59	106	106	118	39.0	90.5	79.8	55.7	31.7	—
58	104	104	117	38.6	90.0	79.5	55.0	30.7	—
57	103	103	115	38.1	89.4	79.2	54.4	29.7	—
56	101	101	114	37.7	88.8	78.8	53.7	28.7	—
55	100	100	112	37.2	88.2	78.5	53.0	27.7	—
54	—	—	111	36.8	87.7	78.2	52.4	26.7	—
53	—	—	110	36.3	86.5	77.9	51.7	25.7	—

Continued on next page.

Table 4—Approximate Hardness Conversion Numbers for Nonaustenitic Steels[a] (Rockwell B to Other Hardness Numbers) (*continued*)

						Rockwell Superficial Hardness			
Rockwell B Scale, 981-N (100-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	Vickers Hardness Number	Brinell Hardness, 24.92-kN (3000-kgf) Load, 10-mm Ball	Knoop Hardness, 4.903-N (500-gf) Load and Over	Rockwell A Scale, 588-N (60-kgf) Load, Diamond Penetrator	Rockwell F Scale, 588-N (60-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	15T Scale, 147-N (15-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	30T Scale, 294-N (30-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	45T Scale, 441-N (45-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	Approximate Tensile Strength, MPa (ksi)
52	—	—	109	35.9	86.0	77.5	51.0	24.7	—
51	—	—	108	35.5	85.4	77.2	50.3	23.7	—
50	—	—	107	35.0	84.8	76.9	49.7	22.7	—
49	—	—	106	34.6	84.3	76.6	49.0	21.7	—
48	—	—	105	34.1	83.7	76.2	48.3	20.7	—
47	—	—	104	33.7	83.1	75.9	47.7	19.7	—
46	—	—	103	33.3		75.6	47.0	18.7	—
45	—	—	102	32.9	82.6	75.3	46.3	17.7	—
44	—	—	101	32.4	82.0	74.9	45.7	16.7	—
43	—	—	100	32.0	81.4	74.6	45.0	15.7	—
42	—	—	99	31.6	80.8	74.3	44.3	14.7	—
41	—	—	98	31.2	80.3	74.0	43.7	13.6	—
40	—	—	97	30.7	79.7	73.6	43.0	12.6	—
39	—	—	96	30.3	79.1	73.3	42.3	11.6	—
38	—	—	95	29.9	78.6	73.0	41.6	10.6	—
37	—	—	94	29.5	78.0	72.7	41.0	9.6	—
36	—	—	93	29.1	77.4	72.3	40.3	8.6	—
35	—	—	92	28.7	76.9	72.0	39.6	7.6	—
34	—	—	91	28.2	76.3	71.7	39.0	6.6	—
33	—	—	90	27.8	75.7	71.4	38.3	5.6	—
32	—	—	89	27.4	75.2	71.0	37.6	4.6	—
31	—	—	88	27.0	74.6	70.7	37.0	3.6	—
30	—	—	87	26.6	74.0	70.4	36.3	2.6	—

[a] This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness–tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. Where more precise conversions are required, they should be developed specially for each steel composition, heat-treatment, and part.

Table 5—Approximate Hardness Conversion Numbers for Austenitic Steels (Rockwell C to Other Hardness Numbers)

Rockwell C Scale, 1471-N (150-kgf) Load, Diamond Penetrator	Rockwell A Scale, 588-N (60-kgf) Load, Diamond Penetrator	Rockwell Superficial Hardness		
		15N Scale, 147-N (15-kgf) Load, Diamond Penetrator	30N Scale, 294-N (30-kgf) Load, Diamond Penetrator	45N Scale, 441-N (45-kgf) Load, Diamond Penetrator
48	74.4	84.1	66.2	52.1
47	73.9	83.6	65.3	50.9
46	73.4	83.1	64.5	49.8
45	72.9	82.6	63.6	48.7
44	72.4	82.1	62.7	47.5
43	71.9	81.6	61.8	46.4
42	71.4	81.0	61.0	45.2
41	70.9	80.5	60.1	44.1
40	70.4	80.0	59.2	43.0
39	69.9	79.5	58.4	41.8
38	69.3	79.0	57.5	40.7
37	68.8	78.5	56.5	39.6
36	68.3	78.0	55.7	38.4
35	67.8	77.5	54.9	37.3
34	67.3	77.0	54.0	36.1
33	66.8	76.5	53.1	35.0
32	66.3	75.9	52.3	33.9
31	65.8	75.4	51.4	32.7
30	65.3	74.9	50.5	31.6
29	64.8	74.4	49.6	30.4
28	64.3	73.9	48.8	29.3
27	63.8	73.4	47.9	28.2
26	63.3	72.9	47.0	27.0
25	62.8	72.4	46.2	25.9
24	62.3	71.9	45.3	24.8
23	61.8	71.3	44.4	23.6
22	61.3	70.8	43.5	22.5
21	60.8	70.3	42.7	21.3
20	60.3	69.8	41.8	20.2

Table 6—Approximate Hardness Conversion Numbers for Austenitic Steels (Rockwell B to Other Hardness Numbers)

Rockwell B Scale, 981-N (100-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	Brinell Indentation Dia, mm	Brinell Hardness, 29.42-kN (3000-kgf) Load, 10-mm Ball	Rockwell A Scale, 588-N (60-kgf) Load, Diamond Penetrator	Rockwell Superficial Hardness		
				15 T Scale, 147-N (15-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	30T Scale, 294-N (30-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball	45 T Scale, 441-N (45-kgf) Load, 1.588-mm ($^1/_{16}$-in.) Ball
100	3.79	256	61.5	91.5	80.4	70.2
99	3.85	248	60.9	91.2	79.7	69.2
98	3.91	240	60.3	90.8	79.0	68.2
97	3.96	233	59.7	90.4	78.3	67.2
96	4.02	226	59.1	90.1	77.7	66.1
95	4.08	219	58.5	89.7	77.0	65.1
94	4.14	213	58.0	89.3	76.3	64.1
93	4.20	207	57.4	88.9	75.6	63.1
92	4.24	202	56.8	88.6	74.9	62.1
91	4.30	197	56.2	88.2	74.2	61.1
90	4.35	192	55.6	87.8	73.5	60.1
89	4.40	187	55.0	87.5	72.8	59.0
88	4.45	183	54.5	87.1	72.1	58.0
87	4.51	178	53.9	86.7	71.4	57.0
86	4.55	174	53.3	86.4	70.7	56.0
85	4.60	170	52.7	86.0	70.0	55.0
84	4.65	167	52.1	85.6	69.3	54.0
83	4.70	163	51.5	85.2	68.6	52.9
82	4.74	160	50.9	84.9	67.9	51.9
81	4.79	156	50.4	84.5	67.2	50.9
80	4.84	153	49.8	84.1	66.5	49.9

16. BRINELL TEST

16.1. *Description*:

16.1.1. A specified load is applied to a flat surface of the specimen to be tested, through a hard ball of specified diameter. The average diameter of the indentation is used as a basis for calculation of the Brinell hardness number. The quotient of the applied load divided by the area of the surface of the indentation, which is assumed to be spherical, is termed the Brinell hardness number (HBW) in accordance with the following equation:

For applied loads in newtons of force:

$$HBW = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \tag{4}$$

where:

HBW = Brinnell hardness number;

P = applied load, N;

D = diameter of the ball, mm; and

d = average diameter of the indentation, mm.

For applied loads in kilogram-force units:

$$HBW = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \qquad (5)$$

where:

HBW = Brinnell hardness number;

P = applied load, kgf;

D = diameter of the ball, mm; and

d = average diameter of the indentation, mm.

Note 11—The Brinell hardness is more conveniently secured from standard tables such as Table 6, which show numbers corresponding to the various indentation diameters, usually in increments of 0.05 mm.

Note 12—In Test Method ASTM E 10; the values are in SI units, whereas in this section kg/m units are used.

16.1.2. The standard Brinell test using a 10-mm tungsten carbide ball employs a 29.42-kN (3000 kgf) load for hard materials and a 14.71 or 4.903-kN (1500 or 500 kgf) load for thin sections or soft materials. (See Annex A2 on Steel Tubular Products.) Other loads and different size indentors may be used when specified. In recording hardness values, the diameter of the ball and the load must be stated when a 10-mm ball and 29.42-kN (3000 kgf) load are used.

16.1.3. A range of hardness can properly be specified only for quenched and tempered or normalized and tempered material. For annealed material, a maximum figure only should be specified. For normalized material, a minimum or a maximum hardness may be specified by agreement. In general, no hardness requirements should be applied to untreated material.

16.1.4. Brinell hardness may be required when tensile properties are not specified.

16.2. *Apparatus*—Equipment shall meet the following requirements.

16.2.1. *Testing Machine*—A Brinell hardness testing machine is acceptable for use over a loading range within which its load measuring device is accurate to ±1 percent.

16.2.2. *Measuring Microscope*—The divisions of the micrometer scale of the microscope or other measuring devices used for the measurement of the diameter of the indentations shall be such as to permit the direct measurement of the diameter to 0.1 mm and the estimation of the diameter to 0.05 mm.

Note 13—This requirement applies to the construction of the microscope only and is not a requirement for measurement of the indentation. See Section 16.4.3.

16.2.3. *Standard Ball*—The standard tungsten carbide ball for Brinell hardness testing is 10 mm (0.3937 in.) in diameter with a deviation from this value of not more than 0.005 mm (0.0002 in.) in any diameter. A tungsten carbide ball suitable for use must not show a permanent change in diameter greater than 0.01 mm (0.0004 in.) when pressed with a force of 29.42-kN (3000 kgf) against the test specimen. Steel ball indentors are no longer permitted for use in Brinell hardness testing in accordance with these test methods.

16.3. *Test Specimen*—Brinell hardness tests are made on prepared areas and sufficient metal must be removed from the surface to eliminate decarburized metal and other surface irregularities. The thickness of the piece tested must be such that no bulge or other marking showing the effect of the load appears on the side of the piece opposite the indentation.

16.4. *Procedure*:

16.4.1. It is essential that the applicable product specification state clearly the position at which Brinell hardness indentations are to be made and the number of such indentations required. The distance of the center of the indentation from the edge of the specimen or edge of another indentation must be at least $2^1/_2$ times the diameter of the indentation.

16.4.2. Apply the load for 10 to 15 seconds.

16.4.3. Measure two diameters of the indentation at right angles to the nearest 0.1 mm, estimate to nearest 0.05 mm and average to nearest 0.05 mm. If the two diameters differ by more than 0.1 mm, discard the readings and make a new indentation.

16.4.4. Do not use a steel ball on steels having a hardness greater than 450 HBW nor a carbide ball on steels having a hardness more than 650 HBW. The Brinell hardness test is not recommended for materials having a hardness greater than 650 HBW.

16.4.4.1. If a ball is used in a test of a specimen that shows a Brinell hardness number greater than the limit for the ball as detailed in Section 16.4.4, the ball shall be either discarded and replaced with a new ball or remeasured to ensure conformance with the requirements of ASTM E 10.

16.5. *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of ASTM E 10.

17. ROCKWELL TEST

17.1. *Description*:

17.1.1. In this test, a hardness value is obtained by determining the depth of penetration of a diamond point or a steel ball into the specimen under certain arbitrarily fixed conditions. A minor load of 98 N (10 kgf) is first applied, which causes an initial penetration, sets the penetrator on the material, and holds it in position. A major load that depends on the scale being used is applied, increasing the depth of indentation. The major load is removed and, with the minor load still acting, the Rockwell number, which is proportional to the difference in penetration between the major and minor loads, is determined; this is usually done by the machine and shows on a dial, digital display, printer, or other device. This is an arbitrary number that increases with increasing hardness. The scales most frequently used appear in Table 7.

Table 7—Scales I

Scales I			
Scale Symbol	Penetrator	Major Load, N (kgf)	Minor Load, N (kgf)
B	1.588-mm ($^1/_{16}$-in.) steel ball	981 (100)	98 (10)
C	Diamond brale	1471 (150)	98 (10)

17.1.2. Rockwell superficial hardness machines are used for testing very thin steel or thin surface layers. Loads of 147, 294, or 441 N (15, 30, or 45 kgf) are applied on a hardened steel ball or diamond penetrator to cover the same range of hardness values as for the heavier loads. The superficial hardness scales appear in Table 8.

Table 8—Scales II

Scales II			
Scale Symbol	Penetrator	Major Load, N (kgf)	Minor Load, N (kgf)
15T	1.588-mm ($^1/_{16}$-in.) steel ball	147 (15)	29 (3)
30T	1.588-mm ($^1/_{16}$-in.) steel ball	294 (30)	29 (3)
45T	1.588-mm ($^1/_{16}$-in.) steel ball	441 (45)	29 (3)
15N	Diamond brale	147 (15)	29 (3)
30N	Diamond brale	294 (30)	29 (3)
45N	Diamond brale	441 (45)	29 (3)

17.2. *Reporting Hardness*—In recording hardness values, the hardness number should always precede the scale symbol, for example 96 HRB, 40 HRC, 75 HR15N, or 77 HR 30T.

17.3. *Test Blocks*—Machines should be checked to make certain they are in good order by means of standardized Rockwell test blocks.

17.4. *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of T 80.

18. PORTABLE HARDNESS TEST

18.1. Although the use of the standard, stationary Brinell or Rockwell hardness tester is generally preferred, it is not always possible to perform the hardness test using such equipment due to the part size or location. In this event, hardness testing using portable equipment as described in ASTM A 833 or ASTM E 110 shall be used.

CHARPY IMPACT TESTING

19. SUMMARY

19.1. A Charpy V-notch impact test is a dynamic test in which a notched specimen is struck and broken by a single blow in a specially designed testing machine. The measured test values may be the energy absorbed, the percentage shear fracture, the lateral expansion opposite the notch, or a combination thereof.

19.2. Testing temperatures other than room (ambient) temperature often are specified in product or general requirement specifications (hereinafter referred to as the specification). Although the testing temperature is sometimes related to the expected service temperature, the two temperatures need not be identical.

20. SIGNIFICANCE AND USE

20.1. *Ductile vs. Brittle Behavior*—Body-centered-cubic or ferritic alloys exhibit a significant transition in behavior when impact tested over a range of temperatures. At temperatures above transition, impact specimens fracture by a ductile (usually microvoid coalescence) mechanism, absorbing relatively large amounts of energy. At lower temperatures, they fracture in a brittle (usually cleavage) manner, absorbing less energy. Within the transition range, the fracture generally will be a mixture of areas of ductile fracture and brittle fracture.

20.2. The temperature range of the transition from one type of behavior to the other varies according to the material being tested. This transition behavior may be defined in various ways for specification purposes.

20.2.1. The specification may require a minimum test result for absorbed energy, fracture appearance, lateral expansion, or a combination thereof, at a specified test temperature.

20.2.2. The specification may require the determination of the transition temperature at which either the absorbed energy or fracture appearance attains a specified level when testing is performed over a range of temperatures. Alternatively, the specification may require the determination of the fracture appearance transition temperature (FATTn) as the temperature at which the required minimum percentage of shear fracture (n) is obtained.

20.3. Further information on the significance of impact testing appears in Annex A5.

21. APPARATUS

21.1. *Testing Machines*:

21.1.1. A Charpy impact machine is one in which a notched specimen is broken by a single blow of a freely swinging pendulum. The pendulum is released from a fixed height. Since the height to which the pendulum is raised prior to its swing and the mass of the pendulum are known, the energy of the blow is predetermined. A means is provided to indicate the energy absorbed in breaking the specimen.

21.1.2. The other principal feature of the machine is a fixture (see Figure 10) designed to support a test specimen as a simple beam at a precise location. The fixture is arranged so that the notched face of the specimen is vertical. The pendulum strikes the other vertical face directly opposite the notch. The dimensions of the specimen supports and striking edge shall conform to Figure 10.

21.1.3. Charpy machines used for testing steel generally have capacities in the 300 to 400 J (220 to 300 ft-lbf) energy range. Sometimes machines of lesser capacity are used; however, the capacity of the machine should be substantially in excess of the absorbed energy of the specimens. (See T 266.) The linear velocity at the point of impact should be in the range of 4.9 to 5.8 m/s (16 to 19 ft/s)

Note 14—An investigation of striker radius effect is available as Research Report A01-1001 from ASTM International Headquarters.

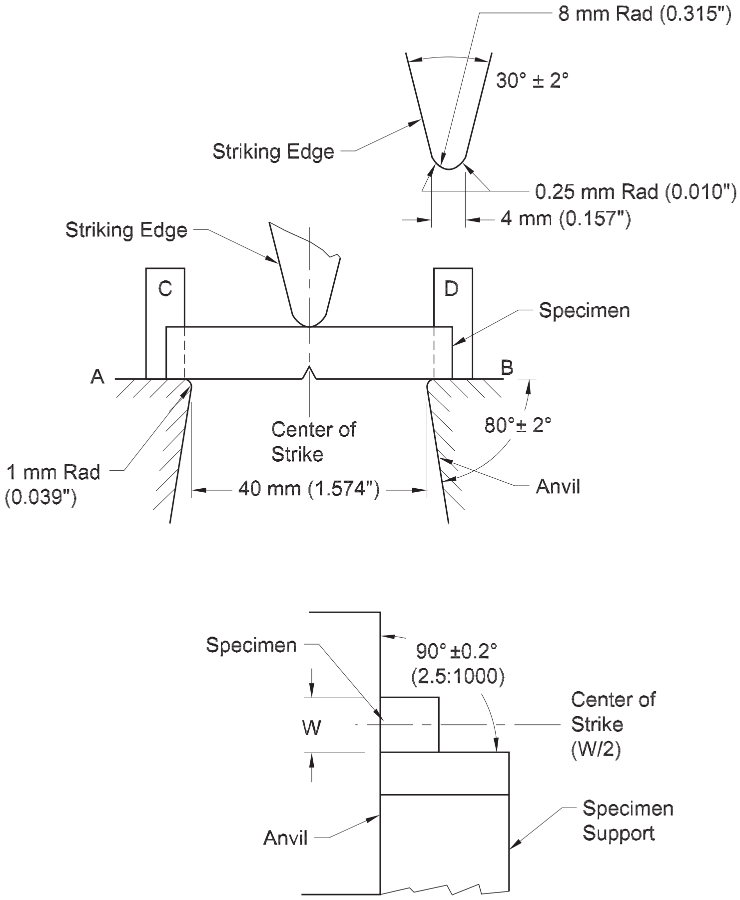
21.2. *Temperature Media*:

21.2.1. For testing at other than room temperature, it is necessary to condition the Charpy specimens in media at controlled temperatures.

21.2.2. Low temperature media usually are chilled fluids (such as water, ice plus water, dry ice plus organic solvents, or liquid nitrogen) or chilled gases.

21.2.3. Elevated temperature media are usually heated liquids, such as mineral or silicone oils. Circulating air ovens may be used.

21.3. *Handling Equipment*—Tongs, especially adapted to fit the notch in the impact specimen, normally are used for removing the specimens from the medium and placing them on the anvil (refer to T 266). In cases in which the machine fixture does not provide for automatic centering of the test specimen, the tongs may be precision machined to provide centering.



Notes:

1. All dimensional tolerances shall be ±0.05 mm (0.002 in.) unless otherwise specified.
2. *A* shall be parallel to *B* within 2:1000 and coplanar with *B* within 0.05 mm (0.002 in.).
3. *C* shall be parallel to *D* within 20:1000 and coplanar with *D* within 0.125 mm (0.005 in.).
4. Finish on unmarked parts shall be 4 µm (125 µ in.).

Figure 10—Charpy (Simple-Beam) Impact Test

Table 9—Brinell Hardness Numbers[a]

	Brinell Hardness Number				Brinell Hardness Number				Brinell Hardness Number				Brinell Hardness Number		
Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load
2.00	158	473	945	2.28	121	363	725	2.56	95.5	287	573	2.84	77.3	232	464
2.01	156	468	936	2.29	120	359	719	2.57	94.8	284	569	2.85	76.8	230	461
2.02	154	463	926	2.30	119	355	712	2.58	94.0	282	564	2.86	76.2	229	457
2.03	153	459	917	2.31	118	353	706	2.59	93.3	280	560	2.87	75.7	227	454
2.04	151	454	908	2.32	117	350	700	2.60	92.6	278	555	2.88	75.1	225	451
2.05	150	450	899	2.33	116	347	694	2.61	91.8	276	551	2.89	74.6	224	448
2.06	148	445	890	2.34	115	344	688	2.62	91.1	273	547	2.90	74.1	222	444
2.07	147	441	882	2.35	114	341	682	2.63	90.4	271	543	2.91	73.6	221	441
2.08	146	437	873	2.36	113	338	676	2.64	89.7	269	538	2.92	73.0	219	438
2.09	144	432	865	2.37	112	335	670	2.65	89.0	267	534	2.93	72.5	218	435
2.10	143	428	856	2.38	111	332	665	2.66	88.4	265	530	2.94	72.0	216	432
2.11	141	424	848	2.39	110	330	659	2.67	87.7	263	526	2.95	71.5	215	429
2.12	140	420	840	2.40	109	327	653	2.68	87.0	261	522	2.96	71.0	213	426
2.13	139	416	832	2.41	108	324	648	2.69	86.4	259	518	2.97	70.5	212	423
2.14	137	412	824	2.42	107	322	643	2.70	85.7	257	514	2.98	70.1	210	420
2.15	136	408	817	2.43	106	319	637	2.71	85.1	255	510	2.99	69.6	209	417
2.16	135	404	809	2.44	105	316	632	2.72	84.4	253	507	3.00	69.1	207	415
2.17	134	401	802	2.45	104	313	627	2.73	83.8	251	503	3.01	68.6	206	412
2.18	132	397	794	2.46	104	311	621	2.74	83.2	250	499	3.02	68.2	205	409
2.19	131	393	787	2.47	103	308	616	2.75	82.6	248	495	3.03	67.7	203	406
2.20	130	390	780	2.48	102	306	611	2.76	81.9	246	492	3.04	67.3	202	404
2.21	129	386	772	2.49	101	303	606	2.77	81.3	244	488	3.05	66.8	200	401
2.22	128	383	765	2.50	100	301	601	2.78	80.8	242	485	3.06	66.4	199	398
2.23	126	379	758	2.51	99.4	298	597	2.79	80.2	240	481	3.07	65.9	198	395
2.24	125	376	752	2.52	98.6	296	592	2.80	79.6	239	477	3.08	65.5	196	393
2.25	124	372	745	2.53	97.8	294	587	2.81	79.0	237	474	3.09	65.0	195	390
2.26	123	369	738	2.54	97.1	291	582	2.82	78.4	235	471	3.10	64.6	194	388
2.27	122	366	732	2.55	96.3	289	578	2.83	77.9	234	467	3.11	64.2	193	385
3.12	63.8	191	383	3.69	45.1	135	271	4.26	33.4	100	200	4.83	25.6	76.8	154
3.13	63.3	190	380	3.70	44.9	135	269	4.27	33.2	99.7	199	4.84	25.5	76.4	153
3.14	62.9	189	378	3.71	44.6	134	268	4.28	33.1	99.2	198	4.85	25.4	76.1	152
3.15	62.5	188	375	3.72	44.4	133	266	4.29	32.9	98.8	198	4.86	25.3	75.8	152
3.16	62.1	186	373	3.73	44.1	132	265	4.30	32.8	98.3	197	4.87	25.1	75.4	151
3.17	61.7	185	370	3.74	43.9	132	263	4.31	32.6	97.8	196	4.88	25.0	75.1	150
3.18	61.3	184	368	3.75	43.6	131	262	4.32	32.4	97.3	195	4.89	24.9	74.8	150

Note: Ball 10 mm in diameter, applied loads of 4.903, 14.71, and 29.42 kN (500, 1500, and 3000 kgf).

Continued on next page.

Table 9—Brinell Hardness Numbers[a] (*continued*)

Dia of Indention, mm	Brinell Hardness Number			Dia of Indention, mm	Brinell Hardness Number			Dia of Indention, mm	Brinell Hardness Number			Dia of Indention, mm	Brinell Hardness Number		
	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load		4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load		4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load		4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load
3.19	60.9	183	366	3.76	43.4	130	260	4.33	32.3	96.8	194	4.90	24.8	74.4	149
3.20	60.5	182	363	3.77	43.1	129	259	4.34	32.1	96.4	193	4.91	24.7	74.1	148
3.21	60.1	180	361	3.78	42.9	129	257	4.35	32.0	95.9	192	4.92	24.6	73.8	148
3.22	59.8	179	359	3.79	42.7	128	256	4.36	31.8	95.5	191	4.93	24.5	73.5	147
3.23	59.4	178	356	3.80	42.4	127	255	4.37	31.7	95.0	190	4.94	24.4	73.2	146
3.24	59.0	177	354	3.81	42.2	127	253	4.38	31.5	94.5	189	4.95	24.3	72.8	146
3.25	58.6	176	352	3.82	42.0	126	252	4.39	31.4	94.1	188	4.96	24.2	72.5	145
3.26	58.3	175	350	3.83	41.7	125	250	4.40	31.2	93.6	187	4.97	24.1	72.2	144
3.27	57.9	174	347	3.84	41.5	125	249	4.41	31.1	93.2	186	4.98	24.0	71.9	144
3.28	57.5	173	345	3.85	41.3	124	248	4.42	30.9	92.7	185	4.99	23.9	71.6	143
3.29	57.2	172	343	3.86	41.1	123	246	4.43	30.8	92.3	185	5.00	23.8	71.3	143
3.30	56.8	170	341	3.87	40.9	123	245	4.44	30.6	91.8	184	5.01	23.7	71.0	142
3.31	56.5	169	339	3.88	40.6	122	244	4.45	30.5	91.4	183	5.02	23.6	70.7	141
3.32	56.1	168	337	3.89	40.4	122	242	4.46	30.3	91.0	182	5.03	23.5	70.4	141
3.33	55.8	167	335	3.90	40.2	121	241	4.47	30.2	90.5	181	5.04	23.4	70.1	140
3.34	55.4	166	333	3.91	40.0	120	240	4.48	30.0	90.1	180	5.05	23.3	69.8	140
3.35	55.1	165	331	3.92	39.8	119	239	4.49	29.9	89.7	179	5.06	23.2	69.5	139
3.36	54.8	164	329	3.93	39.6	119	237	4.50	29.8	89.3	179	5.07	23.1	69.2	138
3.37	54.4	163	326	3.94	39.4	118	236	4.51	29.6	88.8	178	5.08	23.0	68.9	138
3.38	54.1	162	325	3.95	39.1	117	235	4.52	29.5	88.4	177	5.09	22.9	68.6	137
3.39	53.8	161	323	3.96	38.9	117	234	4.53	29.3	88.0	176	5.10	22.8	68.3	137
3.40	53.4	160	321	3.97	38.7	116	232	4.54	29.2	87.6	175	5.11	22.7	68.0	136
3.41	53.1	159	319	3.98	38.5	116	231	4.55	29.1	87.2	174	5.12	22.6	67.7	135
3.42	52.8	158	317	3.99	38.3	115	230	4.56	28.9	86.8	174	5.13	22.5	67.4	135
3.43	52.5	157	315	4.00	38.1	114	229	4.57	28.8	86.4	173	5.14	22.4	67.1	134
3.44	52.2	156	313	4.01	37.9	114	228	4.58	28.7	86.0	172	5.15	22.3	66.9	134
3.45	51.8	156	311	4.02	37.7	113	226	4.59	28.5	85.6	171	5.16	22.2	66.6	133
3.46	51.5	155	309	4.03	37.5	113	225	4.60	28.4	85.4	170	5.17	22.1	66.3	133
3.47	51.2	154	307	4.04	37.3	112	224	4.61	28.3	84.8	170	5.18	22.0	66.0	132
3.48	50.9	153	306	4.05	37.1	111	223	4.62	28.1	84.4	169	5.19	21.9	65.8	132
3.49	50.6	152	304	4.06	37.0	111	222	4.63	28.0	84.0	168	5.20	21.8	65.5	131
3.50	50.3	151	302	4.07	36.8	110	221	4.64	27.9	83.6	167	5.21	21.7	65.2	130
3.51	50.0	150	300	4.08	36.6	110	219	4.65	27.3	83.3	167	5.22	21.6	64.9	130
3.52	49.7	149	298	4.09	36.4	109	218	4.66	27.6	82.9	166	5.23	21.6	64.7	129
3.53	49.4	148	297	4.10	36.2	109	217	4.67	27.5	82.5	165	5.24	21.5	64.4	129

Note: Ball 10 mm in diameter, applied loads of 4.903, 14.71, and 29.42 kN (500, 1500, and 3000 kgf).

Continued on next page.

Table 9—Brinell Hardness Numbers[a] (*continued*)

	Brinell Hardness Number				Brinell Hardness Number				Brinell Hardness Number				Brinell Hardness Number		
Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load
3.54	49.2	147	295	4.11	36.0	108	216	4.68	27.4	82.1	164	5.25	21.4	64.1	128
3.55	48.9	147	293	4.12	35.8	108	215	4.69	27.3	81.8	164	5.26	21.3	63.9	128
3.56	48.6	146	292	4.13	35.7	107	214	4.70	27.1	81.4	163	5.27	21.2	63.6	127
3.57	48.3	145	290	4.14	35.5	106	213	4.71	27.0	81.0	162	5.28	21.1	63.3	127
3.58	48.0	144	288	4.15	35.3	106	212	4.72	26.9	80.7	161	5.29	21.0	63.1	126
3.59	47.7	143	286	4.16	35.1	105	211	4.73	26.8	80.3	161	5.30	20.9	62.8	126
3.60	47.5	142	285	4.17	34.9	105	210	4.74	26.6	79.9	160	5.31	20.9	62.6	125
3.61	47.2	142	283	4.18	34.8	104	209	4.75	26.5	79.6	159	5.32	20.8	62.3	125
3.62	46.9	141	282	4.19	34.6	104	208	4.76	26.4	79.2	158	5.33	20.7	62.1	124
3.63	46.7	140	280	4.20	34.4	103	207	4.77	26.3	78.9	158	5.34	20.6	61.8	124
3.64	46.4	139	278	4.21	34.2	103	205	4.78	26.2	78.5	157	5.35	20.5	61.5	123
3.65	46.1	138	277	4.22	34.1	102	204	4.79	26.1	78.2	156	5.36	20.4	61.3	123
3.66	45.9	138	275	4.23	33.9	102	203	4.80	25.9	77.8	156	5.37	20.3	61.0	122
3.67	45.6	137	274	4.24	33.7	101	202	4.81	25.8	77.5	155	5.38	20.3	60.8	122
3.68	45.4	136	272	4.25	33.6	101	201	4.82	25.7	77.1	154	5.39	20.2	60.6	121
5.40	20.1	60.3	121	5.80	17.2	51.5	103	6.20	14.7	44.3	88.7	6.60	12.8	38.4	76.8
5.41	20.0	60.1	120	5.81	17.1	51.3	103	6.21	14.7	44.2	88.3	6.61	12.8	38.3	76.5
5.42	19.9	59.8	120	5.82	17.0	51.1	102	6.22	14.7	44.0	88.0	6.62	12.7	38.1	76.2
5.43	19.9	59.6	119	5.83	17.0	50.9	102	6.23	14.6	43.8	87.7	6.63	12.7	38.0	76.0
5.44	19.8	59.3	119	5.84	16.9	50.7	101	6.24	14.6	43.7	87.4	6.64	12.6	37.9	75.7
5.45	19.7	59.1	118	5.85	16.8	50.5	101	6.25	14.5	43.5	87.1	6.65	12.6	37.7	75.4
5.46	19.6	58.9	118	5.86	16.8	50.3	101	6.26	14.5	43.4	86.7	6.66	12.5	37.6	75.2
5.47	19.5	58.6	117	5.87	16.7	50.2	100	6.27	14.4	43.2	86.4	6.67	12.5	37.5	74.9
5.48	19.5	58.4	117	5.88	16.7	50.0	99.9	6.28	14.4	43.1	86.1	6.68	12.4	37.3	74.7
5.49	19.4	58.2	116	5.89	16.6	49.8	99.5	6.29	14.3	42.9	85.8	6.69	12.4	37.2	74.4
5.50	19.3	57.9	116	5.90	16.5	49.6	99.2	6.30	14.2	42.7	85.5	6.70	12.4	37.1	74.1
5.51	19.2	57.7	115	5.91	16.5	49.4	98.8	6.31	14.2	42.6	85.2	6.71	12.3	36.9	73.9
5.52	19.2	57.5	115	5.92	16.4	49.2	98.4	6.32	14.1	42.4	84.9	6.72	12.3	36.8	73.6
5.53	19.1	57.2	114	5.93	16.3	49.0	98.0	6.33	14.1	42.3	84.6	6.73	12.2	36.7	73.4
5.54	19.0	57.0	114	5.94	16.3	48.8	97.7	6.34	14.0	42.1	84.3	6.74	12.2	36.6	73.1
5.55	18.9	56.8	114	5.95	16.2	48.7	97.3	6.35	14.0	42.0	84.0	6.75	12.1	36.4	72.8
5.56	18.9	56.6	113	5.96	16.2	48.5	96.9	6.36	13.9	41.8	83.7	6.76	12.1	36.3	72.6
5.57	18.8	56.3	113	5.97	16.1	48.3	96.6	6.37	13.9	41.7	83.4	6.77	12.1	36.2	72.3
5.58	18.7	56.1	112	5.98	16.0	48.1	96.2	6.38	13.8	41.5	83.1	6.78	12.0	36.0	72.1
5.59	18.6	55.9	112	5.99	16.0	47.9	95.9	6.39	13.8	41.4	82.8	6.79	12.0	35.9	71.8

Note: Ball 10 mm in diameter, applied loads of 4.903, 14.71, and 29.42 kN (500, 1500, and 3000 kgf).

Continued on next page.

Table 9— Brinell Hardness Numbers[a] (*continued*)

	Brinell Hardness Number				Brinell Hardness Number				Brinell Hardness Number				Brinell Hardness Number		
Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load	Dia of Indention, mm	4.903-kN (500-kgf) Load	14.71-kN (1500-kgf) Load	29.42-kN (3000-kgf) Load
5.60	18.6	55.7	111	6.00	15.9	47.7	95.5	6.40	13.7	41.2	82.5	6.80	11.9	35.8	71.6
5.61	18.5	55.5	111	6.01	15.9	47.6	95.1	6.41	13.7	41.1	82.2	6.81	11.9	35.7	71.3
5.62	18.4	55.2	110	6.02	15.8	47.4	94.8	6.42	13.6	40.9	81.9	6.82	11.8	35.5	71.1
5.63	18.3	55.0	110	6.03	15.7	47.2	94.4	6.43	13.5	40.8	81.6	6.83	11.8	35.4	70.8
5.64	18.2	54.8	110	6.04	15.7	47.0	94.1	6.44	13.5	40.6	81.3	6.84	11.8	35.3	70.6
5.65	18.2	54.6	109	6.05	15.6	46.8	93.7	6.45	13.5	40.5	81.0	6.86	11.7	35.2	70.4
5.66	18.1	54.4	109	6.06	15.6	46.7	93.4	6.46	13.4	40.4	80.7	6.86	11.7	35.1	70.1
5.67	18.1	54.2	108	6.07	15.5	46.5	93.0	6.47	13.4	40.2	80.4	6.87	11.6	34.9	69.9
5.68	18.0	54.0	108	6.08	15.4	46.3	92.7	6.48	13.4	40.1	80.1	6.88	11.6	34.8	69.6
5.69	17.9	53.7	107	6.09	15.4	46.2	92.3	6.49	13.3	39.9	79.8	6.89	11.6	34.7	69.4
5.70	17.8	53.5	107	6.10	15.3	46.0	92.0	6.50	13.3	39.8	79.6	6.90	11.5	34.6	69.2
5.71	17.8	53.3	107	6.11	15.3	45.8	91.7	6.51	13.2	39.6	79.3	6.91	11.5	34.5	68.9
5.72	17.7	53.1	106	6.12	15.2	45.7	91.3	6.52	13.2	39.5	79.0	6.92	11.4	34.3	68.7
5.73	17.6	52.9	106	6.13	15.2	45.5	91.0	6.53	13.1	39.4	78.7	6.93	11.4	34.2	68.4
5.74	17.6	52.7	105	6.14	15.1	45.3	90.6	6.54	13.1	39.2	78.4	6.94	11.4	34.1	68.2
5.75	17.5	52.5	105	6.15	15.1	45.2	90.3	6.55	13.0	39.1	78.2	6.95	11.3	34.0	68.0
5.76	17.4	52.3	105	6.16	15.0	45.0	90.0	6.56	13.0	38.9	78.0	6.96	11.3	33.9	67.7
5.77	17.4	52.1	104	6.17	14.9	44.8	89.6	6.57	12.9	38.8	77.6	6.97	11.3	33.8	67.5
5.78	17.3	51.9	104	6.18	14.9	44.7	89.3	6.58	12.9	38.7	77.3	6.98	11.2	33.6	67.3
5.79	17.2	51.7	103	6.19	14.8	44.5	89.0	6.59	12.8	38.5	77.3	6.99	11.2	33.5	67.0

Note: Ball 10 mm in diameter, applied loads of 4.903, 14.71, and 29.42 kN (500, 1500, and 3000 kgf).

[a] Prepared by the Engineering Mechanics Section, National Institute of Standards and Technology.

22. SAMPLING AND NUMBER OF SPECIMENS

22.1. *Sampling*:

22.1.1. Test location and orientation should be addressed by the specifications. If not, for wrought products, the test location shall be the same as that for the tensile specimen and the orientation shall be longitudinal with the notch perpendicular to the major surface of the product being tested.

22.1.2. *Number of Specimens*:

22.1.2.1. A Charpy impact test consists of all specimens taken from a single test coupon or test location.

22.1.2.2. When the specification calls for a minimum average test result, three specimens shall be tested.

22.1.2.3. When the specification requires determination of a transition temperature, 8 to 12 specimens are usually needed.

22.2. *Type and Size*:

22.2.1. Use a standard full-sized Charpy V-notch specimen (Type A) as shown in Figure 11, except as allowed in Section 22.2.2.

22.2.2. *Sub-sized Specimens*:

22.2.2.1. For flat material less than 11 mm ($^7/_{16}$ in.) thick, or when the absorbed energy is expected to exceed 80 percent of full scale, use standard sub-sized test specimens.

22.2.2.2. For tubular materials tested in the transverse direction, where the relationship between diameter and wall thickness does not permit a standard full-sized specimen, use standard sub-sized test specimens or standard-sized specimens containing outer diameter (OD) curvature as follows:

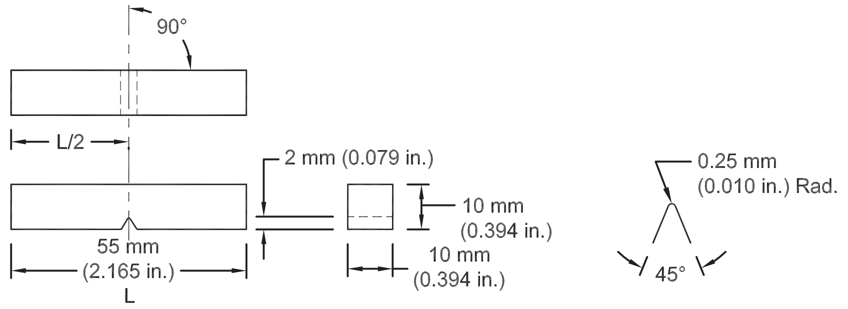
1. Standard-sized specimens and sub-sized specimens may contain the original OD surface of the tubular product as shown in Figure 12. All other dimensions shall comply with the requirements of Figure 11.

Note 15—For materials with toughness levels in excess of about 70 J (50 ft-lbf), specimens containing the original OD surface may yield values in excess of those resulting from the use of conventional Charpy specimens.

22.2.2.3. If a standard full-sized specimen cannot be prepared, the largest feasible standard sub-sized specimen shall be prepared. The specimens shall be machined so that the specimen does not include material nearer to the surface than 0.5 mm (0.020 in.).

22.2.2.4. Tolerances for standard sub-sized specimens are shown in Figure 11. Standard sub-sized test specimen sizes are: 10 by 7.5 mm, 10 by 6.7 mm, 10 by 5 mm, 10 by 3.3 mm, and 10 by 2.5 mm.

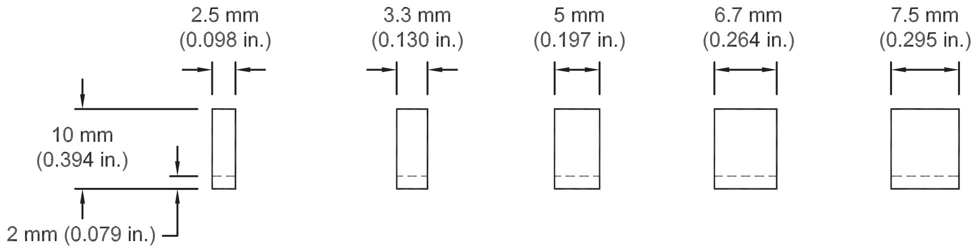
22.2.2.5. Notch the narrow face of the standard sub-sized specimens so that the notch is perpendicular to the 10-mm wide face.



Note: Permissible variations shall be as follows :

Notch Length to Edge	90.0 ± 0.2°
Adjacent Sides shall be at	90.0 ± 10 Min
Cross-Section Dimensions	± 0.075 mm (0.003 in.)
Length of Specimen (L)	+0, −0.25 mm (+0, −0.100 in.)
Centering of Notch (L/2)	± 1 mm (±0.039 in.)
Angle of Notch	±1°
Radius of Notch	±0.025 mm (±0.001 in.)
Notch Depth	±0.025 mm (±0.001 in.)
Finish Requirements	2 µm (63 µ in.) on Notched Surface and Opposite Face; 4 µm (125 µ in.) on Other Two Surfaces

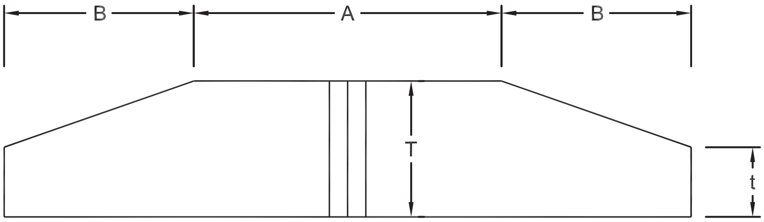
(a) Standard Full-Size Specimen



Note: On sub-size specimens, all dimensions and tolerances of the standard specimen remain constant with the exception of the width, which varies as shown above and for which the tolerance shall be ±1 percent.

(b) Standard Sub-Size Specimens

Figure 11—Charpy (Simple Beam) Impact Test Specimens



Dimension	Description	Requirement
A	Machined Surfaced	28 mm Minimum
B	Original OD Surface	13.5 mm Maximum
T	Specimen Thickness	Figure 11
t	End Thickness	½ T Minimum

Figure 12—Tubular Impact Specimen Containing Original OD Surface

23. CALIBRATION

23.1. *Accuracy and Sensitivity*—Calibrate and adjust Charpy impact machines in accordance with the requirements of T 266.

24. CONDITIONING—TEMPERATURE CONTROL

24.1. When a specific test temperature is required by the specification or purchaser, control the temperature of the heating or cooling medium with ±1ºC (2ºF).

Note 16—For some steels, there may not be a need for this restricted temperature; for example, austenitic steels.

Note 17—Because the temperature of a testing laboratory often varies from 15 to 32ºC (60 to 90ºF), a test conducted at "room temperature" might be conducted at any temperature in this range.

25. PROCEDURE

25.1. *Temperature*:

25.1.1. Condition the specimens to be broken by holding them in the medium at test temperature for at least 5 minutes in liquid media and 30 minutes in gaseous media.

25.1.2. Prior to each test, maintain the tongs for handling test specimens at the same temperature as the specimen, so as not to affect the temperature at the notch.

25.2. *Positioning and Breaking Specimens*:

25.2.1. Carefully center the test specimen in the anvil and release the pendulum to break the specimen.

25.2.2. If the pendulum is not released within 5 seconds after removing the specimen from the conditioning medium, do not break the specimen. Return the specimen to the conditioning medium for the period required in Section 25.1.1.

25.3. *Recovering Specimens*—In the event that fracture appearance or lateral expansion must be determined, recover the matched pieces of each broken specimen before breaking the next specimen.

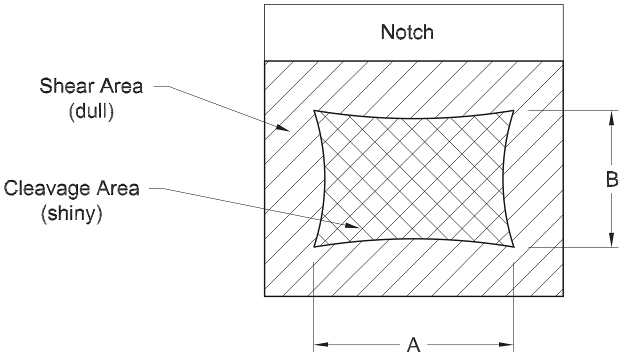
25.4. *Individual Test Values*:

25.4.1. *Impact Energy*—Record the impact energy absorbed to the nearest J (ft-lbf).

25.4.2. *Fracture Appearance*:

25.4.2.1. Determine the percentage of shear fracture area by any of the following methods:

1. Measure the length and width of the brittle portion of the fracture surface, as shown in Figure 13 and determine the percent shear area from either Table 10 or 11 depending on the units of measurement.
2. Compare the appearance of the fracture of the specimen with a fracture appearance chart as shown in Figure 14.
3. Magnify the fracture surface and compare it to a pre-calibrated overlay chart or measure the percent shear fracture area by means of a planimeter.
4. Photograph the fractured surface at a suitable magnification and measure the percent shear fracture area by means of a planimeter.



Notes:
1. Measure average dimensions *A* and *B* to the nearest 0.5 mm (0.02 in.).
2. Determine the percent shear fracture using Table 10 or Table 11.

Figure 13—Determination of Percent Shear Fracture

Figure 14—Fracture Appearance Charts and Percent Shear Fracture Comparator

25.4.2.2. Determine the individual fracture appearance values to the nearest 5 percent shear fracture and record the value.

25.4.3. *Lateral Expansion*:

25.4.3.1. Lateral expansion is the increase in specimen width, measured in 0.025-mm increments (thousandths of an inch), on the compression side, opposite the notch of the fractured Charpy V-notch specimen as shown in Figure 15.

25.4.3.2. Examine each specimen half to ascertain that the protrusions have not been damaged by contacting the anvil, machine mounting surface, and so forth. Discard such samples since they may cause erroneous readings.

25.4.3.3. Check the sides of the specimens perpendicular to the notch to ensure that no burrs were formed on the sides during impact testing. If burrs exist, remove them carefully by rubbing with an emery cloth or similar abrasive surface, making sure that the protrusions being measured are not rubbed during the removal of the burr.

25.4.3.4. Measure the amount of expansion on each side of each half relative to the plane defined by the undeformed portion of the side of the specimen using a gauge similar to that shown in Figures 16 and 17.

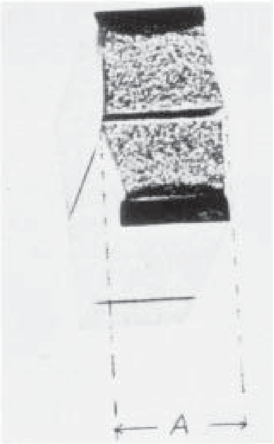


Figure 15—Halves of Broken Charpy V-Notch Impact Specimen Joined for the Measurement of Lateral Expansion, Dimension A

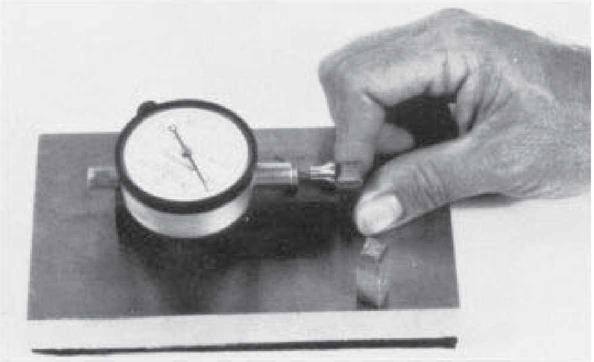
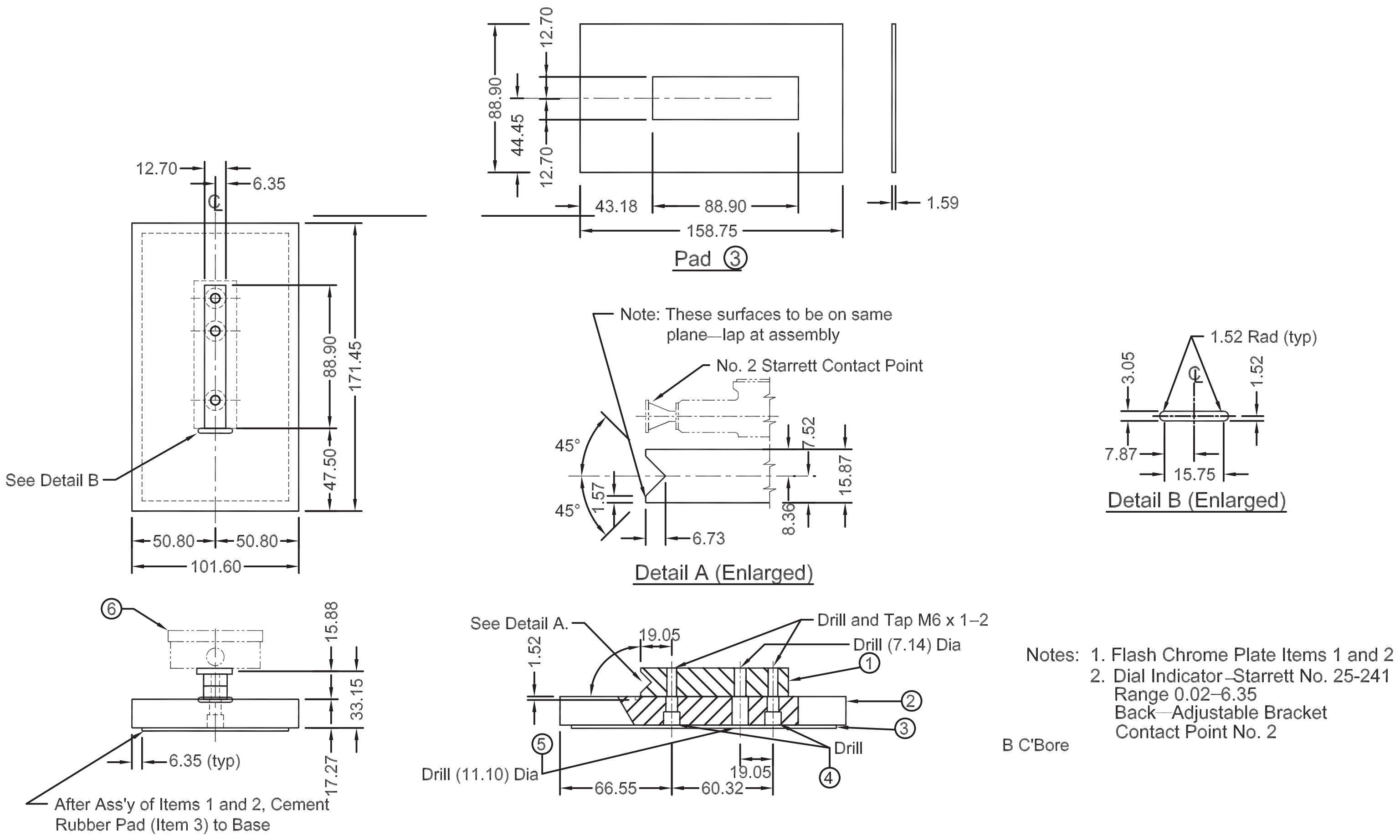


Figure 16—Lateral Expansion Gauge for Charpy Impact Specimens



Note: All dimensions in millimeters unless otherwise indicated.

Figure 17—Assembly and Details for Lateral Expansion Gauge

Bill of Material

Item No.	Quantity	Description	Material and Size
1	1	Dual Mount and Stop 102 by 16 by 13	Steel SAE 1015-1020
2	1	Base Plate 178 by 102 by 19	Steel SAE 1015-1020
3	1	Pad 159 by 102 by 19	Rubber
4	2	Screw-Socket Head Cap	Steel M6 by 1 by 25
5	1	Screw-Socket Head Cap	Steel M6 by 1 by 19
6	1	Dial Indicator	(See Note 2)

Figure 17—Assembly and Details for Lateral Expansion Gauge (*continued*)

25.4.3.5. Since the fracture path seldom bisects the point of maximum expansion on both sides of a specimen, the sum of the larger values measured for each side is the value of the test. Arrange the halves of one specimen so that compression sides are facing each other. Using the gauge, measure the protrusion on each half specimen, ensuring that the same side of the specimen is measured. Measure the two broken halves individually. Repeat the procedure to measure the protrusions on the opposite side of the specimen halves. The larger of the two values for each side is the expansion of that side of the specimen.

25.4.3.6. Measure the individual lateral expansion values to the nearest 0.025 mm (0.001 in.) and record the values.

25.4.3.7. With the exception described as follows, any specimen that does not separate into two pieces when struck by a single blow shall be reported as unbroken. If the specimen can be separated by force applied by bare hands, the specimen may be considered as having been separated by the blow.

26. INTERPRETATION OF TEST RESULT

26.1. When the acceptance criterion of any impact test is specified to be a minimum average value at a given temperature, the test result shall be the average (arithmetic mean) of the individual test values of three specimens from one test location.

26.1.1. When a minimum average test result is specified:

26.1.1.1. The test result is acceptable when all of the below are met:

1. The test result equals or exceeds the specified minimum average (given in the specification),
2. The individual test value for not more than one specimen measures less than the specified minimum average, and
3. The individual test value for any specimen measures not less than two-thirds of the specified minimum average.

26.1.1.2. If the acceptance requirements of Section 26.1.1.1 are not met, perform one retest of three additional specimens from the same test location. Each individual test value of the retested specimens shall be equal to or greater than the specified minimum average value.

Table 10—Percent Shear for Measurements Made in Millimeters

Dimension B, mm	Dimension A, mm																		
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10
1.0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88
1.5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81
2.0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75
2.5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69
3.0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62
3.5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56
4.0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50
4.5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44
5.0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37
5.5	93	90	96	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31
6.0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25
6.5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19
7.0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12
7.5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6
8.0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0

Note: Since this table is set up for finite measurements or dimensions A and B, 100 percent shear is to be reported when either A or B is zero.

Table 11—Percent Shear for Measurements Made in Inches

Dimension B, in.	Dimension A, in.																
	0.05	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40
0.05	98	96	95	94	94	93	92	91	90	90	89	88	87	86	85	85	84
0.10	96	92	90	89	87	85	84	82	81	79	77	76	74	73	71	69	68
0.12	95	90	88	86	85	83	81	79	77	75	73	71	69	67	65	63	61
0.14	94	89	86	84	82	80	77	75	73	71	68	66	64	62	59	57	55
0.16	94	87	85	82	79	77	74	72	69	67	64	61	59	56	53	51	48
0.18	93	85	83	80	77	74	72	68	65	62	59	56	54	51	48	45	42
0.20	92	84	81	77	74	72	68	65	61	58	55	52	48	45	42	39	36
0.22	91	82	79	75	72	68	65	61	57	54	50	47	43	40	36	33	29
0.24	90	81	77	73	69	65	61	57	54	50	46	42	38	34	30	27	23
0.26	90	79	75	71	67	62	58	54	50	46	41	37	33	29	25	20	16
0.28	89	77	73	68	64	59	55	50	46	41	37	32	28	23	18	14	10
0.30	88	76	71	66	61	56	52	47	42	37	32	27	23	18	13	9	3
0.31	88	75	70	65	60	55	50	45	40	35	30	25	20	18	10	5	0

Note: Since this table is set up for finite measurements or dimensions A and B, 100 percent shear is to be reported when either A or B is zero.

26.2. *Test Specifying a Minimum Transition Temperature*:

26.2.1. *Definition of Transition Temperature*—For specification purposes, the transition temperature is the temperature at which the designated material test value equals or exceeds a specified minimum test value.

26.2.2. *Determination of Transition Temperature*:

26.2.2.1. Break one specimen at each of a series of temperatures above and below the anticipated transition temperature using the procedures in Section 25. Record each test temperature to the nearest 0.5ºC (1ºF).

26.2.2.2. Plot the individual test results m/N (ft/lbf or percent shear) as the ordinate versus the corresponding test temperature as the abscissa and construct a best-fit curve through the plotted data points.

26.2.2.3. If transition temperature is specified as the temperature at which a test value is achieved, determine the temperature at which the plotted curve intersects the specified test value by graphical interpolation (extrapolation is not permitted). Record this transition temperature to the nearest 3ºC (5ºF). If the tabulated test results clearly indicate a transition temperature lower than specified, it is not necessary to plot the data. Report the lowest test temperature for which test value exceeds the specified value.

26.2.2.4. Accept the test result if the determined transition temperature is equal to or lower than the specified value.

26.2.2.5. If the determined transition temperature is higher than the specified value, but not more than 12ºC (20ºF) higher than the specified value, test sufficient samples in accordance with Section 25 to plot two additional curves. Accept the test results if the temperatures determined from both additional tests are equal to or lower than the specified value.

26.3. When sub-sized specimens are permitted or necessary, or both, modify the specified test requirement according to Table 12 or test temperature according to ASME Boiler and Pressure Vessel Code, Table UG-84.2, or both. Greater energies or lower test temperatures may be agreed upon by purchaser and supplier.

Table 12—Charpy V-Notch Test Acceptance Criteria for Various Subsize Specimens

Full Size, 10 by 10 mm		$^3/_4$ Size, 10 by 7.5 mm		$^2/_3$ Size, 10 by 6.7 mm		$^1/_2$ Size, 10 by 5 mm		$^1/_3$ Size, 10 by 3.3 mm		$^1/_4$ Size, 10 by 2.5 mm	
J	[ft·lbf]	J	[ft·lbf]	J	[ft·lbf]	J	[ft·lbf]	J	[ft·lbf]	J	[ft·lbf]
54	[40]	41	[30]	37	[27]	27	[20]	18	[13]	14	[10]
48	[35]	35	[26]	31	[23]	24	[18]	16	[12]	12	[9]
41	[30]	30	[22]	27	[20]	20	[15]	14	[10]	11	[8]
34	[25]	26	[19]	23	[17]	16	[12]	11	[8]	8	[6]
27	[20]	20	[15]	18	[13]	14	[10]	10	[7]	7	[5]
22	[16]	16	[12]	15	[11]	11	[8]	7	[5]	5	[4]
20	[15]	15	[11]	14	[10]	11	[8]	7	[5]	5	[4]
18	[13]	14	[10]	12	[9]	8	[6]	5	[4]	4	[3]
16	[12]	12	[9]	11	[8]	8	[6]	5	[4]	4	[3]
14	[10]	11	[8]	10	[7]	7	[5]	4	[3]	3	[2]
10	[7]	7	[5]	7	[5]	5	[4]	3	[2]	3	[2]

27. RECORDS

27.1. The test record should contain the following information as appropriate:

27.1.1. Full description of material tested (that is, specification number, grade, class or type, size, heat number).

27.1.2. Specimen orientation with respect to the material axis.

27.1.3. Specimen size.

27.1.4. Test temperature and individual test value for each specimen broken, including initial tests and retests.

27.1.5. Test results.

27.1.6. Transition temperature and criterion for its determination, including initial tests and retests.

28. REPORT

28.1. The specification should designate the information to be reported.

29. KEYWORDS

29.1. Bend test; Brinell hardness; Charpy impact test; elongation; FATT (Fracture Appearance Transition Temperature); hardness test; portable hardness; reduction of area; Rockwell hardness; tensile strength; tension test; yield strength.

ANNEXES

(Mandatory Information)

A1. STEEL BAR PRODUCTS

A1.1 *Scope*:

A1.1.1 This annex contains testing requirements for steel bar products that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements in the product specifications shall prevail.

A1.2 *Orientation of Test Specimens*:

A1.2.1 Carbon and alloy steel bars and bar-size shapes, due to their relatively small cross-sectional dimensions, are customarily tested in the longitudinal direction. In special cases in which size permits and the fabrication or service of a part justifies testing in a transverse direction, the selection and location of test or tests are a matter of agreement between the manufacturer and the purchaser.

A1.3 *Tension Test*:

A1.3.1 *Carbon Steel Bars*—Carbon steel bars are not commonly specified to tensile requirements in the as-rolled condition for sizes of rounds, squares, hexagons, and octagons under 13 mm ($^1/_2$ in.) in diameter or distance between parallel faces nor for other bar-sized sections, other than flats, less than 645 mm^2 (1 in.^{2}) in cross-sectional area.

A1.3.2 *Alloy Steel Bars*—Alloy steel bars are usually not tested in the as-rolled condition.

A1.3.3 When tension tests are specified, the practice for selecting test specimens for hot-rolled and cold-finished steel bars of various sizes shall be in accordance with Table A1.1, unless otherwise specified in the product specification.

A1.4 *Bend Test*:

A1.4.1 When bend tests are specified, the recommended practice for hot-rolled and cold-finished steel bars shall be in accordance with Table A1.2.

A1.5 *Hardness Test:*

A1.5.1 *Hardness Tests on Bar Products*—flats, rounds, squares, hexagons, and octagons—is conducted on the surface after a minimum removal of 0.4 mm (0.015 in.) to provide for accurate hardness penetration.

Table A1.1—Practices for Selecting Tension Test Specimens for Steel Bar Products

Flats

Thickness, mm (in.)	Width, mm (in.)	Hot-Rolled Bars	Cold-Finished Bars
Under 16 ($^{5}/_{8}$)	Up to 40 ($1^{1}/_{2}$), incl	Full section by 200-mm (8-in.) gauge length (Figure 3)	Mill reduced section to 50-mm (2-in.) gauge length and approximately 25 percent less than test specimen width
	Greater than 40 ($1^{1}/_{2}$)	Full section, or mill to 40-mm ($1^{1}/_{2}$-in.) wide by 200-mm (8-in.) gauge length (Figure 3)	Mill reduced section to 50-mm (2-in.) gauge length and 40-mm ($1^{1}/_{2}$-in.) wide
16 to 40 ($^{5}/_{8}$ to $1^{1}/_{2}$), excl	Up to 40 ($1^{1}/_{2}$), incl	Full section by 200-mm (8-in.) gauge length or machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from center of section (Figure 4)	Mill reduced section to 50-mm (2-in.) gauge length and approximately 25 percent less than test specimen width or machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from center of section (Figure 4)
	Greater than 40 ($1^{1}/_{2}$)	Full section, or mill to 40-mm ($1^{1}/_{2}$-in.) width by 200-mm (8-in.) gauge length (Figure 3) or machine standard (12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from midway between edge and center of section (Figure 4)	Mill reduced section to 50-mm (2-in.) gauge length and 40-mm ($1^{1}/_{2}$-in.) wide or machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from midway between edge and center of section (Figure 4)
40 ($^{1}/_{2}$) and over		Full section by 200-mm (8-in.) gauge length, or machine standard 12.5 by 50 mm ($^{1}/_{2}$ by 2 in.) gauge length specimen from midway between surface and center (Figure 4)	Machine standard 12.5 by 50 mm ($^{1}/_{2}$ in. by 2 in.) gauge length specimen from midway between surface and center (Figure 4)

Rounds, Squares, Hexagons, and Octagons

Diameter or Distance between Parallel Faces, mm (in.)	Hot-Rolled Bars	Cold-Finished Bars
Under 16 ($^{5}/_{8}$)	Full section by 200-mm (8-in.) gauge length or machine to sub-size specimen (Figure 4)	Machine to sub-size specimen (Figure 4)
16 to 40 ($^{5}/_{8}$ to $1^{1}/_{2}$), excl	Full section by 200-mm (8-in.) gauge length or machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from center of section (Figure 4)	Machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from center of section (Figure 4)
40 ($1^{1}/_{2}$) and over	Full section by 200-mm (8-in.) gauge length or machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from midway between surface and center of section (Figure 4)	Machine standard 12.5- by 50-mm ($^{1}/_{2}$- by 2-in.) gauge length specimen from midway between surface and center of section (Figure 4)

Other Bar-Size Sections

	Hot-Rolled Bars	Cold-Finished Bars
All sizes	Full section by 200-mm (8-in.) gauge length or prepare test specimen 40-mm ($1^{1}/_{2}$-in.) wide (if possible) by 200-mm (8-in.) gauge length	Mill reduced section to 50-mm (2-in.) gauge length and approximately 25 percent less than test specimen width

Note: For bar sections for which it is difficult to determine the cross-sectional area by simple measurement, the area in square inches may be calculated by dividing the weight per linear inch of specimen in pounds by 0.2833 (weight of 1 in.^{3} of steel) or by dividing the weight per linear foot of specimen by 3.4 (weight of steel 1 in. square and 1 ft long).

Table A1.2—Recommended Practice for Selecting Bend Test Specimens for Steel Bar Products

Flats		
Thickness, mm (in.)	Width, mm (in.)	Recommended Size
Up to 13 ($^1/_2$), incl	Up to 19 mm ($^3/_4$), incl	Full section
	Over 19 mm ($^3/_4$)	Full section or machine to not less than 19 mm ($^3/_4$ in.) in width by thickness of specimen
Over 13 ($^1/_2$)	All	Full section or machine to 25 by 13 mm (1 by $^1/_2$ in.) specimen from midway between center and surface

Rounds, Squares, Hexagons, and Octagons	
Diameter or Distance Between Parallel Faces, mm (in.)	Recommended Size
Up to 38 (1$^1/_2$), incl	Full section
Over 38 (1$^1/_2$)	Machine to 25 mm by 13-mm (1 by $^1/_2$-in.) specimen from midway between center and surface

Notes: 1. The length of all specimens is to be not less than 150 mm (6 in.).
2. The edges of the specimens may be rounded to a radius not exceeding 1.6 mm ($^1/_{16}$ in.).

A2. STEEL TUBULAR PRODUCTS

A2.1 *Scope*:

A2.1.1 This annex contains testing requirements for steel bar products that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements in the product specifications shall prevail.

A2.1.2 Tubular shapes covered by this specification include, round, square, rectangle, and special shapes.

A2.2 *Tension Test*:

A2.2.1 *Full-Sized Longitudinal Test Specimens*:

A2.2.1.1 As an alternative to the use of longitudinal strip test specimens or longitudinal round test specimens, tension test specimens of full-size tubular sections are used, provided that the testing equipment has sufficient capacity. Snug-fitting metal plugs should be inserted far enough in the end of such tubular specimens to permit the testing machine jaws to grip the specimens properly without crushing. A design that may be used for such plugs is shown in Figure A2.1. The plugs shall not extend into that part of the specimen on which the elongation is measured (Figure A2.1). Care should be exercised to see that insofar as practicable, the load in such cases is applied axially. The length of the full-section specimen depends on the gauge length prescribed for measuring the elongation.

A2.2.1.2 Unless otherwise required by the individual product specification, the gauge length is 50 mm (2 in.), except that for tubing having an outside diameter of 9.5 mm ($^3/_8$ in.) or less, it is customary for a gauge length equal to four times the outside diameter to be used when elongation comparable to that obtainable with larger test specimens is required.

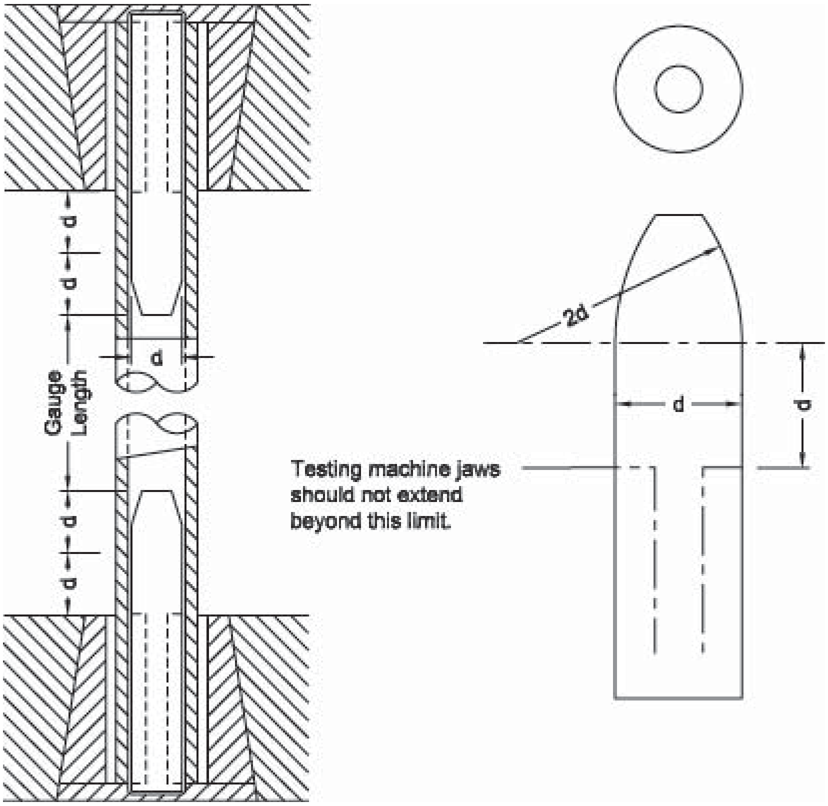


Figure A2.1—Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine

A2.2.1.3 To determine the cross-sectional area of the full-section specimen, measurements shall be recorded as the average or mean between the greatest and least measurements of the outside diameter and the average or mean wall thickness, to the nearest 0.025 mm (0.001 in.) and the cross-sectional area is determined by the following equation:

$$A = 3.1416t\,(D - t) \qquad (A2.1)$$

where:

A = sectional area, mm^2 (in.^{2});

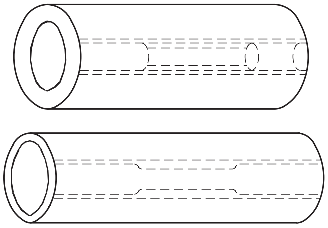
D = outside diameter, mm (in.); and

t = thickness of tube wall, mm (in.).

Note A1—There are other methods of cross-sectional area determination, such as by weighing of the specimens, that are equally accurate or appropriate for this purpose.

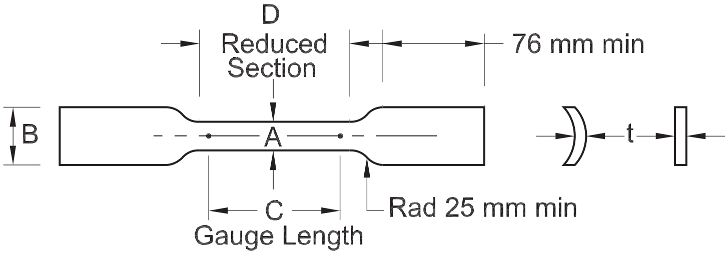
A2.2.2 *Longitudinal Strip Test Specimens*:

A2.2.2.1 As an alternate to the use of full-size longitudinal test specimens or longitudinal round test specimens, longitudinal strip test specimens, obtained from strips cut from the tubular product as shown in Figure A2.2 and machined to the dimensions shown in Figure A2.3, are used. For welded structural tubing, such test specimens shall be from a location at least 90 degrees from the weld; for other welded tubular products, such test specimens shall be from a location approximately 90 degrees from the weld. Unless otherwise required by the product specification, the gauge length is 50 mm (2 in.). The test specimen shall be tested using grips that are flat or have a surface contour corresponding to the curvature of the tubular product, or the ends of the test specimens shall be flattened without heating prior to the test specimens being tested using flat grips. The test specimen shown as Specimen No. 4 in Figure A2.3 shall be used, unless the capacity of the testing equipment or the dimensions and nature of the tubular product to be tested makes the use of specimen notes 1, 2, or 3 necessary.



Note: The edges of the blank for the specimen shall be cut parallel to each other.

Figure A2.2—Location of Strip Tension Test Specimens in Large Diameter Tubing



Dimensional Equivalents

Specimen No.	Dimensions, mm (in.)			
	A	B	C	D
1	12.50 ± 0.38 ($^{1}/_{2}$ ± 0.015)	17 ($^{11}/_{16}$) approximately	50.00 ± 0.13 (2 ± 0.005)	57 min (2$^{1}/_{4}$) minutes
2	19.00 ± 0.79 ($^{3}/_{4}$ ± 0.031)	25 (1) approximately	50.00 ± 0.13 (2 ± 0.005) 100.00 ± 0.13 (4 ± 0.005)	57 min (2$^{1}/_{4}$) minutes 114 minutes (4$^{1}/_{2}$) minutes
3	25.00 ± 1.57 (1 ± 0.062)	40 (1$^{1}/_{2}$) approximately	50.00 ± 0.13 (2 ± 0.005) 100.00 ± 0.13 (4 ± 0.005)	57 minutes (2$^{1}/_{4}$) minutes 114 minutes (4$^{1}/_{2}$) minutes
4	40.00 ± 3.18 (1$^{1}/_{2}$ ± $^{1}/_{8}$)	50 (2) approximately	50.00 ± 0.25 (2 ± 0.010) 100.00 ± 0.38 (4 ± 0.015) 200 ± 0.51 (8 ± 0.020)	57 minutes (2$^{1}/_{4}$) minutes 114 minutes (4$^{1}/_{2}$) minutes 229 minutes (9) minutes

Notes:

1. Cross-sectional area may be calculated by multiplying A and t.
2. The dimension t is the thickness of the test specimen as provided for in the applicable material specifications.
3. The reduced section shall be parallel within 0.25 mm (0.010 in.) and may have a gradual taper in width from the ends toward the center, with the ends not more than 0.25 mm (0.010 in.) wider than the center.
4. The ends of the specimen shall be symmetrical with the centerline of the reduced section within 2.5 mm (0.10 in.).
5. Dimensional equipment: 25.4 mm = 1 in.
6. Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (a) the above tolerances are used; (b) an adequate number of marks are provided for determination of elongation; and (c) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2A from the edge of the gripping device, the tensile properties determined may not be representative of the material. If the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

Figure A2.3—Dimensions and Tolerances for Longitudinal Strip Tension Test Specimens Tubular Products

Note A2—An exact formula for calculating the cross-sectional area of specimens of the type shown in Figure A2.3 taken from a circular tube is given in T 68/T 68M.

A2.2.2.2 The width should be measured at each end of the gauge length to determine parallelism and also at the center. The thickness should be measured at the center and used with the center measurement of the width to determine the cross-sectional area. The center width dimension should be recorded to the nearest 0.13 mm (0.005 in.), and the thickness measurement to the nearest 0.025 mm (0.001 in.).

A2.2.3 *Transverse Strip Test Specimens*:

A2.2.3.1 In general, transverse tension tests are not recommended for tubular products in sizes smaller than 200 mm (8 in.) in nominal diameter. When required, transverse tension tests specimens may be taken from rings cut from ends of tubes or pipe as shown in Figure A2.4. Flattening of the specimen may be done either after separating it from the tube as in Figure A2.4 (A), or before separating it as in Figure A2.4 (B), and may be done hot or cold; but if the flattening is done cold, the specimen may subsequently be normalized. Specimens from tubes or pipe for which heat-treatment is specified, after being flattened either hot or cold, shall be given the same treatment as the tubes or pipe. For tubes or pipe having a wall thickness of less than 19 mm ($^{3}/_{4}$ in.), the transverse test specimen shall be of the form and dimensions shown in Figure A2.5 and either or both surfaces may be machined to secure uniform thickness. Specimens for transverse tension tests on welded steel tubes or pipe to determine strength of welds shall be located perpendicular to the welded seams with the weld at about the middle of their length.

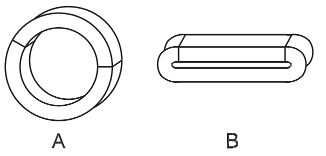
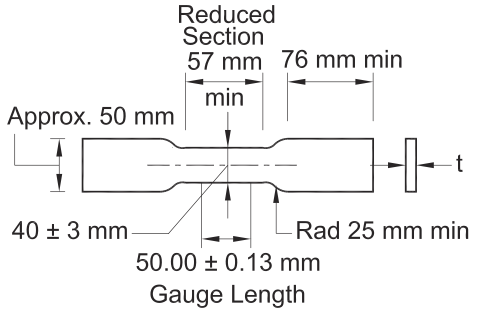


Figure A2.4—Location of Transverse Tension Test Specimens in Ring Cut from Tubular Products



Dimensional Equivalents

mm	76	57	50.00 ± 0.13	50	40 ± 3	25
(in.)	(3)	($2^{1}/_{4}$)	(2.000 ± 0.005)	(2)	($1^{1}/_{2} \pm {}^{1}/_{8}$)	(1)

Notes:

1. The dimension t is the thickness of the test specimen as provided for in the applicable material specifications.
2. The reduced section shall be parallel within 0.25 mm (0.010 in.) and may have a gradual taper in width from the ends toward the center, with the ends not more than 0.25 mm (0.010 in.) wider than the center.
3. The ends of the specimen shall be symmetrical with the centerline of the reduced section within 2.5 mm (0.10 in.).

Figure A2.5—Transverse Tension Test Specimen Machined from Ring Cut from Tubular Products

A2.2.3.2 The width should be measured at each end of the gauge length to determine parallelism and also at the center. The thickness should be measured at the center and used with the center measurement of the width to determine the cross-sectional area. The center width dimension should be recorded to the nearest 0.13 mm (0.005 in.) and the thickness measurement to the nearest 0.025 mm (0.001 in.).

A2.2.4 *Round Test Specimens*:

A2.2.4.1 When provided for in the product specification, the round test specimen shown in Figure 4 may be used.

A2.2.4.2 The diameter of the round test specimen is measured at the center of the specimen to the nearest 0.025 mm (0.001 in.).

A2.2.4.3 Small-sized specimens proportional to standard, as shown in Figure 4, may be used when it is necessary to test material from which the standard specimen cannot be prepared. Other sizes of small-sized specimens may be used. In any such small-sized specimen, it is important that the gauge length for measurement of elongation be four times the diameter of the specimen. (See note 4 of Figure 4.) The elongation requirements for the round specimen 50-mm (2-in.) gauge length in the product specification shall apply to the small-sized specimens.

A2.2.4.4 For transverse specimens, the section from which the specimen is taken shall not be flattened or otherwise deformed.

A2.2.4.5 Longitudinal test specimens are obtained from strips cut from the tubular product as shown in Figure A2.2.

A2.3 *Determination of Transverse Yield Strength, Hydraulic Ring-Expansion Method*:

A2.3.1 Hardness tests are made on the outside surface, inside surface, or wall cross section depending upon product specification limitation. Surface preparation may be necessary to obtain accurate hardness values.

A2.3.2 A testing machine and method for determining the transverse yield strength from an annular ring specimen have been developed and described in Sections A2.3.3 through A2.3.5.

A2.3.3 A diagrammatic vertical cross-sectional sketch of the testing machine is shown in Figure A2.6.

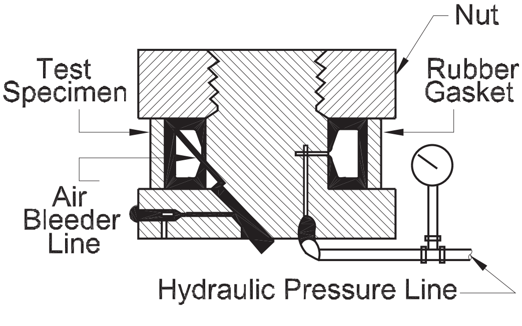


Figure A2.6—Testing Machine for Determination of Transverse Yield Strength from Annular Ring Specimens

A2.3.4 In determining the transverse yield strength on this machine, a short ring (commonly 76 mm (3 in.) in length) test specimen is used. After the large circular nut is removed from the machine, the wall thickness of the ring specimen is determined and the specimen is telescoped over the oil-resistant rubber gasket. The nut is then replaced, but is not turned down tight against the specimen. A slight clearance is left between the nut and specimen for the purpose of permitting free radial movement of the specimen as it is being tested. Oil under pressure is then admitted to the interior of the rubber gasket through the pressure line under the control of a suitable valve. An accurately calibrated pressure gauge serves to measure oil pressure. Any air in the system is removed through the bleeder line. As the oil pressure is increased, the rubber gasket expands, which, in turn, stresses the specimen circumferentially. As the pressure builds up, the lips of the rubber gasket act as a seal to prevent oil leakage. With continued increase in pressure, the ring specimen is subjected to a tension stress and elongates accordingly. The entire outside circumference of the ring specimen is considered as the gauge length and the strain is measured with a suitable extensometer, which will be described later. When the desired total strain or extension under load is reached on the extensometer, the oil pressure in pascals (pounds per square inch) is read and by employing Barlow's formula, the unit yield strength is calculated. The yield strength, thus determined, is a true result since the test specimen has not been cold worked by flattening and closely approximates the same condition as the tubular section from which it is cut. Further, the test closely simulates service conditions in pipe lines. One testing machine unit may be used for several different sizes of pipe by the use of suitable rubber gaskets and adapters.

Note A3—Barlow's formula may be stated two ways:

$$P = 2St/D \qquad (A2.2)$$

$$S = PD/2t \qquad (A2.3)$$

where:

P = internal hydrostatic pressure, Pa (psi);

S = unit circumferential stress in the wall of the tube produced by the internal hydrostatic pressure, Pa (psi);

t = thickness of the tube wall, mm (in.); and

D = outside diameter of the tube, mm (in.).

A2.3.5 A roller chain type extensometer that has been found satisfactory for measuring the elongation of the ring specimen is shown in Figures A2.6 and A2.7. Figure A2.6 shows the extensometer in position, but unclamped, on a ring specimen. A small pin, through which the strain is transmitted to and measured by the dial gauge, extends through the hollow threaded stud. When the extensometer is clamped, as shown in Figure A2.7, the desired tension which is necessary to hold the instrument in place and to remove any slack is exerted on the roller chain by the spring. Tension on the spring may be regulated as desired by the knurled thumbscrew. By removing or adding rollers, the roller chain may be adapted for different sizes of tubular sections.

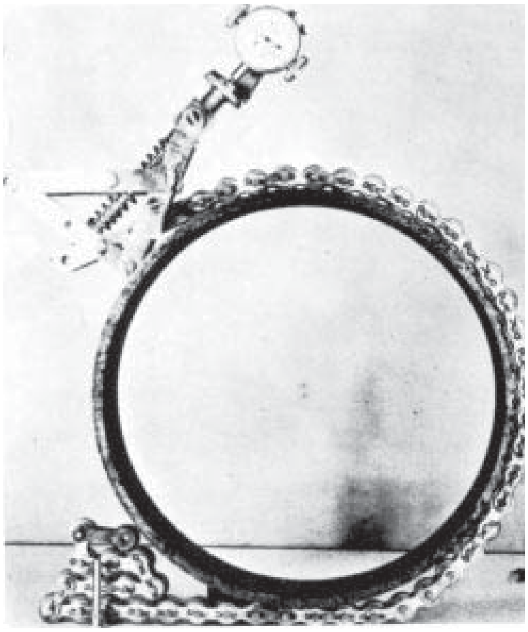


Figure A2.6—Roller Chain Type Extensometer, Unclamped

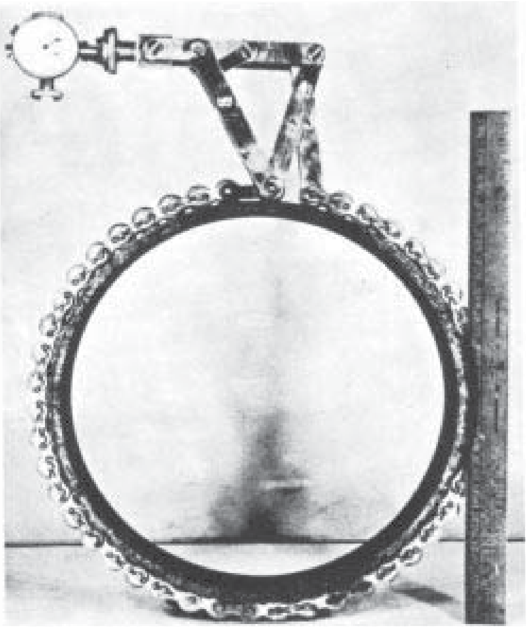


Figure A2.7—Roller Chain Type Extensometer, Clamped

A2.4 *Hardness Tests*:

A2.4.1 Hardness tests are made either on the outside or the inside surfaces on the end of the tube as appropriate.

A2.4.2 The standard 29.42 kN (3000 kgf) Brinell load may cause too much deformation in a thin-walled tubular specimen. In this case, the 4.903 kN (500 kgf) load shall be applied or inside stiffening by means of an internal anvil should be used. Brinell testing shall not be applicable to tubular products less than 50 mm (2 in.) in outside diameter, or less than 5.1 mm (0.200 in.) in wall thickness.

A2.4.3 The Rockwell hardness tests are normally made on the inside surface, a flat on the outside surface, or on the wall cross section, depending upon the product limitation. Rockwell hardness tests are not performed on tubes smaller than 8 mm ($^5/_{16}$ in.) in outside diameter, nor are they performed on the inside surface of tubes with less than 6.4 mm ($^1/_4$ in.) inside diameter. Rockwell hardness tests are not performed on annealed tubes with walls less than 1.65 mm (0.065 in.) thick or cold-worked or heat-treated tubes with walls less than 1.24 mm (0.049 in.) thick. For tubes with wall thicknesses less than those permitting the regular Rockwell hardness test, the Superficial Rockwell test is sometimes substituted. Transverse Rockwell hardness readings can be made on tubes with a wall thickness of 4.75 mm (0.187 in.) or greater. The curvature and the wall thickness of the specimen impose limitations on the Rockwell hardness test. When a comparison is made between Rockwell determinations made on the outside surface and determinations made on the inside surface, adjustment of the readings will be required to compensate for the effect of curvature. The Rockwell B scale is used on all materials having an expected hardness range of B 0 to B 100. The Rockwell C scale is used on material having an expected hardness range of C 20 to C 68.

A2.4.4 Superficial Rockwell hardness tests are normally performed on the outside surface whenever possible and whenever excessive spring back is not encountered. Otherwise, the tests may be performed on the inside. Superficial Rockwell hardness tests shall not be performed on tubes with an inside diameter of less than 6.4 mm ($^1/_4$ in.). The wall thickness limitations for the Superficial Rockwell hardness test are given in Tables A2.1 and A2.2.

Table A2.1—Wall Thickness Limitations of Superficial Hardness Test on Annealed or Ductile Materials for Steel Tubular Products[a]

"T" Scale [1.588-mm ($^1/_{16}$-in.) Ball]

Wall Thickness, mm (in.)	Load, N (kgf)
Over 1.27 (0.050)	441 (45)
Over 0.89 (0.035)	294 (30)
0.51 (0.020) and over	147 (15)

[a] The heaviest load recommended for a given wall thickness is generally used.

Table A2.2—Wall Thickness Limitations of Superficial Hardness Test on Cold-Worked or Heat-Treated Material for Steel Tubular Products[a]

"N" Scale [Diamond Penetrator]

Wall Thickness, mm (in.)	Load N, (kgf)
Greater than 0.89 (0.035)	441 (45)
0.51 (0.025) and larger	294 (30)
0.38 (0.015) and larger	147 (15)

[a] The heaviest load recommended for a given wall thickness is generally used.

A2.4.5 When the outside diameter, inside diameter, or wall thickness precludes obtaining accurate hardness values, tubular products shall be specified to tensile properties and so tested.

A2.5 *Manipulating Tests*:

A2.5.1 The following tests are made to prove ductility of certain tubular products:

A2.5.1.1 *Flattening Test*—The flattening test as commonly made on specimens cut from tubular products is conducted by subjecting rings from the tube or pipe to a prescribed degree of flattening between parallel plates (Figure A2.4). The severity of the flattening test is measured by the distance between the parallel plates and is varied according to the dimensions of the tube or pipe. The flattening test specimen should not be less than 63.5 mm ($2^1/_2$ in.) in length and should be flattened cold to the extent required by the applicable material specification.

A2.5.1.2 *Reverse Flattening Test*—The reverse flattening test is designed primarily for application to electric-welded tubing for the detection of lack of penetration or overlaps resulting from flash removal in the weld. The specimen consists of a length of tubing approximately 100 mm (4 in.) long, which is split longitudinally 90 degrees on each side of the weld. The sample is then opened and flattened with the weld at the point of maximum bend (Figure A2.8).

A2.5.1.3 *Crush Test*—The crush test, sometimes referred to as an upsetting test, is usually made on boiler and other pressure tubes, for evaluating ductility (Figure A2.9). The specimen is a ring cut from the tube, usually about 63.5 mm ($2^1/_2$ in.) long. It is placed on end and crushed endwise by hammer or press to the distance prescribed by the applicable material specification.

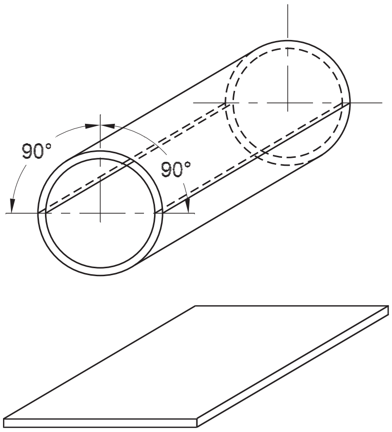


Figure A2.9—Reverse Flattening Test

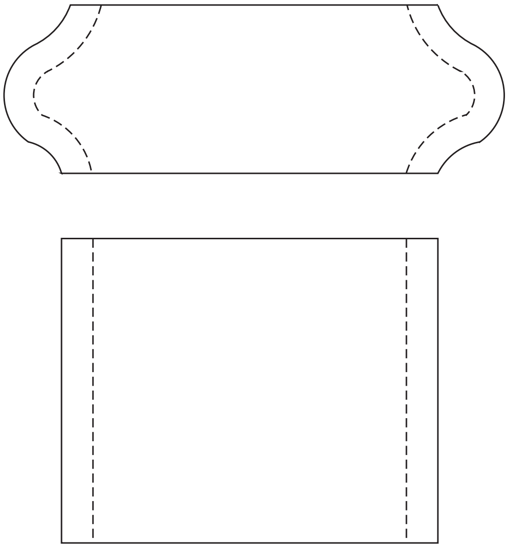
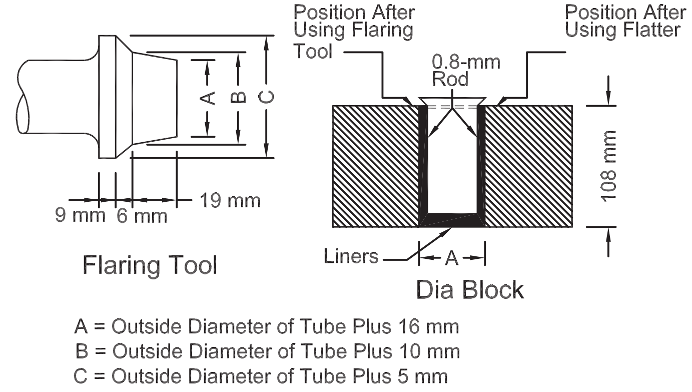


Figure A2.10—Crush-Test Specimen

A2.5.1.4 *Flange Test*—The flange test is intended to determine the ductility of boiler tubes and their ability to withstand the operation of bending into a tube sheet. The test is made on a ring cut from a tube, usually not less than 100 mm (4 in.) long and consists of having a flange turned over at right angles to the body of the tube to the width required by the applicable material specifications. The flaring tool and die block shown in Figure A2.10 are recommended for use in making this test.

A2.5.1.5 *Flaring Test*—For certain types of pressure tubes, an alternate to the flange test is made. This test consists of driving a tapered mandrel having a slope of 1 in 10 as shown in Figure A2.11 or a 60-degree included angle as shown in Figure A2.11 into a section cut from the tube, approximately 100 mm (4 in.) in length, and thus expanding the specimen until the inside diameter has been increased to the extent required by the applicable material specifications.



Note: Dimensional equivalent: 25.4 mm = 1 in.

Figure A2.11—Flaring Tool and Die Block for Flange Test

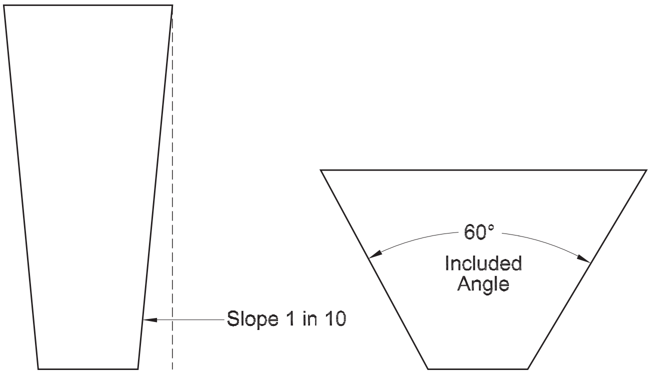
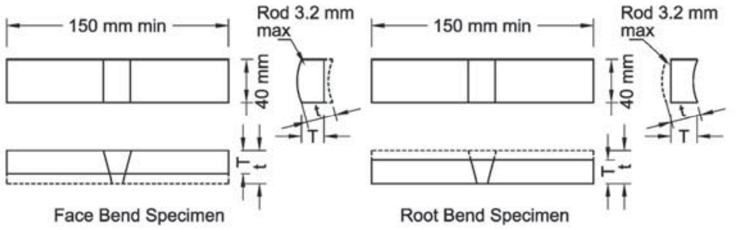


Figure A2.12—Tapered Mandrels for Flaring Test

A2.5.1.6 *Bend Test*—For pipe used for coiling in sizes 50 mm (2 in.) and under, a bend test is made to determine its ductility and the soundness of weld. In this test, a sufficient length of full-sized pipe is bent cold through 90 degrees around a cylindrical mandrel having a diameter 12 times the nominal diameter of the pipe. For close coiling, the pipe is bent cold through 180 degrees around a mandrel having a diameter eight times the nominal diameter of the pipe.

A2.5.1.7 *Transverse Guided Bend Test of Welds*—This bend test is used to determine the ductility of fusion welds. The specimens used are approximately 40 mm ($1^1/_2$ in.) wide, at least 150 mm (6 in.) in length with the weld at the center, and are machined in accordance with Figure A2.13 for face and root bend tests and in accordance with Figure A2.14 for side bend tests. The dimensions of the plunger shall be as shown in Figure A2.15 and the other dimensions of the bending jig shall be substantially as given in this same figure. A test shall consist of a face bend specimen and a root bend specimen or two side bend specimens. A face bend test requires bending with the inside surface of the pipe against the plunger; a root bend test requires bending with the outside surface of the pipe against the plunger; and a side bend test requires bending so that one of the side surfaces becomes the convex surface of the bend specimen.

Failure of the bend test depends upon the appearance of cracks in the area of the bend, of the nature and extent described in the product specifications.

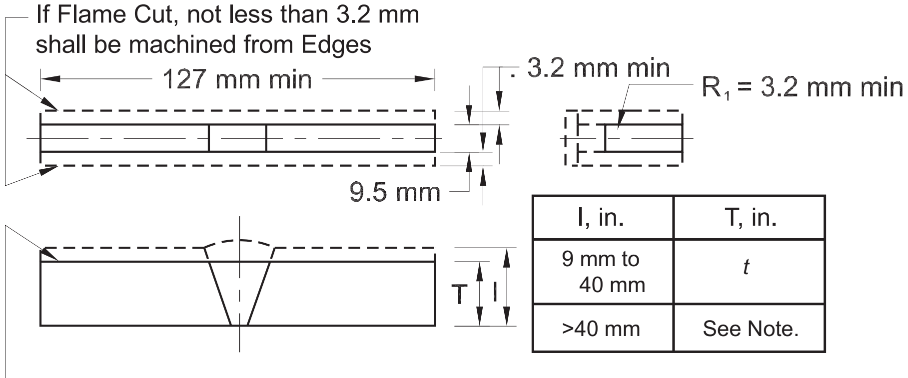


Pipe Wall and Test Specimen Thicknesses

Pipe Wall Thickness (*t*), mm (in.)	Test Specimen Thickness, mm (in.)
Up to 9.5 ($^3/_8$), incl	t
More than 9.5 ($^3/_8$)	9.5 ($^3/_8$)

Note: Dimensional equivalent: 25.4 mm = 1 in.

Figure A2.13—Transverse Face and Root Bend Test Specimens



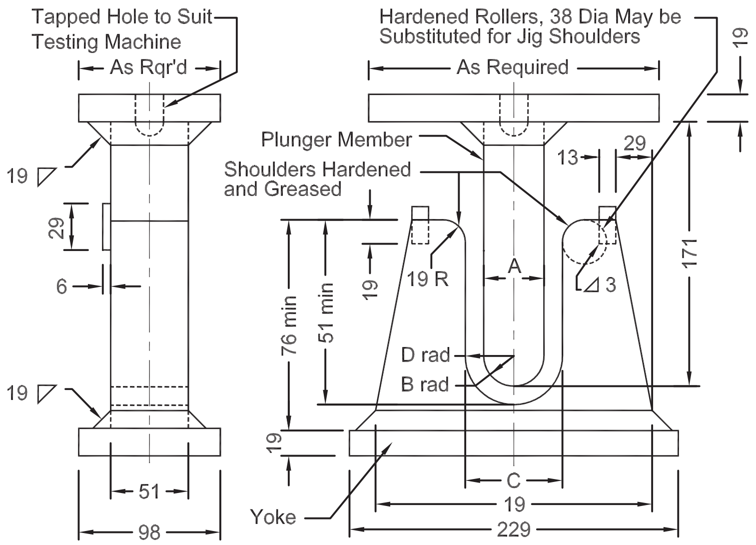
I, in.	T, in.
9 mm to 40 mm	*t*
>40 mm	See Note.

When I exceeds 40 mm, use one of the following:

1. Cut along line indicated by arrow. Edge may be flame cut and may or may not be machined.
2. Specimens may be cut into approximately equal strips between 19 mm and 40 mm wide for testing or the specimens may be bent at full width. (See Requirements on Jig Width in Figure A2.15.)

Note: Dimensional equivalent: 25.4 mm = 1 in.

Figure A2.14—Side Bend Specimen for Ferrous Materials



Dimensional Equivalents

Test Specimen Thickness, mm	A	B	C	D	
9.5	38	19	60	30	
t	4*t*	2*t*	6*t* + 3 mm	3*t* + 1.5 mm	
					Material
9.5	63.5	31.8	85.7	42.9	Materials with a specified minimum Tensile strength of 655 MPa or greater
t	$6\,^{2}/_{3}t$	$3\,^{1}/_{3}t$	$8\,^{2}/_{3}t$ + 3 mm	$4\,^{1}/_{2}t$ + 1.5 mm	

Note: All dimensions shown in millimeters unless otherwise noted. Dimensional equivalent: 25.4 mm = 1 in.

Figure A2.15—Guided-Bend Test Jig

A3. STEEL FASTENERS

A3.1 *Scope*:

A3.1.1 This annex contains testing requirements for steel fasteners that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements in the product specifications shall prevail.

A3.1.2 These tests are set up to facilitate production control testing and acceptance testing with certain more precise tests to be used for arbitration in case of disagreement over test results.

A3.2 *Tension Tests*:

A3.2.1 It is preferred that bolts be tested full sized, and it is customary, when so testing bolts, to specify a minimum ultimate load in newtons (pounds), rather than a minimum ultimate strength in pascals (pounds per square inch). Three times the bolt nominal diameter has been established as the minimum bolt length subject to the tests described in the remainder of this section. Sections A3.2.1.1 through A3.2.1.3 apply when testing bolts full sized. Section A3.2.1.4 shall apply where the individual product specifications permit the use of machined specimens.

A3.2.1.1 *Proof Load*—Due to particular uses of certain classes of bolts, it is desirable to be able to stress them, while in use, to a specified value without obtaining any permanent set. To be certain of obtaining this quality, the proof load is specified. The proof load test consists of stressing the bolt with a specified load that the bolt must withstand without permanent set. An alternate test that determines yield strength of a full sized bolt is also allowed. Either of the following Methods, 1 or 2, may be used, but Method 1 shall be the arbitration method in case of any dispute as to acceptance of the bolts.

A3.2.1.2 *Proof Load Testing Long Bolts*—When full-sized tests are required, proof load Method 1 is to be limited in application to bolts the length of which does not exceed 200 mm (8 in.) or eight times the nominal diameter, whichever is greater. For bolts longer than 200 mm (8 in.) or eight times the nominal diameter, whichever is greater, proof load Method 2 shall be used.

- *Method 1, Length Measurement*—The overall length of a straight bolt shall be measured at its true centerline with an instrument capable of measuring changes in length of 0.0025 mm (0.0001 in.) with an accuracy of 0.0025 mm (0.0001 in.) in any 0.025-mm (0.001 in.) range. The preferred method of measuring the length shall be between conical centers machined on the centerline of the bolt, with mating centers on the measuring anvils. The head or body of the bolt shall be marked so that it can be placed in the same position for all measurements. The bolt shall be assembled in the testing equipment as outlined in Section A3.2.1.4, and the proof load specified in the product specification shall be applied. Upon release of this load, the length of the bolt shall be again measured and shall show no permanent elongation. A tolerance of ±0.0127 mm (0.0005 in.) shall be allowed between the measurement made before loading and that made after loading. Variables, such as straightness and thread alignment (plus measurement error), may result in apparent elongation of the fasteners when the proof load is initially applied. In such cases, the fastener may be retested using a 3 percent greater load, and may be considered satisfactory if the length after this loading is the same as before this loading (within the 0.0127 mm (0.0005 in.) tolerance for measurement error).
- *Method 2, Yield Strength*—The bolt shall be assembled in the testing equipment as outlined in Section A3.2.1.4. As the load is applied, the total elongation of the bolt or any part of the bolt that includes the exposed six threads shall be measured and recorded to produce a load–strain or a stress–strain diagram. The load or stress at an offset equal to 0.2 percent of the length of bolt occupied by six full threads shall be determined by the method described in Section 13.2.1 of T 244. This load or stress shall not be less than that prescribed in the product specification.

A3.2.1.3 *Proof Load Time of Loading*—The proof load is to be maintained for a period of 10 seconds before release of load when using Method 1.

A3.2.1.4 *Axial Tension Testing of Full-Sized Bolts*—Bolts are to be tested in a holder with the load axially applied between the head and a nut or suitable fixture (Figure A3.1), either of which shall have sufficient thread engagement to develop the full strength of the bolt. The nut or fixture shall be assembled on the bolt leaving six complete bolt threads unengaged between the grips, except for heavy hexagon structural bolts which shall have four complete threads unengaged between the grips. To meet the requirements of this test, there shall be a tensile failure in the body or threaded section with no failure at the junction of the body and head. If it is necessary to record or report the tensile strength of bolts as MPa (psi) values, the stress area shall be calculated from the mean of the mean root and pitch diameters of Class 3 external threads as follows:

$$A_s = 0.7854\,[D - (0.9743)/n]^2 \qquad (A3.1)$$

where:

A_s = stress area, mm^2 (in.^{2});

D = nominal diameter, mm (in.); and

n = number of threads per mm (in.).

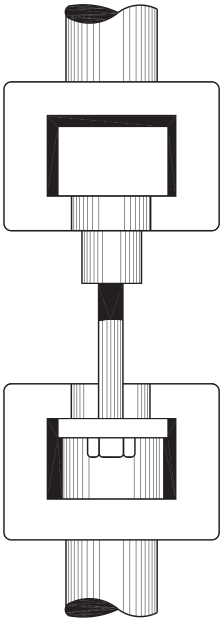


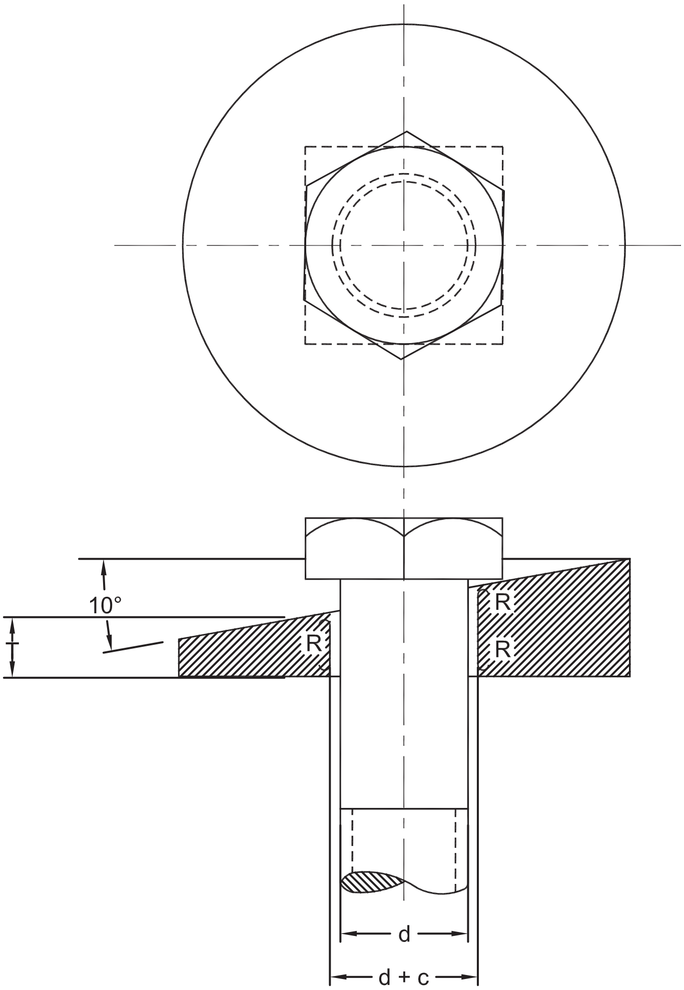
Figure A3.1—Tension Testing Full-Size Bolt

A3.2.1.5 *Tension Testing of Full-Sized Bolts with a Wedge*—The purpose of this test is to obtain the tensile strength and demonstrate the "head quality" and ductility of a bolt with a standard head by subjecting it to eccentric loading. The ultimate load on the bolt shall be determined as described in Section A3.2.1.4, except that a 10-degree wedge shall be placed under the same bolt previously tested for the proof load. (See Section A3.2.1.1.) The bolt head shall be so placed that no corner of the hexagon or square takes a bearing load; that is, a flat of the head shall be aligned with the direction of uniform thickness of the wedge (Figure A3.2). The wedge shall have an included angle of 10 degrees between its faces and shall have a thickness of one-half of the nominal bolt diameter at the short side of the hole. The hole in the wedge shall have the following clearance over the nominal size of the bolt, and its edges, top and bottom, shall be rounded to the radius in Table A3.1.

A3.2.1.6 *Wedge Testing of HT Bolts Threaded to Head*—For heat-treated bolts over 690 MPa (100000 psi) minimum tensile strength and threaded one diameter and closer to the underside of the head, the wedge angle shall be six degrees for sizes 6.4 to 19.0 mm ($^1/_4$ to $^3/_4$ in.) and four degrees for sizes greater than 19.0 mm ($^3/_4$ in.).

Table A3.1—Radius

Nominal Bolt Size, mm (in.)	Clearance in Hole, mm (in.)	Radius on Corners of Hole, mm (in.)
6.4 to 12.7 ($^1/_4$ to $^1/_2$)	0.76 (0.030)	0.76 (0.030)
14.3 to 19.0 ($^9/_{16}$ to $^3/_4$)	1.27 (0.050)	1.52 (0.060)
22.2 to 25.4 ($^7/_8$ to 1)	1.60 (0.063)	1.52 (0.060)
28.6 to 31.8 ($1^1/_8$ to $1^1/_4$)	1.60 (0.063)	3.18 (0.125)
34.9 to 38.4 ($1^3/_8$ to $1^1/_2$)	2.39 (0.094)	3.18 (0.125)



Note: *c* = clearance of pf wedge hole; *d* = diameter of bolt; *r* = radius; and *T* = thickness of wedge at short side of hole equal to one-half diameter of bolt.

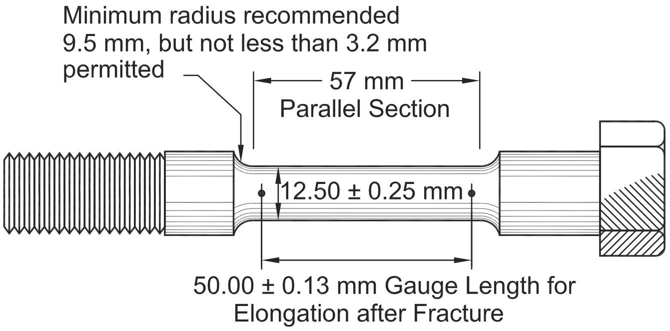
Figure A3.2—Wedge Test Details

A3.2.1.7 *Tension Testing of Bolts Machined to Round Test Specimens*:

1. Bolts less than 40 mm ($1^1/_2$ in.) in diameter that require machined tests shall use a standard 12.5-mm ($^1/_2$-in.) round 50-mm (2-in.) gauge length test specimen (Figure 4); however, bolts of small cross section that will not permit the taking of this standard test specimen shall use one of the small-sized specimens proportional to standard (Figure 4) and the specimen shall have a reduced section as large as possible. In all cases, the longitudinal axis of the specimen

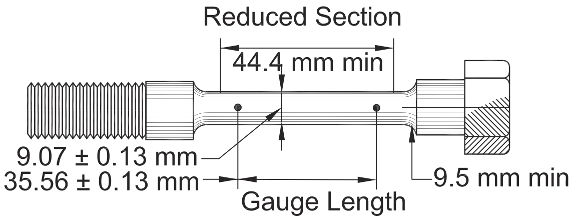
shall be concentric with the axis of the bolt; the head and threaded section of the bolt may be left intact, as in Figures A3.3 and A3.4, or shaped to fit the holders or grips of the testing machine so that the load is applied axially. The gauge length for measuring the elongation shall be four times the diameter of the specimen.

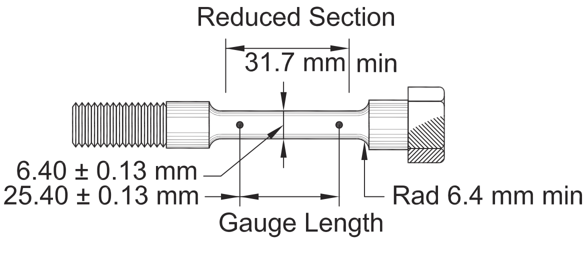
2. For bolts 40 mm ($1^1/_2$ in.) and more in diameter, a standard 12.5-mm ($^1/_2$-in.) round 50-mm (2-in.) gauge length test specimen shall be turned from the bolt, having its axis midway between the center and outside surface of the body of the bolt as shown in Figure A3.5.
3. Machined specimens are to be tested in tension to determine the properties prescribed by the product specifications. The methods of testing and determination of properties shall be in accordance with Section 13 of these methods.



Note: Dimensional equivalent: 25.4 mm = 1 in.

Figure A3.3—Tension Test Specimen for Bolt with Turned-Down Shank





Note: Dimensional equivalent: 25.4 mm = 1 in.

Figure A3.4—Examples of Small-Sized Specimens Proportional to Standard 50-mm (2-in.) Gauge Length Specimen

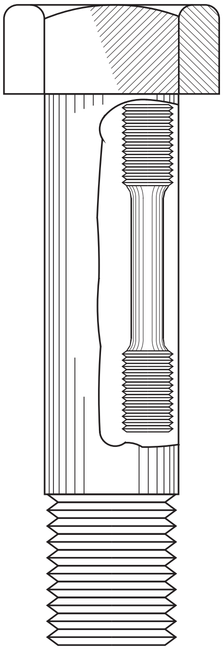


Figure A3.5—Location of Standard Round 50-mm (2-in.) Gauge Length Tension Test Specimen When Turned from Large Size Bolt

A3.3 *Hardness Tests for Externally Threaded Fasteners*:

A3.3.1 When specified, externally threaded fasteners shall be hardness tested. Fasteners with hexagonal or square heads shall be Brinell or Rockwell hardness tested on the side or top of the head. Externally threaded fasteners with other types of heads and those without heads shall be Brinell or Rockwell hardness tested on one end. Due to possible distortion from the Brinell load, care should be taken that this test meets the requirements of Section 16 of these test methods. Where the Brinell hardness test is impractical, the Rockwell hardness test shall be substituted. Rockwell hardness test procedures shall conform to Section 17 of these test methods.

A3.3.2 In cases in which a dispute exists between buyer and seller as to whether externally threaded fasteners meet or exceed the hardness limit of the product specification, for purposes of arbitration, hardness may be taken on two transverse sections through a representative sample fastener selected at random. Hardness readings shall be taken at the locations shown in Figure A3.6. All hardness values must conform to the hardness limit of the product specification for the fasteners represented by the sample to be considered in compliance. This provision for arbitration of a dispute shall not be used to accept clearly rejectable fasteners.

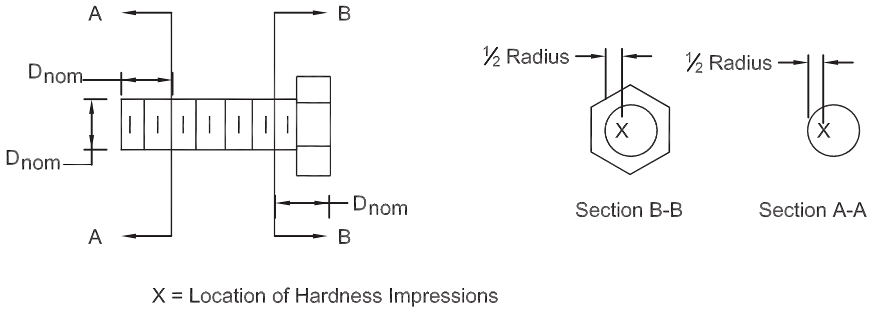


Figure A3.6—Hardness Test Locations for Bolts in a Dispute

A3.4 *Testing of Nuts*:

A3.4.1 *Hardness Test*—Rockwell hardness of nuts shall be determined on the top or bottom face of the nut. Brinell hardness shall be determined on the side of the nuts. Either method may be used at the option of the manufacturer, taking into account the size and grade of the nuts under test. When the standard Brinell hardness test results in deforming the nut, it will be necessary to use a minor load or substitute a Rockwell hardness test.

A4. ROUND WIRE PRODUCTS

A4.1 *Scope*:

A4.1.1 This annex contains testing requirements for round wire products that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements in the product specifications shall prevail.

A4.2 *Apparatus*:

A4.2.1 *Gripping Devices*—Grips of either the wedge or snubbing types as shown in Figures A4.1 and A4.2 shall be used (Note A4). When using grips of either type, care shall be taken that the axis of the test specimen is located approximately at the centerline of the head of the testing machine (Note A5). When using wedge grips, the liners used behind the grips shall be of the proper thickness.

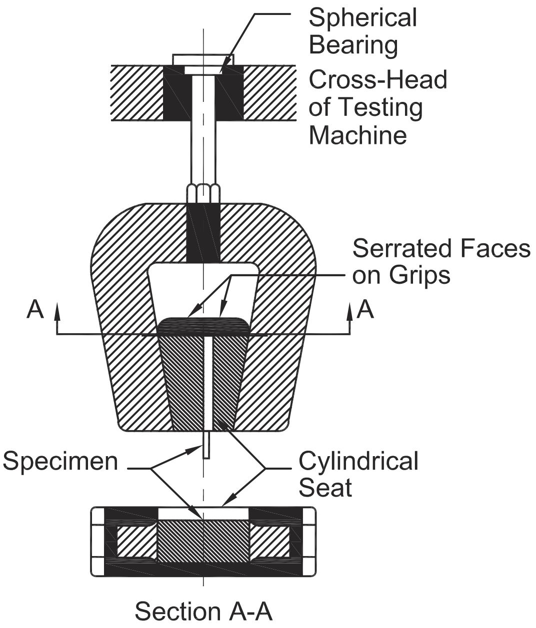


Figure A4.1—Wedge-Type Gripping Device

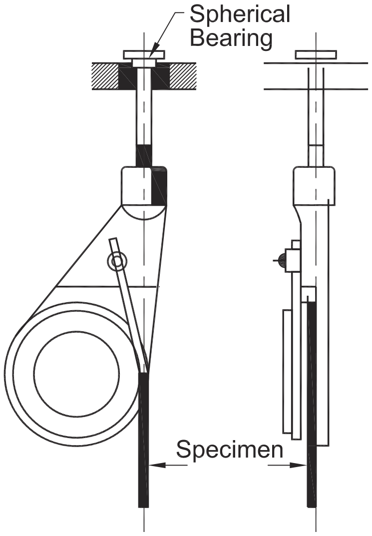


Figure A4.2—Snubbing-Type Gripping Device

Note A4—Testing machines usually are equipped with wedge grips. These wedge grips, irrespective of the type of testing machine, may be referred to as the "usual type" of wedge grips. The use of fine (180 to 240) grit abrasive cloth in the "usual" wedge type grips, with the abrasive contacting the wire specimen, can be helpful in reducing specimen slipping and breakage at the grip edges at tensile loads up to about 454 kg (1000 lb). For tests of specimens of wire that are liable to be cut at the edges by the "usual type" of wedge grips, the snubbing type gripping device has proved satisfactory.

For testing round wire, the use of cylindrical seat in the wedge gripping device is optional.

Note A5—Any defect in a testing machine that may cause non-axial application of load should be corrected.

A4.2.2 *Pointed Micrometer*—A micrometer with a pointed spindle and anvil suitable for reading the dimensions of the wire specimen at the fractured ends to the nearest 0.025 mm (0.001 in.) after breaking the specimen in the testing machine shall be used.

A4.3 *Test Specimens*:

A4.3.1 Test specimens having the full cross-sectional area of the wire they represent shall be used. The standard gauge length of the specimens shall be 254 mm (10 in.). However, if the determination of elongation values is not required, any convenient gauge length is permissible. The total length of the specimens shall be at least equal to the gauge length (254 mm (10 in.)) plus twice the length of wire required for the full use of the grip employed. For example, depending upon the type of testing machine and grips used, the minimum total length of specimen may vary from 360 to 610 mm (14 to 24 in.) for a 254-mm (10-in.) gauge length specimen.

A4.3.2 Any specimen breaking in the grips shall be discarded and a new specimen tested.

A4.4 *Elongation*:

A4.4.1 In determining permanent elongation, the ends of the fractured specimen shall be carefully fitted together and the distance between the gauge marks measured to the nearest 0.25 mm (0.01 in.) with dividers and scale or other suitable device. The elongation is the increase in length of the gauge length, expressed as a percentage of the original gauge length. In recording elongation values, both the percentage increase and the original gauge length shall be given.

A4.4.2 In determining total elongation (elastic plus plastic extension) autographic or extensometer methods may be employed.

A4.4.3 If fracture takes place outside of the middle third of the gauge length, the elongation value obtained may not be representative of the material.

A4.5 *Reduction of Area*:

A4.5.1 The ends of the fractured specimen shall be carefully fitted together and the dimensions of the smallest cross section measured to the nearest 0.025 mm (0.001 in.) with a pointed micrometer. The difference between the area thus found and the area of the original cross section, expressed as a percentage of the original area, is the reduction of area.

A4.5.2 The reduction of area test is not recommended in wire diameters less than 2.34 mm (0.092 in.) due to the difficulties of measuring the reduced cross section.

A4.6 *Rockwell Hardness Test*:

A4.6.1 On heat-treated wire of diameter 2.54 mm (0.100 in.) and larger, the specimen shall be flattened on two parallel sides by grinding before testing. The hardness test is not recommended for any diameter of hard drawn wire or heat-treated wire less than 2.54 mm (0.100 in.) in diameter. For round wire, the tensile strength test is greatly preferred over the hardness test.

A4.7 *Wrap Test*:

A4.7.1 This test is used as a means for testing the ductility of certain kinds of wire.

A4.7.2 The test consists of coiling the wire in a closely spaced helix tightly against a mandrel of a specified diameter for a required number of turns. (Unless otherwise specified, the required number of turns shall be five.) The wrapping may be done by hand or a power device. The wrapping rate may not exceed 15 turns per minute. The mandrel diameter shall be specified in the relevant wire product specification.

A4.7.3 The wire tested shall be considered to have failed if the wire fractures or if any longitudinal or transverse cracks develop that can be seen by the unaided eye after the first complete turn. Wire that fails in the first turn shall be retested, as such fractures may be caused by bending the wire to a radius less than specified when the test starts.

A4.8 *Coiling Test*:

A4.8.1 This test is used to determine whether imperfections are present to the extent that they may cause cracking or splitting during spring coiling and spring extension. A coil of specified length is closed wound on an arbor of a specified diameter. The closed coil is then stretched to a specified permanent increase in length and examined for uniformity of pitch with no splits or fractures. The required arbor diameter, closed coil length, and permanent coil extended length increase may vary with wire diameter, properties, and type.

A5. NOTES ON SIGNIFICANCE OF NOTCHED-BAR IMPACT TESTING

A5.1 *Notch Behavior*:

A5.1.1 The Charpy and Izod type tests bring out notch behavior (brittleness versus ductility) by applying a single overload of stress. The energy values determined are quantitative comparisons on a selected specimen but cannot be converted into energy values that would serve for engineering design calculations. The notch behavior indicated in an individual test applies only to the specimen size, notch geometry, and testing conditions involved and cannot be generalized to other sizes of specimens and conditions.

A5.1.2 The notch behavior of the face-centered cubic metals and alloys, a large group of nonferrous materials and the austenitic steels, can be judged from their common tensile properties. If they are brittle in tension, they will be brittle when notched, while if they are ductile in tension, they will be ductile when notched, except for unusually sharp or deep notches (much more severe than the standard Charpy or Izod specimens). Even low temperatures do not alter this characteristic of these materials. In contrast, the behavior of the ferritic steels under notch conditions cannot be predicted from their properties as revealed by the tension test. For the study of these materials, the Charpy and Izod type tests are accordingly very useful. Some metals that display normal ductility in the tension test may nevertheless break in brittle fashion when tested or when used in the notched condition. Notched conditions include restraints to deformation in directions perpendicular to the major stress, or multiaxial stresses, and stress concentrations. It is in this field that the Charpy and Izod tests prove useful for determining the susceptibility of a steel to notch-brittle behavior, though they cannot be directly used to appraise the serviceability of a structure.

A5.1.3 The testing machine itself must be sufficiently rigid or tests on high-strength, low-energy materials will result in excessive elastic energy losses either upward through the pendulum shaft or downward through the base of the machine. If the anvil supports the pendulum striking edge, or the machine foundation bolts are not securely fastened, tests on ductile materials in the range of 108 J (80 ft·lbf) may actually indicate values in excess of 122 to 136 J (90 to 100 ft·lbf).

A5.2 *Notch Effect*:

A5.2.1 The notch results in a combination of multiaxial stresses associated with restraints to deformation in directions perpendicular to the major stress, and a stress concentration at the base of the notch.

A severely notched condition is generally not desirable, and it becomes of real concern in those cases in which it initiates a sudden and complete failure of the brittle type. Some metals can be deformed in a ductile manner even down to the low temperatures of liquid air, while others may crack. This difference in behavior can be best understood by considering the cohesive strength of a material (or the property that holds it together) and its relation to the yield point. In cases of brittle fracture, the cohesive strength is exceeded before significant plastic deformation occurs and the fracture appears crystalline. In cases of the ductile or shear type of failure, considerable deformation precedes the final fracture and the broken surface appears fibrous instead of crystalline. In intermediate cases, the fracture comes after a moderate amount of deformation and is part crystalline and part fibrous in appearance.

A5.2.2 When a notched bar is loaded, there is a normal stress across the base of the notch that tends to initiate fracture. The property that keeps it from cleaving, or holds it together, is the "cohesive strength." The bar fractures when the normal stress exceeds the cohesive strength. When this occurs without the bar deforming it, this is the condition for brittle fracture.

A5.2.3 In testing, though not in service, because of side effects, it happens more commonly that plastic deformation precedes fracture. In addition to the normal stress, the applied load also sets up shear stresses, which are about 45 degrees to the normal stress. The elastic behavior terminates as soon as the shear stress exceeds the shear strength of the material and deformation or plastic yielding sets in. This is the condition for ductile failure.

A5.2.4 This behavior, whether brittle or ductile, depends on whether the normal stress exceeds the cohesive strength before the shear stress exceeds the shear strength. Several important facts of notch behavior follow from this. If the notch is made sharper or more drastic, the normal stress at the root of the notch will be increased in relation to the shear stress and the bar will be more prone to brittle fracture. (See Table A5.1.) Also, as the speed of deformation increases, the shear strength increases and the likelihood of brittle fracture increases. On the other hand, by raising the temperature, leaving the notch and the speed of deformation the same, the shear strength is lowered and ductile behavior is promoted, leading to shear failure.

Table A5.1—Effect of Varying Notch Dimensions on Standard Specimens

	High-Energy Specimens, J (ft·lbf)	High-Energy Specimens, J (ft·lbf)	Low-Energy Specimens, J (ft·lbf)
Specimen with standard dimensions	103.0 ± 5.2 (76.0 ± 3.8)	60.3 ± 3.0 (44.5 ± 2.2)	16.9 ± 1.4 (12.5 ± 1.0)
Depth of notch, 2.13 mm (0.084 in.)[a]	97.9 (72.2)	56.0 (41.3)	15.5 (11.4)
Depth of notch, 2.04 mm (0.0805 in.)[a]	101.8 (75.1)	57.2 (42.2)	16.8 (12.4)
Depth of notch, 1.97 mm (0.0775 in.)[a]	104.1 (76.8)	61.4 (45.3)	17.2 (12.7)
Depth of notch, 1.88 mm (0.074 in.)[a]	107.9 (79.6)	62.4 (46.0)	17.3 (12.8)
Radius at base of notch, 0.13 mm (0.005 in.)[b]	98.0 (72.3)	56.5 (41.7)	14.6 (10.8)
Radius at base of notch, 0.38 mm (0.015 in.)[b]	108.5 (80.0)	64.3 (47.4)	21.4 (15.8)

[a] Standard 2.00 ± 0.05 mm (0.079 ± 0.002 in.).

[b] Standard 0.25 ± 0.02 mm (0.010 ± 0.001 in.).

A5.2.5 Variations in notch dimensions will seriously affect the results of the tests. Tests on E4340 steel specimens have shown the effect of dimensional variations on Charpy results. (See Table A5.1.)[3]

A5.3 *Size Effect*:

A5.3.1 Increasing either the width or the depth of the specimen tends to increase the volume of metal subject to distortion, and by this factor, tends to increase the energy absorption when breaking the specimen. However, any increase in size, particularly in width, also tends to increase the degree of restraint and, by tending to induce brittle fracture, may decrease the amount of energy absorbed. Where a standard-sized specimen is on the verge of brittle fracture, this is particularly true, and a double-width specimen may actually require less energy for rupture than one of standard width.

A5.3.2 In studies of such effects where the size of the material precludes the use of the standard specimen, as for example when the material is 6-mm ($^1/_4$-in.) plate, sub-sized specimens are necessarily used. Such specimens (Figure A3.1 of T 266) are based on the Type A specimen of Figure 1 of T 266.

A5.3.3 General correlation between the energy values obtained with specimens of different size or shape is not feasible, but limited correlations may be established for specification purposes on the basis of special studies of particular materials and particular specimens. On the other hand, in a study of the relative effect of process variations, evaluation by use of some arbitrarily selected specimen with some chosen notch, in most instances, will place the methods in their proper order.

A5.4 *Effects of Testing Conditions*:

A5.4.1 The testing conditions also affect the notch behavior. So pronounced is the effect of temperature on the behavior of steel when notched, the comparisons are frequently made by examining specimen fractures and by plotting energy value and fracture appearance versus temperature from tests of notched bars at a series of temperatures. When the test temperature has been carried low enough to start cleavage fracture, there may be an extremely sharp drop in impact value or there may be a relatively gradual falling off toward the lower temperatures. This drop in energy value starts when a specimen begins to exhibit some crystalline appearance in the fracture. The transition temperature at which this embrittling effect takes place varies considerably with the size of the part or test specimen and with the notch geometry.

A5.4.2 Some of the many definitions of transition temperature currently being used are: (1) the lowest temperature at which the specimen exhibits 100 percent fibrous fracture, (2) the temperature where the fracture shows a 50 percent crystalline and a 50 percent fibrous appearance, (3) the temperature corresponding to the energy value 50 percent of the difference between values obtained at 100 percent and zero percent fibrous fracture, and (4) the temperature corresponding to a specific energy value.

A5.4.3 A problem peculiar to Charpy type tests occurs when high-strength, low-energy specimens are tested at low temperatures. These specimens may not leave the machine in the direction of the pendulum swing but rather in a sidewise direction. To ensure that the broken halves of the specimens do not rebound off some component of the machine and contact the pendulum before it completes its swing, modifications may be necessary in older model machines. These modifications differ with machine design. Nevertheless, the basic problem is the same in that provisions must be made to prevent rebounding of the fractured specimens into any part of the swinging pendulum. Where design permits, the broken specimens may be deflected out of the sides of the machine and yet in other designs it may be necessary to contain the broken specimens within a certain area until the pendulum passes through the anvils. Some low-energy high-strength steel specimens leave impact machines at speeds in excess of 15 m/s (50 ft/s) although they were struck by a pendulum traveling at speeds approximately 5 m/s (17 ft/s). If the force exerted on the pendulum by the broken specimens is sufficient, the pendulum will slow down and erroneously high-energy values will be recorded. This problem accounts for many of the inconsistencies in Charpy results reported by various investigators within the 14- to 34-J (10- to 25-ft·lbf) range. The Apparatus Section (the paragraph regarding Specimen Clearance) of T 266 discusses the two basic machine designs and a modification found to be satisfactory in minimizing jamming.

A5.5 *Velocity of Straining*:

A5.5.1 Velocity of straining is likewise a variable that affects the notch behavior of steel. The impact test shows somewhat higher energy absorption values than the static tests above the transition temperature and yet, in some instances, the reverse is true below the transition temperature.

A5.6 *Correlation with Service*:

A5.6.1 While Charpy or Izod tests may not directly predict the ductile or brittle behavior of steel as commonly used in large masses or as components of large structures, these tests can be used as acceptance tests of identity for different lots of the same steel or in choosing between different steels, when correlation with reliable service behavior has been established. It may be necessary to make the tests at properly chosen temperatures other than room temperature. In this, the service temperature or the transition temperature of full-scale specimens does not give the desired transition temperatures for Charpy or Izod tests since the size and notch geometry may be so different. Chemical analysis, tension, and hardness tests may not indicate the influence of some of the important processing factors that affect susceptibility to brittle fracture, nor do they comprehend the effect of low temperatures in inducing brittle behavior.

A6. PROCEDURE FOR CONVERTING PERCENTAGE ELONGATION OF A STANDARD ROUND TENSION TEST SPECIMEN TO EQUIVALENT PERCENTAGE ELONGATION OF A STANDARD FLAT SPECIMEN

A6.1 *Scope*:

A6.1.1 This method specifies a procedure for converting percentage elongation after fracture obtained in a standard 12.5-mm (0.500-in.) diameter by 50-mm (2-in.) gauge length test specimen to standard flat test specimens 12.5 mm by 50 mm ($^1/_2$ in. by 2 in.) and 40 mm by 200 mm ($1^1/_2$ in. by 8 in.).

A6.2 *Basic Equation*:

A6.2.1 The conversion data in this method are based on an equation by Bertella,[4] and used by Oliver[5] and others. The relationship between elongations in the standard 12.5-mm (0.500-in.) diameter by 50-mm (2.0-in.) test specimen and other standard specimens can be calculated as follows:

$$e = e_o\left[4.47\left(\sqrt{\mathrm{A}}\right)/\mathrm{L}\right]^a \qquad (A6.1)$$

where:

e_o = percentage elongation after fracture on a standard test specimen having a 50-mm (2-in.) gauge length and a 12.5-mm (0.5-in.) diameter,

e = percentage elongation after fracture on a standard test specimen having a gauge length L and a cross-sectional area A, and

a = constant characteristic of the test material.

A6.3 *Application*:

A6.3.1 In applying the above equation, the constant a is characteristic of the test material. The value $a = 0.4$ has been found to give satisfactory conversions for carbon, carbon-manganese, molybdenum, and chromium-molybdenum steels within the tensile strength range of 275 to 585 MPa (40000 to 85000 psi) and in the hot-rolled, in the hot-rolled and normalized, or in the annealed condition, with or without tempering. Note that the cold-reduced and quenched and the tempered states are excluded. For annealed austenitic stainless steels, the value $a = 0.127$ has been found to give satisfactory conversions.

A6.3.2 Table 19 has been calculated taking $a = 0.4$, with the standard 12.5-mm (0.500-in.) diameter by 50-mm (2-in.) gauge length test specimen as the reference specimen. In the case of the sub-sized specimens 8.89 mm (0.350 in.) in diameter by 35.6-mm (1.4-in.) gauge length, and 6.35-mm (0.250-in.) diameter by 25-mm (1.0-in.) gauge length, the factor in the equation is 4.51 instead of

4.47. The small error introduced by using Table 19 (20) for the sub-sized specimens may be neglected. Table 21 (22) for annealed austenitic steels has been calculated taking $a = 0.127$, with the standard 12.5-mm (0.5-in.) diameter by 50-mm (2-in.) gauge length test specimen as the reference specimen.

A6.3.3 Elongation given for a standard 12.5-mm (0.5-in.) diameter by 50-mm (2-in.) gauge length specimen may be converted to elongation for 12.5-mm by 50-mm ($^1/_2$-in. by 2-in.) or 40-mm by 200-mm ($1^1/_2$-in. by 8-in.) flat specimens by multiplying by the indicated factor in Tables A6.1, A6.2, A6.3, and A6.4.

Table A6.1—*Carbon and Alloy Steels*—Material Constant *a* = 0.4 Multiplication Factors for Converting Percent Elongation from 12.5-mm Diameter by 50-mm Gauge Length Standard Tension Test Specimen to Standard 12.5-mm by 50-mm Flat Specimens and 40-mm by 200-mm Flat Specimens

Thickness, mm	12.5 by 50 mm Specimen	40 by 200 mm Specimen	Thickness, mm	12.5 by 50 mm Specimen	40 by 200 mm Specimen
0.625	0.574	—	13.50	1.062	0.769
0.70	0.587	—	14.00	1.069	0.775
0.80	0.603	—	14.50	1.077	0.781
0.90	0.618	—	15.00	1.084	0.786
1.00	0.631	—	15.50	1.091	0.791
1.10	0.643	—	16.00	1.098	0.796
1.20	0.654	—	16.50	1.105	0.801
1.30	0.665	—	17.00	1.112	0.806
1.40	0.675	—	17.50	1.118	0.810
1.50	0.684	—	18.00	1.125	0.815
1.60	0.693	—	18.50	1.131	0.820
1.70	0.701	—	19.00	1.137	0.824
1.80	0.710	—	19.50	—	0.828
1.90	0.717	—	20.00	—	0.832
2.00	0.725	0.525	21.00	—	0.841
2.10	0.732	0.530	22.00	—	0.848
2.20	0.739	0.535	23.00	—	0.856
2.30	0.745	0.540	24.00	—	0.863
2.40	0.752	0.545	25.00	—	0.870
2.50	0.758	0.549	27.50	—	0.887
2.60	0.764	0.554	30.00	—	0.903
2.80	0.775	0.562	32.50	—	0.917
3.00	0.786	0.570	35.00	—	0.931
3.20	0.796	0.577	37.50	—	0.944
3.40	0.806	0.584	40.00	—	0.956
3.60	0.815	0.591	42.50	—	0.968
3.80	0.824	0.597	45.00	—	0.979
4.00	0.832	0.603	47.50	—	0.990
4.20	0.841	0.609	50.00	—	1.000
4.40	0.848	0.615	52.50	—	1.010
4.60	0.856	0.620	55.00	—	1.019
4.80	0.863	0.626	57.50	—	1.028
5.00	0.870	0.631	60.00	—	1.037
5.50	0.887	0.643	62.50	—	1.045
6.00	0.903	0.654	65.00	—	1.054
6.50	0.917	0.665	67.50	—	1.062
7.00	0.931	0.675	70.00	—	1.069
7.50	0.944	0.684	72.50	—	1.077
8.00	0.956	0.693	75.00	—	1.084
8.50	0.968	0.701	77.50	—	1.091
9.00	0.979	0.710	80.00	—	1.098
9.50	0.990	0.717	82.50	—	1.105
10.00	1.000	0.725	85.00	—	1.112
10.50	1.010	0.732	87.50	—	1.118
11.00	1.019	0.739	90.00	—	1.125
11.50	1.028	0.745	92.50	—	1.131
12.00	1.037	0.752	95.00	—	1.137
12.50	1.045	0.758	97.50	—	1.143
13.00	1.054	0.764	100.00	—	1.148

Table A6.2—*Carbon and Alloy Steels*—Material Constant *a* = 0.4 Multiplication Factors for Converting Percent Elongation from $^1/_2$-in. Diameter by 2-in. Gauge Length Standard Tension Test Specimen to Standard $^1/_2$- by 2-in. and $1^1/_2$-by 8-in. Flat Specimens

Thickness, in.	$^1/_2$ by 2 in. Specimen	$1^1/_2$ by 8 in. Specimen	Thickness, in.	$1^1/_2$ by 8 in. Specimen
0.025	0.574	—	0.800	0.822
0.030	0.596	—	0.850	0.832
0.035	0.614	—	0.900	0.841
0.040	0.631	—	0.950	0.850
0.045	0.646	—	1.000	0.859
0.050	0.660	—	1.125	0.880
0.055	0.672	—	1.250	0.898
0.060	0.684	—	1.375	0.916
0.065	0.695	—	1.500	0.932
0.070	0.706	—	1.625	0.947
0.075	0.715	—	1.750	0.961
0.080	0.725	—	1.875	0.974
0.085	0.733	—	2.000	0.987
0.090	0.742	0.531	2.125	0.999
0.100	0.758	0.542	2.250	1.010
0.110	0.772	0.553	2.375	1.021
0.120	0.786	0.562	2.500	1.032
0.130	0.799	0.571	2.625	1.042
0.140	0.810	0.580	2.750	1.052
0150	0.821	0.588	2.875	1.061
0.160	0.832	0.596	3.000	1.070
0.170	0.843	0.603	3.125	1.079
0.180	0.852	0.610	3.250	1.088
0.190	0.862	0.616	3.375	1.096
0.200	0.870	0.623	3.500	1.104
0.225	0.891	0.638	3.625	1.112
0.250	0.910	0.651	3.750	1.119
0.275	0.928	0.664	3.875	1.127
0.300	0.944	0.675	4.000	1.134
0.325	0.959	0.686	—	—
0.350	0.973	0.696	—	—
0.375	0.987	0.706	—	—
0.400	1.000	0.715	—	—
0.425	1.012	0.724	—	—
0.450	1.024	0.732	—	—
0.475	1.035	0.740	—	—
0.500	1.045	0.748	—	—
0.525	1.056	0.755	—	—
0.550	1.066	0.762	—	—
0.575	1.075	0.770	—	—
0.600	1.084	0.776	—	—
0.625	1.093	0.782	—	—
0.650	1.101	0.788	—	—
0.675	1.110	—	—	—
0.700	1.118	0.800	—	—
0.725	1.126	—	—	—
0.750	1.134	0.811	—	—

Table A6.3—*Annealed Austentitic Stainless Steels*—Material Constant $a = 0.127$ Multiplication Factors for Converting Percent Elongation from 12.5-mm Diameter by 50-mm Gauge Length Standard Tension Test Specimen to Standard 12.5-mm by 50-mm Flat Specimens and 40-mm by 200-mm Flat Specimens

Thickness, mm	12.5 by 50 mm Specimen	40 by 200 mm Specimen	Thickness, mm	12.5 by 50 mm Specimen	40 by 200 mm Specimen
0.625	0.839	—	13.50	1.019	0.920
0.70	0.845	—	14.00	1.022	0.922
0.80	0.852	—	14.50	1.024	0.924
0.90	0.858	—	15.00	1.026	0.926
1.00	0.864	—	15.50	1.028	0.928
1.10	0.869	—	16.00	1.030	0.930
1.20	0.874	—	16.50	1.032	0.932
1.30	0.878	—	17.00	1.034	0.934
1.40	0.883	—	17.50	1.036	0.935
1.50	0.886	—	18.00	1.038	0.937
1.60	0.890	—	18.50	1.040	0.939
1.70	0.894	—	19.00	1.042	0.940
1.80	0.897	—	19.50	—	0.942
1.90	0.900	—	20.00	—	0.943
2.00	0.903	0.815	21.00	—	0.946
2.10	0.906	0.818	22.00	—	0.949
2.20	0.908	0.820	23.00	—	0.952
2.30	0.911	0.822	24.00	—	0.954
2.40	0.913	0.825	25.00	—	0.957
2.50	0.916	0.827	27.50	—	0.963
2.60	0.918	0.829	30.00	—	0.968
2.80	0.922	0.833	32.50	—	0.973
3.00	0.926	0.836	35.00	—	0.978
3.20	0.930	0.840	37.50	—	0.982
3.40	0.934	0.843	40.00	—	0.986
3.60	0.937	0.846	42.50	—	0.990
3.80	0.940	0.849	45.00	—	0.993
4.00	0.943	0.852	47.50	—	0.997
4.20	0.946	0.854	50.00	—	1.000
4.40	0.949	0.857	52.50	—	1.003
4.60	0.952	0.859	55.00	—	1.006
4.80	0.954	0.862	57.50	—	1.009
5.00	0.957	0.864	60.00	—	1.012
5.50	0.963	0.869	62.50	—	1.014
6.00	0.968	0.874	65.00	—	1.017
6.50	0.973	0.878	67.50	—	1.019
7.00	0.978	0.883	70.00	—	1.022
7.50	0.982	0.886	72.50	—	1.024
8.00	0.986	0.890	75.00	—	1.026
8.50	0.990	0.894	77.50	—	1.028
9.00	0.993	0.897	80.00	—	1.030
9.50	0.997	0.900	82.50	—	1.032
10.00	1.000	0.903	85.00	—	1.034
10.50	1.003	0.908	87.50	—	1.036
11.00	1.006	0.908	90.00	—	1.038
11.50	1.009	0.911	92.50	—	1.040
12.00	1.012	0.913	95.00	—	1.042
12.50	1.014	0.916	97.50	—	1.043
13.00	1.017	0.918	100.00	—	1.045

Table A6.4—*Annealed Austenitic Stainless Steels*—Material Constant *a* = 0.127. Multiplication Factors for Converting Percent Elongation from $^1/_2$-in. Diameter by 2-in. Gauge Length Standard Tension Test Specimen to Standard $^1/_2$- by 2-in. and $1^1/_2$- by 8-in. Flat Specimens

Thickness, in.	$^1/_2$ by 2 in. Specimen	$1^1/_2$ by 8 in. Specimen	Thickness, in.	$1^1/_2$ by 8 in. Specimen
0.025	0.839	—	0.800	0.940
0.030	0.848	—	0.850	0.943
0.035	0.857	—	0.900	0.947
0.040	0.864	—	0.950	0.950
0.045	0.870	—	1.000	0.953
0.050	0.876	—	1.125	0.960
0.055	0.882	—	1.250	0.966
0.060	0.886	—	1.375	0.972
0.065	0.891	—	1.500	0.978
0.070	0.895	—	1.625	0.983
0.075	0.899	—	1.750	0.987
0.080	0.903	—	1.875	0.992
0.085	0.906	—	2.000	0.996
0.090	0.909	0.818	2.125	1.000
0.095	0.913	0.821	2.250	1.003
0.100	0.916	0.823	2.375	1.007
0.110	0.921	0.828	2.500	1.010
0.120	0.926	0.833	2.625	1.013
0.130	0.931	0.837	2.750	1.016
0.140	0.935	0.841	2.875	1.019
0150	0.940	0.845	3.000	1.022
0.160	0.943	0.848	3.125	1.024
0.170	0.947	0.852	3.250	1.027
0.180	0.950	0.855	3.375	1.029
0.190	0.954	0.858	3.500	1.032
0.200	0.957	0.860	3.625	1.034
0.225	0.964	0.867	3.750	1.036
0.250	0.970	0.873	3.875	1.038
0.275	0.976	0.878	4.000	1.041
0.300	0.982	0.883	—	—
0.325	0.987	0.887	—	—
0.350	0.991	0.892	—	—
0.375	0.996	0.895	—	—
0.400	1.000	0.899	—	—
0.425	1.004	0.903	—	—
0.450	1.007	0.906	—	—
0.475	1.011	0.909	—	—
0.500	1.014	0.912	—	—
0.525	1.017	0.915	—	—
0.550	1.020	0.917	—	—
0.575	1.023	0.920	—	—
0.600	1.026	0.922	—	—
0.625	1.029	0.925	—	—
0.650	1.031	0.927	—	—
0.675	1.034	—	—	—
0.700	1.036	0.932	—	—
0.725	1.038	—	—	—
0.750	1.041	0.936	—	—

A6.3.4 These elongation conversions shall not be used where the width-to-thickness ratio of the test piece exceeds 20, as in sheet specimens under 0.635 mm (0.025 in.) in thickness.

A6.3.5 While the conversions are considered to be reliable within the stated limitations and may generally be used in specification writing where it is desirable to show equivalent elongation requirements for the several standard AASHTO tension specimens covered in Method T 244, consideration must be given to the metallurgical effects dependent on the thickness of the material as processed.

A7. METHOD OF TESTING MULTI-WIRE STRAND FOR PRESTRESSED CONCRETE

A7.1 *Scope*:

A7.1.1 This method provides procedures for the tension testing of multi-wire strand for prestressed concrete. This method is intended for use in evaluating the strand properties prescribed in specifications for "prestressing steel strands."

A7.2 *General Precaution*:

A7.2.1 Premature failure of the test specimens may result if there is any appreciable notching, cutting, or bending of the specimen by the gripping devices of the testing machine.

A7.2.2 Errors in testing may result if the seven wires constituting the strand are not loaded uniformly.

A7.2.3 The mechanical properties of the strand may be materially affected by excessive heating during specimen preparation.

A7.2.4 These difficulties may be minimized by following the suggested methods of gripping described in Section A7.3.

A7.3 *Gripping Devices*:

A7.3.1 The true mechanical properties of the strand are determined by a test in which fracture of the specimen occurs in the free span between the jaws of the testing machine. Therefore, it is desirable to establish a test procedure with suitable apparatus that will consistently produce such results. Due to inherent physical characteristics of individual machines, it is not practical to recommend a universal gripping procedure that is suitable for all testing machines. Therefore, it is necessary to determine which of the methods of gripping described in Section A7.3.2 to A7.3.8 is most suitable for the testing equipment available.

A7.3.2 *Standard V-Grips with Serrated Teeth (Note A6)*:

A7.3.3 *Standard V-Grips with Serrated Teeth (Note A6), Using Cushioning Material*—In this method, some material is placed between the grips and the specimen to minimize the notching effect of the teeth. Among the materials that have been used are lead foil, aluminum foil, carborundum cloth, brass shims, etc. The type and thickness of material required are dependent on the shape, condition, and coarseness of the teeth.

A7.3.4 *Standard V-Grips with Serrated Teeth (Note A6), Using Special Preparation of the Gripped Portions of the Specimen*—One of the methods used is tinning, in which the gripped portions are cleaned, fluxed, and coated by multiple dips in molten tin alloy held just above the melting point. Another method of preparation is encasing the gripped portions in metal tubing or flexible conduit, using epoxy resin as the bonding agent. The encased portion should be approximately twice the length of lay of the strand.

A7.3.5 *Special Grips with Smooth, Semi-Cylindrical Grooves (Note A7)*—The grooves and the gripped portions of the specimen are coated with an abrasive slurry, which holds the specimen in the smooth grooves, preventing slippage. The slurry consists of an abrasive, such as Grade 3-F aluminum oxide, and a carrier, such as water or glycerin.

A7.3.6 *Standard Sockets of the Type Used for Wire Rope*—The gripped portions of the specimen are anchored in the sockets with zinc. The special procedures for socketing usually employed in the wire rope industry must be followed.

A7.3.7 *Dead-End Eye Splices*—These devices are available in sizes designed to fit each size of strand to be tested.

A7.3.8 *Chucking Devices*—Use of chucking devices of the type generally employed for applying tension to strands in casting beds is not recommended for testing purposes.

Note A6—The number of teeth should be approximately 600 to 1200 per meter (15 to 30 per inch) and the minimum effective gripping length should be approximately 100 mm (4 in.).

Note A7—The radius of curvature of the grooves is approximately the same as the radius of the strand being tested, and is located 0.8 mm ($^1/_{32}$ in.) above the flat face of the grip. This prevents the two grips from closing tightly when the specimen is in place.

A7.4 *Specimen Preparation*:

A7.4.1 If the molten-metal temperatures employed during hot-dip tinning or socketing with metallic material are too high, more than approximately 370ºC (700ºF), the specimen may be heat affected, with a subsequent loss of strength and ductility. Careful temperature controls should be maintained if such methods of specimen preparation are used.

A7.5 *Procedure*:

A7.5.1 *Yield Strength*—For determining the yield strength use a Class B-1 extensometer (Note A8) as described in ASTM E 83. Apply an initial load of 10 percent of the expected minimum breaking strength to the specimen, then attach the extensometer and adjust it to a reading of 1 mm/m (0.001 in./in.) of gauge length. Then increase the load until the extensometer indicates an extension of 1 percent. Record the load for this extension as the yield strength. The extensometer may be removed from the specimen after the yield strength has been determined.

A7.5.2 *Elongation*—For determining the elongation, use a Class D extensometer (Note A8), as described in ASTM E 83, having a gauge length of not less than 600 mm (24 in.) (Note A9). Apply an initial load of 10 percent of the required minimum breaking strength to the specimen, then attach the extensometer (Note A8) and adjust it to a zero reading. The extensometer may be removed from the specimen prior to rupture after the specified minimum elongation has been exceeded. It is not necessary to determine the final elongation value.

A7.5.3 *Breaking Strength*—Determine the maximum load at which one or more wires of the strand are fractured. Record this load as the breaking strength of the strand.

Note A8—The yield strength extensometer and the elongation extensometer may be the same instrument or two separate instruments. Two separate instruments are advisable since the more sensitive yield strength extensometer, which could be damaged when the strand fractures, may be removed following the determination of yield strength. The elongation extensometer may be constructed with less sensitive parts or be constructed in such a way that little damage would result if fracture occurs while the extensometer is attached to the specimen.

Note A9—Specimens that break outside of the extensometer or in the jaws and yet meet the minimum specified values are considered as meeting the mechanical property requirements of the product specification, regardless of what procedure of gripping has been used. Specimens that break outside of the extensometer or in the jaws and do not meet the minimum specified values are subject to retest. Specimens that break between the jaws of the extensometer and do not meet the minimum specified values are subject to retest as provided in the applicable specification.

A8. ROUNDING OF TEST DATA

A8.1 *Rounding*:

A8.1.1 An observed value or a calculated value shall be rounded off in accordance with the applicable product specification. In the absence of a specified procedure, the rounding-off method of E 29 shall be used.

A8.1.1.1 Values shall be rounded up or rounded down as determined by the rules of E 29.

A8.1.1.2 In the special case of rounding the number "5" when no additional numbers other than "0" follow the "5", rounding shall be done in the direction of the specification limits if following E 29 would cause rejection of material.

A8.1.2 Recommended levels for rounding reported values of test data are given in Table A8.1. These values are designed to provide uniformity in reporting and data storage, and should be used in all cases except where they conflict with specific requirements of a product specification.

Table A8.1—Recommended Values for Rounding Test Data

Test Quantity	Test Data Range	Rounded Value[a]
Yield Point, Yield Strength, Tensile Strength	Up to 500 MPa	1 MPa
	500 to 1000 MPa	5 MPa
	1000 MPa and above	10 MPa
	Up to 50 000 psi	100 psi
	50 000 to 100 000 psi	500 psi
	100 000 psi and above	1000 psi
Elongation	0 to 10 percent	0.5 percent
	10 percent and above	1 percent
Reduction of Area	0 to 10 percent	0.5 percent
	10 percent and above	1 percent
Impact Energy	0 to 325 J (0 to 240 ft·lbf)	1 J (1 ft·lbf)[b]
Brinnell Hardness	All values	Tabular Value[c]
Rockwell Hardness	All scales	1 Rockwell Number

[a] Round test data to the nearest integral multiple of the values in this column. If the data value is exactly midway between two rounded values, round to the higher value.

[b] These units are not equivalent but the rounding occurs in the same numerical ranges for each (1.356 J = 1 ft·lbf).

[c] Round the mean diameter of the Brinell impression to the nearest 0.05 mm and report the corresponding Brinell hardness number read from the table without further rounding.

Note A10—To minimize cumulative errors, whenever possible, values should be carried to at least one figure beyond that of the final (rounded) value during intervening calculations (such as calculation of stress from load and area measurements) with rounding occurring as the final operation. The precision may be less than that implied by the number of significant figures.

A9. METHODS FOR TESTING STEEL REINFORCING BARS

A9.1 *Scope*:

A9.1.1 This annex contains testing requirements for steel reinforcing bars that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements in the product specifications shall prevail.

A9.2 *Test Specimens*:

A9.2.1 All test specimens shall be the full section of the bar as rolled.

A9.3 *Tension Testing*:

A9.3.1 *Test Specimen*—Specimens for tension tests shall be long enough to provide for a 200-mm (8-in.) gauge length, a distance of at least two bar diameters between each gauge mark and the grips, plus sufficient additional length to fill the grips completely, leaving some excess length protruding beyond each grip.

A9.3.2 *Gripping Device*—The grips shall be shimmed so that no more than 13 mm ($^1/_2$ in.) of a grip protrudes from the head of the testing machine.

A9.3.3 *Gauge Marks*—The 200-mm (8-in.) gauge length shall be marked on the specimen using a preset 200-mm (8-in.) punch or, alternately, may be punch marked every 50 mm (2 in.) along the 200-mm (8-in.) gauge length, on one of the longitudinal ribs, if present, or in clear spaces of the deformation pattern. The punch marks shall not be put on a transverse deformation. Light punch marks are desirable because deep marks severely indent the bar and may affect the results. A bullet-nose punch is desirable.

A9.3.4 The yield strength or yield point shall be determined by one of the following methods:

A9.3.4.1 Extension under load using an autographic diagram method or an extensometer as described in Sections 13.1.2 and 13.1.3.

A9.3.4.2 By the drop of the beam or halt in the gauge of the testing machine as described in Section 13.1.1 where the steel tested has a sharp-kneed or well-defined type of yield point.

A9.3.5 The unit stress determinations for yield and tensile strength on full-sized specimens shall be based on the nominal bar area.

A9.4 *Bend Testing*:

A9.4.1 Bend tests shall be made on specimens of sufficient length to ensure free bending and with apparatus that provides:

A9.4.1.1 Continuous and uniform application of force throughout the duration of the bending operation,

A9.4.1.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate, and

A9.4.1.3 Close wrapping of the specimen around the pin during the bending operation.

A9.4.2 Other acceptable, more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fix pin, may be used.

A9.4.3 When retesting is permitted by the product specification, the following shall apply:

A9.4.3.1 Sections of bar containing identifying roll marking shall not be used.

A9.4.3.2 Bars shall be so placed that longitudinal ribs lie in a plane at right angles to the plane of bending.

A10. PROCEDURE FOR USE AND CONTROL OF HEAT-CYCLE SIMULATION

A10.1 *Purpose*:

A10.1.1 To ensure consistent and reproducible heat treatments of production forgings and the test specimens that represent them when the practice of heat-cycle simulation is used.

A10.2 *Scope*:

A10.2.1 Generation and documentation of actual production time–temperature curves (master charts).

A10.2.2 Controls for duplicating the master cycle during heat-treatment of production forgings. (Heat-treating within the essential variables established during Section A10.1.).

A10.2.3 Preparation of program charts for the simulator unit.

A10.2.4 Monitoring and inspection of the simulated cycle within the limits established by the ASME Code.

A10.2.5 Documentation and storage of all controls, inspections, charts, and curves.

A10.3 *Referenced Documents*:

A10.3.1 *ASME Standards*:[2]

- ASME Boiler and Pressure Vessel Code Section III, latest edition.
- ASME Boiler and Pressure Vessel Code Section VIII, Division 2, latest edition.

A10.4 *Terminology*:

A10.4.1 *Definitions*:

A10.4.1.1 *master chart*—a record of the heat treatment received from a forging essentially identical to the production forgings that it will represent. It is a chart of time and temperature showing the output from thermocouples embedded in the forging at the designated test immersion and test location or locations.

A10.4.1.2 *program chart*—the metalized sheet used to program the simulator unit. Time–temperature data from the master chart are manually transferred to the program chart.

A10.4.1.3 *simulator chart*—a record of the heat-treatment that a test specimen had received in the simulator unit. It is a chart of time and temperature and can be compared directly to the master chart for accuracy of duplication.

A10.4.1.4 *simulator cycle*—one continuous heat-treatment of a set of specimens in the simulator unit. The cycle includes heating from ambient, holding at temperature, and cooling. For example, a simulated austenitize and quench of a set of specimens would be one cycle; a simulated temper of the same specimens would be another cycle.

A10.5 *Procedure*:

A10.5.1 *Production Master Charts*:

A10.5.1.1 Thermocouples shall be embedded in each forging from which a master chart is obtained. Temperature shall be monitored by a recorder with resolution sufficient to clearly define all aspects of the heating, holding, and cooling process. All charts are to be clearly identified with all pertinent information and identification required for maintaining permanent records.

A10.5.1.2 Thermocouples shall be embedded 180 degrees apart if the material specification requires test locations 180 degrees apart.

A10.5.1.3 One master chart (or two, if required in accordance with Section A10.5 3.1) shall be produced to represent essentially identical forgings (same size and shape). Any change in size or geometry (exceeding rough machining tolerances) of a forging will necessitate that a new master cooling curve be developed.

A10.5.1.4 If more than one curve is required per master forging (180 degrees apart) and a difference in cooling rate is achieved, then the most conservative curve shall be used as the master curve.

A10.5.2 *Reproducibility of Heat Treatment Parameters on Production Forgings*:

A10.5.2.1 All information pertaining to the quench and temper of the master forging shall be recorded on an appropriate permanent record, similar to the one shown in Table A10.1.

A10.5.2.2 All information pertaining to the quench and temper of the production forgings shall be appropriately recorded, preferably on a form similar to that used in Section A10.5.2.1. Quench records of production forgings shall be retained for future reference. The quench and temper record of the master forging shall be retained as a permanent record.

A10.5.2.3 A copy of the master forging record shall be stored with the heat-treatment record of the production forging.

A10.5.2.4 The essential variables, as set forth on the heat-treat record, shall be controlled within the given parameters on the production forging.

A10.5.2.5 The temperature of the quenching medium prior to quenching each production forging shall be equal to or lower than the temperature of the quenching medium prior to quenching the master forging.

Table A10.1—Heat-Treat Record—Essential Variables

	Master Forging	Production Forging 1	Production Forging 2	Production Forging 3	Production Forging 4	Production Forging 5
Program chart number						
Time at temperature and actual temperature of heat treatment						
Method of cooling						
Forging thickness						
Thermocouple immersion						
Beneath buffer (yes/no)						
Forging number						
Product						
Material						
Thermocouple location—zero degrees						
Thermocouple location—180 degrees						
Quench tank number						
Data of heat treatment						
Furnace number						
Cycle number						
Heat-treater						
Starting quench medium temperature						
Time from furnace to quench						
Heating rate above 538˚C (1000˚F)						
Temperature upon removal from quench after 5 minutes						
Orientation of forging in quench						

A10.5.2.6 The time elapsed from opening the furnace door to quench for the production forging shall not exceed that elapsed for the master forging.

A10.5.2.7 If the time parameter is exceeded in opening the furnace door to beginning of quench, the forging shall be placed back into the furnace and brought back up to equalization temperature.

A10.5.2.8 All forgings represented by the same master forging shall be quenched with like orientation to the surface of the quench bath.

A10.5.2.9 All production forgings shall be quenched in the same quench tank, with the same agitation as the master forging.

A10.5.2.10 *Uniformity of Heat-Treat Parameters*—(1) The difference in actual heat-treating temperature between production forgings and the master forging used to establish the simulator cycle for them shall not exceed ±14ºC (±25ºF) for the quench cycle. (2) The tempering temperature of the production forgings shall not fall below the actual tempering temperature of the master forging. (3) At least one contact surface thermocouple shall be placed on each forging in a production load. Temperature shall be recorded for all surface thermocouples on a Time–Temperature Recorder and such records shall be retained as permanent documentation.

A10.5.3 *Heat-Cycle Simulation*:

A10.5.3.1 Program charts shall be made from the data recorded on the master chart. All test specimens shall be given the same heating rate above the AC1, the same holding time, and the same cooling rate as the production forgings.

A10.5.3.2 The heating cycle above the AC1, a portion of the holding cycle, and the cooling portion of the master chart shall be duplicated and the allowable limits on temperature and time, as specified in (1)–(3), shall be established for verification of the adequacy of the simulated heat treatment.

1. *Heat-Cycle Simulation of Test Coupon Heat Treatment for Quenched and Tempered Forgings and Bars*—If cooling rate data for the forgings and bars and cooling rate control devices for the test specimens are available, the test specimens may be heat-treated in the device.
2. The test coupons shall be heated to substantially the same maximum temperature as the forgings or bars. The test coupons shall be cooled at a rate similar to and no faster than the cooling rate representative of the test locations and shall be within 14ºC (25ºF) and 20 seconds at all temperatures after cooling begins. The test coupons shall be subsequently heat-treated in accordance with the thermal treatments below the critical temperature, including tempering and simulated postweld heat-treatment.
3. *Simulated Postweld Heat-Treatment of Test Specimens (for ferritic steel forgings and bars)*—Except for carbon steel (P Number 1, Section 1X of the Code) forgings and bars with a nominal thickness or diameter of 50 mm (2 in.) or less, the test specimens shall be given a heat-treatment to simulate any thermal treatments below the critical temperature that the forgings and bars may receive during fabrication. The simulated heat-treatment shall utilize temperatures, times, and cooling rates as specified on the order. The total time at temperature(s) for the test material shall be at least 80 percent of the total time at temperature(s) to which the forgings and bars are subjected during postweld heat-treatment. The total time at temperature(s) for the test specimens may be performed in a single cycle.

A10.5.3.3 Prior to heat-treatment in the simulator unit, test specimens shall be machined to standard sizes that have been determined to allow adequately for subsequent removal of decarb and oxidation.

A10.5.3.4 At least one thermocouple per specimen shall be used for continuous recording of temperature on an independent external temperature-monitoring source. Due to the sensitivity and design peculiarities of the heating chamber of certain equipment, it is mandatory that the hot junctions of control and monitoring thermocouples always be placed in the same relative position with respect to the heating source (generally infrared lamps).

A10.5.3.5 Each individual specimen shall be identified, and such identification shall be clearly shown on the simulator chart and simulator cycle record.

A10.5.3.6 The simulator chart shall be compared to the master chart for accurate reproduction of simulated quench in accordance with Section A10.5.3.2(1). If any one specimen is not heat-treated within the acceptable limits of temperature and time, such specimen shall be discarded and replaced by a newly machined specimen. Documentation of such action and reasons for deviation from the master chart shall be shown on the simulator chart and on the corresponding nonconformance report.

A10.5.4 *Reheat Treatment and Retesting*:

A10.5.4.1 In the event of a test failure, retesting shall be handled in accordance with rules set forth by the material specification.

A10.5.4.2 If retesting is permissible, a new test specimen shall be heat-treated the same as previously. The production forging that it represents will have received the same heat-treatment. If the test passes, the forging shall be acceptable. If it fails, the forging shall be rejected or shall be subject to reheat treatment if permissible.

A10.5.4.3 If reheat treatment is permissible, proceed as follows: (1) Reheat treatment same as original heat treatment (time, temperature, cooling rate): Using new test specimens from an area as close as possible to the original specimens, repeat the austenitize and quench cycles twice, followed by the tempering cycle (double quench and temper). The production forging shall be given the identical double quench and temper as its test specimens above. (2) Reheat treatment using a new heat-treatment practice. Any change in time, temperature, or cooling rate shall constitute a new heat-treatment practice. A new master curve shall be produced and the simulation and testing shall proceed as originally set forth.

A10.5.4.4 In summation, each test specimen and its corresponding forging shall receive identical heat-treatment or repeated heat-treatment; otherwise the testing shall be invalid.

A10.5.5 *Storage, Recall, and Documentation of Heat-Cycle Simulation Data*—All records pertaining to heat-cycle simulation shall be maintained and held for a period of 10 years or as designated by the customer. Information shall be so organized that all practices can be verified by adequate documented records.

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[1] This test method agrees technically with ASTM A 370-09a, except for minor differences.

[2] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

[3] Fahey, N. H., "Effects of Variables in Charpy Impact Testing," *Materials Research and Standards*, MTRSA Vol. 1, No. 11, November 1961, *p*. 872.

[4] Bertella, C. A., *Giornale del Genio Civile*, Vol. 60, 1922, *p*. 343.

[5] Oliver, D. A., *Proceedings of Institute of Mechanical Engineers*, Vol. 11, 1928, *p*. 827.

Standard Method of Test for

Notched Bar Impact Testing of Metallic Materials (CVN)

AASHTO Designation: T 266-08
ASTM Designation: E 23-07a

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Notched Bar Impact Testing of Metallic Materials (CVN)

AASHTO Designation: T 266-08
ASTM Designation: E 23-07a

AASHTO T 266-08 is identical to ASTM E 23-07a except that the Izod Method is not included.

Standard Method of Test for

Non-Instrumental Determination of Metallic Zinc in Zinc-Rich Primers

AASHTO Designation: T 337-09[1]

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Non-Instrumental Determination of Metallic Zinc in Zinc-Rich Primers

AASHTO Designation: T 337-09[1]

1. SCOPE

1.1. This test method determines the amount of metallic zinc in the dried paint film (nonvolatile matter) of inorganic zinc-rich and organic zinc-rich primers.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- D 521, Standard Test Methods for Chemical Analysis of Zinc Dust (Metallic Zinc Powder)
- D 2369, Standard Test Method for Volatile Content of Coatings
- D 2371, Standard Test Method for Pigment Content of Solvent-Reducible Paints

3. PROCEDURES

3.1. *Procedure A—Individual Components*:

Note 1—Procedure A does not purport to determine the percentage of metallic zinc in the total pigment. Procedure A does not take into account any additional pigmentation that may be present in the mixed primer.

3.1.1. Prepare a sample of the liquid primer by mixing weighed amounts of the zinc-dust pigment component with weighed amounts of the liquid component(s), using mix ratios (by mass) supplied by the manufacturer. The quantity of mixed primer shall be a minimum of 100 g, with the mass of each component determined to the nearest 0.1 g.

3.1.2. Determine the nonvolatile matter percentage by mass of the mixed primer in accordance with ASTM D 2369.

Note 2—It is extremely important to keep the mixed primer sample well agitated immediately prior to performing the ASTM D 2369 or D 2371 test method so as not to allow the zinc dust to appreciably settle out of the sample.

3.1.3. Determine the percentage of metallic zinc in the initial, dry zinc-dust pigment component in accordance with ASTM D 521.

3.2. *Procedure B—Premixed Components*:

3.2.1. Prepare a sample of the liquid primer by mixing weighed amounts of the liquid components (the zinc-dust pigment will be supplied incorporated in one of the liquid components) using the mix ratios by mass supplied by the manufacturer. The quantity of mixed primer shall be a minimum of 100 g, with the mass of each component determined to the nearest 0.1 g.

3.2.2. Determine the nonvolatile matter percentage by mass of the mixed primer in accordance with ASTM D 2369. See Note 2.

3.2.3. Determine the pigment content percentage by mass of the mixed primer in accordance with ASTM D 2371 (high-speed centrifugation). See Note 2.

3.2.4. Determine the metallic zinc percentage by mass of the pigment in accordance with ASTM D 521 using the extracted dried pigment obtained from the ASTM D 2371 test method.

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4. CALCULATIONS

4.1. *Procedure A Calculations*:

4.1.1. Calculate the percentage of volatile matter, V, in the mixed primer as follows (ASTM D 2369):

$$V_A = 100 - [((W_2 - W_1)/S_A) \times 100] \qquad (1)$$

where:

V_A = percentage of volatiles (first determination);

W_1 = weight of dish;

W_2 = weight of dish plus specimen after heating;

S_A = specimen weight; and

V_B = percentage of volatiles (duplicate determination, calculated in the same manner as V_A).

$$V = (V_A + V_B)/2$$

4.1.2. Calculate the percentage of nonvolatile matter, N, in the mixed primer as follows (ASTM D 2369):

$$N = (N_A + N_B)/2 \qquad (2)$$

where:

N_A = $100 - V_A$; and

N_B = $100 - V_B$.

4.1.3. Calculate the percentage of zinc dust by mass of the mixed primer, Zn_{PT}, as follows:

$$Zn_{PT} = (Z/(Z + L)) \times 100 \qquad (3)$$

where:

Z = mass of zinc-dust component; and

L = mass of liquid component(s).

4.1.4. Calculate the percentage of metallic zinc, Zn_{PG}, by mass of the zinc-dust component as follows (ASTM D 521):

$Zn_{PG} = [(V_3 - B_3)(N \times 0.0327)/S_2] \times 100$ (4)

where:

V_3 = titrant solution required for titration of the specimen, mL;

B_3 = titrant solution required for titration of the blank, mL;

N = normality of the titrant solution;

S_2 = sample used, grams; and

0.0327 = milliequivalent weight of zinc.

4.1.5. Determine the amount of metallic zinc in the dried paint film (nonvolatile matter), by calculating the percentage of metallic zinc of the nonvolatile matter, Zn_{NV}, as follows:

$Zn_{NV} = (Zn_{PG} \times Zn_{PT})/N$ (5)

where:

Zn_{PG} = percentage of metallic zinc, percentage by mass of zinc dust component, from Section 4.1.4;

Zn_{PT} = percentage of zinc-dust component by mass of mixed primer, from Section 4.1.3; and

N = percentage of nonvolatile matter, from Section 4.1.2.

4.2. *Procedure B Calculations*:

4.2.1. Calculate volatile and nonvolatile content as in Sections 4.1.1 and 4.1.2.

4.2.2. Calculate the percentage of pigment, P, as follows (ASTM D 2371):

$P = [(W_1 - W_2)/S] \times 100$ (6)

where:

W_1 = weight of the tube (including stirring rod) plus pigment, grams;

W_2 = weight of tube (including stirring rod), grams; and

S = weight of paint sample used, grams.

4.2.3. Calculate the percentage of metallic zinc, Zn_P, in the pigment as follows (ASTM D 521):

$Zn_P = [(V_3 - B_3)(N \times 0.0327)/S_2] \times 100$ (7)

where:

V_3 = titrant solution required for titration of the specimen, mL;

B_3 = titrant solution required for titration of the blank, mL;

N = normality of the titrant solution;

S_2 = sample used, grams; and

0.0327 = milliequivalent weight of zinc.

4.2.4. Calculate the percentage of pigment in the nonvolatile matter, P_{NV}, as follows:

$P_{NV} = (P/N) \times 100$ (8)

where:

P = percentage of pigment calculated from Section 4.2.2; and

N = percentage of nonvolatile matter (total solids) from Section 4.2.1.

4.2.5. Determine the amount of metallic zinc in the dried paint film (nonvolatile matter), by calculating the percentage of metallic zinc of the nonvolatile matter, Zn_{NV}, as follows:

$$Zn_{NV} = (Zn_p/100) \times P_{NV} \qquad (9)$$

where:

Zn_p = percentage of metallic zinc, percent by mass of pigment, from Section 4.2.3; and

P_{NV} = percentage of pigment, by mass of the nonvolatile matter, from Section 4.2.4.

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[1] Formerly AASHTO Provisional Standard TP 65.

Standard Method of Test for

Analysis of Structural Steel Coatings for Hindered Amine Light Stabilizer (HALS)

AASHTO Designation: T 338-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Analysis of Structural Steel Coatings for Hindered Amine Light Stabilizer (HALS)

AASHTO Designation: T 338-09[1]

1. SCOPE

1.1. This method is designed to determine the presence of hindered amine light stabilizer (HALS) in the polyol portion of a two-component acrylic urethane coating.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. APPARATUS AND MATERIALS

2.1. Gas Chromatograph with Mass Spectrometer Detector.

2.2. 5 percent Phenyl Methyl Siloxane Capillary Column.

2.3. Reference HALS sample.

2.4. Hexane, HPLC grade.

2.5. Centrifuge.

3. INSTRUMENT CONDITIONS

3.1. Install and condition the column in the chromatograph in accordance with manufacturer's recommendations. Establish operating conditions which yield acceptable separation of the components. See Table 1 as a guide for initial instrument conditions. Values may need to be altered to achieve necessary resolution of components. Allow sufficient time for the instrument to reach equilibrium and to produce a stable base line.

Table 1—Initial Instrument Conditions

Injection Port	
Mode	Splitless
Carrier gas	Helium
Initial temperature	250°C
Pressure	7.6 psi
Total flow	54 mL/min
Purge flow	50 mL/min
Purge time	2 min
Injection volume	1.0 µl
Column Parameters	
Nominal length	30 m
Nominal diameter	0.25 mm
Nominal film thickness	0.25 µm
Maximum temperature	325°C
Mode	Constant flow
Initial flow	1.0 mL/min
Oven Parameters	
Initial temperature	50°C
Maximum temperature	325°C
Equilibration time	0.5 min
Initial time	1.0 min
Temperature ramp 1	25.0°C/min to 250°C
Hold time 1	15.0 min
Temperature ramp 2	50.0°C/min to 300°C
Hold time 2	5.0 min
Mass Spectrometer	
Transfer line heater	280°C
Solvent delay	2.0 min

4. PROCEDURE

4.1. Prepare standards by adding reference HALS compounds to hexane to obtain the desired concentrations. Record the weights of hexane and reference HALS used to the nearest 0.1 mg. These standards will be used to obtain retention time data and atomic masses incidental to the specific HALS.

4.2. Prepare samples by thoroughly mixing two parts hexane to one part polyol in a centrifuge tube. (Note: 10.0 mL of hexane and 5.0 mL of polyol is a suitable working volume.) Record the weights of hexane and sample polyol used to the nearest 0.1 mg. Cap the centrifuge tube and centrifuge for five minutes at a minimum relative centrifugal force (RCF) of 43. See Section 5.1 for RCF equation. Fill a sample vial with the resulting supernate.

4.3. Inject a 1.0 µl aliquot of the appropriately prepared reference HALS standard. Determine the retention times for the associated peaks and the atomic masses of the reference HALS compounds.

4.4. Inject a 1.0 µl aliquot of the prepared sample. Determine qualitative presence of the specific HALS by comparing retention times and verifying atomic masses of the HALS compounds.

5. CALCULATIONS

5.1. Calculation for Relative Centrifugal Force (RCF):

$$\mathrm{RCF} = 0.00001118 \times r \times N^2 \quad (1)$$

where:

RCF = Relative Centrifugal Force,

r = rotating radius (cm), and

N = revolutions per minute.

6. REPORT

6.1. Report qualitative results for the presence of the HALS compound.

6.2. Report quantitative results to the nearest 0.01 percent.

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[1] Formerly AASHTO Provisional Standard TP 66.

Standard Method of Test for

Analysis of Structural Steel Coatings for Isocyanate Content

AASHTO Designation: T 339-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Analysis of Structural Steel Coatings for Isocyanate Content

AASHTO Designation: T 339-10[1]

1. SCOPE

1.1. This method is designed for the determination of the isocyanate (NCO) content of the resin system found in polyurethane paints.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. APPARATUS AND MATERIALS

2.1. Analytical balance.

2.2. High-speed centrifuge.

2.3. Centrifuge tubes, minimum 50-mL heavy-wall glass with vinyl-lined screw caps or 50-mL high-speed [9400 relative centrifugal force (RCF)] polypropylene tubes with screw caps.

2.4. 10-mL syringes with Luer slip tip and caps.

2.5. Automatic titrator with stirrer (Mettler-Toledo DL 50 or equivalent).

2.6. pH electrodes.

2.7. Fleaker or other vessel with stopper or cap, 200 mL minimum volume.

2.8. o-xylene, reagent grade, dried over 3A molecular sieve (see Section 4.1).

2.9. Standard buffer solutions, pH 4.00 and pH 7.00.

2.10. Dibutylamine, 99 percent assay.

2.11. Methanol, ACS reagent grade, dried over 3A molecular sieve (see Section 4.1).

2.12. Hydrochloric acid solution, 1.0 N.

3. PROCEDURE

3.1. To analyze a one-component material, the resin system must first be separated from the whole paint.

3.2. Place a 45-mL sample of the whole paint into a high-speed centrifuge tube and cap immediately.

3.3. Centrifuge the sample to produce a minimum RCF of 4300 until the pigment and resin have separated. See Section 5.1 for RCF equation.

3.4. No separation is required for multi-component materials when the resin system is packaged separately. The resin system is generally labeled "curing agent" or "part B."

3.5. Calibrate the titrimeter and pH electrodes with standard buffer pH 7.00 and pH 4.00 solutions.

3.6. Place 25 mL of dried o-xylene into an appropriately sized vessel.

3.7. Weigh a 10.0 g sample of resin solution from materials having an expected isocyanate value of less than 15.0 percent or 4.0 g sample of resin solution from materials having an expected isocyanate value of 15.0 percent or greater into the vessel from Section 3.6.

3.8. Record the sample weight to the nearest 1.0 mg.

3.9. Add 20.00 mL of 1.7 N dibutylamine solution to the vessel from Section 3.6. The 1.7 N dibutylamine solution is prepared by diluting 290 mL of dibutylamine to 1.0 L with dried o-xylene.

3.10. Cap the vessel immediately.

3.11. Allow the sample to stir for a minimum of 15 minutes but no longer than 60 minutes at 25 ± 2ºC.

3.12. Prepare a blank in the same manner, omitting the resin solution.

3.13. Wash down the sides of each vessel with 100 mL of dried methanol.

3.14. Titrate the stirred blank with 1.0 N hydrochloric acid to the end point, which occurs at pH 5.0.

3.15. Record the volume of titrant used to the nearest 0.01 mL.

3.16. Titrate the stirred sample with 1.0 N hydrochloric acid to the end point, which occurs at pH 5.0.

3.17. Record the volume of titrant used to the nearest 0.01 mL.

3.18. Prepare and titrate a duplicate sample.

3.19. Calculate the weight percent isocyanate. Duplicate analyses should not differ by more than 0.1 weight percent. See Section 5.2 for weight percent isocyanate calculation.

4. NOTES

4.1. Methanol and o-xylene used for this titration should be passed through separate columns containing 3A molecular sieve to remove any moisture that may be present. A recommended flow rate for passing methanol or o-xylene through a drying column is approximately 100 mL per minute. Dried stock may be collected into amber bottles and preserved by placing a small amount of 3A molecular sieve in the bottles.

5. CALCULATIONS

5.1. Calculation for Relative Centrifugal Force (RCF):

$$\text{RCF} = 0.00001118 \times r \times N^2 \qquad (1)$$

where:

RCF = Relative Centrifugal Force,
r = rotating radius (cm), and
N = revolutions per minute.

5.2. Calculation of weight percent isocyanate of the sample:

$$\%\text{NCO} = (((B - S) \times N \times 42)/(1000 \times W)) \times 100 \qquad (2)$$

where:

B = the amount of titrant used to titrate the blank in milliliters,
S = the amount of titrant used to titrate the sample in milliliters,
N = the normality of the hydrochloric acid solution in equivalents per liter,
42 = the equivalent weight of an isocyanate group,
1000 = the factor converting liters to milliliters, and
W = the weight of the resin solution sample in grams.

6. REPORT

6.1. Report the resin solution sample weight to the nearest milligram, 0.001 g.

6.2. Report the percent isocyanate of the resin system in duplicate to the nearest 0.1 percent.

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[1] Formerly AASHTO Provisional Standard TP 67.

Standard Method of Test for

Pavement Deflection Measurements

AASHTO Designation: T 256-01 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Pavement Deflection Measurements

AASHTO Designation: T 256-01 (2006)

1. SCOPE

1.1 This test method provides standards for measuring pavement surface deflections, directly under, or at locations radially outward (offset) from a known static, steady-state, or impulse load. Deflections are measured with sensors that monitor the vertical movement of a pavement surface due to the load. This test method describes procedures for the deflection measurement using various deflection testing devices and provides the general information that should be obtained regardless of the type of testing device used.

1.2 This test method is applicable for deflection measurements performed on flexible asphalt concrete (AC), rigid portland cement concrete (PCC), or composite (AC/PCC) pavements. Rigid pavements may be plain, jointed, jointed reinforced, or continuously reinforced or fractured concrete.

1.3 The values stated in SI units are to be regarded as standard. Inch-pound units given in parentheses are for information purposes only.

1.4 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- D 4602, Standard Guide for Nondestructive Testing of Pavements Using Cyclic-Loading Dynamic Deflection Equipment
- D 4694, Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device
- D 4695, Standard Guide for General Pavement Deflection Measurements
- D 5858, Standard Guide for Calculating In Situ Equivalent Elastic Moduli of Pavement Materials Using Layered Elastic Theory
- STP 1026, *Nondestructive Testing of Pavements and Backcalculation of Moduli*

2.2 *Other Documents*:

- AASHTO, *Pavement Deflection Data Exchange*: *Technical Data Guide*, Version 1.0, April 1998
- FHWA-RD-98-085, *Temperature Predictions and Adjustment Factors for Asphalt Pavements*
- SHRP-P-661, *Manual for FWD Testing in the Long-Term Pavement Performance (LTPP) Study*

3. TERMINOLOGY

3.1 *Definitions of Terms Specific to This Standard*:

3.1.1 *deflection sensor*—electronic device(s) capable of measuring the relative vertical movements of a pavement surface and mounted in such a manner as to minimize angular rotation with respect to its measuring plane at the expected movement. Such devices may include seismometers, velocity transducers, or accelerometers.

3.1.2 *load cell*—capable of accurately measuring the load that is applied perpendicular to the loading plate and is placed in a position to minimize the mass between the load cell and the pavement. The load cell shall be positioned in such a way that it does not restrict the ability to obtain deflection measurements under the center of the load plate. The load cell shall be water resistant, and shall be resistant to mechanical shocks from road impacts during testing or traveling.

3.1.3 *loading plate*—capable of an even distribution of the load over the pavement surface. Loading plates may be circular in shape (or rectangular in some cases), one piece or segmented, for measurements on conventional roads and airfields or similar stiff pavements. The plate shall be suitably constructed to allow pavement surface deflection measurements at the center of the plate.

3.1.4 *deflection basin*—the idealized bowl shape of the deformed pavement surface due to a specified load as depicted from the peak measurements of a series of deflection sensors placed at radial offsets from the center of the loading plate.

3.1.5 *deflection basin test*—a test with deflection sensors placed at various radial offsets from the center of the loading plate. The test is used to record the shape of the deflection basin resulting from an applied load. Information from this test can be used to estimate material properties for a given pavement structure.

3.1.6 *load transfer test*—a test, usually on PCC pavement, with deflection sensors on both sides of a transverse break in the pavement. The test is used to determine the ability of the pavement to transfer load from one side of the break to the other. Also, the load-deflection data can be used to predict the existence of voids under the pavement.

3.1.7 *test location*—the point at which the center of the applied load(s) is located.

4. SUMMARY OF TEST METHOD AND LIMITATIONS

4.1 This test method consists of standards for measuring pavement surface deflections directly under and/or at appropriate offset locations from the load center. Each nondestructive testing (NDT) device is operated according to the standard operating procedure applicable to the device.

4.2 This test method includes general descriptions of the various types of static and semi-continuous deflection testing devices, and procedures for deflection measurement corresponding to each testing device.

4.3 Standards for collection of general information, such as test setup, ambient temperature, pavement temperature, equipment calibration, number of tests, and test locations, pertain to all devices.

5. SIGNIFICANCE AND USE

5.1 NDT measurement of pavement surface deflections provides information that can be used for the structural evaluation of new or in-service pavements. These deflection measurements may be used to determine the following pavement characteristics:

5.1.1 Modulus of each layer;

5.1.2 Overall stiffness of the pavement system;

5.1.3 Load transfer efficiency of PCC pavement joints;

5.1.4 Modulus of subgrade reaction; and

5.1.5 Effective thickness, structural number, or soil support value.

5.2 These parameters may be used for the analysis and design of reconstructed and rehabilitated flexible and rigid pavements, pavement structural adequacy assessment including joint efficiency of PCC pavement, void detection in PCC pavements, research, and/or network structural inventory purposes.

6. APPARATUS

6.1 The apparatus used in this test method shall be one of the deflection measuring devices described in Section 6.2 and shall consist of some type of probe or surface contact sensor(s) to measure vertical pavement movements or deformations when subjected to a given load.

6.2 *Deflection Measuring Devices*:

6.2.1 *Noncontinuous Static Loading Device*[1] that operates on a single lever-arm principle. This device should have a minimum 2.5-m (8.2-ft) long probe, and the extension of the probe shall depress a dial gauge or electronic sensor that measures maximum pavement surface deflection with a resolution of 0.025 mm (0.001 in.) or better. The vehicle used to carry the static deflection device shall be a truck carrying an 80-kN (18 000-lbf) test load on a single rear axle. The loading configuration, including axle loads, tire sizes, and inflation pressures, can be obtained using the manufacturer's specification; however, this information must be clearly indicated in the engineering report.

6.2.2 *Semi-Continuous Static Loading Device*[2] that operates on a double lever-arm principle. The vehicle used to carry this device shall be a truck carrying a l30-kN (29 000-lbf) single-axle test load. The loading configuration, including axle loads, tire sizes, and inflation pressures, can be obtained using the manufacturer's specification; however, this information must be clearly indicated in the engineering report. The test vehicle should be equipped with a double lever arm with probes, the geometry and size of which makes it possible to measure the maximum pavement surface deflection in both wheelpaths with a resolution of 0.025 mm (0.001 in.) or better. The extension of each lever arm holding the probe should depress an electronic sensor, which may be of any type provided the sensor delivers an analog or digital signal. The digital signal shall be correlated with the movement of this extension and, therefore, with the deflection of the pavement surface under the effect of the moving test load. The truck should be able to lift and move the probes from one measurement point to the next, lower them onto the pavement surface, and make another set of measurements in a fully automated process at a constant vehicle speed.

6.2.3 *Steady-State Loading Device*[3] that uses a dynamic force generator to produce a dynamic load. The force generator may use, for example, a counter-rotating mass or a servo-controlled hydraulic actuator to produce the dynamic load. The device that uses a counter-rotating mass operates at a fixed frequency to produce a dynamic load under a static weight applied through a pair of rigid steel wheels. Both loading frequency and the magnitude of the dynamic loads may be varied by the operator of the devices that use a servo-controlled hydraulic actuator. Depending on the model, normal operating frequencies range from 8 to 60 Hz and maximum dynamic forces range from 2.2 to 35.5 kN (500 to 8000 lbf) applied through a single circular or dual rectangular plate. These loading devices may be mounted in a van, on the front of a vehicle, or on a trailer. Deflection measurement devices should have five or more sensors to satisfactorily measure the deflection basin with a resolution of 0.001 mm (0.00004 in.) or better.

6.2.4 *Impulse Loading Device*[4] that creates an impulse load on the pavement by dropping a mass from different heights onto a rubber or spring buffer system. Generally known as a Falling Weight Deflectometer (FWD), the force-generating device shall be capable of being raised to one or more predetermined heights and dropped. The resulting force pulse, transmitted to the pavement through a 300-mm (11.8-in.) diameter loading plate, shall not vary from each other by more than 3 percent. The force pulse shall approximate the shape of a haversine or half-sine wave and a peak force that can be varied within the range of 7 to 105 kN (1500 to 24 000 lbf) shall be achievable. The impulse loading device shall measure pavement surface deflections using six or more sensors with a resolution of 0.001 mm (0.00004 in.) or better.

7. CALIBRATION

7.1 The deflection sensor(s) and load cell (if applicable) of the deflection device should be calibrated to ensure that all readings are accurate within specified limits. For devices in which the load is assumed to be constant and is not measured, the accuracy of the magnitude of load imparted should be checked periodically.

7.2 *Load Cell:*

7.2.1 *General*—The procedure for calibrating the load cell (if the device uses a load cell) depends upon the type of device used. The calibration of the load cell may be checked informally by observing the load cell readings and comparing them against expected readings based on experience or shunt calibration values in the case of a FWD. Load cell reference (or absolute) calibration shall be performed at least once a year except for the noncontinuous and semi-continuous loading devices. (See Table 1.)

Table 1—Load Cell Frequency of Calibration

Device Type	Frequency of Calibration
Noncontinuous and Semi-Continuous Static Loading Types	Prior to testing
Steady-State Loading Types (see Section 7.2.3 for devices that do not have a load cell)	At least once a year using manufacturer's instructions or using the procedure in Appendix A of SHRP Report SHRP-P-661
Impulse Loading Types (Falling Weight Deflectometer)	At least once a year using the procedure in Appendix A of SHRP Report SHRP-P-661

7.2.2 *Noncontinuous and Semi-Continuous Static Loading Devices*—Immediately prior to testing, weigh the axle load of the truck if the ballast consists of a material that can absorb moisture (sand or gravel, etc.) or could have changed for any reason. Trucks with steel or concrete block loads only need to be weighed if the loads are changed or could have shifted.

7.2.3 *Steady-State Loading Devices*—Devices that are equipped with load cells may be calibrated by measuring the load cell output under known static loading conditions, such as the load of the device itself. Load cells should be calibrated at least once a year following the manufacturer's instructions or using the SHRP procedure in Appendix A of SHRP Report SHRP-P-661. Calibration of a dynamic load application device that does not have a load cell requires specialized equipment generally not available except at the manufacturer's location. Potential error from variations in applied loads for this device is nominal; retesting after leaving the factory may not be considered a requirement. Calibration for applied load should be conducted indirectly once a month by checking the frequency of the counter-rotating fly wheels with a strobe light.

7.2.4 *Impulse Loading Devices*—Reference load cell calibration should be carried out at least once per year. Appendix A of SHRP Report SHRP-P-661[5] contains an example outline for such a task.

7.3 *Deflection Sensors*:

7.3.1 *General*—The procedure for calibrating the deflection sensors depends upon the type of apparatus used. Calibration of the deflection sensors should be checked at least once a month during production testing except noncontinuous and semi-continuous loading devices. (See Table 2.)

7.3.2 *Noncontinuous and Semi-Continuous Static Loading Devices*—Static loading devices should be calibrated daily with feeler gauges. When performing deflection sensor calibration, induced deflections should be similar in magnitude to the deflections encountered during normal testing.

7.3.3 *Steady-State Loading Devices*—A routine calibration check of the deflection sensors shall be conducted once a month. If significant differences are noted for a sensor, it shall be returned to the manufacturer for check or calibration under standard calibration oscillatory vibrations. Deflection sensors shall be calibrated annually.

Table 2—Deflection Sensor Frequency of Calibration

Device Type	Frequency of Calibration	Min Frequency of Calibration Check
Noncontinuous and Semi-Continuous Static Loading Types	Daily during operation	Daily during operation
Steady-State Loading Types	At least once a year	Once a month during operation
Impulse Loading Types (Falling Weight Deflectometer)	Reference calibration at least once a year using the procedure in Appendix A of SHRP Report SHRP-P-661	Relative calibration once a month during operation using the procedure in Appendix A of SHRP Report SHRP-P-661

7.3.4 *Impulse Loading Devices*—Reference deflection sensor calibration should be carried out in accordance with the SHRP Protocol (see Appendix A of SHRP Report SHRP-P-661 for impulse loading devices). A relative calibration check should be conducted once a month using the SHRP Protocol (see Appendix A of SHRP Report SHRP-P-661).

7.4 *Temperature Sensors*:

Pavement temperature sensor calibration should be carried out using a calibrated reference thermometer and two reference surfaces such as a "cool" and "hot" surface. Air temperature sensor (if equipped) calibration should be carried out using two reference temperatures; e.g., stirred ice-water (0°C) and boiling water (100°C). Calibration of the temperature sensors should be carried out at least once a year.

8. FIELD DATA COLLECTION AND TESTING PROCEDURE

8.1 *General*—The procedure to be followed is, to some extent, dependent upon which type of device is used. The following general information is suggested as the minimum data that need to be collected, regardless of the type of device used.

8.1.1 *Load*—For impulse loading devices, record the peak load applied to the pavement surface by the deflection device. For steady-state loading devices, record the calculated peak-to-peak load. For static loading devices, record the axle load of the test vehicle.

8.1.2 *Load Frequency*—If applicable, record the frequency of calculated oscillatory load for vibratory loading devices.[6]

8.1.3 *Geometry of the Loaded Area and Deflection Sensor Locations*—For proper modeling of the pavement structure and/or backcalculation of layer parameters, etc., it is necessary that the locations of the load, deflection sensors, pavement surface cracks, and PCC joints are known and recorded. Record the location of cracks and joints between the load and each sensor within 2 m (6.5 ft) from the center of the load toward the sensors. Record the location and orientation of all sensors as measured radially outward from the center of the load; for example, "300 mm (11.8 in.) ahead of the applied load." In accordance with the selected method of evaluating joint efficiency or load transfer, the load(s) and deflection sensor(s) should be properly positioned; for example, with one or more sensors on each side of the joint and the load placed as close as possible to the leave (downstream) side of the joint in question. Failure to note the presence of joints and cracks within the zone of influence of the load could result in errors in the subsequent analysis of the recorded deflections. Similarly, failure to properly note the actual position of the deflection sensors could result in major analysis errors.

8.1.4 *Time of Test*—Record the date and time the deflection measurements are obtained.

8.1.5 *Stationing or Chainage*—Record the station number or location of the test point for each deflection test conducted.

8.1.6 *Air and Pavement Temperatures*—At a minimum, record the ambient air temperature and pavement surface temperature at specified intervals as recommended by the engineer. Additional temperatures may be required for specific postprocessing methods. For example, pavement layer temperatures may be determined by drilling holes to one or more depths within the pavement layer and filling the bottom of these holes with water, glycerin, or an oil-based product and recording the temperature of the fluid at the bottom of each hole. If testing is conducted over an extended period of time, take temperature measurements of the fluid every hour to establish a direct correlation between the air, pavement surface, and/or at-depth temperature measurements. If this is not possible, some procedures also exist for estimating the pavement temperature as a function of depth using the high and low air temperatures for the previous 24-hour day and the current pavement surface temperature.[7]

8.2 *Testing Locations*—Record the test location at the beginning of the testing sequence. The frequency of field testing is dependent upon the testing level selected, as discussed in Section 9 of this standard.

8.3 *Test Method*—Depending on the type of apparatus used, different test methods can be used. Steady-state loading devices capable of variable loads and frequencies can be used to conduct "frequency sweeps" (multiple tests at various frequencies, at the same test location and load). Impulse loading devices are typically capable of applying various loads; some devices can control the shape and duration of the load pulse. Joint efficiency measurements on jointed PCC pavements can be carried out with devices equipped with multiple deflection sensors by placing the load on one side of the joint and positioning one or more sensors on each side of the joint.

8.4 *Procedure for Deflection Measurements*:

8.4.1 *General*—Procedures for conducting the specific deflection testing should be those furnished by the manufacturer of the device, as supplemented to reflect the general guidelines provided in this standard. The following steps shall be performed irrespective of the device used.

8.4.1.1 Calibrate the deflection sensor and load cell (if applicable) of the device, following the procedure discussed in Section 7.

8.4.1.2 Transport the device to the test location over the desired test point.

8.4.1.3 Measure the ambient air temperature and pavement temperatures in accordance with the guidelines in Section 8.1.6.

8.4.1.4 Record the following information for each pavement tested: project location, operator name, date and time, calibration factors, the beginning and ending station or physical location such as the "Jct. IH 635 and Beltline road," location of cut and fill, culvert locations, bridges, and other vertical control features, and the limits and extent of surface distress, weather condition, and a description of the pavement type.

8.4.1.5 The test location shall be free from all rocks and debris to ensure that the loading plate (if applicable) will be properly seated. Gravel or soil surfaces shall be as smooth as possible and all loose material shall be avoided or removed.

8.4.2 *Noncontinuous Static Loading Device (e.g., Benkelman Beam)*:

8.4.2.1 Position the beam between the tires so that the probe is 1.37 m (4.5 ft) forward of and perpendicular to the rear axle.

8.4.2.2 Adjust the dial gauge to read 0.000 mm (0.000 in.).

8.4.2.3 Drive the test vehicle approximately 8 m (26.3 ft) forward at creep speed and record the maximum dial reading (D_m) with a resolution of 0.025 mm (0.001 in.) or better.

8.4.2.4 After the dial needle has stabilized, record the final dial reading (D_f) with a resolution of 0.025 mm (0.001 in.) or better.

8.4.2.5 Pavement surface deflection = 2 ($D_m - D_f$).

8.4.2.6 Repeat this process at the measurement intervals specified in Section 10. Normally, both wheel tracks are measured using two instruments. However, when testing with only one instrument, the testing can be alternated between wheel tracks, obtaining two measurements in the outer wheel track for every one measurement in the inner wheel track throughout the test section.

8.4.2.7 Report the average (mean) deflection for each wheel track.

8.4.3 *Semi-Continuous Static Loading Device*:

8.4.3.1 Obtain pavement surface deflection measurements for both wheel tracks as specified in Section 9 on a continuous chart.

8.4.3.2 Read the deflection measurements from the deflection traces with a resolution of 0.025 mm (0.001 in.) or better, and tabulate using deflection data sheets along with any accompanying notes.

8.4.3.3 Calculate and report the average (mean) deflections for both wheel tracks.

8.4.4 *Steady-State Loading Device*:

8.4.4.1 Record the information that identifies the exact configuration of the deflection device at the time of testing. The device configuration data usually include number and spacing of deflection sensors and orientation of the deflection sensors.

8.4.4.2 Locate the device such that the center of load is at the selected test location and the sensor bar is parallel to the direction of travel (or across the joint for longitudinal or skewed joints).[8]

8.4.4.3 Lower the sensor bar to position the sensors and the loading plate (or plates) or loading wheels. Initiate force generation until stability is reached at the selected loading frequency and load magnitude.[9]

8.4.4.4 Read and record the measured deflections for each of the sensors, either manually on data sheets or directly if data recording is automated.

8.4.5 *Impulse Loading Device*:

8.4.5.1 Set up the software for data collection.

8.4.5.2 Input the information that identifies the exact configuration of the deflection device at the time of testing. The device configuration data are stored in the data output file and are a direct input to data analysis. This information usually includes the size of load plate, number and spacing of deflection sensors, and the orientation of deflection sensors with respect to the load plate.

8.4.5.3 Select the appropriate data file format. Several file formats are available; e.g., U.S. Customary units, SI units, and other options.

8.4.5.4 Lower the loading plate and sensors to ensure that they are resting on a firm and stable surface.

8.4.5.5 Raise the force generator to the desired height and drop the “weight.” Perform at least one seating drop and one or more test drop(s) at any load level. Record the peak surface deflections and peak load (excluding seating drops) or record the full load response and deflection-time history as recommended by the engineer.

8.4.5.6 When the engineer desires to determine the nonlinearity of the pavement materials, perform testing at multiple-load levels. The analyst may use basin averaging if random error is of sufficient concern.

9. LOCATION AND SAMPLING FREQUENCY

9.1 The test location will vary with the intended application of the data. For the most part, the common approach is to test primarily in wheelpaths, since the pavement response at these locations reflects the effect of damage that has been accumulated. Deflection testing between wheelpaths on AC pavement may be performed to compare testing in the wheelpaths to indicate relative damage.

9.2 *Network Level Testing*—This testing level provides for a general overview of a pavement's bearing capacity with limited testing. Deflection testing is typically performed at 200 m to 500 m (656 ft to 1640 ft) intervals, depending on the specific pavement conditions. A minimum of seven tests per uniform pavement section is recommended to ensure a statistically significant sample. At a minimum, the load for AC and continuously reinforced concrete pavements (CRCP) should be positioned along the outer wheelpath or, alternatively, along the centerline of CRCP slabs. For jointed concrete pavements (JCP), the load should first be positioned at the geometric center of the slab. For network level testing, at least 10 percent of the slabs covered should be tested at the joints, as well, for deflection or load transfer efficiency.

9.3 *General Project Level Testing*—This testing level provides for a more detailed analysis of the pavement; for example, for the purpose of overlay or rehabilitation design. Testing should be performed at 50 to 200-m (164 to 656-ft) intervals, depending on the specific pavement conditions, with a minimum of 15 tests recommended per uniform pavement section. At a minimum, the load for AC or CRCP pavements is generally positioned along the outer wheelpath or, alternatively, along the centerline of CRCP slabs. For JCP pavements, the load should first be positioned at or near the geometric center of the slab, and then moved to the nearest joint and positioned along the same line, generally on the leave side of the joint. On roads, streets, and highways, joint tests are often conducted along the outer wheelpath. For general project level testing, generally, not every joint associated with each interior slab test is covered; however, a minimum joint coverage rate of 25 percent is recommended. On airfield JCP pavements, joint efficiency measurements should be carried out on both transverse and longitudinal joints.

9.4 *Detailed Project Level Testing*—This test level provides for a highly detailed and specific analysis of the pavement, for purposes such as identifying localized areas of high deflection or detecting subsurface voids on PCC pavements, etc. For AC or CRCP pavements, testing is typically performed at 10 to 50-m (32.8 to 164-ft) intervals as recommended by the engineer. On roads, streets, and highways, testing is often carried out in both wheelpaths. For JCP pavements, the load should first be positioned at or near the geometric center of every slab along the length of the test section, and then moved to the nearest joint or crack on each slab, either along the outer wheelpath or at the corner of the slab, or both. On airfield JCP pavements, joint efficiency measurements should be carried out on both transverse and longitudinal joints.

10. OTHER DATA NEEDED PRIOR TO DEFLECTION ANALYSIS

10.1 The following pavement system data may be needed to facilitate the load-deflection analysis:

10.1.1 Pavement layer material types and thicknesses.

10.1.2 Depth to bedrock or stiff layer.

10.1.3 Project ID or roadway name and subsection.

11. DEFLECTION TESTING REPORT

11.1 Field reports (both electronic and hard copy) for each deflection test that was performed should contain information on the following items as a minimum.

11.2 Purpose of deflection testing.

11.3 Date and time of testing.

11.4 Operator identification.

11.5 Vehicle information.

11.6 Weather conditions.

11.7 Air and pavement temperatures.

11.8 *Section Information*—These are usually agency-specified, but the section information generally includes the following:

11.8.1 Roadway and county or district in which it is located.

11.8.2 Type of pavement being tested.

11.8.3 Direction of travel.

11.8.4 Lane being tested (e.g., driving or passing lane).

11.9 *Load and Deflection Data*:

11.9.1 Type of deflection device.

11.9.2 Type of deflection test, such as deflection basin or load transfer.

11.9.3 Location of sensors.

11.9.4 Applied load and load frequency.

11.9.5 Measured deflections under load.

12. DATA ACQUISITION SOFTWARE

12.1 Some deflection testing devices use their own field program to acquire load and deflection data. Traditionally, pavement surface deflection data files have been structured using ASCII formats that are very device dependent. Although ASCII format allows users and agencies to easily access the data output files, a separate program is needed to access the output file for each type of testing device. To mitigate this problem, AASHTO has developed a universal pavement surface deflection data exchange (PDDX) format specification. A description of this specification can be found in the first reference in Section 2.2 of this standard (AASHTO, *Pavement Deflection Data Exchange: Technical Data Guide,* Version 1.0 April 1998).

13. DATA PROCESSING SOFTWARE (FOR REFERENCE)

13.1 Several backcalculation software programs have been developed for deflection data processing and analysis. An ASTM Standard (see Section 2 for reference) provides a discussion regarding some of the major differences among the most commonly used backcalculation programs. If backcalculation techniques are employed, use the latest program version for backcalculation of pavement layer moduli.

14. PRECISION AND BIAS

14.1 Since this test method covers the use of various NDT devices used on any type of bound pavement surface, the precision and bias of this test method will be a function of both the characteristics of the pavement tested and the device used. Information on reliability, accuracy, and repeatability of various vibratory and impulse loading devices can be found in the experiment performed at the Waterways Experiment Station (WES) in Vicksburg, Mississippi.[10]

15. KEYWORDS

15.1 Benkelman beam; deflection sensor; deflection surveys; falling-weight deflectometer (FWD); impulse deflection testing device; load cell; load/deflection testing; nondestructive testing (NDT); pavement surface deflection; pavement testing; sampling frequency; static deflection testing device; and steady-state dynamic deflection testing device.

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[1] An example of this instrument is the Soiltest Benkelman Beam.

[2] An example of this instrument is the Lacroix Deflectograph.

[3] Examples of this instrument are the Geolog Dynaflect and the Foundation Mechanics Road Rater.

[4] Examples of this instrument are the Dynatest FWD, the KUAB FWD, the Phoenix FWD, and the Jils FWD.

[5] Report SHRP-P-661—*Manual for FWD Testing in the Long-Term Pavement Performance (LTPP) Study.*

[6] For devices such as the Dynaflect, the manufacturer generally presets the cyclic loading frequency at a typical default value of 8 Hz.

[7] Federal Highway Administration: *Temperature Predictions and Adjustment Factors for Asphalt Pavements*, Report No. FHWA-RD-98-085.

[8] When testing longitudinal joints, a "star bar" is used to measure joint efficiency at right angle.

[9] When using steady-state devices, the first few vibrations are unstable in terms of output because the sensors have not yet responded to the output frequency.

[10] Bentsen, Nazarian, and Harrison, "Reliability Testing of Seven Nondestructive Pavement Testing Devices." *Nondestructive Testing of Pavements and Backcalculation of Moduli*, ASTM STP 1026, A. J. Bush. III and G. Y. Baladi, eds, American Society of Testing and Materials, Philadelphia, 1989, *pp*. 41–58.

Standard Method of Test for

Instrumental Photometric Measurements of Retroreflective Materials and Retroreflective Devices

AASHTO Designation: T 257-96 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Instrumental Photometric Measurements of Retroreflective Materials and Retroreflective Devices

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1. SCOPE

1.1. This standard covers procedures for instrumental determinations of photometric characteristics of retroreflective materials and retroreflective devices.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- E 184, Standard Practice for Effects of High-Energy Neutron Radiation on the Mechanical Properties of Metallic Materials, E706 (IB) (Withdrawn 2002)
- E 308, Standard Practice for Computing the Colors of Objects by Using the CIE System
- E 809, Standard Practice for Measuring Photometric Characteristics of Retroreflectors
- E 810, Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry

3. SIGNIFICANCE AND USE

3.1. This method describes procedures used to measure photometric quantities that relate to the visual perception of retroreflected light. The most significant usage is in the relation of the night time vehicle headlamps, retroreflector, and driver's eye geometry. For this reason, the CIE Standard Source A is used to represent a tungsten vehicle headlamp and the receptor has the photopic, $V(\lambda)$, spectral responsivity corresponding to the light-adapted human eye. Although the geometry must be specified by the user, it will, in general, correspond to the relation between the vehicle headlamp, the retroreflectometer, and the driver's eye position.

4. TERMINOLOGY

4.1. *Retroreflective Terms*:

4.1.1. *retroreflector*—a surface or device which reflects and returns a relatively high proportion of light in a direction close to the direction from which it came. This characteristic is maintained over a wide variation of the angle made by the incident light ray and the normal to the retroreflective surface.

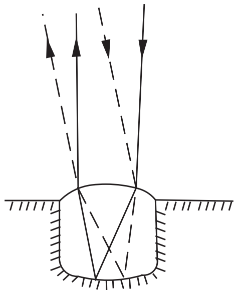
4.1.2. *retroreflective element*—One optical unit which by refraction and/or reflection produces the phenomenon of retroreflection.

4.1.3. *retroreflective device*—a complete device, ready for use, consisting of one or more retroreflective elements (for example, a device containing cats' eyes, a cube corner device, or a safety retroreflective device).

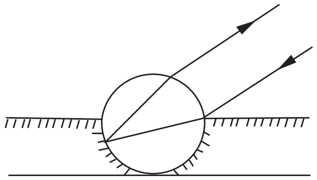
4.1.4. *retroreflective material*—a retroreflective material which consists of a thin continuous layer of small retroreflective elements on or very near the exposed surface (for example, retroreflective sheeting, beaded paint, highway sign surfaces, or pavement striping).

4.1.4.1. *retroreflective sheeting*—a retroreflective material preassembled as a thin film ready for use.

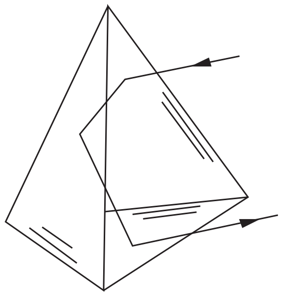
4.2. *geometric terms*—(Figures 1–3).



Cat's Eye Element



Spherical Element



Cube Corner Element

Figure 1—Geometry of Retroflective Elements

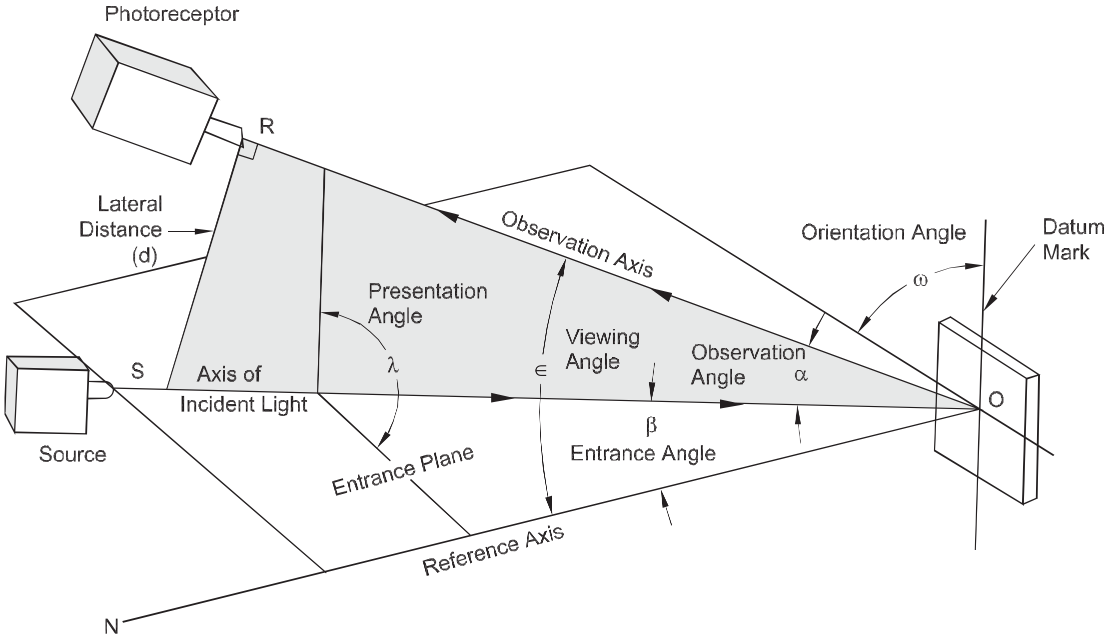


Figure 2—Pictorial View with the Presentation Angle (λ) Illustrated at 90 Degrees (A presentation angle of 0 degrees is normally used.)

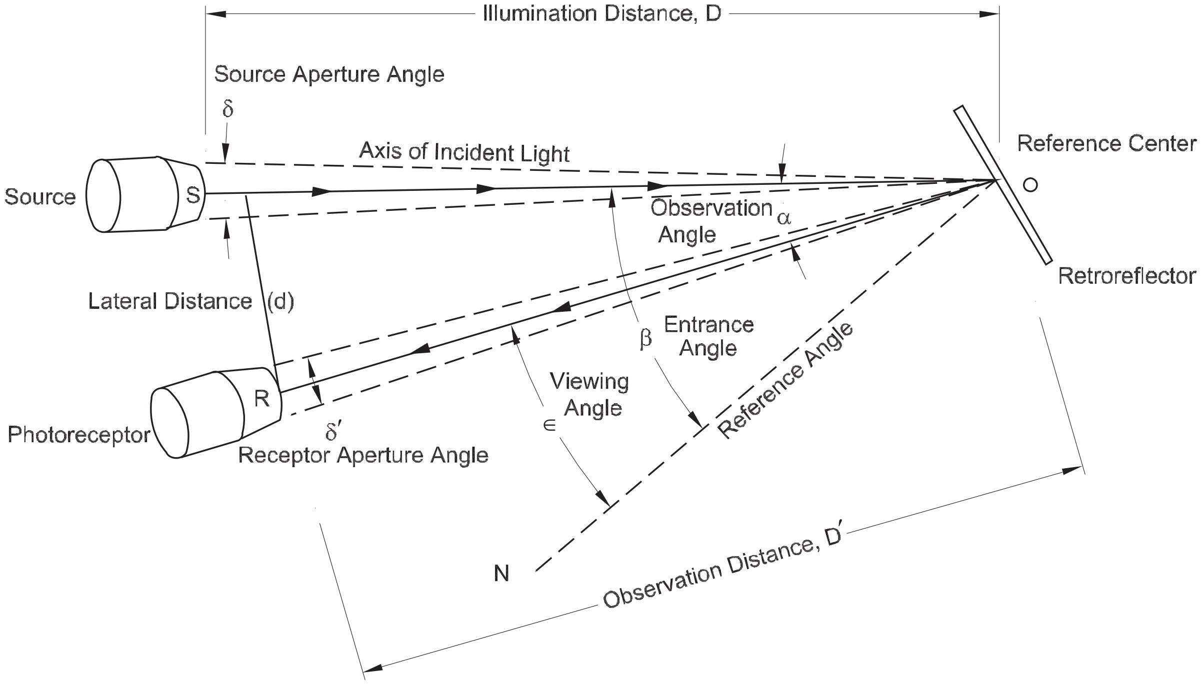


Figure 3—Plane View from Above with the Presentation Angle Illustrated at 0 Degrees

4.2.1. *reference center (O)*—the defined center of a retroreflector.

4.2.2. *reference axis (ON)*—the defined axis used to determine the entrance angle in photometric measurements and in practical use. This axis passes through the reference center (O) (Note 13).

4.2.3. *axis of incident light (OS)*—the line between the reference center and the center of the exit aperture of the light source.

4.2.4. *observation axis (OR)*—the line between the reference center and the center of the entrance aperture of the photoreceptor.

4.2.5. *entrance angle (β)*—the angle between the reference axis and the axis of incident light. Counter-clockwise rotation of the reference axis relative to the axis of incident light is considered positive as shown in Figure 3.

Note 1—Entrance angles are normally in the range of 0 to 90 degrees. However, negative entrance angles can be used to indicate a change of 180 degrees in the presentation angle, provided the 0 degree orientation of the datum mark is defined relative to the observation plane.

4.2.6. *viewing angle (∊)*—the angle between the observation axis and the reference axis.

Note 2—Since this angle is determined by other defined angles, the viewing angle is introduced simply for convenience in defining the specific luminance and the luminance factor.

4.2.7. *observation angle (a)*—the angle between the axis of incident light and the observation axis (“divergence angle” is an obsolete term for this angle).

4.2.8. *datum mark*—the mark placed on the sample by the manufacturer which defines the initial (0 degree) orientation position, and from which the orientation angle is measured.

4.2.9. *orientation angle (ω)*—the angle, when viewed from Point N, through which the sample may be rotated about the reference axis, from the initial 0 degree orientation of the datum mark. The initial 0 degree orientation angle may be defined relative to either the observation plane or the entrance plane.

4.2.9.1. When defined relative to the observation plane, the 0 degree orientation is when the datum mark is in the observation plane and on the same side of the axis of incident light as the photoreceptor.

4.2.9.2. When defined relative to the entrance plane, the 0 degree orientation is when the datum mark is in the entrance plane and on the same side of the axis of incident light as the reference axis.

4.2.10. *presentation angle (λ)*—the dihedral angle between the entrance plane formed by the axis of incident light and the reference axis, and the observation plane formed by the axis of incident light and the observation axis. Zero degree is formed when the photoreceptor is placed in the plane formed by the axis of incident light and the reference axis, with the receptor on the same side of the source as the reference axis. A presentation angle of 0 degree as shown in Figure 3 is used, unless otherwise specified. Figure 2 shows the presentation angle at plus 90 degrees.

4.2.11. *illumination distance (D Equal to OS)*—the distance between the center of the exit aperture of the light source and the reference center.

4.2.12. *observation distance (D′ Equal to OR)*—the distance between the reference center and the center of the entrance aperture of the photoreceptor.

4.2.13. *lateral distance (d)*—the distance from the center of the entrance aperture of the photoreceptor to the axis of incident light, measured perpendicularly to the observation axis. It may be computed by multiplying the observation distance *D′* by the tangent of the observation angle.

$$d = D' \tan\alpha \qquad (1)$$

4.2.14. *source aperture angle (δ)*—the angle at the sample subtended by a given dimension of the source aperture.

4.2.15. *receptor aperture angle (δ′)*—the angle at the sample subtended by a given dimension of the receptor aperture.

4.3. *Photometric Terms*:

4.3.1. *Commission Internationale de l'Eclairage (CIE) photopic standard observer*—a receptor of radiation with a spectral sensitivity curve (Table 1) which conforms to the V(λ) distributions specified in Table 1.

Table 1—Spectral Response of the CIE Standard Photopic Observer (Section 13.1)

Wavelength (mm)	Relative V(λ), %	Wavelength (mm)	Relative V(λ), %
380	0.00	570	95.20
390	0.01	580	87.00
400	0.04	590	75.70
410	0.12	600	63.10
420	0.40	610	50.30
430	1.16	620	38.10
440	2.30	630	26.50
450	3.80	640	17.50
460	6.00	650	10.70
470	9.10	660	6.10
480	13.90	670	3.20
490	20.80	680	1.70
500	32.30	690	0.82
510	50.30	700	0.41
520	71.00	710	0.21
530	86.20	720	0.10
540	95.40	730	0.05
550	99.50	740	0.02
555	100.00	750	0.01
560	99.50		

4.3.2. *illuminance (E)*—the ratio of the luminous flux to the area of the surface, when the latter is uniformly illuminated.

$$E = \frac{\varphi}{A} \qquad (2)$$

where:

φ = luminous flux (lumen), and

A = area of the surface.

4.3.2.1. *normal illuminance (E_n)*—normal illuminance is an expression used in the photometry of retroreflectors to designate the normal illuminance from the source on a retroreflective surface, and is measured in the plane which passes through the reference center and is perpendicular to the axis of incident light. In SI units, normal illuminance is measured in lux; in U.S. units, it is measured in foot-candles.

4.3.3. *inverse-square law*—the normal illuminance which a point-source produces at a point on a surface varies directly with the luminous intensity of the point source and inversely as the square of the distance between the source and that point, expressed as follows:

$$E_n = \frac{I}{D^2} \tag{3}$$

where:

I = luminous intensity.

4.3.4. *photoreceptor*—an instrument for measuring luminous flux.

4.3.4.1. *photometer*—a photoreceptor used for determining illuminance at a surface, and usually calibrated in units of foot-candles or lux.

4.3.4.2. *telephotometer*—a photoreceptor used for determining luminance at a distance or illuminance from a restricted field of view. The device is equipped with an objective lens that may be focused on a target.

4.3.5. *goniometer*—an instrument for measuring or setting angles.

5. QUANTITIES AND UNITS FOR RETROREFLECTIVE PHOTOMETRIC MEASUREMENTS

5.1. Photometric quantities used to specify the performance of retroreflective materials and devices are specific intensity (SI), specific luminance (SL), specific intensity per unit area (SIA), specific intensity per unit length (SIL), and luminance factor (LF).

5.1.1. *Specific Intensity (SI)*—The ratio of the luminous intensity of the retroreflector to the normal illuminance.

$$SI = \frac{E'\left(D'\right)^2}{E_n} \tag{4}$$

where:

E' = illuminance at the observation position, and

D' = distance between the center of the photoreceptor entrance aperture and the reference center.

Specific intensity is expressed in candelas per foot-candle (cd fc^{-1}).

Note 3—The CIE vocabulary defines the above relationship as the coefficient of luminous intensity (CIL), which is expressed in metric units of candelas per lux.

Note 4—The quantity SI is recommended for determining the performance of such retroreflectors as button reflectors, delineators, or automotive reflectors, since it depends on a unit device and the area need not be measured.

5.1.2. *Specific Luminance (SL)*—The ratio of the luminous intensity of the projected surface to the normal illuminance at the surface on a plane normal to the incident light. The ratio is expressed as follows:

$$SL = \frac{E'\left(D'\right)^2 \big/ \left(A \cos \in\right)}{E_n} = \frac{I' \big/ \left(A \cos \in\right)}{E_n} = \frac{SI}{A \cos \in} \tag{5}$$

where:

I' = $E'(D')^2$ = retroflective luminous intensity of the sample,

A = surface area of the sample, and

$\in$ = viewing angle.

Specific luminance is expressed in candelas per square meter per lux (candelas per square foot per foot-candle). Candela replaces the term candlepower. It is used in both SI and U.S. units.

Note 5—The CIE vocabulary defines this relationship as the coefficient of luminance, which is expressed in metric units of candelas per square meter per lux.

Note 6—The quantity SL treats the retroreflector as a surface source whose projected area is visible as an area at the observation position. The quantity SL relates to the way the effective retroreflective surface is focused on the retina of the human eye and to the visual effect thereby produced. It is recommended for describing the performance of highway signs and striping, or large vehicular markings, which are commonly viewed as discernible surface areas.

5.1.3. *Specific Intensity per Unit Area (SIA)*—The ratio of the luminous intensity of the surface to the normal illuminance and to the area of the retroreflective surface.

$$SIA = \frac{E'\left(D'\right)^2 / E_n}{A} \qquad (6)$$

Specific intensity per unit area is expressed in candelas per lux per square meter (candelas per foot-candle per square foot).

Note 7—The CIE vocabulary defines this relationship as the coefficient of luminous intensity (CIL) per unit area, which is expressed in SI units of candelas per lux per square meter.

Note 8—The quantity SIA treats the retroreflector as an apparent point source whose retroreflected luminous intensity is dependent on the area of the retroreflective surface involved. It is a useful engineering quantity for determining the photometric performance of such retroreflective surfaces as highway delineators or warning devices. SIA may also be used to determine the minimum area of retroreflective sheeting necessary for a desired level of photometric performance.

5.1.4. *Specific Intensity per Unit Length (SIL)*—The ratio of the luminous intensity of the sample to the normal illuminance and to the length of the retroreflective sample.

$$SIL = \frac{E'\left(D'\right)^2 / E_n}{L} \qquad (7)$$

where:

L = length of the sample.

Specific intensity per unit length is candelas per lux per meter (candelas per foot-candle per foot).

Note 9—The CIE vocabulary defines the above relationship as the coefficient of luminous intensity (CIL) per unit length, which is expressed in metric units of candelas per lux per meter.

5.1.5. *Luminance Factor (LF)*—The ratio of the luminance of the surface to that of a perfect diffusing surface such that:

$$LF = \frac{\pi E'\left(D'\right)^2}{A\ E_n \cos\beta \cos\in} = \frac{\pi\left(SIA\right)}{\cos\beta \cos\in} \qquad (8)$$

The luminance factor has no dimensions.

Note 10—In this formula, the dimensions associated with the reflectance of the perfect diffusing surface are the same as those of SIA, and are thus canceled.

6. REQUIREMENTS TO BE STATED IN SPECIFICATIONS

6.1. When stating photometric retroreflective requirements, the following shall be specified in the specification for the material.

6.1.1. The retroreflective photometric quantities to be measured, limited to the following: specific intensity (SI), specific luminance (SL), specific intensity per unit area (SIA), specific intensity per unit length (SIL), or luminance factor (LF).

6.1.2. The units (SI or English) in which each quantity is to be measured.

6.1.3. The minimum acceptable quantitative value.

6.1.4. The observation angle.

6.1.5. The entrance angle.

Note 11—When specifying an entrance angle near 0 degrees, care must be taken to prevent specular reflection from entering the photoreceptor. In this case, the entrance angle should be specified so that specular light will be reflected away from the photoreceptor.

6.1.6. The orientation angle and the 0 degree orientation of the datum mark shall be specific if random orientation of the sample is not suitable.

6.1.7. The presentation angle shall be specified if other than 0 degrees.

6.1.8. The minimum test distance between the sample and the photoreceptor.

6.1.9. Sample dimensions and shape.

6.1.10. The maximum photoreceptor angular aperture [the angle at the sample (δ' in Figure 3) subtended by the maximum dimension of this aperture]. The solid angle subtended by the photoreceptor aperture at the reference center shall be specified. This can be accomplished by specifying the photoreceptor dimensions and test distance, or the maximum receptor aperture angle (generally 6 minutes of arc).

Note 12—The maximum value of the angle at the sample subtended by the maximum aperture diameter of the photoreceptor should be specified in the material specification; it should be in the order of 6 minutes of arc. (See Figure 3.) However, the maximum diameter of both apertures varies with the test distance. Reading R_1 and R_2 must be made with the same apertures. (See Section 10.3.)

6.1.11. The maximum angular aperture of the light projector [the angle at the sample (δ' in Figure 3) subtended by the maximum dimension of this aperture]. The solid angle subtended by the light source aperture at the reference center shall be specified. This can be accomplished by specifying the source aperture dimensions and test distance or the maximum source aperture angle (generally 6 minutes of arc).

6.1.12. The reference center.

6.1.13. The reference axis.

Note 13—The reference axis usually is perpendicular to the surface of sheeting. In such complex devices as automobile or bicycle reflectors, the reference axis and reference center may be defined with respect to the viewing direction.

Note 14—When evaluation requirements are different from those stated in this standard, it is recommended that the variations be defined relative to the test conditions used in this standard.

7. APPARATUS

7.1. The apparatus shall consist of a photoreceptor, a light projector source, a goniometer sample holder, and a photometric range.

7.1.1. *Photoreceptor*—The photoreceptor shall be equipped with:

7.1.1.1. *CIE Standard Observer Filter*—A light filter to yield a response curve matching that of the CIE standard observer. (See Note 21.)

7.1.1.2. *Photoreceptor Stability and Linearity*—The stability and linearity of the photometric scale reading shall be within ±1 percent over the range to be measured.

7.1.1.3. *Light Filter Holder Attachment*—If the filter correction factor is to be used, the photoreceptor shall be equipped with an attachment to mount filters in a way which prevents inter-reflection between the filter and the photoreceptor.

7.1.1.4. *Angular Field Aperture*—If the photoreceptor is equipped with field apertures, a range of 2 minutes to 3 degrees is desirable. In any case, baffling shall be used to reduce the effect of stray light to a negligible factor. This is particularly important when a photometer-type instrument is used.

Note 15—Because retroreflective material specifications require various test distances that affect the actual field aperture, a selection of angular field apertures may be necessary. The field of view should be limited to the smallest aperture that includes the entire sample. (See Section 10.3.1.)

7.1.1.5. *Objective Lens*—If the photoreceptor is equipped with an objective lens, it shall focus at the test distance.

7.2. *Light Projector Source*—The light source shall be a lamp with appropriate reflector and lenses to provide normal illumination on the test sample with a spectral energy distribution conforming to the 1931 CIE Standard Source A (a tungsten filament lamp operated at a color temperature of 2583ºC (2856 K) (Table 2). The normal illuminance on the sample shall be uniform within 5 percent of the average normal illuminance over the area of the retroreflector at the test distance. The light projector shall be equipped with an adjustable iris diaphragm or a selection of fixed apertures. The intensity of light shall be regulated and shall not vary more than 1 percent for the duration of the test.

Table 2—Energy Distribution of CIE Source A (Section 13.2)

Wavelength (mm)	Relative Energy	Wavelength (mm)	Relative Energy
380	9.79	580	114.44
390	12.09	590	121.73
400	14.71	600	129.04
410	17.68	610	136.34
420	21.00	620	143.62
430	24.67	630	150.83
440	28.70	640	157.98
450	33.09	650	165.03
460	37.82	660	171.96
470	42.87	670	178.77
480	48.25	680	185.43
490	53.91	690	191.93
500	59.86	700	198.26
510	66.06	710	204.41
520	72.50	720	210.36
530	79.13	730	216.12
540	85.95	740	221.66
550	92.91	750	227.00
560	100.00	760	232.11
570	107.18		

Note 16—Many projection lamps are designed to operate at color temperatures higher than 2583ºC (2856 K). In such cases, the terminal voltage at the lamp shall be adjusted to provide the specified temperature.

Note 17—The maximum diameter of the projector exit aperture and the angle at the test sample, thus subtended, should not exceed that specified in Section 6.

7.3. *Goniometer Sample Holder*—The goniometer shall support the test sample so that the complement of the specified entrance angle does not change more than ±0.5 percent. (A simple goniometer can be constructed using a rotary milling table and an adjustable angle milling vise attached to the table platform.) The vertical angle of the goniometer shall be set perpendicular to the axis of incident light. The horizontal angle movement (the goniometer table) shall permit photometric measurements which require plus or minus angle settings.

7.4. *Photometric Range*—To minimize the effect of stray light, the background behind the sample shall be flat black. Light baffles shall be located, as necessary, between the projector and the sample. Goniometer parts, range wall, ceiling, and floor exposed to the light beam shall be painted flat black.

Note 18—The working distance should be sufficiently large so that the focusing or beam displacement properties of the retroreflective elements do not affect the readings. For most materials, 30 m (100 ft) is sufficient. This facilitates measurements which require an observation angle of 0.2 degrees. In Table 3, the lateral distance (*d*) (Section 4.2.13) is given for various distances and observation angles.

Table 3—Lateral Distance as a Function of Observation Angle and Observation Distance

Observation Angle (α), (degrees)	Observation Distance (D'), m (ft)	Lateral Distance (d), mm (in.)
0.2	15.2 (50)	53.1 (2.09)
0.33	15.2 (50)	87.9 (3.46)
0.5	15.2 (50)	133.1 (5.24)
1.33	15.2 (50)	353.8 (13.93)
2.0	15.2 (50)	532.1 (20.95)
8.0	15.2 (50)	2141.7 (84.32)
0.1	30.5 (100)	53.1 (2.09)
0.2	30.5 (100)	106.4 (4.19)
0.33	30.5 (100)	175.5 (6.91)
0.5	30.5 (100)	265.9 (10.47)
1.33	30.5 (100)	707.6 (27.86)
2.0	30.5 (100)	1064.3 (41.90)
8.0	30.5 (100)	4283.7 (168.65)

8. TEST SPECIMENS

8.1. When testing retroreflective devices, the test specimen shall consist of one entire retroreflector. A large retroreflector may be tested by summing the values obtained from segments of the device.

8.2. When testing retroreflective sheeting, it is recommended that the minimum test area be 0.09 ± 0.05 m^2 (1 ± 0.5 ft^2). This may be accomplished, for example, by measuring a single square test specimen 0.3 m (1 ft) on each side or by averaging the measurements over several representative pieces totaling 0.09 m^2 (1 ft^2) in area.

9. CALIBRATION

9.1. The following components required in this standard practice must be calibrated prior to use.

9.2. *Projector Source*—The source must be calibrated to a correlated color temperature of 2583ºC (2856 K) and loosely duplicate the spectral power distribution of CIE Standard Source A. A method of calibration is described in Appendix X1 based on tristimulus colorimetry. Spectroradiometric methods of calibration are also suitable. A tolerance of *fi*-248ºC (25 K) allows about 1.5 percent variation in test results of colored retroreflectors.

9.3. *Photoreceptor Spectral Response*—The photoreceptor spectral response must be verified in terms of the spectral power distributions measured in this method. A procedure for verification of spectral response is described in Appendix X3. Errors in the photopic fit of the receptor are direct systematic errors in the test result. A maximum variation of *fi* 2 percent relative to both illuminant *A* and the spectral power distribution of the retroreflector when illuminated by source *A* is recommended.

9.4. *Photoreceptor Linearity*—The procedures in this method require the measurement of both incident and reflected light levels which may be several orders of magnitude different in value. To insure accuracy, the photoreceptor and readout system must be linear or appropriate corrections for nonlinearity applied. Appendix X2 describes a method for verification of photoreceptor linearity.

9.5. *Goniometer Calibration*—The goniometer shall be calibrated at the 0 degree entrance angle position. All measurements shall be made relative to this point and shall be checked each time the goniometer or light projector is moved. If measurements are to be made at extreme angles of 75 degrees to near 90 degrees, it is recommended that the goniometer be calibrated at the 90 degrees entrance angle position for greatest accuracy. Calibration of the goniometer may be accomplished by several means. One example is by locating an approximately 300-mm (12-in.) square, high-quality, plane mirror in place of the sample. A 300-mm (12-in.) cross, centered on the surface of the mirror, can be made with photographic black tape. A 600-mm (24-in.) square piece of white construction paper, with a hole in the center, can be placed over the light projector exit aperture. By observing the white paper, the goniometer can be adjusted so that the shadow of the cross is reflected directly on the exit aperture of the projector. This horizontal position of the goniometer is the 0 degree entrance angle of the test sample.

10. TEST PROCEDURES

10.1. *General*—The geometry used to determine the performance of retroreflective materials shall be in accordance with Figures 1 and 2.

10.2. *Goniometer Calibration*—The goniometer shall be calibrated at the 0 degree entrance angle position in the vertical and horizontal planes of the test sample. All measurements shall be made relative to this point and shall be checked each time the goniometer or light projector is moved.

10.3. *Photometric Measurements*—In this method, the same instrument with the same apertures and field of view shall be used to measure $E\tau$ and E_n. Therefore, the photoreceptor need not be calibrated, and the uncalibrated readings of $E\tau$ and E_n are referred to as R_1 and R_2, respectively.

10.3.1. *Procedure I*—The smallest available field aperture large enough to include both the entire retroreflector as seen from the photoreceptor, and the source as viewed from the retroreflector shall be chosen for measurement of R_1 and R_2. The normal illuminance at the face of the sample shall be measured by substituting the photoreceptor for the sample. The photoreceptor entrance aperture shall be placed where the sample is mounted and R_2 shall be recorded. Then, the photoreceptor and the sample shall be returned to their original positions, and R_1 shall be recorded in the same units as R_2.

A measure of the amount of stray light shall be made by replacing the sample with a black surface of the same shape and area. The stray light readings, R_s, shall be subtracted from the reading R_1. The value R_1 in the following equations is the value of R_1 less the stray light reading R_s.

Note 19—To stabilize the instrument and improve the accuracy of the measurements, the photoreceptor must remain energized between measurement of R_2 and R_1.

Note 20—Color correction of the photoreceptor may be necessary because of deficiencies in the photoreceptor's CIE photopic standard observer filter. A correction factor K can be applied by means of a filter having a spectral transmittance proportional to the spectral retroreflectance of the sample. If close spectral matches in permanent filters are not available, it is recommended that the correction factor not be used. When the calibration factor is used, it is determined by the following relation:

$$K = R_2 T / R_f \qquad (9)$$

where:

K = correction factor;

R_2 = reading of the photoreceptor while measuring the normal illuminance at the face of the retroreflective sample (i.e., an uncalibrated E_n);

R_f = reading of the photoreceptor placed at the same position as for the R_2 reading, but with the addition of the color filter placed immediately in front of the acceptance aperture; and

T = known (total) luminance transmittance of the filter for a 2583ºC (2856 K) source (CIE Source A).

10.3.1.1. *Specific Intensity (SI)*:

$$SI = \frac{R_1 \left(D'\right)^2}{R_2} \qquad (10)$$

where:

R_1 = uncalibrated E' (Section 10.3).

The color corrected specific intensity is:

$$SI = \frac{K\ R_1 \left(D'\right)^2}{R_2} = \frac{R_1 \left(D'\right)^2 T}{R_f} \qquad (11)$$

10.3.1.2. *Specific Luminance (SL)*:

$$SL = \frac{R_1 \left(D'\right)^2}{R_2 A \cos \in} \qquad (12)$$

The color corrected specified luminance is:

$$SL = \frac{K\ R_1 \left(D'\right)^2}{R_2 A \cos \in} = \frac{R_1 \left(D'\right) T}{R_f A \cos \in} \qquad (13)$$

10.3.1.3. *Specific Intensity per Unit Area (SIA)*:

$$SIA = \frac{R_1 \left(D'\right)^2}{R_2 A} \qquad (14)$$

The color corrected intensity per unit area is:

$$SIA = \frac{K\ R_1 \left(D'\right)^2}{R_2 A} = \frac{R_1 \left(D'\right)^2 T}{R_f A} \qquad (15)$$

10.3.1.4. *Specific Intensity per Unit Length (SIL)*:

$$SIL = \frac{R_1 \left(D'\right)^2}{R_2\ L} \qquad (16)$$

The color corrected intensity per unit length is:

$$SIL = \frac{K\ R_1 \left(D'\right)^2}{R_2 L} = \frac{R_1 \left(D'\right)^2 T}{R_f L} \qquad (17)$$

10.3.1.5. *Luminance factor (LF)*:

$$LF = \frac{\pi R_1 \left(D'\right)^2}{R_2 A \cos\beta \cos\in} \qquad (18)$$

The color corrected luminance factor is:

$$\begin{aligned} LF &= \frac{\pi\ K\ R_1 \left(D'\right)^2}{R_2 A \cos\beta \cos\in} \\ &= \frac{\pi\ R_1 \left(D'\right)^2 T}{R_f A \cos\beta \cos\in} \end{aligned} \qquad (19)$$

10.3.2. *Procedure II*—This procedure shall be used to determine the performance of a material or a device, using a working standard similar to the material or device being tested. The performance value of the working standard shall be determined in accordance with Procedure I. For each test condition, the values to be used for each of the geometric terms in Section 4.2 shall be defined. The photometric performance values [specific intensity (SI), specific luminance (SL), specific intensity per unit area (SIA), specific intensity per unit length (SIL), or the luminance factor (LF)] shall be assigned to the working standard. Photometric performance of the sample shall be determined by comparison of the sample to the working standard. These comparative measurements shall be accomplished by following Procedure I, except that the working standard shall be placed on the goniometer and reading $R_{1\text{std}}$ shall be taken. The standard shall then be replaced with the sample, and reading $R_{1\text{test}}$ shall be taken.

Note 21—Procedure II offers many advantages where a large number of performance measurements on similar samples are to be determined. However, the working standard and the sample must be similar in size, color, and performance value. Also, periodic recalibration of the working standard is required to compensate for aging. The photoreceptor must be corrected to the photopic standard observer, but does not require the color correction factor *K*, since the standard and the sample are similar in color. (See Note 20.) Optical means to shorten the photometric range, such as high quality mirrors, are allowable under Procedure II.

10.3.2.1. *Specific Intensity (SI)*:

$$SI = \frac{R_{1\text{test}}}{R_{1\text{std}}}\left(SI_{\text{std}}\right) \qquad (20)$$

10.3.2.2. *Specific Luminance (SL)*:

$$SL = \frac{A_{\text{std}} R_{1\text{test}}}{A_{\text{test}} R_{1\text{std}}}\left(SL_{\text{std}}\right) \qquad (21)$$

10.3.2.3. *Specific Intensity per Unit Area (SIA)*:

$$SIA = \frac{A_{\text{std}} R_{1\text{test}}}{A_{\text{test}} R_{1\text{std}}}\left(SIA_{\text{std}}\right) \qquad (22)$$

10.3.2.4. *Specific Intensity per Unit Length (SIL)*:

$$SIL = \frac{L_{\text{std}} R_{1\text{test}}}{L_{\text{test}} R_{1\text{std}}}\left(SIL_{\text{std}}\right) \qquad (23)$$

10.3.2.5. *Luminance Factor (LF)*:

$$LF = \frac{A_{\text{std}} R_{1\text{test}}}{A_{\text{test}} R_{1\text{std}}}\left(LF_{\text{std}}\right) \qquad (24)$$

where:

$R_{1\text{std}}$ = uncalibrated illuminance of the working standard at the aperture, measured in accordance with Procedure I;

$R_{1\text{test}}$ = uncalibrated illuminance of the sample at the photoreceptor aperture, measured in accordance with Procedure I;

SI_{std} = specific intensity determined by Procedure I (relative to a fixed set of test conditions) and assigned to the working standard;

SIA_{std} = specific intensity per unit area determined by Procedure I (relative to a fixed set of test conditions) and assigned to the working standard;

SIL_{std} = specific intensity per unit length determined by Procedure I (relative to a fixed set of test conditions) and assigned to the working standard;

SL_{std} = specific luminance per projected area determined by Procedure I (relative to a fixed set of test conditions) and assigned to the working standard;

LF_{std} = luminance factor determined by Procedure I (relative to a fixed set of test conditions) and assigned to the working standard;

A_{std} = retroreflective area of the working standard;

A_{test} = retroreflective area of the sample;

L_{std} = length of the working standard; and

L_{test} = length of the sample.

11. REPORT

11.1. The report shall indicate the value of the photometric quantity determined, the procedure used (I or II), and all of the measurement requirements stated in Section 6 of this method.

12. PRECISION AND ACCURACY

12.1. The precision and accuracy of this method will vary with the materials tested and the test geometry and, therefore, a specific statement is not included. In general, however, under some test geometries (0.2° observation angle and –4° entrance angle) agreement between laboratories in the order of 5 to 10 percent (standard deviation) has been reported (Section 13.4).

13. REFERENCES

13.1. *International Lighting Vocabulary.* [CIE Publication 17 (E-1.1)] Available from the National Bureau of Standards (Code 232.14), Gaithersburg, MD 20899.

13.2. Kaufman, J. E., ed. *IES Lighting Handbook*, Fifth Edition. Illuminating Engineering Society, 345 East 47th Street, New York, NY 10017, 1972, *pp*. 1–19.

13.3. Mineroff, I., and W. A. Hall. *Instrumental Colorimetry of Retroreflective Sign Materials*. (Report No. FHWA-RD-75-4). National Technical Information Service, Springfield, VA 22161, 1975.

13.4. MCCA Collaborative Reference Program, B360 Polymer Building, National Bureau of Standards, Gaithersburg, MD 20899.

APPENDIX

(Nonmandatory Information)

X1. DETERMINING CORRELATED COLOR TEMPERATURE

X1.1. *Scope*:

X1.1.1. Procedure for determination of correlated color temperature of a projector source of illumination using a tristimulus photoreceptor and standard reference lamp for use in the photometry of retroreflectors.

X1.2. *Apparatus*:

X1.2.1. Standard reference lamp and holder with voltage and current specified for 2856 K.

X1.2.2. Voltmeter (accurate to 0.5 percent) or ammeter (accurate to 0.25 percent), as appropriate to voltages or currents specified for standard reference lamp.

X1.2.3. Photoreceptor equipped with tristimulus filters (X_r, X_b, Y, and Z filters).

X1.2.4. MgO, $BaSO_4$, or other neutral white diffusing surface.

X1.2.5. Test enclosure or photometric range.

X1.3. *Procedure*:

X1.3.1. Set up standard reference lamp, projector to be calibrated, white diffusing surface and tristimulus receptor in a darkroom as shown in Figure X1.1.

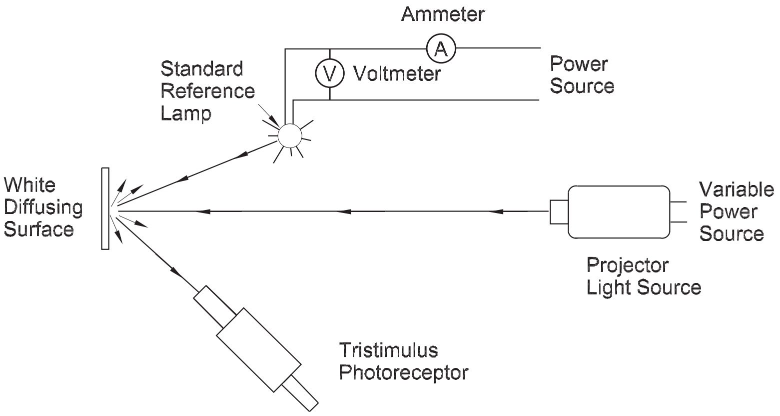


Figure X1.1—Arrangement of Apparatus for Correlated Temperature Measurement of Projector

X1.3.2. Adjust the position (distance between source and diffusing surface) of the standard lamp and projector so that the illumination of each individually on the white diffusing surface is about the same. Allow lamps to warm up until stable (usually about 30 minutes).

X1.3.3. Allow standard lamp only to illuminate white diffusing surface. Carefully adjust the voltage or current as specified on calibration report for the standard reference lamp to obtain 2583ºC (2856 K).

X1.3.4. Measure the relative X_r, X_b, Y, and Z tristimulus filter readings with the tristimulus photoreceptor.

X1.3.5. Turn off the standard lamp and turn on the projector. Measure and record the X_r, X_b, Y, and Z tristimulus values at several voltages bracketing the estimated correct setting for 2583ºC (2856 K).

X1.3.6. Calculate the CIE chromaticity coordinates for each voltage on the projector using the tristimulus readings of the standard lamp as a reference. That is, for 2583ºC (2856 K) the correct tristimulus values are:

- $X_r = 104.4$
- $X_b = 5.38$
- $Y = 100$
- $Z = 35.55$

Thus, each of the "as read" values on the projector must be corrected to the reference standard as follows:

$$X_r\ (\text{corrected}) = X_r\ (\text{as read}) \times \frac{104.4}{X_r\ (\text{as read std. lamp})} \tag{X1.1}$$

$$X_b\ (\text{corrected}) = X_b\ (\text{as read}) \times \frac{5.38}{X_b\ (\text{as read std. lamp})} \tag{X1.2}$$

$$Y\ (\text{corrected}) = Y\ (\text{as read}) \times \frac{100}{Y\ (\text{as read std. lamp})} \tag{X1.3}$$

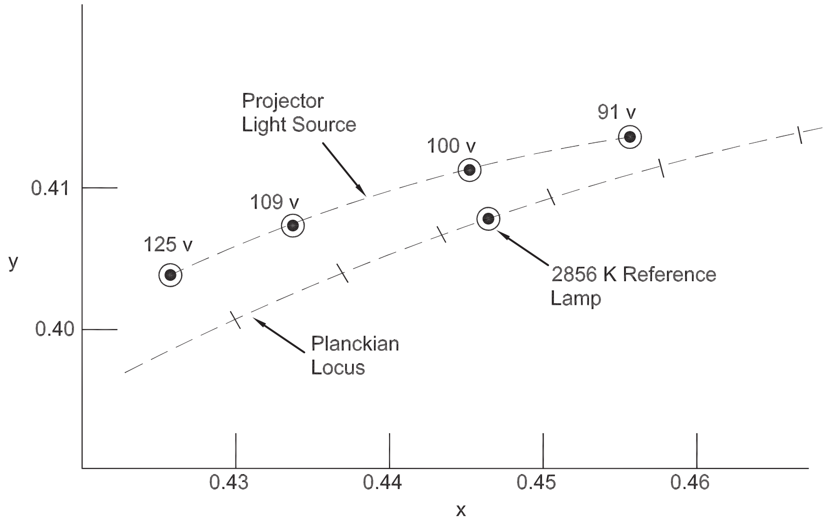
$$Z\ (\text{corrected}) = Z\ (\text{as read}) \times \frac{35.5}{Z\ (\text{as read std. lamp})} \tag{X1.4}$$

X1.3.7. Then the small x, small y chromaticity coordinates are calculated.

$$x = \frac{X_r + X_b}{X_r + X_b + Y + Z} \tag{X1.5}$$

$$y = \frac{Y}{X_r + X_b + Y + Z} \tag{X1.6}$$

X1.3.8. Finally, the chromaticity coordinates are plotted on graph paper and the nearest point of 2856 K is selected as the best voltage to operate the projector for CIE Source A. See Figure X1.2.



Note: 100 volts would be the proper voltage at which to operate the projector source.

Figure X1.2—Chromaticity Plot Projector Light Source Relative to 2856 K Reference Lamp

X1.4. *References*:

X1.5. Judd, D. B. Changes in Color Temperature of Tungsten-Filament Lamps at Constant Voltage. *J. Opt. Soc. Am.* 26, 1936, *pp*. 409–420.

X1.6. Kelly, K. L. Lines of Constant Correlated Color Temperature Based on MacAdam's (u,v) Uniform Chromaticity Transformation of the CIE Diagram. *J. Opt. Soc. Am.* 53, 1963, *pp*. 999–1002.

X2. DETERMINING PHOTORECEPTOR LINEARITY

X2.1. *Scope*:

X2.1.1. Determination of Photoreceptor Linearity Corrections for use in the Photometry of Retroreflectors.

X2.2. *Equipment*:

X2.2.1. Two-projector sources of illumination.

X2.2.2. Two adjustable irises and holders.

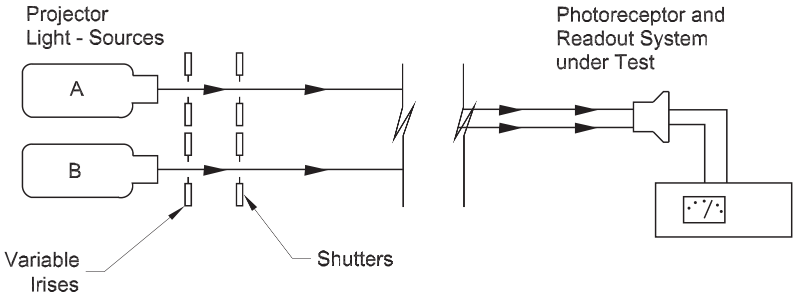
X2.2.3. Two shutters and holders.

X2.2.4. Enclosure or photometric range (large enough so that photoreceptor can be illuminated approximately perpendicularly from both light sources).

X2.3. *Procedure:*

X2.3.1. *Test Method*:

X2.3.1.1. Set up the two light sources, irises, shutters, and photoreceptor/readout system to be calibrated as shown in Figure X2.1. The light sources should be arranged such that the illumination from each source is perpendicular (±*fi*1º) to the entrance aperture of the photoreceptor. The light sources must be stabilized, and their voltages or currents monitored.



DATA SHEET FOR
PHOTO RECEIVER LINEARITY TEST

1 READING SOURCE A ONLY	**2 READING SOURCE B ONLY**	**3 READING SOURCE A & B ONLY**	**4 CALCULATED SUM A & B**	**5 RATIO 3 ÷ 4**	**6 CUMULATIVE RATIO**	**7 NORMALIZED CELL LINEARITY CORRECTION**

Figure X2.1—Arrangement of Apparatus for Two-Source Linearity Test

X2.3.1.2. Determine the lowest reading attainable on the photoreceptor/readout device (for example 0.000001 units). This will be the starting illumination level for the test.

X2.3.1.3. With both shutters closed, set the photoreceptor/readout device to read zero.

X2.3.1.4. Open the shutter on Source A and adjust the iris for the starting reading determined in Section X2.3.1.2 above. Close the shutter on Source A and open the shutter on Source B and adjust the iris for the same reading. Record these readings in Columns 1 and 2 of the data sheet. (Note: Switch back and forth between the two sources and the zero readings to be sure irises and zero are accurately set.)

X2.3.1.5. Now open both shutters simultaneously. Record the reading in Column 3 of the data sheet.

X2.3.1.6. Next, independently adjust each projector to combined reading obtained in Section X2.3.1.5. Record the individual readings in Columns 1 and 2 on the next line of the data sheet.

X2.3.1.7. Repeat Section X2.3.1.5 for the new illumination levels set in Section X2.3.1.6, and record the total in Column 3 of the data sheet.

X2.3.1.8. Repeat Sections X2.3.1.4, 5, and 6 until the maximum illumination levels available for the two light sources are reached.

X2.3.1.9. Starting with a new data sheet, repeat Sections X2.3.1.2 through 8 except use starting with illuminations 12, 14, 16, and 18 times the lowest illumination detectable with the photoreceptor/readout system.

X2.3.2. *Calculations*:

X2.3.2.1. Add each reading in Column 1 to the reading in Column 2 to determine the result expected if the system is linear. Enter this mathematical sum in Column 4.

X2.3.2.2. Determine the ratio of the theoretical result to the actual result by dividing the individual readings in Column 3 by the individual readings in Column 4 and enter in Column 5.

X2.3.2.3. Determine the cumulative nonlinearity by multiplying the proportion in Column 5 times the previous cumulative result in Column 4 and enter in Column 6.

X2.3.2.4. Repeat the above calculations for all data points taken.

X2.3.2.5. Now interpolate between reading the Column 3 and Column 6 to determine the correction factor for a readout response in the middle of the range (for example, 0.001 units) to use as a reference point. Divide all the values in Column 6 by this result and enter in Column 7.

X2.3.2.6. The result in Column 7 is the normalized correction factor computed about the midrange reference point (e.g., 0.001 units). Note: The correction factors are normalized in this way so that all will be on the same basis for averaging below.

X2.3.2.7. Repeat the calculations in Sections X2.3.2.1 through X2.3.2.6 for remaining data sheets.

X2.3.2.8. Finally, determine the correction factors at log equal spacing throughout the range of calibration by interpolation.

X2.3.2.9. Average these factors to determine the best linearity correction curve.

X2.3.2.10. These final values may be used to plot a linearity correction curve on semilog paper for manual correction or entered into a computer program for automatic correction of photometric test data for linearity.

X2.3.2.11. Linearity correction of data taken in the photometric test of a retroreflector is then obtained by dividing the "as read" value from the readout device by the correction factor obtained from the linearity correction curve just plotted.

X3. VERIFYING PHOTOPIC RESPONSIVITY

X3.1. *Scope*:

X3.1.1. This Appendix describes a procedure for verifying the adequacy of the spectral response of the photoreceptor used in the photometry of retroreflectors. Adequate color correction for one product does not necessarily imply adequate correction of other products. Color correction for whites and greens is much easier to obtain than for deep blues and highly saturated reds.

X3.2. *Introduction*:

X3.2.1. A method of determining the adequacy of the photopic match of the photoreceptor and the possible need for correction is to compare the photoreceptor responsivity to the retroreflected spectral curve. The spectroradiometric test in Section X3.3 provides an outline of this method. In many cases where facilities to actually make these spectroradiometric measurements are unavailable, the spectral responsivity and spectral reflectance factors can be obtained directly from the manufacturer of the photoreceptor and the manufacturer of the retroreflector.

X3.2.2. The use of the color correction factor *K* generated by using a colored filter with spectral transmittance matching the retroreflected spectrum is a suitable method of compensating for errors in the spectral responsivity of the photoreceptor. This method is described in Note 21 of the main document. The "Caution" paragraphs should be carefully followed if they apply.

X3.3. *Spectroradiometric Test Method*:

X3.3.1. *Determination of the Spectral Responsivity of a Photoreceptor*:

X3.3.1.1. Set up a regulated tungsten light source, a monochromator for the visible spectrum to negligible levels.

X3.3.1.2. Using either a thermopile reference receiver with a flat responsivity with respect to wavelength or a calibrated silicon detector, calibrate the monochromator and source through the visible spectrum at 10-nm intervals and as far into the UV and IR as necessary to cover the photoreceptor responsivity.

X3.3.1.3. Now replace the calibrated reference receivers with the photoreceptor to be used in the testing of the retroreflector. Measure and compute the responsivity of the photoreceptor at 10-nm intervals.

X3.3.1.4. Taking the response of the thermopile equal to 100 at each wavelength, tabulate the relative responsivity [$R(\lambda)$] of the photoreceptor at 10-nm intervals.

X3.3.1.5. Normalize the response of the photoreceptor at each wavelength so that the summation $\Sigma R(\lambda) = \Sigma V(\lambda)$, where $V(\lambda)$ is the CIE Standard Luminosity Curve (obtainable from standard reference texts on photometry and ASTM E 308).

X3.3.2. *Determination of the Retroflected Spectrum of the Retroflector*:

X3.3.2.1. Set up the apparatus used to test the retroreflector as described in the geometry section of the photometric test method, except substitute a spectroradiometer for the photoreceptor.

X3.3.2.2. Now tabulate the intensity of the retroreflected light [W(λ)] at 10-nm intervals using the spectroradiometer.

X3.3.3. *Calculation of Error in Integrated Response of Photoreceptor*:

X3.3.3.1. Calculate the percent difference between the integrated response of the photoreceptor and that of the standard luminosity curve times the retroreflected spectrum of retroreflector for Source A using the following equation:

Percent error:

$$100 \times \frac{\sum\left[V(\lambda)-R(\lambda)\right]\cdot W(\lambda)}{\sum V(\lambda)\cdot W(\lambda)} \qquad \textit{(X3.1)}$$

Perform this summation at 10-nm intervals over the visible spectrum and as far into the IR or UV as any appreciable response was detected.

X3.3.3.2. The "percent error" for the above equation is direct systematic error in the photometric test of the retroreflector for which the calculation is made.

X3.3.3.3. If the error is more than 2 percent, a suitable correction factor must be applied to the reading for that particular product color.

Standard Method of Test for

Sampling and Testing Calcium Chloride for Roads and Structural Applications

AASHTO Designation: T 143-04 (2009)
ASTM Designation: D 345-02

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling and Testing Calcium Chloride for Roads and Structural Applications

AASHTO Designation: T 143-04 (2009)
ASTM Designation: D 345-02

AASHTO T 143-04 is identical to ASTM D 345-02 except for the following provisions:

1. All references to ASTM Standards C 136 and D 98 shall be replaced with AASHTO Standards T 27 and M 144, respectively.
2. Replace Section 5 of ASTM D 345-02 with the following:

   5. Sampling

   5.1 *Solid*—Sample a shipment of the solid form calcium chloride for test purposes by selecting not less than three containers at random from the shipment. Sample each of the containers by scraping aside the top layer to a depth of approximately 25 mm (1 in.) and taking 0.5-kg (1-lb) samples by means of a sampling thief or other method that will ensure a sample that is representative of a cross section of the material in the container to a depth of at least 152 mm (6 in.). Take precautions during the sampling operation to avoid exposing the sample unduly to atmospheric moisture. Immediately and thoroughly mix the individual samples to form a representative composite sample of material and store in a sealed glass or suitable plastic container.

   5.2 *Liquid*—Sample a shipment of liquid form calcium chloride for testing purposes by selecting not less than three samples from each container of the shipment by means of an appropriate sampling device or other method that will ensure a sample that is representative of the contents of the container. Take precautions during the sampling operation to avoid exposing the sample unduly to atmospheric moisture. Immediately and thoroughly mix the individual samples to form a representative composite sample of material and store in a sealed glass or suitable plastic container.
3. Section X1.2.2 of ASTM D 345-02 is not included in AASHTO T 143-04.
4. Replace the first two sentences of Section X1.5.1 of ASTM 345-02 with the following sentence:

   In a weighing bottle, weigh a sample of approximately 20 g to the nearest 0.1 g and dissolve in distilled water.

Standard Method of Test for

Testing Epoxy Resin Adhesive

AASHTO Designation: T 237-05 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Testing Epoxy Resin Adhesive

AASHTO Designation: T 237-05 (2009)

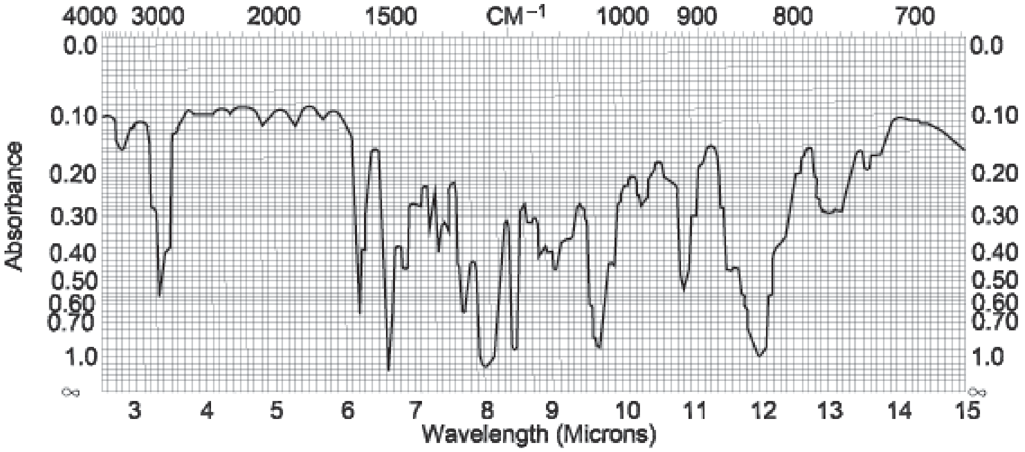
1. SCOPE

1.1. The methods given cover the examination of epoxy resin adhesives for use in bonding traffic markers to pavements, cured concrete to cured concrete, fresh concrete to cured concrete, and are divided into two parts:

1.2. Part I (Sections 3 through 25) covers AASHTO M 235M/M 235, Class I and II, and AASHTO M 237, Class I adhesives. (See Figure 1.)

1.3. Part II (Sections 26 through 35) covers AASHTO M 235M/M 235, Class III and AASHTO M 237, Class II adhesives. (See Figure 1.)

1.4. The values stated in SI units are to be regarded as the standard.



A Component

Epoxy adhesive for bonding traffic markers to cured concrete, AASHTO M 237 - Class I

Epoxy adhesive for bonding cured to cured concrete, AASHTO M 235 - Class II

Epoxy adhesive for bonding fresh to cured concrete, AASHTO M 235 - Class I

Figure 1—Epoxy Adhesive for Bonding Traffic Markers to Cured Concrete

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 6, Fine Aggregate for Hydraulic Cement Concrete
- M 85, Portland Cement
- M 235M/M 235, Epoxy Resin Adhesives
- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortar (Using 50-mm or 2-in. Cube Specimens)
- T 132, Tensile Strength of Hydraulic Cement Mortars

2.2. *ASTM Standards*:

- C 778, Standard Specification for Standard Sand
- D 570, Standard Test Method for Water Absorption of Plastics
- D 1002, Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)
- D 1084, Standard Test Methods for Viscosity of Adhesives

2.3. *Federal Standards*:

- Fed. Std. No. 141, Paint, Varnish, Lacquer, and Related Materials: Methods of Inspection, Sampling and Testing, Method 4184 Percent Air, Method 4242 Color of Transparent Liquids (Hellige Scale)

PART I

3. GEL TIME—APPARATUS AND MATERIALS

3.1. Gel Timer.

3.2. Disposable wire stirrers.

3.3. Unwaxed paper cups, 60 mL (2 oz), 38-mm (1-$^1/_2$ in.) diameter base.

3.4. Unwaxed paper cups, 240 mL (8 oz), 76-mm (3-in.) diameter base.

3.5. Stainless Steel Spatula with blade 150 × 25 mm (6 × 1 in.), and with end cut square.

3.6. Stop watch.

Note 1—Equipment available from: SHYODU Gel Timer Model 100, SHYODU Instrument Company, 6351 Old Tipton Road, Millington, TN 38053, Telephone (901) 872-6894, Facsimile (901) 872-6868.

4. GEL TIME—PROCEDURE

4.1. Condition both A and B components to 25 ± 1°C (77 ± 2°F).

4.2. Stir the separate components vigorously with a spatula to redisperse any settled material. Use separate spatula for each component.

4.3. Using the 60-mL cups, prepare 100 g of epoxy adhesive by measuring each component in the proper ratio into a 240-mL paper cup.

4.4. Start stopwatch immediately and mix the components for 60 seconds using a spatula and taking care to scrape the sides and bottom of the cup periodically.

4.5. Place the sample at 25 ± 1°C (77 ± 2°F) in a retaining ring on the gel timer.

4.6. Insert wire stirrer into the sample and attach to the gel timer. Check to insure the stirrer does not touch the side or bottom of the cup.

4.7. Zero the gel timer.

4.8. Start the gel timer.

4.9. Stop the stopwatch and record the initial mixing time.

4.10. Record the time from the gel timer when it stops.

4.11. The gel time is the initial time of mixing plus the elapsed time recorded by the gel timer.

5. POT LIFE (OPTIONAL PROCEDURE)—APPARATUS AND MATERIALS

5.1. Unwaxed paper cups, 240 mL (8 oz), 50 ± 6-mm (2 ± $^1/_4$-in.) diameter base.

5.2. Unwaxed paper cups, 60 mL (2 oz), 38-mm ($1^1/_2$-in.) diameter base.

5.3. Wooden tongue depressor with ends cut square.

5.4. Stainless steel spatula with blade 150 × 25 mm (6 × 1 in.), and with the end cut square.

6. POT LIFE (OPTIONAL PROCEDURE)—PROCEDURE

6.1. Condition both A and B components to 25 ± 1°C (77 ± 2°F).

6.2. Stir the separate components vigorously with a spatula to redisperse any settled materials. Use separate spatula for each component.

6.3. Using the 60-mL cups, measure each component, in the proper ratio, into the 240-mL cup.

6.4. Start stopwatch immediately and mix the components for 60 seconds using a wooden tongue depressor and taking care to scrape the sides and bottom of the cup periodically.

6.5. Place the sample at 25 ± 1°C (77 ± 2°F) on a wooden bench top that is free of excessive drafts.

6.6. Probe the mixture once with the tongue depressor every 30 seconds, starting 5 minutes prior to the minimum specified pot life.

6.7. The time at which a soft stringy mass forms in the center of the cup is the pot life.

INFRARED SPECTRUM

7. APPARATUS

7.1. Double-beam infrared recording spectrophotometer,[1] 2.5 microns to 15 microns.

7.2. Disk holder for a disk approximately 25 mm in diameter.

7.3. Two sodium chloride crystal disks approximately 25 mm in diameter.

7.4. Superspeed centrifuge able to separate the liquid and solid phases of the adhesive components without previous dilution with solvents.[2]

8. PROCEDURE

8.1. Place about 15 g of Component A into a stainless steel centrifugal tube.

8.2. Counterbalance with Component B in a second centrifuge tube.

8.3. Centrifuge the two components until there is a supernatant liquid layer present in each tube. This takes 20 to 30 minutes at 17 000 r/min.

8.4. Place a drop of Component A liquid layer on a sodium chloride disk.

8.4.1. Place another sodium chloride disk over the drop, rotate and press down until the liquid has flowed into a uniform layer of proper thickness between the two sodium chloride disks.

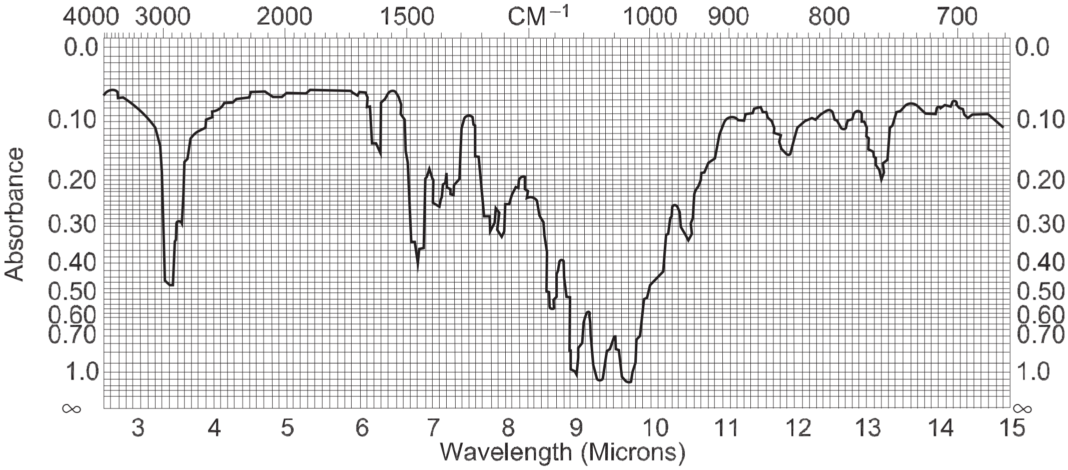
8.4.2. Place the disks in the holder and run an absorption curve with the infrared spectrophotometer.

8.4.2.1. More or less liquid may be used between the disks so as to produce a maximum absorption of 0.7 to 1.0 for the strongest absorption point on the curve.

8.4.3. Clean the disks with toluene and dry.

8.4.4. Repeat steps in Sections 8.4 through 8.4.3 with the liquid layer from Component B.

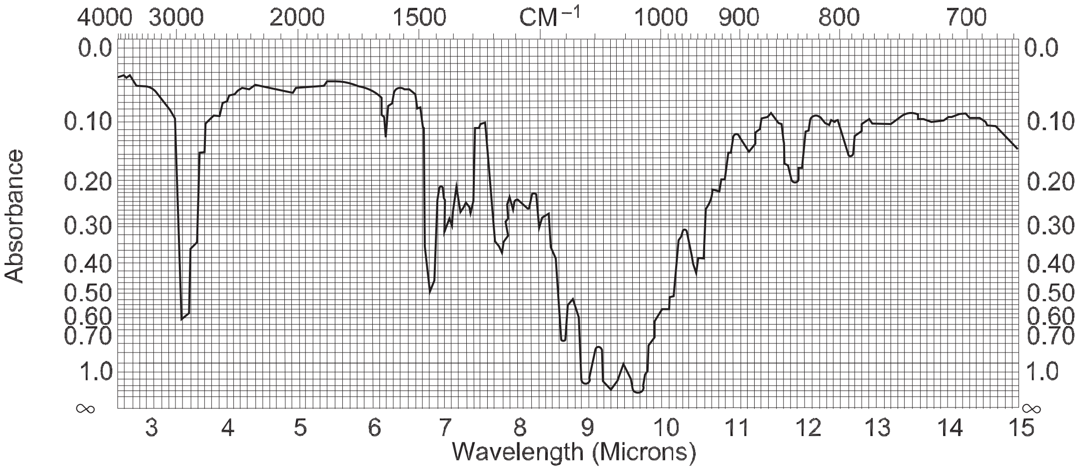
8.5. Compare each curve with the appended absorption curves for standard materials. Two materials are considered to be identical if all of the absorption points agree as to wave length and relative magnitude of the peaks in comparison with the other points of absorption. (See Figures 2a, 2b, and 2c.)



B Component

Epoxy adhesive for bonding fresh to cured
concrete, AASHTO M 235 - Class I

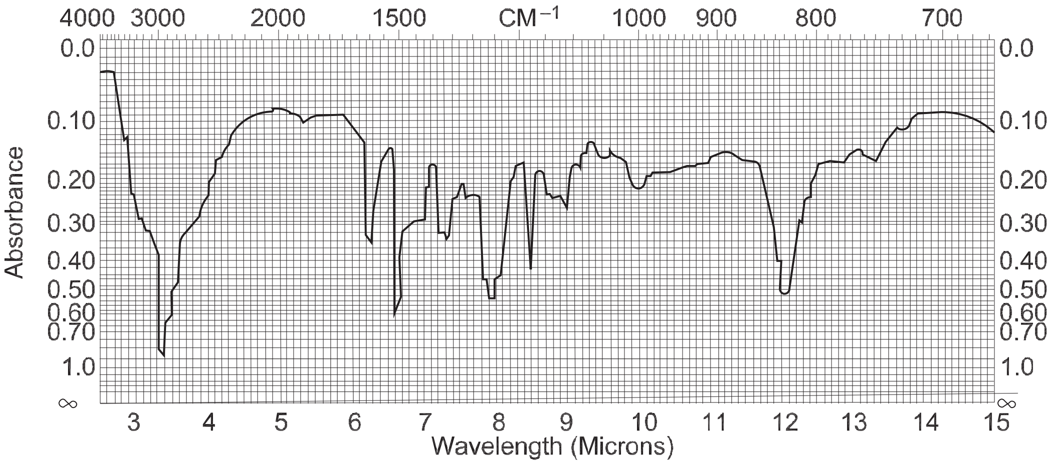
Figure 2a—Epoxy Adhesive for Bonding Fresh to Cured Concrete



B Component

Epoxy adhesive for bonding cured to
cured concrete, AASHTO M 235 - Class II

Figure 2b—Epoxy Adhesive for Bonding Cured to Cured Concrete



B Component

Epoxy adhesive for bonding traffic markers to
cured concrete, AASHTO M 237 - Class I

Figure 2c—Epoxy Adhesive for Bonding Traffic Markers to Cured Concrete

DENSITY

9. APPARATUS AND PROCEDURE

9.1. Follow Federal Standard No. 141, Method 4184.

BROOKFIELD VISCOSITY

10. APPARATUS AND MATERIALS

10.1. Brookfield Syncro-Electric Viscometer, Model RVT, Brookfield Engineering Laboratories, Stroughton, Massachusetts.

10.2. Brookfield Helipath Stand, Model C, with TD spindle and spindle weight.

10.3. Round 475-mL (1-pt) paint cans.

10.4. Stainless steel spatula having a blade 150 by 25 mm (6 by 1 in.) with the end cut square.

11. PROCEDURE

11.1. Fill a 475-mL (1-pt) can within 25 mm (1 in.) of the top with well-mixed Component A.

11.2. Condition the material to 25°C (77°F).

11.3. Stir the material vigorously for 30 seconds with a spatula.

11.4. Remove entrained air bubbles by vigorous tapping.

11.5. Insert the spindle and make a viscosity reading at 5 r/min within 10 minutes after stirring.

11.5.1. Make additional readings at 2.5 r/min and 0.5 r/min for use in the Shear Ratio Test (Sections 23 through 25).

11.6. Repeat to determine viscosity of Component B.

12. CALCULATION

12.1. Follow manufacturer's instructions for calculating Brookfield Viscosity.

SAG TEST

13. APPARATUS AND MATERIALS

13.1. Stiff glazed paper 254 by 139 mm (10 by $5^1/_2$ in.).[3]

13.2. Clipboard.

13.3. Metal shims 0.76 ± 0.03 mm (0.030 ± 0.001 in.) thick approximately 25 mm by 250 mm (1 by 10 in.).

13.4. Doctor blade.

14. PROCEDURE

14.1. Place the paper on the clipboard with glazed surface up.

14.2. Place two pieces of metal shim stock on top of the glazed paper to produce a space 230 mm (9 in.) long by 64 mm ($2^1/_2$ in.) wide. Use the clip to hold the shim stock and chart in place.

14.3. Condition both A and B components to 25°C (77°F).

14.4. Stir the components vigorously for 30 seconds with a spatula.

14.5. Mix for 30 seconds sufficient material in the specified ratio of Component A to Component B and immediately apply the mixed material to the glazed paper between the shim material.

14.6. Draw the doctor blade over the surface to produce a film 64 mm ($2^1/_2$ in.) wide by 152 mm (6 in.) long, 0.76 ± 0.10 mm (0.03 ± 0.004 in.) thick.

14.7. Release the clip and carefully remove the shims by lifting them upward while holding the glazed paper down.

14.8. Support the paper vertically with the 152-mm (6-in.) side of the strip in a horizontal position.

14.9. After 30 minutes, record the sag to the nearest 2.5 mm (0.1 in.).

BOND STRENGTH TO CONCRETE

15. APPARATUS AND MATERIALS

15.1. Stopwatch, 1 second or smaller divisions.

15.2. A sandblasted, 50-mm (2-in.) diameter steel or aluminum plug approximately 50 mm (2 in.) long, drilled, and threaded on one end to accept a threaded steel rod or hook for insertion into the testing press or apparatus.[4]

15.3. A sandblasted concrete block 305 mm (12 in.) square by 75 mm (3 in.) thick, prepared with 390 kg/m^3 (7 sack) concrete and having a tensile strength in excess of 1725 kPa (250 psi).

15.4. Testing press operating at a load rate of 22.2 kN/min (5000 lbf/min). Alternately, a maximum indicating dynamometer fitted with 25-mm (1-in.) eyes and mounted in a housing allowing application of an upward vertical pull may be used.

16. PROCEDURE

16.1. Condition the test equipment, materials and epoxy components for 24 hours at the testing temperature specified.

16.2. Stir the separate components vigorously for 30 seconds.

16.3. Measure the components in the proper ratio onto a tin plate and mix with a spatula for 60 ± 5 seconds.

16.4. Place the adhesive on the sandblasted surface of the plug and concrete surface.

16.5. Press the plug firmly in place and remove the excess adhesive.

16.6. Just before the required test time, insert the threaded rod or hook into the plug.

16.7. Apply loading at the specified rate until failure and record the maximum load attained before failure.

16.8. Calculate the bond strength to concrete attained before failure as follows:

$$\text{Bond Strength, kPa (psi)} = \frac{TL}{A} \qquad (1)$$

where:

TL = total load N (lbf), and

A = area of bond m^2 (in.^{2}).

TENSILE ADHESION AND COHESION

17. APPARATUS AND MATERIALS

17.1. Use the testing apparatus described in Section 15.

17.2. Cold box capable of maintaining –9.5 ± 1.0°C (15 ± 2°F).

17.3. Oven capable of maintaining 60 ± 1°C (140 ± 2°F).

17.4. As specimens, use pavement markers representative of those intended for installation.

18. PROCEDURE

18.1. Stir the separate components vigorously for 30 seconds.

18.2. Measure the components in the proper ratio onto a tin plate and mix with a trowel or spatula for 60 ± 5 seconds.

18.3. Place the adhesive on the plug and the marker surface.

18.4. Press the plug firmly in place and remove excess adhesive.

18.5. Cure all specimens for 24 hours at 25 ± 1°C (77 ± 2°F).

18.6. Proceed according to Sections 16.6 to 16.8.

18.7. Post cure at least one of the specimens further as follows:

18.7.1. Cure 48 hours at 60°C (140°F);

18.7.2. Return to 25°C, and then place in cold box for 24 hours at –9.5°C (15°F); and

18.7.3. Return to 25°C, and test as in Section 18.6.

SLANT SHEAR STRENGTH

19. MATERIALS

19.1. Graded standard (Ottawa) sand conforming to AASHTO T 106M/T 106, Section 6, “Materials,” and ASTM C 778.

19.2. Type II portland cement conforming to AASHTO M 85.

19.3. Water.

20. APPARATUS

20.1. Suitable mold to make diagonal concrete mortar blocks with a square base with 50.8-mm (2-in.) sides and having one diagonal face 50.8 by 101.6 mm (2 in. by 4 in.) standing about 19 mm ($^3/_4$ in.) above the base. After sandblasting, the diagonal faces of two such blocks are bonded together, producing a block 50.8 by 50.8 by 127 mm (2 in. by 2 in. by 5 in.).

20.2. Test blocks are made from the following composition in parts-by-mass.

- Standard, 20.1
- Portland cement, 12.1
- Water, 4.8

20.3. Suitable testing press.

21. PROCEDURE

21.1. Mix adhesive as described in Section 16.2 and apply a coat to each diagonal surface. Press diagonal surfaces of each block together by hand and remove excess adhesive.

21.2. Align the blocks so that the ends and sides are square and form a block 50.8 by 50.8 mm by 127 mm (2 in. by 2 in. by 5 in.). Use blocks of wood or metal against each end to keep diagonal faces from slipping.

21.3. After the required cure time as specified, apply a suitable capping compound to each end and test by applying a compression load at the rate of 22.2 kN/minute (5000 lbf/minute) until failure.

21.4. For wet shear strength, bond another set of blocks together as described above. Cure 24 hours at 25 ± 1°C (77 ± 2°F) and immerse in water 7 days at 25 ± 1°C (77 ± 2°F), remove and immediately test as described above in Section 21.3.

22. CALCULATIONS

22.1. Calculate the test value of kPa (psi) using the 50.8 by 50.8 mm (2 by 2 in.) dimensions to calculate specimen area:

$$\text{Stress, kPa (psi)} = \frac{TL}{A} \qquad (2)$$

where:

TL = total load N (lbf), and

A = end area of specimen.

SHEAR RATIO

23. APPARATUS AND MATERIALS

23.1. Same as Section 10.

24. PROCEDURE

24.1. Same as Section 11.

25. CALCULATIONS

25.1. Shear ratio = [viscosity in Pa·s (Centipoise) at 0.5 r/min)/(viscosity in Pa·s (Centipoise) at 2.5 r/min].

PART II

26. PREPARATION OF SAMPLE

26.1. For all tests on the mixed adhesive, the two components shall be proportioned by mass. The gallon mass of each component shall be determined by Federal Standard No. 141, Method 4184. The mass ratio of the components shall be calculated using the gallon masses and the proper volume ratio.

27. CONSISTENCY

27.1. A minimum sample of 475 mL (1 pt) of the mixed adhesive shall be used for viscosity determinations.

27.2. ASTM D 1084, Method B, using a speed of 20 r/min. Initial temperature of samples shall be 25 ± 0.5°C (77 ± 1°F). In the case of marker adhesives, the spindle shall be allowed to rotate for two minutes before taking a reading. For the concrete adhesives, a total of 400 g (0.88 lb) of the components shall be weighed into a pint can and stirred together for five minutes before determining viscosity. Allow spindle to rotate for 30 seconds before taking reading.

28. POT LIFE

28.1. The initial temperature of the adhesive components and the ambient temperature shall be 25 ± 1°C (77 ± 2°F) for this test. A total of 100 g (0.22 lb) of the adhesive shall be weighed into a 180-mL (6-oz) metal ointment can approximately 70 mm (2.75 in.) in diameter, the time recorded and the two components mixed for 3 minutes with a nonreactive spatula. The sides and bottom of the container should be scraped periodically during the mixing. The container shall then be set on a wooden block and probed with a glass stirring rod. For Type I and I-M through III and III-M marker adhesives, probe every minute starting 5 minutes from the initiation of mixing. For Type IV and IV-M marker adhesive and the concrete adhesives, probe every 2 minutes, starting 16 minutes from the initiation of mixing. In all cases, the time at which the material becomes unworkable or begins to solidify is recorded as the pot life.

29. SET TIME

29.1. The ambient temperature and the initial temperature of the individual components used in this test shall be either 4.4 ± 1.0°C or 25 ± 1°C (40 ± 2°F or 77 ± 2°F).

29.2. Cement mortar briquettes shall be prepared according to AASHTO T 132 using Type III cement complying with AASHTO M 85 and sand complying with AASHTO M 6. The briquettes shall be cured for a minimum of 7 days and then sawed at the centerline perpendicular to the long axis. A diamond tooth saw or other cutting tool capable of producing clean smooth faces on the briquette halves shall be used. The halves shall be allowed to dry before use. Approximately 50 g of the adhesive shall be mixed with a spatula in a 180-mL (6-oz) nonreactive container for 3 minutes. The cut faces of the briquettes shall then be coated with the adhesive and put together with light pressure. The excess adhesive shall be removed from the edges of the bonded area and the briquettes should remain undisturbed until time for testing. No more than 10 minutes after mixing shall elapse during preparation and bonding of the briquettes. A minimum of three briquettes shall be prepared. The briquettes shall be subjected to tensile loading with the Riehle briquette tester and the load at failure recorded.

29.3. This test shall be performed at the manufacturer's specified maximum set time and must yield an average strength of 1240 kPa (180 psi).

30. THIXOTROPY

30.1. This test shall be performed with the initial temperature of the adhesive and materials used in the test at 25 ± 1°C (77 ± 2°F) and also at 49 ± 1.5°C (120 ± 3°F).

30.2. The two components of the epoxy adhesive shall be stirred together for at least 1 minute, but not more than 2 minutes and then applied to a smooth, clean steel plate to form a panel of epoxy material 50 mm (2 in.) wide, 100 mm (4 in.) in length, and 2.5 mm (or 100 mL) in thickness. A removable form of the proper dimensions shall be used in placing the epoxy on the steel plate. The epoxy shall be poured into the form and the excess struck off level with the top edge and then the form removed. Immediately after forming the epoxy adhesive, the steel panel shall be placed so that the 100-mm (4-in.) dimension of the epoxy panel is vertical. For thixotropy at 25°C (77°F), the panel shall be placed in a room maintained at 25 ± 1°C (77 ± 2°F). For thixotropy at 49°C (120°F), the panel shall be placed in an oven maintained at 49 ± 1.5°C (120 ± 3°F). Not more than 4 minutes shall elapse between the initiation of mixing and placing the panel in the vertical position. After the adhesive has hardened, draw two lines parallel with the 100-mm (4-in.) dimension 13 mm (0.5 in.) from each edge of the epoxy and four lines parallel to the 50-mm (2-in.) dimension spaced 25 mm (1 in.) apart beginning 13 mm (0.5 in.) from the top edge of the panel. Measure the combined thickness of the panel and epoxy adhesive remaining within the original 50 by 100 mm (2 by 4 in.) area by averaging the eight readings and subtracting the thickness of the steel plate.

31. ADHESIVE SHEAR STRENGTH

31.1. The adhesive shear strength is to be determined in accordance with ASTM D 1002. Steel specimens shall be used. The surfaces of the test specimens used in the adhesive shear strength test shall be prepared by blasting to white metal using a 6.4-mm ($^1/_4$-in.) diameter nozzle and a gun pressure of 345 to 565 kPa (50 to 75 psi). The abrasive used shall be equivalent to Garnet Blasting Abrasive, 250 μm (60 mesh), manufactured by Idaho Garnet Abrasive Company, Kellogg, Idaho. The specimens shall be cured 7 days at 24 ± 3°C (75 ± 5°F).

32. WATER GAIN

32.1. The water gain (24 hours emerged at 23°C) shall be determined in accordance with ASTM D 570, with the following modifications. The specimens shall be prepared by casting disks of the epoxy adhesive 70 mm ($2^3/_4$ in.) in diameter and approximately 10 mm ($^3/_8$ in.) thick. Prior to testing, the plane surfaces of the disks shall be ground or machined flat and parallel. The machining or grinding must be done in such a way as to not heat the disks above 48.9°C (120°F). The thickness of the disks after preparing the surfaces shall be 7.6 ± 0.5 mm (0.30 ± 0.02 in.). The specimens shall be cured 7 days at 24 ± 3°C (75 ± 5°F).

33. IMPACT STRENGTH

33.1. The ambient temperature and temperature of equipment shall be 24 ± 3°C (75 ± 5°F). The specimens shall be prepared as outlined in Section 32, Water Gain. The specimens shall be cured 7 days at 24 ± 3°C (75 ± 5°F) before testing. The specimens shall be placed on a smooth concrete slab or a smooth steel plate at least 13 mm ($^1/_2$ in.) thick firmly attached to a concrete slab. A 454-g (1-lb) steel ball shall be dropped onto the center of the disks from an initial height of 1.5 m (5 ft). The height shall be increased by 0.150 m ($^1/_2$ ft) for each successive drop until the specimen fails by cracking or shattering. The height of drop at which failure occurs shall be recorded as the impact strength in joules (foot-pounds). A minimum of four specimens shall be tested and the average reported to the nearest 0.68 J ($^1/_2$ foot-pound).

34. BONDING OF FRESH PORTLAND CEMENT CONCRETE TO CURED PORTLAND CEMENT CONCRETE

34.1. Approximately 50 g of the adhesive shall be mixed with a spatula in a nonreactive container for 3 minutes. The adhesive shall then be applied to the cut faces of briquette halves prepared as described in Section 29.2, Set Time. After the adhesive has become tacky, new mortar prepared as described in the Set Time determination shall be molded against it to form a complete briquette. The resulting briquettes shall be cured according to the method set forth in T 132 and then subjected to tensile loading with a briquette tester after 7 days' cure.

34.2. A minimum of six briquettes shall be tested. If the average strength of the briquettes tested is less than 2755 kPa (400 psi) and any of these briquettes failed in the mortar at strengths below 2755 kPa (400 psi), an additional set of specimens shall be prepared and tested.

35. WET STRENGTH

35.1. A minimum of three specimens shall be prepared as described under Section 29.2, Set Time. The bonded briquettes shall be allowed to cure for 1 day at 24 ± 3°C (75 ± 5°F), followed by 2 days in an oven maintained at 49.0 ± 1.5°C (120 ± 3°F). The cured specimens shall be immersed in distilled water maintained at 38.0 ± 1.5°C (100 ± 3°F) for a total of 7 days. The specimens shall then be removed from the bath, placed in water maintained at 23.0 ± 1.5°C (75 ± 3°F) for 60 minutes, then subjected to tensile loading with a briquette tester and the load at failure recorded. If the average strength of the briquettes tested is less than 2070 kPa (300 psi) and any of these briquettes failed in the mortar at strengths below 2070 kPa (300 psi), an additional set of specimens shall be prepared and tested.

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[1] The Perkin-Elmer Model 137-B Infracord Spectrophotometer has been found satisfactory.
[2] The Sorvall SS-3 Automatic Superspeed Centrifuge has been found satisfactory.
[3] Form 2A—Opacity obtained from The Leneta Co., P.O. Box 576, Ho Ho Kus, NJ 07428, has proven satisfactory.
[4] Other diameter plugs may be used. However, use of the specified diameter simplifies calculations.

Standard Method of Test for

Thermoplastic Traffic Line Material

AASHTO Designation: T 250-05 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Thermoplastic Traffic Line Material

AASHTO Designation: T 250-05 (2009)

1. SCOPE

1.1. The procedures used for testing thermoplastic traffic line material are described in this method. This includes the method for obtaining a representative test sample, preparation of the test specimens, and performing the specified tests. The material is a mixture of resins, fillers, pigments, and reflective spheres. These materials are combined by heating to obtain a product with the desired properties suitable for traffic line striping.

1.2. This test method is divided into the following parts:

1.2.1. Section 3, Sampling of Thermoplastic Material;

1.2.2. Section 4, Sample Meltdown and Preparation;

1.2.3. Section 5, Binder Content;

1.2.4. Section 6, Glass Bead Content;

1.2.5. Section 7, Glass Bead Grading Analysis;

1.2.6. Section 8, Reflectance, Color, and Yellowness Index;

1.2.7. Section 9, Titanium Dioxide Determination;

1.2.8. Section 10, Lead Chromate Determination;

1.2.9. Section 11, Flowability (Percent Residue);

1.2.10. Section 12, Low Temperature Stress Resistance;

1.2.11. Section 13, Bond Strength;

1.2.12. Section 14, Impact Resistance;

1.2.13. Section 15, Ring-and-Ball Softening Point;

1.2.14. Section 16, Specific Gravity;

1.2.15. Section 17, Flowability (Percent Residue) Extended Heating;

1.2.16. Section 18, Ultraviolet Light and Condensate Exposure;

1.2.17. Section 19, Hardness; and

1.2.18. Section 20, Flash Point.

1.3. The values stated in SI units are to be regarded as the standard.

Note 1—**Warning:** Due to the elevated temperatures used in these tests and the nature of the material, extreme care should be used when working with the thermoplastic materials. Use heat-resistant gloves and safety glasses or face shield when handling in the fluid state. Severe burns can result from spilled thermoplastics or mishandled equipment. Should melted thermoplastic come in contact with the skin, do not attempt to wipe off. Immediately hold or submerge the affected area under cold water. Inform someone in the immediate vicinity that an accident has occurred. Seek proper medical attention.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- M 247, Glass Beads Used in Pavement Markings
- M 249, White and Yellow Reflective Thermoplastic Striping Material (Solid Form)
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- D 36, Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)
- D 92, Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester
- D 256, Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics
- D 792, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- D 4764, Standard Test Method for Determination by X-ray Fluorescence Spectroscopy of Titanium Dioxide Content in Paint
- D 4796, Standard Test Method for Bond Strength of Thermoplastic Traffic Marking Materials
- D 4797, Standard Test Methods for Chemical and Gravimetric Analysis of White and Yellow Thermoplastic Traffic Marking Containing Lead Chromate and Titanium Dioxide
- D 4960, Standard Test Method for Evaluation of Color for Thermoplastic Traffic Marking Materials
- E 313, Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates
- E 1349, Standard Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional (45°:0° or 0°:45°) Geometry
- G 154, Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials

2.3. *Federal Standards*:

- Federal Test Method Standards, No. 141

3. SAMPLING OF THERMOPLASTIC MATERIAL

3.1. It is important to obtain a truly representative sample of the thermoplastic material for testing. This can be difficult due to the wide ranges of sizes, shapes, and densities of the particular raw materials that are used in the material formulation. The following three methods provide a way to obtain representative samples from a production lot of thermoplastic pavement marking material for testing.

3.2. *Quartering Method*.

3.2.1. *Apparatus and Materials*:

3.2.1.1. 1.2 m by 1.2 m (4 ft by 4 ft) section of cardboard, smooth wood, or metal;

3.2.1.2. Metal scooping pan;

3.2.1.3. Metal splitting device;

3.2.1.4. Three 22-kg (50-lb) bags of thermoplastic (randomly selected); and

3.2.1.5. Unlined 3.8-L (1-gal) cans.

3.2.2. *Procedure*:

3.2.2.1. Randomly select three 22-kg (50-lb) bags from the lot to be sampled (up to 22 000 kg (50 000 lb)).

3.2.2.2. Place the selection of cardboard, wood, or metal on a level section of floor.

3.2.2.3. Empty the contents of one of the 22-kg (50-lb) bags onto the sample area. Using the metal scoop, mix the material, breaking up any large lumps. Shape the pile of thermoplastic into as high a pile as possible, forming a symmetrical inverted cone.

3.2.2.4. Take the metal splitting device and center it over the apex of the thermoplastic. Lower the device onto the material, thus splitting it into four quarter sections.

3.2.2.5. Take the material from any two opposing quarters and return it to the thermoplastic bag. The two remaining quarters are to be mixed and split in the same manner as explained above, rotating between the two quarters that are retained at the end of each step. Repeat the process for a total of four times. Retain the final two opposing quarters as a part of the composite sample and place in the unlined 3.8-L (1-gal) can.

3.2.2.6. Perform the same procedure as outlined using the two remaining bags. When the final quarters are taken from the two bags, the sum of the three bags should fill the 3.8-L (1-gal) sample container and should weigh between 4 and 4.5 kg (9 and 10 lb).

3.2.2.7. Label the outside of the 3.8-L (1-gal) sample can with adequate identification markings including: manufacturer, product number, batch number, date of manufacture, color, and specification.

3.2.2.8. The entire composite sample should be melted for the preparation of test samples as called for in Section 4, Sample Meltdown and Preparation.

3.3. *Splitter Method*.

3.3.1. *Apparatus and Material*:

3.3.1.1. 1:1 Splitter with pans;

3.3.1.2. Three 22-kg (50-lb) bags of thermoplastic (randomly selected); and

3.3.1.3. Unlined 3.8-L (1-gal) can.

3.3.2. *Procedure*:

3.3.2.1. Randomly select three 22-kg (50-lb) bags of thermoplastic from the lot to be tested (up to 22 000 kg (50 000 lb)).

3.3.2.2. Empty the contents of one of the bags into one of the pans and place on top of the 1:1 splitter.

3.3.2.3. Place a pan underneath each of the two discharge sections of the splitter.

3.3.2.4. Empty the contents in the top pan such that the material passes through the splitter.

3.3.2.5. Take each half and split individually to form quarters. Return two opposing pans, or quarters, to the bag. Split the two remaining pans individually to form quarters. Repeat the above procedure by splitting the two opposing pans while returning the others to the bag. This splitting procedure is performed four times before placing the final quarters into the sample container.

3.3.2.6. Perform the same procedure on the two remaining bags of thermoplastic. When the final quarters are taken from the two bags, the sum of the three bags should fill the 3.8-L (1-gal) sample container and should weigh between 4 and 4.5 kg (9 and 10 lb).

3.3.2.7. Label the outside of the 3.8-L (1-gal) sample can with adequate identification markings including: manufacturer, product number, batch number, date of manufacture, color, and specification.

3.3.2.8. The entire composite sample should be melted for the preparation of test samples as called for in Section 4, Sample Meltdown and Preparation.

3.4. *Thieving Method*.

3.4.1. *Apparatus and Materials*:

3.4.1.1. 5-cm (2-in.) ID metal pipe approximately 1 m (3 ft) long.

3.4.1.2. Three 22-kg (50-lb) bags of thermoplastic (randomly selected); and

3.4.1.3. Unlined 3.8-L (1-gal) cans.

3.4.2. *Procedure*:

3.4.2.1. Randomly select three 22-kg (50-lb) bags of thermoplastic from the lot to be sampled (up to 22 000 kg (50 000 lb)).

3.4.2.2. Place the bag on a flat surface.

3.4.2.3. Carefully cut the bag at the top or bottom to allow the pipe to be inserted into the bag.

3.4.2.4. Insert the sample pipe into the bag and push through the thermoplastic material through the entire length of the bag.

3.4.2.5. Carefully remove the pipe and empty the thermoplastic material that is retained in the pipe into the unlined 3.8-L (1-gal) can.

3.4.2.6. Repeat the process, pushing the pipe through a different area of the 22-kg (50-lb) bag. Continue with the process until an approximate 1.5-kg (3-lb) sample has been obtained from the 22-kg (50-lb) bag.

3.4.2.7. Repeat steps in Sections 3.4.2.2 through 3.4.2.6 with the other two 22-kg (50-lb) bags that were selected for testing. The final sample size should weigh between 4 and 5.5 kg (9 and 12 lb).

3.4.2.8. Label the outside of the 3.8-L (1-gal) sample can with adequate identification markings, including: manufacturer, product number, batch number, date of manufacture, color, and specification. The entire composite sample should be melted for the preparation of test samples as called for in Section 4, Sample Meltdown and Preparation.

4. SAMPLE MELTDOWN AND PREPARATION

4.1. This procedure covers the melting of thermoplastic road striping materials using a heating mantle and an air stirrer. This procedure stimulates the actual melting process and equipment found in the field.

4.2. *Apparatus and Materials*:

4.2.1. A stainless steel 4000-mL beaker, 15-cm (6-in.) diameter by 23 cm (9 in.) high, such as a Volrath No. 84000 or equivalent such as an unlined metal 3.8-L (1-gal) can.

4.2.2. Suitable heating mantle, such as a Glas-Col heating mantle, Model TM620 or equivalent.

4.2.3. Temperature indicator-controller, such as an Omega Engineering Model 400JF or equivalent.

4.2.4. Thermocouple, such as an Omega Engineering No. TJ36-ICSS-116G-12 with 1.6-mm ($^1/_{16}$-in.) 304SS sheath, or equivalent.

4.2.5. Air powered variable speed mixer, such as a Lightning Model 30 with two Lightning A310 stainless steel impellers or similar equipment.

4.2.6. Aluminum lid to cover the top of the stainless steel 4000-mL beaker with slot to clear the air motor agitator shaft and thermocouple.

4.2.7. Stainless steel ladle with pouring spout, 60-mL (2-oz) capacity.

4.2.8. Tachometer to measure shaft speed of mixer.

4.2.9. Copper or stainless steel tubing approximately 3 mm ($^1/_8$ in.) and 25 cm (10 in.) long.

4.2.10. Porcelain dish, 150 mL.

4.2.11. Crucibles, 30 mL.

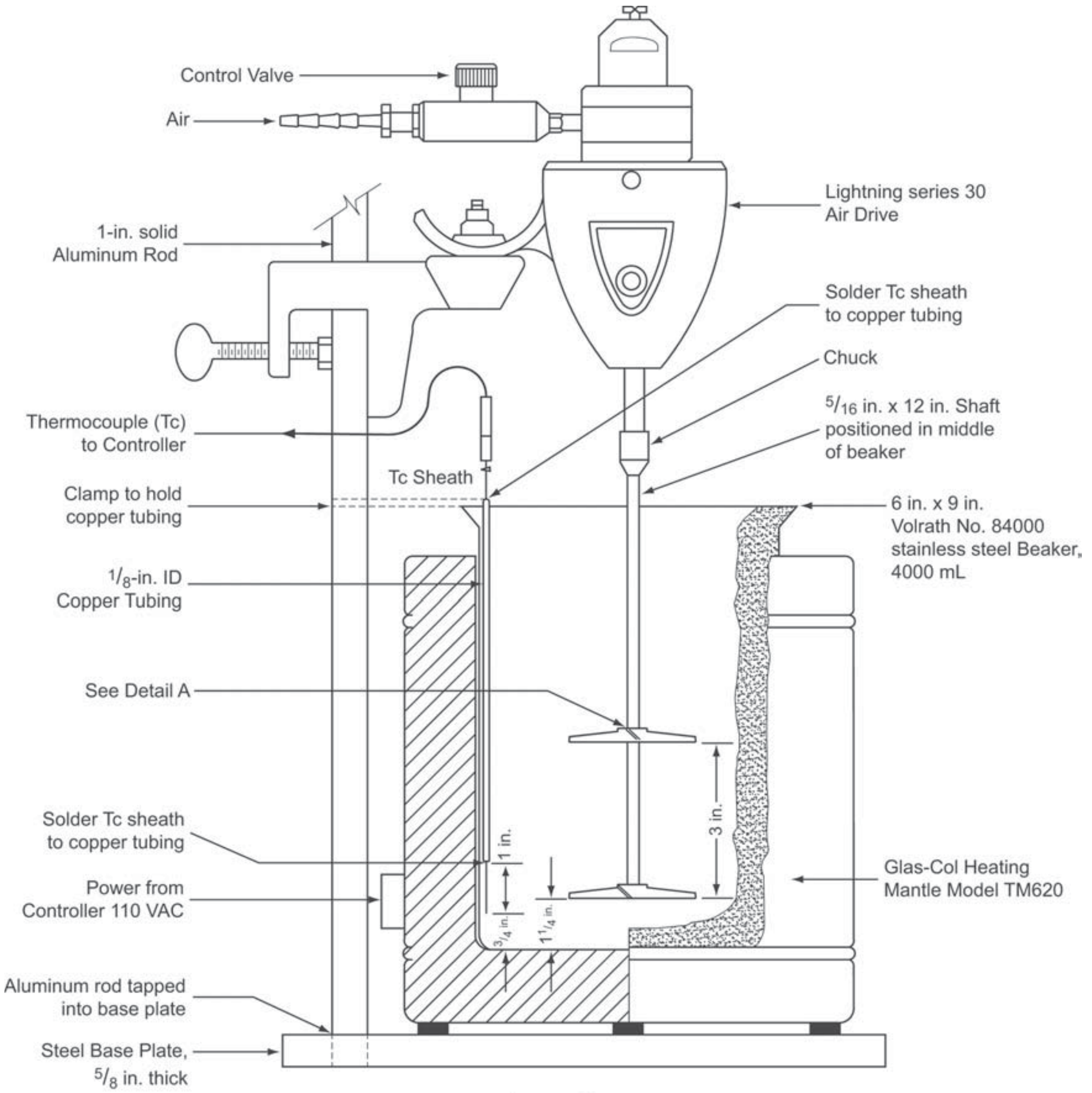
4.2.12. Glass beaker, 2 L.

4.3. *Procedure*:

4.3.1. Set up the apparatus as shown in Figure 1. Wire the heating mantle power cord to the temperature indicator controller according to manufacturer's instructions. Mount the controller-indicators in a panel that can be wall mounted to keep the unit away from heat, dirt, and vibrations. When the unit is ready for operation, make a test melt in order to set the proportional band and other adjustments to give a controlled temperature of 218 ± 1ºC (425 ± 2ºF).

4.3.2. Change about one-half the granular sample into the appropriate container and place in the heating mantle and attach the stirring shaft. Turn on the power to the mantle and controller. As the thermoplastic melts down, add the remainder of the sample. Start the variable speed air agitator when plastic has softened sufficiently to mix. Continue to mix and heat until the temperature reaches 218ºC (425ºF) and the sample is homogeneous, and maintain temperature at 218 ± 1°C (245 ± 2°F).

4.3.3. Remove the thermoplastic sample using a 60-mL (2-oz) ladle and prepare samples or run tests as required.



Assembly

Figure 1A

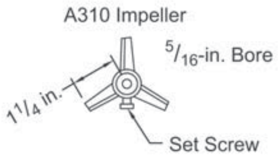


Figure 1—Thermoplastic Melter Apparatus

5. BINDER CONTENT

5.1. Using a 60-mL (2-oz) ladle, remove a portion of the molten thermoplastic from the sample during the first hour of the heating period (after the entire sample becomes molten). Run the binder content as specified in ASTM D 4797 with the exception of using a 50-g sample of thermoplastic marking material and a 150-mL (5-oz) porcelain dish in lieu of a 30-mL crucible.

6. GLASS BEAD CONTENT

6.1. Using the same sample obtained for the determination of binder content, determine the intermix bead content as specified in ASTM D 4797 utilizing a 2-L beaker in lieu of the 400-mL beaker and increasing the quantities of the HCl solution and water used in the rinses by a factor of five (5).

7. GLASS BEAD GRADING ANALYSIS

7.1. Grade the beads according to M 247 using the appropriate sieves. Determine the mass of fractions to the nearest 0.01g.

7.2. Perform a visual inspection of the material larger than 100 mesh to determine that the sample is composed of glass beads only. Any material other than glass beads that are insoluble in the acid wash will appear irregular and opaque. Presence of this type of material in sizes larger than 100 mesh constitutes a failure to comply with the specification or inadequate HCl digestion.

Note 2—All other bead analysis testing should be performed according to AASHTO M 247.

8. REFLECTANCE, COLOR, AND YELLOWNESS INDEX

8.1. Using a 60-mL (2-oz) ladle, remove a portion of the molten thermoplastic from the sample after the material has completed the 4-hour heating period. Cast an approximate 8-cm (3-in.) diameter disc on a tin plate, can lid, or on some other non-stick surface. After the material has reached room temperature, remove and test according to the requirements of ASTM D 4960. Make color measurement according to ASTM E 1349 using two-degree observer and Illuminant D 65. Calculate the Yellowness Index in accordance with ASTM E 313.

9. TITANIUM DIOXIDE DETERMINATION

9.1. *X-Ray Fluorescence Spectroscopy Method*:

9.1.1. Perform the test in accordance with the requirements of ASTM D 4764.

9.2. Jones Reduction Method (Referee Method): as noted in ASTM D 4797.

10. LEAD CHROMATE DETERMINATION

10.1. Calculate the lead chromate pigment content according to ASTM D 4797. X-ray fluorescence spectroscopy may also be used following the general requirements of ASTM D 4764.

11. FLOWABILITY (PERCENT RESIDUE)

11.1. *Apparatus and Materials*:

11.1.1. Round, unlined steel 475-mL (1-pt) can with rim removed from inside the cans.

11.1.2. *Balance*—The balance shall have sufficient capacity and conform to M 231, Class G 1.

11.1.3. *Holder for cans*, allowing suspension of cans at a 45-degree angle with point contact.

11.1.4. *Electric hotplate*, capable of heating material to 218ºC (425ºF).

11.1.5. *Glass stem thermometer*, having a maximum temperature range of at least 218ºC (450ºF).

11.2. *Procedure*:

11.2.1. From the 3.8-L (1-gal) sample of molten thermoplastic material, weigh 400.0 ± 0.1 g of the material into the tared 475-mL can. This sample should be taken after the 4-hour heating period has elapsed.

11.2.2. Using a glass stem thermometer as a stirring rod, place the sample onto a hotplate that has been set on the maximum temperature setting, and stir until the material reaches a temperature of 218 ± 1ºC (425 ± 2ºF). Avoid as much as possible splashing material on the inside of the can.

11.2.3. Remove the can from the hotplate and scrape the material from the thermometer on the rim of the can.

11.2.4. Immediately suspend the can at a 45-degree angle in a holder with point contact. Allow the material to flow over the rim where the thermometer was scraped until flow ceases.

11.2.5. Record the mass of each can plus residue.

11.2.6. Calculate the flowability (percent residue) as follows:

$$\text{Flowability, (percent residue)} = \frac{(A - B) \times 100}{400} \tag{1}$$

where:

A = mass of can plus residue, and

B = mass of can.

Note 3—Precision and Bias data are not available at this time for the flowability test.

12. LOW TEMPERATURE STRESS RESISTANCE

12.1. *Apparatus and Materials*:

12.1.1. *Concrete blocks*, 305 by 305 by 76 mm (12 by 12 by 3 in.), primed with primer recommended for use by the thermoplastic manufacturer.

12.1.2. 1.9-L (0.5-gal) cans with rims removed.

12.1.3. *Spatula*.

12.1.4. *Drawdown Blade*, 10 cm (4 in.) by 125 mL.

12.1.5. *Cold box or freezer*, capable of maintaining a temperature of –9.4 ± 2.0ºC (15 ± 3.6ºF) for 24 hours.

12.2. *Procedure*:

12.2.1. Prepare sample in accordance with Section 4, Sample Meltdown and Preparation. Heat the drawdown blade at 218ºC (425ºF) for one-half hour.

12.2.2. After heating for 4 hours at 218ºC (425ºF), quickly pour the thermoplastic into the heated drawdown blade and draw down a 10-cm (4-in.) wide line on the concrete block at room temperature.

12.2.3. When the test specimen has cooled to room temperature, place it in the cold box or freezer for 24 hours at –9.4 ± 2.0ºC (15 ± 3.6ºF).

12.2.4. At the end of 24 hours, remove and immediately inspect the specimen for cracking. Inspect the specimen from a distance of 305 mm (12 in.) under diffuse lighting.

12.2.5. Any cracking shall constitute failure of the test.

13. BOND STRENGTH

13.1. Using material from the molten sample of thermoplastic after the 4-hour heating period, prepare and test in accordance to ASTM D 4796.

14. IMPACT RESISTANCE

14.1. *Apparatus and Materials*:

14.1.1. *Molds*, 25 by 25 by 150 mm (1 by 1 by 6 in.), for casting impact specimens.

14.1.2. Izod-type impact test apparatus with 0 to 2.82 J (0 to 25 inch-pound) scale.

14.2. *Procedure*:

14.2.1. Preheat the specimen molds for approximately 1 hour at 218ºC (425ºF).

14.2.2. Using the 60-mL (2-oz) ladle, quickly fill the heated molds with the thermoplastic material. This material should be taken from the molten thermoplastic sample after the 4-hour heating period.

14.2.3. After cooling, carefully disassemble the molds and remove the solidified material. Cut each sample into approximately 76-mm (3-in.) long sections.

14.2.4. Determine the impact resistance using the Izod-type impact apparatus following the procedures for use of this apparatus as outlined generally in ASTM D 256, Method A. Do not use a notched specimen. Use the 0 to 2.82 J (0 to 25 inch-pound) scale with the appropriate load on the striker. Average the results of two or more breaks.

15. RING-AND-BALL SOFTENING POINT

15.1. *Apparatus and Materials*:

15.1.1. Ring-and-ball apparatus, refer to ASTM D 36.

15.2. *Procedure*:

15.2.1. Perform the test according to ASTM D 36. Using the 60-mL (2-oz) ladle, obtain a sample from the 4-hour heated molten thermoplastic material and carefully fill the rings and level the surface to the top of the rings. Allow to cool and proceed.

15.2.2. Average the results of two or more tests.

16. SPECIFIC GRAVITY

16.1. Determine the specific gravity of the white and yellow materials according to ASTM D 792, Method A. The sample shall be taken from the sample of molten thermoplastic material following the 4-hour heating period.

17. FLOWABILITY (PERCENT RESIDUE) EXTENDED HEATING

17.1. *Apparatus and Materials*:

17.1.1. Round, unlined steel 475-mL (1-pt) can with rim removed from inside the cans.

17.1.2. *Balance*—The balance shall have sufficient capacity and conform to M 231, Class G l.

17.1.3. *Holder for cans*, allowing suspension of cans at a 45-degree angle with point contact.

17.1.4. *Electric hotplate*, capable of heating material to 218°C (425ºF).

17.1.5. *Glass stem thermometer*, having a maximum temperature range of at least 232ºC (450ºF).

17.2. *Procedure*:

17.2.1. From the initial 3.8-L (1-gal) sample melt, weigh 400.0± 0.1 g of material into the tared 475-mL (1-pt) can. This sample should be taken after the sample has been heated under constant agitation for a period of eight hours. The time required for meltdown and reaching the application temperature of 218ºC (425ºF) is included as part of the eight-hour heating period.

17.2.2. Using the glass stem thermometer as a stirring rod, place the sample onto the hotplate that has been set on a temperature setting of high, and stir until the material reaches a temperature of 218 ± 1ºC (425 ± 2ºF). Avoid as much as possible splashing material on the inside of the can.

17.2.3. Remove the can from the hotplate and scrape the material from the thermometer rim of the can.

17.2.4. Immediately suspend the can at a 45-degree angle in a holder with point contact. Allow the material to flow over the rim where the thermometer was scraped until the flow ceases.

17.2.5. Record the mass of each can plus residue and calculate flowability (percent residue) as follows:

$$\text{Flowability, Extended Heating} = \frac{\left(A - B\right) \times 100}{400} \qquad (2)$$

where:

A = mass of can plus residue, and

B = mass of can.

Note 4—Precision and bias data are not available at this time for the extended heating flowability test.

18. ULTRAVIOLET LIGHT AND CONDENSATE EXPOSURE

18.1. *Apparatus*:

18.1.1. QUV Accelerated Weathering Tester, as described in ASTM G 154.

18.1.2. 7.5 cm by 15 cm (3 in. by 6 in.) aluminum Q panels, Type A or equivalent.

18.1.3. 5-cm (2-in.) wide duct tape.

18.1.4. Steel screed box with inside dimensions of 6 cm by 10 cm (2.5 in. by 4.0 in.) with a 6-mm (0.125-in.) opening across the entire length of one of the 6-cm (2.5-in.) sides.

18.1.5. Oven, capable of maintaining 218ºC (425ºF).

18.1.6. Masking tape, 1 cm ($^1/_2$ in.) wide.

18.2. *Procedure*:

18.2.1. One-half hour before test, place a screed box in the 218ºC (425ºF) oven.

18.2.2. Tape the 7.5 cm by 15 cm (3 in. by 6 in.) aluminum panel to the bench surface with masking tape to hold the panel firmly to the bench.

18.2.3. Remove the screed box from the oven and position at the right angles to the 15 cm (6 in.) length of the aluminum panel and in the middle of the panel.

18.2.4. With the 60-mL (2-oz) ladle, remove a sample from the molten thermoplastic sample and quickly draw down the sample across the aluminum panel.

18.2.5. While hot, trim off excess plastic from the edge of the aluminum panel.

18.2.6. When cool, wrap top and bottom edges of the plastic sample with duct tape to keep the sample in position on the aluminum panel. Lap the edges of the plastic with no more than 6 mm ($^1/_4$ in.) with duct tape.

18.2.7. For the white thermoplastic, measure the color of the samples as outlined in Section 8, Reflectance, Color, and Yellowness Index.

18.2.8. Expose the sample for 300 hours in the QUV apparatus utilizing UVA-340 lamps. Set the QUV for cycles of 4 hours UV exposure at 60ºC (140ºF) and 4 hours condensate exposure at 40ºC (104ºF).

18.2.9. Remove the samples from the QUV and allow them to dry at room temperature. Test the color as outlined in Section 8, Reflectance, Color, and Yellowness Index.

19. HARDNESS (D 2240 TEST METHOD FOR RUBBER PROPERTY–DUROMETER HARDNESS)

19.1. *Apparatus*:

19.1.1. Shore Durometer Hardness Tester Type A-2 with attached weights so that the total weight of the unit is 2002 g.

19.1.2. Incubator oven with the glass inner door, capable of maintaining 46 ± 1ºC (115 ± 2ºF).

19.1.3. Stopwatch.

19.1.4. Aluminum disposable weighing dish, approximately 63 mm (2.5 in.) in diameter and 17.5 mm (0.7 in.) deep.

19.1.5. Mold release.

19.2. *Procedure*:

19.2.1. With the 60-mL (2-oz) ladle, fill the aluminum dish with hot thermoplastic material taken from the 3.8-L (1-gal) molten sample.

19.2.2. Allow the dish to cool to room temperature and strip the aluminum from the sample.

19.2.3. Place the sample on a metal 0.9-L (1-qt) can lid previously coated with mold release to prevent sticking and place in the 46ºC (115ºF) oven for 3 hours. At the same time, place the durometer in the oven.

19.2.4. After 3 hours, place the durometer on top of sample, immediately start stopwatch and close inner glass door.

19.2.5. After 15 seconds contact, read durometer, open inner glass door, turn sample over, and repeat durometer reading.

19.2.6. Report the average of readings made on top and bottom of the sample.

20. FLASH POINT

20.1. Using a 60-mL (2-oz) ladle, remove a portion of the molten thermoplastic from the sample during the first hour of the heating period (after the entire sample becomes molten). Run the flash point as specified in ASTM D 92.

Standard Method of Test for

Linear Coefficient of Shrinkage on Cure of Adhesive Systems

AASHTO Designation: T 333-07

American Association of State Highway and Transportation Officials
444 North Capitol Street, N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Linear Coefficient of Shrinkage on Cure of Adhesive Systems

AASHTO Designation: T 333-07

1. SCOPE

1.1. This method describes the measurement of the linear coefficient of shrinkage on cure of adhesive systems.

1.2. The values stated in SI units shall be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 235M/M 235, Epoxy Resin Adhesives

3. TERMINOLOGY

3.1. *Adhesive system*—a multi-component material that results in a product used as a bonding material.

3.2. *Linear coefficient of shrinkage*—the measured shrinkage of a material on cure expressed as change in length divided by the original sample length.

4. SUMMARY OF TEST METHOD

4.1. This method describes the procedure used to measure the change in length following the cure of a fresh cast adhesive material. Test specimens are cast in a half-cylindrical shaped mold and allowed to cure completely before the linear coefficient of shrinkage is determined.

5. SIGNIFICANCE AND USE

5.1. The reactions that occur when an adhesive system cures generally results in a volume shrinkage of the adhesive specimen. The shrinkage associated with this standard generally occurs after the gelling phase of the material. The shrinkage is the result of a change in the specific volume, caused by the chemical cross-linking reaction, and a volume change as the cast material cools from its cure temperature or from its maximum reaction temperature. This method does not differentiate between these two effects.

5.2. The effects of the mold walls further complicate the measurement of shrinkage. As the reacting system gives off heat, it normally expands. Most of the expansion must take place toward the open side of the mold. When the maximum reaction temperature has passed, the solidifying adhesive should shrink uniformly in all directions. However, friction prevents the free movement of the adhesive over the mold surfaces allowing the greatest shrinkage to occur perpendicular to the open surface of the mold.

5.3. Usually the end user is concerned only with deviations from mold dimensions. It can be assumed that shrinkage perpendicular to surfaces other than the open side will be uniform and proportional to the distance over which the shrinkage occurs. Thus, the measurement of shrinkage in length, the linear shrinkage, when expressed in units such as centimeters shrinkage per centimeter of length (cm/cm) or inches per inch (in./in.), gives a value characteristic of the adhesive. This value is useful in predicting the behavior of the adhesive in molds of other shapes and sizes.

6. APPARATUS

6.1. *Mold*—The mold shall be composed of a material, such as cold-rolled steel, that will not significantly distort during testing and will regain its originally dimensions after cure. The mold shall be 25.400 ± 0.125 cm (10.00 ± 0.05 in.) in length and have an internal radius of 1.270 ± 0.125 cm (0.50 ± 0.05 in.). The wall of the mold shall be 0.630 ± 0.125 cm (0.25 ± 0.05 in.) thick. It will have a removable end plate on each end (Figure 1).

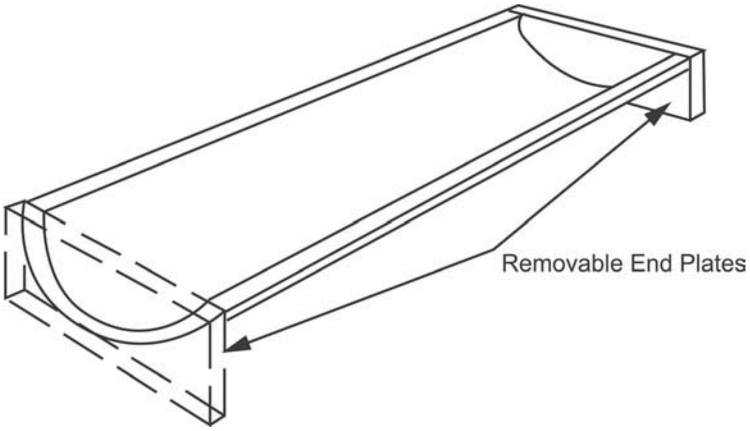


Figure 1—Mold

6.2. *Mineral Oil*.

6.3. *Film liner*—suitable for lining the mold, approximately 0.025 mm (0.001 in.) in thickness. Polytetrafluoroethylene or polyethylene films have been found acceptable.

6.4. *Micrometer*—capable of reading to the nearest 0.0025 mm (0.0001 in.).

6.5. *Temperature-Recording Device*—accurate to the nearest 1°C (2°F).

7. SAMPLING

7.1. The sampling shall be done in accordance with Section 10 of AASHTO M 235M/M 235.

8. PREPARATION OF TEST SPECIMENS

8.1. Measure and record the length of the mold.

8.2. Wipe all interior surfaces of the mold with a thin film of mineral oil, and apply the film to these surfaces, ensuring a smooth surface taking care to remove all wrinkles.

8.3. Condition the mold and the individual components of the system for at least four hours at 23 ± 1°C (73 ± 2°F).

8.4. Mix the components, taking care to minimize the entrapment of air since air inclusions affect the shrinkage characteristics.

8.5. Fill the mold with the mixed adhesive, taking care to avoid air entrapment. If the adhesive is a material that cures at room temperature, pour the mixture before the temperature exceeds 30°C (86°F).

8.6. Cure the casting in the mold at 23 ± 1°C (73 ± 2°F) for the cure time stated in the manufacturer's instructions.

8.7. Record the maximum reaction temperature of the material in cure using a suitable temperature-recording device in the geometric center of the reacting mass.

9. CONDITIONING

9.1. After casting and curing, condition the test specimen at 23 ± 1°C (73 ± 2°F) and 50 ± 5 percent relative humidity for not less than 40 hours prior to testing.

9.2. Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 relative humidity, unless otherwise specified.

10. PROCEDURE

10.1. Following conditioning, remove the specimen from the mold by removing the end plates. The film liner may be removed at this time if necessary for accurate measurements.

10.2. Replace one end plate on the mold and return the specimen to the mold in the same position in which it was prior to removal.

10.3. Making sure that the specimen is in direct contact with the end plate, determine with a micrometer the change in length of the specimen with reference to the mold length. Record four readings spaced across the open end of the mold. Average the four readings and report as the change in length of the specimen.

11. CALCULATION OF RESULTS

11.1. Calculate the linear coefficient of shrinkage in centimeters per centimeter (or inches per inch) as follows:

$$\text{Linear Coefficient of Shrinkage} = (A - 2B)/C \qquad (1)$$

where:

A = change in length, cm (in.);

B = film thickness, if removed from the sample; and

C = inside mold length, cm (in.).

12. REPORT

12.1. Report the following information:

12.1.1. Size of the mold used;

12.1.2. Volume of the casting;

12.1.3. Ambient test temperature;

12.1.4. Maximum reaction temperature;

12.1.5. Conditions of cure of the specimen, if other than standard; and

12.1.6. Linear coefficient of shrinkage expressed in centimeters of shrinkage per centimeter of specimen length (or inches per inch).

13. PRECISION AND BIAS

13.1. *Precision*—The research required to develop precision values has not been conducted.

13.2. *Bias*—The research required to establish the bias of the method has not been conducted.

14. KEYWORDS

14.1. Adhesive system; cure; epoxy; epoxy cure; epoxy shrinkage; linear coefficient; linear coefficient of epoxy; linear coefficient of shrinkage; resin adhesive shrinkage; shrinkage.

Standard Method of Test for

Frictional Properties of Paved Surfaces Using a Full-Scale Tire

AASHTO Designation: T 242-96 (2009)[1]
ASTM Designation: E 274-97

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Frictional Properties of Paved Surfaces Using a Full-Scale Tire

AASHTO Designation: T 242-96 (2009)[1]
ASTM Designation: E 274-97

1. SCOPE

1.1. This method covers the measurement of the frictional properties of paved surfaces with a specified full-scale automotive tire.

1.2. This method utilizes a measurement representing the steady-state friction force on a locked test wheel as it is dragged over a wetted-pavement surface under constant load and at a constant speed while its major plane is parallel to its direction of motion and perpendicular to the pavement.

1.3. The values measured represent the frictional properties obtained with the equipment and procedures stated herein and do not necessarily agree or correlate directly with those obtained by other pavement friction measuring methods. The values are intended for use in comparing certain frictional properties of a pavement relative to those of other pavements or for evaluating changes in these frictional properties of a pavement with the passage of time. The values are insufficient to determine the distance required to stop a vehicle on either a wet or a dry pavement. They are also insufficient for determining the speed at which control of a vehicle would be lost, because peak and side-force friction are also required for these determinations.

1.4. The values stated in SI units are to be regarded as the standard.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 261, Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests
- M 286, Smooth-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests
- T 282, Calibrating a Wheel Force or Torque Transducer Using a Calibration Platform (User Level)

2.2. *ASTM Standards*:

- E 178, Standard Practice for Dealing With Outlying Observations
- E 501, Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests
- E 524, Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests

- E 1136, Standard Specification for A Radial Standard Reference Test Tire
- F 377, Standard Practice for Calibration of Braking/Tractive Measuring Devices for Testing Tires
- F 457, Standard Test Method for Speed and Distance Calibration of Fifth Wheel Equipped With Either Analog or Digital Instrumentation

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3. SUMMARY OF METHOD

3.1. The test apparatus consists of an automotive vehicle with one or more test wheels incorporated into it or forming part of a suitable trailer towed by a vehicle. The apparatus contains a transducer, instrumentation, a water supply and proper dispensing system, and actuation controls for the brake of the test wheel. The test wheel is equipped with a standard pavement test tire, as specified in M 261 or M 286.

3.2. The test apparatus is brought to the desired test speed. Water is delivered ahead of the test tire and the braking system is actuated to lock the test tire. The resulting friction force acting between the test tire and the pavement surface (or some other quantity that is directly related to this force) and the speed of the test vehicle are recorded with the aid of suitable instrumentation.

3.3. Frictional properties of the paved surface are determined from the resulting force or torque record and reported as friction numbers (FN), which are determined from the force required to slide the locked test tire at a stated speed, divided by the effective wheel load and multiplied by 100.

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4. APPARATUS

4.1. *Vehicle*—The vehicle with one test tire locked shall be capable of maintaining test speeds of 65 to 100 km/h (40 to 60 mph) within ±1.5 km/h (±1.0 mph) during a test on a level pavement having a FN of 50.

4.2. *Braking System*—The test wheel shall be equipped with a suitable brake. The brake system shall be capable of locking the wheel at the condition specified in Section 4.1 and maintaining the locked-wheel condition throughout the test.

4.3. *Wheel Load*—The apparatus shall be of such a design as to provide an equal static load of 4800 ± 65 N (1085 ± 15 lbf) to each test wheel and, on detachable trailers, a static download of 450 to 900 N (100 to 200 lbf) at the hitch point.

4.4. *Tire and Rim*—The test tire shall be one of the standard tires for the pavement test, as specified in M 261 or M 286, and it shall be mounted on a suitable 15- by 6-in. rim. Since all rims do not have the same offset from the hub, replacement rims must be of the same offset to ensure consistent alignment of the tire with the water path. The data from the two tires are not interchangeable. Alternative testing for special purposes may be performed with other tires, such as a standard rib tire for pavement skid resistance of M 261 or ASTM E 501.

4.5. *Instrumentation*:

4.5.1. *General Requirements for Measuring System*—The instrumentation system shall conform to the following overall requirements at ambient temperatures between 4 and 40ºC (40 and 100ºF):

4.5.1.1. *Overall System Accuracy*—$\pm 1^1/_2$ percent of applied load from 900 N (200 lbf) to full scale; for example, at 900 N (200 lbf), applied calibration force of the system output shall be determinable within ±14 N (±3 lbf).

4.5.1.2. *Time Stability of Calibration*—10-hour minimum.

4.5.1.3. The exposed portions of the system shall tolerate 100 percent relative humidity (rain or spray) and all other adverse conditions, such as dust, shock, and vibrations, which may be encountered in highway operations.

4.5.2. *Force-Measuring Transducer*—The tire force-measuring transducer shall be of such design as to measure the tire–road interface force with minimum inertial effects. Transducers are recommended to provide an output directly proportional to force with hysteresis less than 1 percent of the applied load, nonlinearity less than 1 percent of the applied load up to the maximum expected loading, and sensitivity to any expected cross-axis loading or torque loading less than 1 percent of the applied load. The force transducer shall be mounted in such a manner as to experience less than 1-degree angular rotation with respect to its measuring plane at the maximum expected loading.

4.5.3. *Torque-Measuring Transducer*—Torque transducers provide an output directly proportional to torque with hysteresis less than 1 percent of the applied load and nonlinearity up to the maximum expected loading less than 1 percent of the applied load. It should have sensitivity to any cross-axis loading less than 1 percent of the applied load.

4.5.4. *Additional Transducers*—Force transducers for measuring quantities such as vertical load, etc., shall meet the recommendations stated in Section 4.5.2.

4.5.5. *Vehicle Speed-Measuring Transducers*—Transducers such as “fifth-wheel” or free-rolling wheel coupled tachometers shall provide speed resolution and accuracy of ±1.5 percent of the indicated speed or ±1.0 km/h (±0.5 mph), whichever is greater. Output shall be directly viewable by the driver and shall be simultaneously recorded. Fifth-wheel systems shall conform to ASTM F 457.

4.6. *Signal Conditioning and Recorder System*:

4.6.1. Transducers that measure parameters sensitive to inertial loading shall be designed or located in such a manner as to minimize this effect. If the foregoing is not practical, data correction must be made for these effects if they exceed 2 percent of the actual data during expected operation. All signal conditioning and recording equipment shall provide linear output and shall allow data reading resolution to meet the requirements of Section 4.5.1. All systems, except the smoothing filter recommended in Section 4.6.2, shall provide a minimum bandwidth of at least 0 to 20 Hz (flat within ±1 percent).

4.6.2. It is recommended that an electronic filter, typically between 4.8 Hz/–3db/4 pole Bessel-type and a 10 Hz/–3db/8 pole Butterworth filter, selected from the types described in Reference (1) (see Section 13.1) be installed in the signal conditioning circuit preceding the electronic divider and integration calculation of FN as described in Section 9.4.

4.6.3. All strain-gauge transducers shall be equipped with resistance shunt calibration resistors or equivalent that can be connected before or after test sequences. The calibration signal shall be at least 50 percent of the normal vertical load and shall be recorded.

4.6.4. Tire friction force or torque and any additional desired inputs, such as vertical load, wheel speed, etc., shall be recorded in phase (±5 degrees over a bandwidth of 0 to 20 Hz). Vehicle speed shall also be recorded. All signals shall be referenced to a common time base.

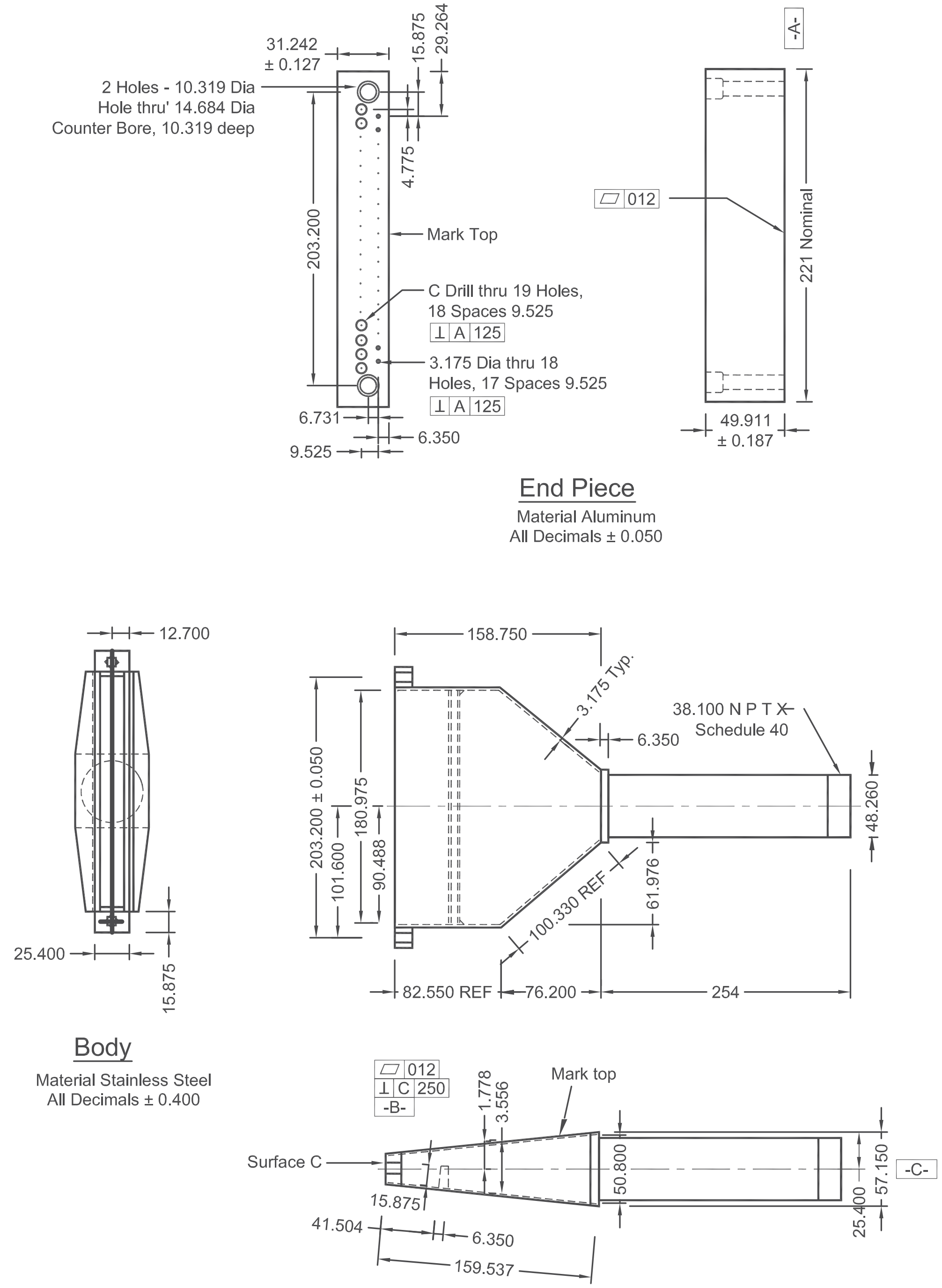
4.6.5. A signal-to-electrical noise ratio of at least 20 to 1 is desirable on all recorded channels.

4.7. *Pavement Wetting System*:

4.7.1. The water applied to the pavement ahead of the test tire shall be supplied by a nozzle conforming to the dimensions in Figure 1. The quantity of water applied at 65 km/h (40 mph) shall be 600 mL/min mm ± 10 percent (4.0 gal/min in. ± 10 percent) of wetted width. The water layer shall be at least 25 mm (1 in.) wider than the test tire tread and applied so the tire is centrally located between the edges. The volume of water per millimeter (inch) of wetted width shall be directly proportional to the test speed.

4.7.2. The nozzle configuration and position shall ensure that the water jets shall be directed toward the test tire and pointed toward the pavement at an angle of 20 to 30 degrees. The water shall strike the pavement 250 to 450 mm (10 to 18 in.) ahead of the vertical axis through the centerline of the test wheel. The nozzle shall be 25 mm (1 in.) above the pavement or the minimum height required to clear obstacles that the tester is expected to encounter, but in no case more than 100 mm (4 in.) above the pavement.

4.7.3. Water used for testing shall be reasonably clean and have no chemicals such as wetting agents or detergents added.



Notes: 1. Dimensions shown are for M 261 and M 286 Standard Tires.
2. All dimensions are in mm.
3. Surface A assembled to B.
4. Surface C must be milled flat and perpendicular to pipe centerline.

Figure 1—Nozzle

5. SAFETY PRECAUTIONS

5.1. The test vehicle, as well as all attachments to it, shall comply with all applicable state and federal laws. All necessary precautions shall be taken beyond those imposed by laws and regulations to ensure maximum safety of operating personnel and other traffic. No test shall be made when there is danger that the dispersed water may freeze on the pavement.

6. CALIBRATION

6.1. *Speed*—Calibrate the test vehicle speed indicator at the test speed by determining the time for traversing at constant speed a reasonably level and straight, accurately measured pavement of a length appropriate for the method of timing. Load the test vehicle to its normal operating mass for this calibration. Record speed variations during a traverse with the friction test system. Make a minimum of three runs at each test speed to complete the calibration. Other methods of equivalent accuracy may be used. Calibration of a fifth wheel shall be performed in accordance with ASTM F 457.

6.2. *Frictional Force*—Calibrate the frictional force in the manner described in T 282.

7. GENERAL

7.1. *Test Preparation*—Condition new tires by running them at or near their rated load and inflation pressure on the test vehicle (or on another suitable vehicle) at normal traffic speeds for at least 300 km (200 miles) or equivalent before they are used for test purposes. Prior to each series of tests, warm up the tire by traveling for at least 10 km (5 miles) at normal traffic speeds. Inspect the tire for flat spots, damage, or other irregularities that may affect test results, and replace if it has been damaged or is worn beyond the wear line. Check the test-wheel load (if adjustable) and adjust, if necessary, prior to each test series to within the value specified in Section 4.3. Set the test tire inflation pressure at 165 ± 3 kPa (24 ± 0.5 psi) at ambient temperature just before the 10-km (5-mi) warm-up.

7.2. *Test Sections*—Test sections shall be defined as sections of pavement of uniform age and uniform composition that have been subjected to essentially uniform wear. For instance, sharp curves and steep grades shall not be included in the same test section with level tangent sections, nor shall passing lanes be included with traffic lanes. Take frictional property measurements only on pavements that are free of obvious contamination.

7.3. *Frictional Properties of a Test Section*—Make at least five determinations of the frictional properties at intervals not greater than 1 km (0.5 mile), in each test section with the test vehicle at the same lateral position in any one lane and at each specified test speed. Consider the arithmetic average of all determinations to be the frictional properties of the test section. If statistical or other criteria applied to the FN for a long test section indicate that it cannot be considered as uniform, treat the section as two or more sections. For treatment of the results of faulty tests, see Section 10.

7.4. *Lateral Positioning of Test Vehicle on Highway*—Normally, testing shall be done in the center of the left wheel track of a traffic lane of a highway. Friction numbers for a highway surface may be quoted without qualification only if the test vehicle was so positioned during the test.

7.5. *Test Speeds*—The standard test speed shall be 65 km/h (40 mph), and tests shall normally be conducted at that speed. Where the legal maximum speed is less than 65 km/h, the tests may have to be conducted at a lower speed. Where the legal speed is considerably in excess of 65 km/h, tests may be made at the prevailing traffic speed, but it is recommended that at the same locations, additional tests be made at 65 km/h (40 mph). Maintain test speeds within 1.5 km/h (1 mph).

7.5.1. When the test speed is 65 km/h (40 mph), it is desirable, but not necessary, to cite the speed when quoting the obtained FN. In all other cases, the speed must be cited when quoting the obtained FN. This is done by adding the test speed in kilometers per hour (miles per hour) in parentheses after FN. For example, FN80 (FN50) indicates a test was run at a test speed of 80 km/h (50 mph). (When referencing a test speed in mph, add the test speed without parentheses in mph after FN. For example, FN50 indicates a test was run at 50 mph.) Unless otherwise indicated, it is understood that the standard ribbed test tire conforming to M 261 was used. When a blank test tire conforming to M 286 is used for the test, the letter "B" shall follow the speed. For example, FN50B indicates a test run at 50 mph with the ASTM E 524 blank test tire. When the SI system is used, the test speed shall be in parentheses. For example, FN(65) indicates that the test was run at a test speed of 65 km/h with a standard ribbed test tire conforming to M 261.

7.6. *Frictional Properties Speed Gradient Determination*—If speed gradients are obtained, report the change of the FN with speed as the slope of the FN versus speed curve, which is plotted from at least three speeds in increments of approximately 15 km/h (10 mph). The standard speed gradient shall be defined as the slope of the FN-speed curve at 65 km/h (40 mph) and shall be so indicated.

8. PROCEDURE

8.1. Bring the apparatus to the desired speed and deliver water to the pavement ahead of the test tire. Approximately 0.5 seconds after beginning of the water delivery, apply the test wheel brake so as to lock the wheel completely. The wheel shall remain locked for the duration of the data averaging interval (Section 8.4.1).

8.2. Water delivery may be terminated as soon as the brake is released.

8.3. Record electrical calibration signals prior to and after testing each section, or as needed to ensure valid data.

8.4. *Data Evaluation*—Evaluate the resulting frictional properties records as follows:

8.4.1. Mark the point of wheel lockup and measure the data from a point not less than 0.2 seconds after this mark for an interval not less than 1.0 seconds nor more than 3.0 seconds. Average the data between these points and use the mean value to read or to calculate the FN.

9. CALCULATION

9.1. Calculate the FN as follows:

$$\mathrm{FN} = \left(F/W\right) \times 100 \tag{1}$$

where:

F = tractive force (horizontal force applied to the test tire at the tire-pavement contact patch), N (lbf); and

W = dynamic vertical load on test wheel; N (lbf).

9.2. For trailers not of the parallelogram design or where the vertical wheel load is not measured directly, the wheel load, *W,* depends on the kinematic layout of the trailer and on the friction force.

Wheel load reduction due to unloading produced by the friction force must be taken into account and the following formula used:

$$\mathrm{FN} = \left(F/W\right) \times 100 \qquad (2)$$

where:

F = tractive force (horizontal force applied to the test tire at the tire-pavement contact patch), N (lbf); and

W = $W_o - (H/L)F$, where:

  W_o = static vertical load on the test tire, N (lbf).

  H = hitch height, mm (in.); and

  L = trailer wheelbase length (center of axle to center of hitch), mm (in.).

9.3. For a vehicle not of a trailer design, the dynamic vertical load must be either measured or computed by analysis of the statics and kinematics of the test vehicle.

9.4. For instrumentation systems that incorporate automatic dynamic FN computation equipment, the horizontal tractive force is automatically divided by the dynamic vertical load in real time (Section 9.1). The arithmetic mean FNs can be recorded on the strip chart as an amplitude trace to the same scale as the dynamic FN trace and scaled directly from the chart or may be digitized and recorded on magnetic tape, or other electronic storage medium, or punched tape, or by the printer on paper tape. When the smooth-tread tire of M 286 is used, the same calculations apply but the designation is FN^{B}. The following equations apply:

$$fn(t) = \frac{f_h(t)}{f_v(t)} \times 100 \qquad (3)$$

$$\mathrm{FN} = \left[1/\left(t_2 - t_1\right)\right] \int_{t_1}^{t_2} fn\left(t\right) dt \qquad (4)$$

where:

$fn(t)$ = dynamic friction number in real time;

$f_h(t)$ = dynamic tractive force in real time, N (lbf);

$f_v(t)$ = dynamic vertical load in real time, N (lbf);

t_1 = time of start of averaging period, s;

t_2 = time of end of averaging period, s; and

FN = mean friction number.

If a 1s averaging interval is used, then $t_1 = 0$, $t_2 = 1$, and the equation reduces to:

$$\mathrm{FN} = \int_0^1 fn\left(t\right) dt \qquad (5)$$

10. FAULTY TESTS

10.1. Test results that are manifestly faulty, or that differ by more than 5 FN from the average of all tests in the same test section, shall be treated in accordance with ASTM E 178.

11. REPORTS

11.1. *Field Report*—The field report for each section shall contain data on the following items:

11.1.1. Location and identification of test section;

11.1.2. Date and time of day;

11.1.3. Weather conditions, principally temperature, cloud cover, and wind;

11.1.4. Lane and wheel path tested;

11.1.5. Speed of test vehicle (for each test); and

11.1.6. Friction number (for each test).

11.2. *Summary Report*—The summary report shall include, for each test section, data on the following items insofar as they are pertinent to the variables or combinations of variables under investigation:

11.2.1. Location and identification of test section;

11.2.2. Number of lanes and presence of lane separators;

11.2.3. Grade and alignment;

11.2.4. Pavement type, mix design of surface course, condition, and aggregate type (specific source, if available);

11.2.5. Age of pavement;

11.2.6. Average of daily traffic;

11.2.7. Posted speed limit;

11.2.8. Date and time of day;

11.2.9. Weather conditions;

11.2.10. Lane and wheel path tested;

11.2.11. Average-, high-, and low-FN for the test section and speed at which the tests were made. (If values are reported that were not used in computing the average, this fact shall be recorded); and

11.2.12. Plot of speed gradient data (if obtained).

12. PRECISION AND BIAS

12.1. The relationship of observed FN units to some “true” value of locked-wheel sliding friction has not been established at this time. As a result, only repeatability is given for this test method.

12.2. The acceptable precision of FN units can be stated in the form of repeatability. As there is no significant correlation between standard deviation and arithmetic mean of sets of test values, it appears that standard deviations are applicable to this test method regardless of the average locked wheel sliding friction of the surface. An acceptable standard deviation of two FN units was obtained from numerous tests conducted on a variety of systems at the Field Test and Evaluation Centers.

12.3. This value is based on evaluations of many friction test trailers. The standard deviation of each was determined at each of three speeds on the basis of 36 individual friction tests, 12 each on each of three pads. It was also determined for each trailer on an overall speed basis of 108 individual friction tests, 12 at each of three speeds on each of three pads.

13. REFERENCE

13.1. Neill, Jr., A. H., P. L. Boyd, and J. Hinch. Filtering Techniques for Measuring Peak Braking Coefficients. *Tire Science and Technology*, Vol. 6, No. 4, November 1978, pp. 263–275. (Also see ASTM F 408.)

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[1] Except for terminology and the use of SI units, this test method is the same as ASTM E 274-97.

Standard Method of Test for

Surface Frictional Properties Using the British Pendulum Tester

AASHTO Designation: T 278-90 (2007)[1]
ASTM Designation: E 303-93 (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

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Surface Frictional Properties Using the British Pendulum Tester

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1. SCOPE

1.1. This method covers the procedure for measuring surface frictional properties using the British Pendulum Skid Resistance Tester. A method for calibration of the tester is included in the Annex.

1.2. The British Pendulum Tester is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The tester is used for laboratory as well as field tests on flat surfaces, and for polish value measurements on curved laboratory specimens from accelerated polishing wheel tests.

1.3. The value measured, British Pendulum (Tester) Number (BPN) for flat surfaces and polish values for accelerated polishing wheel specimens, represents the frictional properties obtained with the apparatus and procedures stated herein, and does not necessarily agree or correlate with other slipperiness measuring equipment results.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENT

2.1. *AASHTO Standard*:

- M 261, Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests

2.2. *ASTM Standard*:

- E 501, Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests

2.3. *Other Documents*:

- "Development and Performance of Portable Skid-Resistance Tester," Giles, C. G., Sabey, Barbara E., and Carden, K. W. F., *Road Research Technical Paper No. 66*, Road Research Laboratory, Department of Scientific and Industrial Research, Crowthorne, England, 1964

3. SUMMARY OF METHOD

3.1. This method consists of using a pendulum-type tester with a standard rubber slider to determine the frictional properties of a test surface.

3.2. The test surface is cleaned and thoroughly wetted prior to testing.

3.3. The pendulum slider is positioned to barely come in contact with the test surface prior to conducting the test. The pendulum is raised to a locked position, then released, thus allowing the slider to make contact with the test surface.

3.4. A drag pointer indicates the BPN. The greater the friction number between the slider and the test surface, the more the swing is retarded and the larger the BPN reading. Four pendulum swings are made on each test surface for natural rubber or five swings for M 261 rubber.

4. SIGNIFICANCE AND USE

4.1. This method provides a measure of a frictional property or microtexture of surfaces, either in the field or in the laboratory.

4.2. This method may be used to determine the relative effects of various polishing techniques on materials or material combinations.

4.3. The values measured in accordance with this method do not necessarily agree or directly correlate with those obtained utilizing other methods of determining friction properties or skid resistance.

Note 1—BPN and polish values from similar types of surfaces will not be numerically equal, primarily because of the differences in slide length and surface shape. Theoretical correction of the polish values to obtain numerical equality, either by mathematical manipulation or by use of special measuring scales, is not recommended.

5. APPARATUS

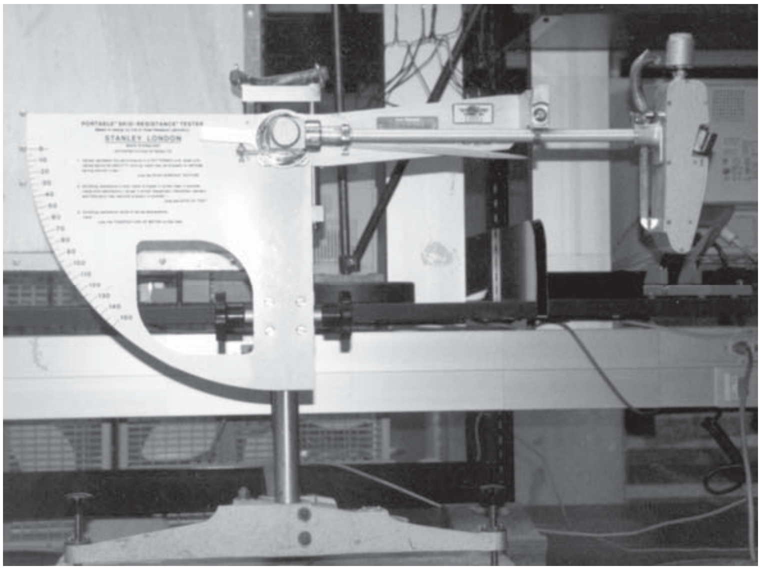

Figure 1—British Pendulum Tester

5.1. *British Pendulum Tester (Figure 1)*—The pendulum with slider and slider mount shall weigh 1500 ± 30 g. The distance of the center of gravity of the pendulum from the center of oscillation shall be 16.2 ± 0.2 in. (411 ± 5 mm). The tester shall be capable of vertical adjustment to provide a slider contact path of from $4^7/_8$ to 5.0 in. (124 to 127 mm) for tests on flat surfaces and $2^{15}/_{16}$ to $3^1/_{16}$ in. (75 to 78 mm) for tests on polishing wheel specimens. The spring and lever arrangement shown in Figure 2 shall give an average normal slider load between the 3 in. (76 mm) wide slider and test surface of 2500 ± 100 g as measured by the method prescribed in the Annex.

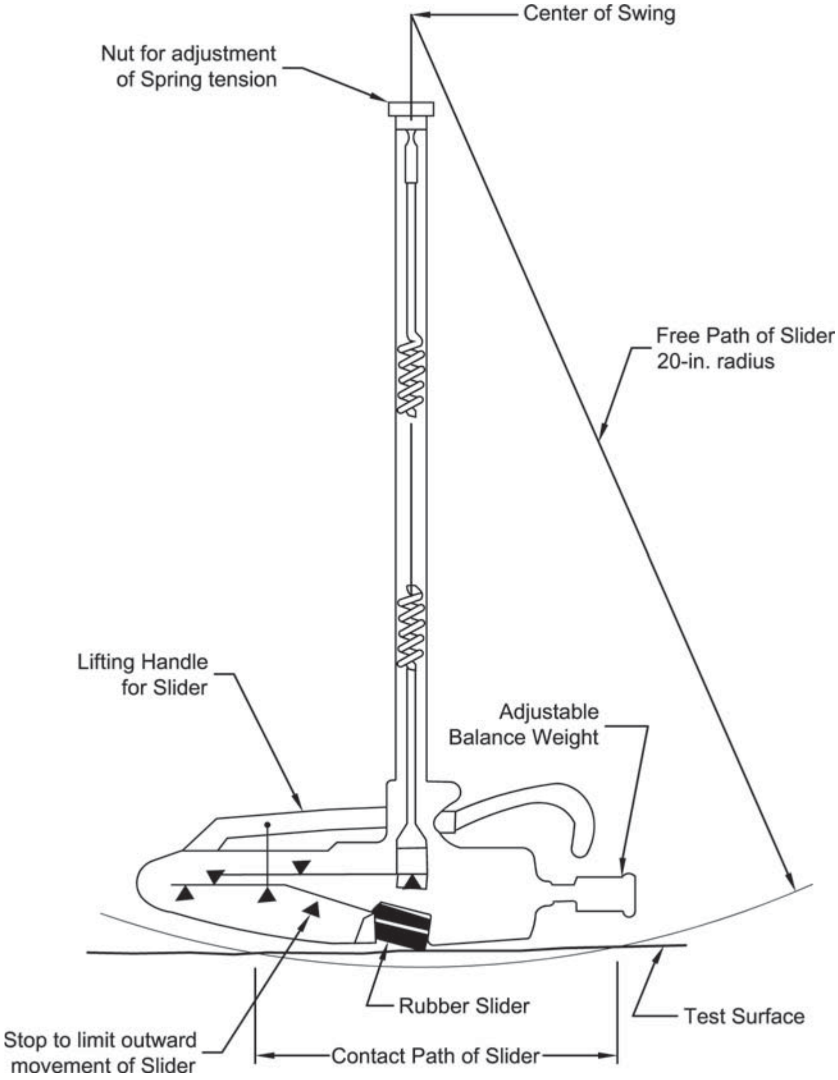

Figure 2—Schematic Drawing of Pendulum Showing Spring and Lever Arrangement

5.2. *Slider*—The slider assembly shall consist of an aluminum backing plate to which is bonded a $^1/_4$ by 1 by 3 in. (6 by 25 by 76 mm) rubber strip for testing flat surfaces or a $^1/_4$ by 1 by $1^1/_4$ in. (6 by 25 by 32 mm) rubber strip for testing curved polishing wheel specimens. The rubber compound shall be natural rubber meeting the requirements of the Road Research Laboratory (see reference under Section 2.3) or synthetic rubber as specified in M 261.

5.2.1. New sliders shall be conditioned prior to use by making 10 swings on No. 60 grade silicon carbide cloth or equivalent under dry conditions. The swings shall be made with a tester adjusted as in Section 7.

Note 2—Carbide cloth material known to be suitable for this purpose is available from 3M Company, St. Paul, MN, under the trade name Type B Safety-Walk.

5.2.2. Wear on the striking edge of the slider shall not exceed $^1/_8$ in. (3.2 mm) in the plane of the slider or $^1/_{16}$ in. (1.6 mm) vertical to it, as illustrated in Figure 3.

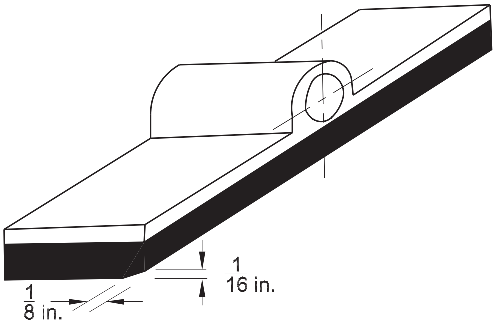

Figure 3—Slider Assembly Illustrating the Maximum Wear on Striking Edge

5.3. *Accessories*:

5.3.1. Contact path gauge shall consist of a thin ruler suitably marked for measuring contact path length between $4^7/_8$ and 5 in. (124 and 127 mm) or between $2^{15}/_{16}$ and $3^1/_{16}$ in. (75 and 78 mm) as required for the particular test.

5.3.2. Miscellaneous equipment, such as water container, surface thermometer, and brush is recommended.

6. TEST SPECIMEN

6.1. *Field*—Field test surfaces shall be free of loose particles and flushed with clean water. The test surface does not have to be horizontal provided the instrument can be leveled in the working position using only the leveling screws and the pendulum head will clear the surface.

6.2. *Laboratory*—Laboratory test panels shall be clean and free of loose particles and shall be held rigidly so as not to be moved by the force of the pendulum.

6.2.1. Flat laboratory samples shall have a test surface of at least $3^1/_2$ by 6 in. (89 by 152 mm).

6.2.2. Accelerated laboratory polishing wheel specimens shall have a test surface of at least $1^3/_4$ by $3^1/_2$ inches (45 by 90 mm) and shall be curved in the arc of a circle 16 in. (406 mm) in diameter.

7. PREPARATION OF APPARATUS

7.1. *Leveling*—Level the instrument accurately by turning leveling screws until the bubble is centered in the spirit level.

7.2. *Zero Adjustments*—Raise the pendulum mechanism by loosening the locking knob (directly behind pendulum pivot) and turn either of the pair of head movement knobs at the center of the tester to allow the slider to swing free of the test surface. Tighten the locking knob firmly. Place the pendulum in the release position and rotate the drag pointer counterclockwise until it comes to rest against the adjustment screw on the pendulum arm. Release the pendulum and note the pointer reading. If the reading is not zero, loosen the locking ring and rotate the friction ring on the bearing spindle slightly and lock again. Repeat the test and adjust the friction ring until the pendulum swing carries the pointer to zero.

7.3. *Slide Length Adjustment*:

7.3.1. With the pendulum hanging free, place the spacer under the adjusting screw of the lifting handle. Lower the pendulum so the edge of the slider just touches the test surface. Lock the pendulum head firmly, raise the lifting handle, and remove spacer.

7.3.2. Raise the slider by lifting the handle, move the pendulum to the right, lower the slider, and allow the pendulum to move slowly to the left until the slider edge touches the test surface. Place the contact path gauge beside the slider and parallel to the direction of swing to verify the length of the contact path. Raise the slider, using the lifting handle, and move the pendulum to the left, then slowly lower it until the slider edge again comes to rest on the surface. If the length of the contact path is not between $4^7/_8$ and 5 in. (124 and 127 mm) on flat test specimens or between $2^{15}/_{16}$ and $3^1/_{16}$ in. (75 and 78 mm) on curved polishing wheel specimens measured from trailing edge to trailing edge of the rubber slider, adjust by raising or lowering the instrument with the front leveling screws. The slide length may also be adjusted by means of the vertical height control knobs. Readjust the level of the instrument, if necessary. Place the pendulum in the release position and rotate the drag pointer counterclockwise until it comes to rest against the adjustment screw on the pendulum arm.

8. PROCEDURE

8.1. Apply sufficient water to cover the test area thoroughly. Execute several swings until consistent results are obtained, but do not record the readings.

Note 3—Always catch the pendulum during the early portion of its return swing. While returning the pendulum to its starting position, raise the slider with its lifting handle to prevent contact between slider and the test surface. Prior to each swing, the pointer should be returned until it rests against the adjustment screw.

8.2. Rewet the test area and without delay make four more swings, rewetting the test area prior to each swing and recording the results.

Note 4—Use four swings for natural rubber and five swings for AASHTO M 261 rubber. Care should be taken that the slider remains parallel to the test surface during the swings, and does not rotate so that one end rather than the entire striking edge makes the initial contact. Available data indicate that tilting of the slider may cause erroneous BPN readings. Installation of a small flat spring will relieve the problem. The spring can be inserted into a slot in the spring clip and the assembly secured by the cotter pin as shown in Figure 4. The free ends of the spring can rest on the slider backing-plate to restrain the slider from tilting.

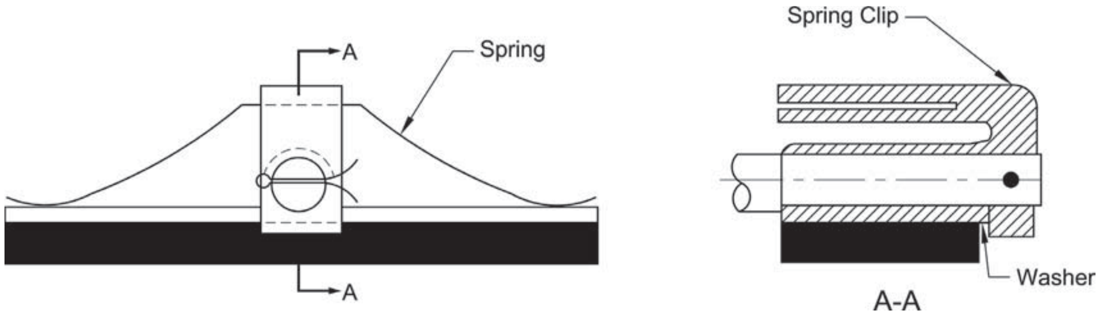

Figure 4—Spring Clip and Spring to Inhibit Slider Rotation

8.3. Recheck the slider contact length in accordance with Section 7.3.

8.4. Recheck the zero adjustment in accordance with Section 7.2.

9. REPORT

9.1. *The report shall include the following*:

9.1.1. Individual values in BPNs or polish values, and the average BPN or average polish value for each test surface.

9.1.2. Temperature of the test surface.

9.1.3. Type, age, condition, texture, and location of the test surface.

9.1.4. Type and source of aggregate for polish value tests.

9.1.5. Type and age of the rubber slider.

10. PRECISION AND BIAS

Note 5—The following material pertains only to the precision and bias of BPN units.

10.1. *Repeated tests show standard deviations as follows*:

- British rubber sliders, 1.0 BPN units
- Sliders conforming to M 261, 1.2 BPN units

In both cases, the upper quartile of variability is represented in prevailing test instruments. As there is no marked correlation between standard deviation and arithmetic mean of sets of test values, it appears that standard deviations are pertinent to this test regardless of the average frictional levels being tested.

10.2. The relationship, if any exists, of observed BPN units to some “true” value frictional level has not been and probably cannot be studied. As a result, precision and bias of this test in relation to a true frictional level measure cannot be evaluated, and only repeatability is given for the method.

10.3. *Determine the testing error as follows*:

$$E = \frac{t(\sigma)}{\sqrt{n}} \qquad (1)$$

where:

E = testing error,

t = normal curve of 1.96 or 2.0 rounded,

σ = standard deviation of individual test results (BPNs), and

n = number of tests.

10.4. In order to assure that the testing error stays within 1.0 BPN at a 95 percent confidence level (corresponding to a normal curve of 1.96 or 2.0 rounded), the following number of record swings are needed per sample:

- British natural rubber sliders, four
- Sliders conforming to M 261, five

ANNEX

(Mandatory Information)

A1. CALIBRATION

A1.1. *Weight of Pendulum*—The pendulum arm with mounted rubber slider shall be disconnected from the instrument and weighed to the nearest 1 g.

A1.2. *Center of Gravity*—The center of gravity of the pendulum with a mounted rubber slider shall be determined by placing the pendulum assembly over a knife edge and experimentally locating the point of balance as shown in Figure A1.1. The adapter nut shall be held at the far end of the arm by a lightweight paper wedge. After the point of balance has been obtained, the position of the balance weight shall be adjusted until the sides of the pendulum foot are horizontal.

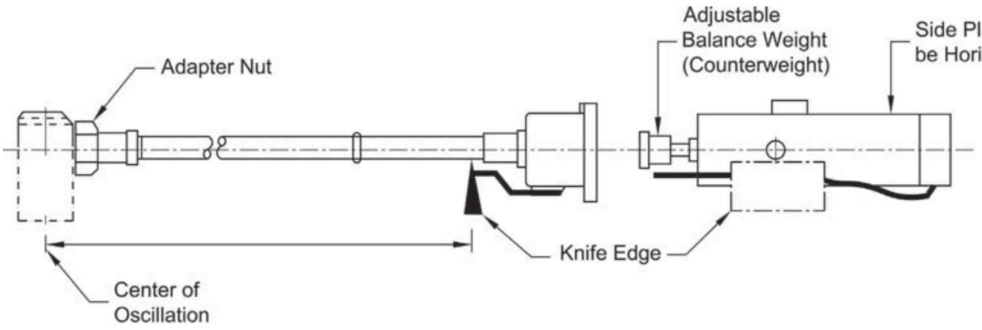

Figure A1.1—Pendulum Assembly Showing Location of the Point of Balance

A1.3. *Distance of Center of Gravity from Center of Oscillation*—With the pendulum reconnected to the tester and knurled bearing cap removed, the distance shall be measured from the center of oscillation (center of bearing nut) to the point of balance (center of gravity). This distance shall be measured directly to the nearest 0.04 in. (1 mm).

A1.4. *Slider Load*—The pendulum shall be clamped to a holder attached to the scale plate of the tester and the tester placed and leveled on a tripod stand as shown in Figure A1.2. Insert the spacer. Adjust the pan balance with a bearing assembly (Note 5) on one pan and tare weights on the other pan so that the balance pointer is at a center scale reading. The pendulum, with a slider, shall be lowered with the vertical height knobs of the tester until the slider is approximately 0.01 in. (0.25 mm) from the top surface of the bearing assembly. Lock the vertical height knob and remove the spacer. This will cause an unbalance, which shall be partially compensated by adding weights to the opposite pan to bring the indicator to within approximately 200 g of the center scale reading. To complete the balance procedure, the pointer is returned to the center scale reading by adding water slowly into a graduated cylinder. Empty the cylinder and repeat the pouring. Record the average weight required to raise the slider so that the balance pointer is at the center of the scale (Note A1). If the average, normal slider load between the 3-in. (76.2-mm) wide slider and the pan balance is not within the requirements stated in Section 5.1, adjust the spring tension nut illustrated in Figure 2 and redetermine the slider load.

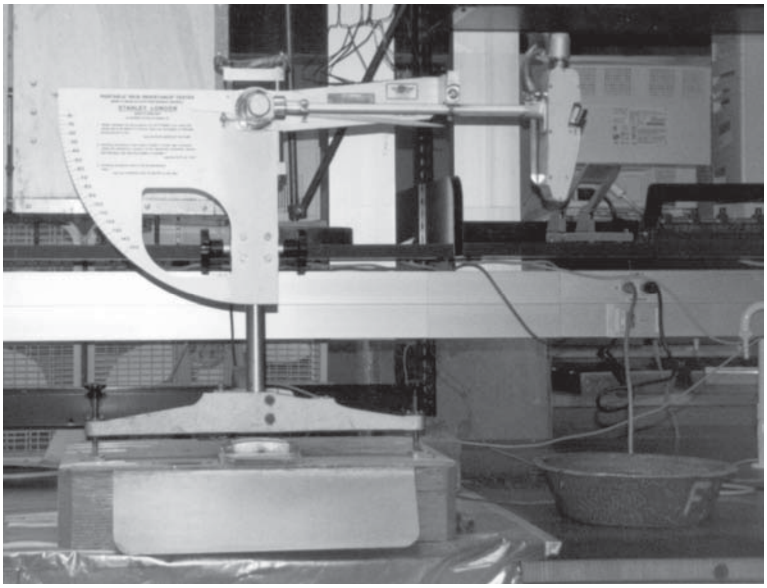

Figure A1.2—Arrangement of the British Pendulum Tester, Showing Pendulum Assembly and Pan Balance Used to Measure Slider Load

Note A1—The bearing assembly may be a "ladder" bearing with a rigid, free-moving top plate or a similar arrangement so that no horizontal loads are introduced while measuring the vertical slider load.

Note A2—It may be necessary to move the pans of the balance up and down to "work" the spring in order to get smooth and consistent readings. If the measurements of the slider load are still irregular after "working" the spring, remove the side and bottom panels of the pendulum foot and inspect for cleanliness of the bearing surfaces and knife edges illustrated in Figure 2 and redetermine the slider load.

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[1] This method agrees with ASTM E 303-93 (2003), except for differences in the number of allowed unrecorded swings in the test procedure and the addition of an optional method of slide length adjustment.

Standard Method of Test for

Calibrating a Wheel Force or Torque Transducer Using a Calibration Platform (User Level)

AASHTO Designation: T 282-01 (2006)
ASTM Designation: E 556-95 (2000)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Calibrating a Wheel Force or Torque Transducer Using a Calibration Platform (User Level)

AASHTO Designation: T 282-01 (2006)
ASTM Designation: E 556-95 (2000)

1. SCOPE

1.1. This method covers the calibration of the force (or torque) transducer and associated instrumentation of a mounted test wheel by using a calibration platform. It is used for establishing correction factors for changes in transducer output due to changes in operating conditions.

1.2. This method is a static calibration, simulating the traction force between a tire and the pavement.

1.3. In the case of a force-measuring system, the instrumentation readout is directly proportional to the calibration force input.

1.4. In the case of a torque-measuring system, the instrumentation readout is a measure of the calibration force input and the effective tire radius.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 261, Rib-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests
- M 286, Smooth-Tread Standard Tire for Special-Purpose Pavement Frictional-Property Tests
- T 242, Frictional Properties of Paved Surfaces Using a Full-Scale Tire

2.2. *ASTM Standards*:

- E 274, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire
- F 377, Standard Practice for Calibration of Braking/Tractive Measuring Devices for Testing Tires

3. SUMMARY OF METHOD

3.1. The vertical static loads (forces) on the test wheel(s) and hitch are established. If the tester is of the trailer type, it must be connected to its tow vehicle. Traction forces are applied to the locked wheel(s) at the tire–platform interface. The wheel transducer is calibrated while trailer and tow vehicle displacements are measured from the initial position for the applied traction force. The calibration platform consists of a bearing that is frictionless in all directions of the horizontal plane supporting a rigid plate with a high-friction surface. The force applied to this platform is measured by a suitable transducer.

3.2. Wheel transducer linearity and hysteresis are determined by recording data using an electronic digital meter and/or an *x-y* plotter, and should also be correlated with data collected from the tow vehicle instrumentation. Techniques are given for establishing reference signals to be used as calibration points.

3.3. With calibration platforms having force-measurement capability also in the vertical direction, test-wheel load (force) is recorded as a function of the applied tractive calibration force.

3.4. With a wheel transducer also having normal load (force)-measuring capability, the transducer output is compared with the corresponding vertical output of the calibration platform.

4. SIGNIFICANCE AND USE

4.1. Wheel force or torque transducers are used under dynamic test conditions, and the measurements are subject to many error sources. The static calibration recommended by the present standard cannot eliminate all error sources. Its significance is in providing an accurate calibration of the transducer and the associated electronics, readout, and recording equipment.

4.2. The calibration result may be used to make either mechanical or electronic adjustments until the readout agrees with the calibration input. Alternatively, calibration curves or tables may be prepared to be used as corrections to measured results.

5. DESCRIPTION OF TERMS SPECIFIC TO THIS STANDARD

5.1. *wheel force transducer system*—a force-to-electrical signal converter system including transducer(s), associated signal condition, zeroing, amplifying, recording, and monitoring instrumentation.

5.2. *calibration reference signals*—repeatable signals in the range of expected wheel-force transducer system loading. These signals could be either constant voltages, preferably, or produced by a strain-gauge calibration shunt resistor.

5.3. *calibration platform*—a moving platform for applying a force in the contact plane of a tire, and associated means for measuring the applied force. The calibration platform consists of a rigid plate with a high-friction surface, in contact with the tire footprint, supported on a frictionless, preferably air, bearing. It may also be instrumented to measure vertical forces (loads).

5.4. *hysteresis*—the maximum difference between corresponding transducer outputs (of the wheel force transducer system) at increasing and decreasing applied calibration force, expressed as a percentage of full load. Proven outliers are excluded.

5.5. *linearity nonlinearity*—the maximum deviation of the transducer output(s) (of the wheel force transducer system) from the “best-fit” linear relation to the applied calibration force, expressed as a percentage of full scale. Proven outliers are excluded.

5.6. *test wheel*—a wheel and test tire assembly mounted to a test vehicle by means of a force or torque transducer.

5.7. *crosstalk*—the undesired effect of force readings appearing on an unloaded axis of a transducer while applying force to another.

5.8. *horizontal traction (traction)*—a force acting in a horizontal axis through the wheel transducer; i.e., locked wheel drag force.

5.9. *vertical load (load)*—force acting in a vertical axis through the wheel transducer; i.e., weight.

6. APPARATUS

6.1. The calibration apparatus shall consist of the basic components described below, and calibrated in accordance with Section 6.3 of ASTM F 377.

6.1.1. A calibration platform for applying tractive forces at the tire–platform interface of a test wheel, with a calibrated internal or external reference force transducer to measure these forces. Capability of measuring vertical forces (wheel loads) also is desirable.

6.1.2. A system for generating traction forces applied through the calibration platform.

6.1.3. Instrumentation for recording or indicating transducer outputs, including digital meters and, optionally, an *x-y* recorder.

6.1.4. An accurate level, tire pressure gauge, and thermometer for measuring ambient temperatures.

6.1.5. Scale(s) for measuring vertical wheel load, accurate within 0.5 percent of maximum expected axle load for the test trailer.

7. PREPARATION OF APPARATUS

7.1. *Site*—Select a sheltered, level, paved area. (A hard surface, preferably under cover, is desirable.)

7.2. *Calibration Platform and Associated Instrumentation*—Prepare the calibration platform and associated instrumentation following established set-up procedures and the manufacturers' manuals where applicable.

7.3. *Test Tires*—Set the inflation pressure under normal vertical load (force). Inflation pressure shall be 165.0 ± 3.5kPa (24.0. ± 0.5 psi) at ambient temperature (cold).

7.4. *Traction Tester Instrumentation*—Check the test vehicle instrumentation by following established set-up procedures for the system with reference to the recommended procedure in the manufacturer's manual, where applicable. Set all gains and offsets at values normally used during friction testing. Record the settings.

7.4.1. *Force-Type Transducer*—Load cross talk into traction; if, with full normal load back on the test wheel, the traction output is different from zero by more than 1 percent of the applied normal load, adjust by either rotating the transducer (if provisions for rotation have been made) or by changing the hitch height; that is, tilting the trailer to orient the transducer horizontal axis parallel to the calibration plane. Then apply 2.2 kN (500 lbf) of traction force and note the change in load reading. If more than 1 percent cross talk, check transducer leveling and repeat this test.

7.4.2. *Torque-Type Transducer*—Use steps in Sections 7.4 and 7.4.1, substituting the torque output for the traction. If the load into torque cross talk is greater than 1 percent of the applied normal load, refer to the manufacturer since there are normally no user adjustments.

7.5. *Test Trailer*—Position the trailer coupled to its tow vehicle on level ground and set the trailer variables such as tire pressure, high height, and inflation pressure of air shock absorbers, where present, to the normal operating values. Measure the hitch height from level ground to the center of the hitch. Decouple the trailer and weigh it at each point of support, maintaining its relative level. Correct the weights, if needed, to comply with T 242. Recouple the trailer to the towing vehicle.

Note 1—The tow vehicle should have one-half tank of water and a full fuel load before leveling the trailer.

7.6. *Wheel Transducer*—With the test wheel loaded, the wheel transducer traction output should be adjusted to zero. Then remove 2.2 kN (500 lbf) of the load and recheck traction zero.

7.7. Record all measures, weights, and dimensions, and the trailer leveling adjustments that give zero transducer outputs.

8. PROCEDURE

8.1. Determine that the calibration platform has been suitably calibrated within a reasonable period of time (see Section 6.1).

8.2. If the test vehicle is of the trailer type, it should be hitched and aligned with the tow vehicle. The calibration may be performed with auxiliary electrical power for the instrumentation. In this case, after completing the calibration, check the system when powered by the vehicle electrical system with the engine running, to assure that the output(s) have not changed. The preparations described in Section 7 shall have been performed.

8.3. Place the test wheel(s) on the calibration platform(s) using blocks, if needed, under the other wheels to maintain a level plane of support for all system tires.

8.4. With the test wheel raised clear of the platform, zero the output(s) of the calibration platform in accordance with established operating procedures. Zero the wheel transducer output(s).

Note 2—**Warning**: Make sure that the wheel brakes do not drag.

8.5. Align the calibration platform(s) and the associated force application system(s) with the test tire(s) and lower the test wheel onto the platform.

8.6. The platform shall be level within ±0.25 degree prior to calibration.

Note 3—Increased accuracy may be obtained by maintaining the aforementioned level throughout the calibration procedure.

8.7. Record the ambient temperature. To meet this standard, calibration can only be done when the ambient temperature is between 4 and 38°C (40 and 100°F).

8.8. Use digital meter(s) and, optionally, x-y recorder(s) to observe the wheel force transducer system signals at the input to the system recorder.

8.8.1. With the trailer level and with full vertical load and zero traction force applied to the test wheel(s), adjust the system vertical load indicator to correspond with the platform vertical load value.

8.8.2. Lock the test wheel and apply a mid-range tractive force (typically 2.2 kN (500 lbf)) via the platform to the test wheel. Adjust the system traction indicator to correspond with the platform traction value. Return the traction force to zero.

8.9. Record the wheel-transducer vertical load output and the force-plate transducer vertical output, on both the system recorder and the meter, while increasing and decreasing the vertical force applied by at least 20 percent of the static wheel load value in 445-N (100-lbf) increments. This can be done by adding 90-kg (200-lb) shot bags; e.g., to the trailer wheel load.

8.10. Establish the linearity and hysteresis characteristics for the vertical transducer output, if applicable, using data in Section 8.9.

8.11. Record the wheel transducer output(s). (Horizontal traction and vertical load readings on both the system recorder and the meter while increasing and decreasing the traction force by 445-N (100-lbf) increments through the full calibration range (typically 0 to 50 percent of vertical load).

Note 4—For a two-wheeled towed test trailer, the test wheel vertical load should decrease linearly from the zero traction value as the applied traction force increases at a slope proportional to the H/L ratio of the trailer, where H is the initial hitch height and L is the initial hitch-to-axle length (see T 242). The non-test wheel load (force) should remain constant at the zero traction value.

8.12. If the test wheel load and traction values obtained in Sections 8.9 and 8.11 agree with the platform values within ±1 percent, apply system load and traction calibration signals and record for future reference. If differences greater than 1 percent are found, the system may require maintenance or the cross talk should be rechecked as described in Section 7.6.

Note 5—Some calibration platforms use ball or roller bearings (instead of air bearings). Any side force on the wheel under calibration will generate additional friction forces in the calibration platform and cause erroneous readings and hysteresis.

8.13. Perform the calibration procedure of Section 8 for the second wheel transducer, if applicable.

9. REPORT

9.1. *The report shall contain the following information*:

9.1.1. Skid measuring system identification;

9.1.2. Wheel-transducer identification;

9.1.3. Date;

9.1.4. Test equipment identification in accordance with calibration report(s);

9.1.5. Test tires identification;

9.1.6. Static weight at wheels and hitch;

9.1.7. Setting of the skid tester variables;

9.1.8. Measured values *H* (hitch height), *L* (length from hitch to wheel center), and *T* (track width);

9.1.9. Tow-vehicle standardization details;

9.1.10. Instrumentation check-out details;

9.1.11. Orientation of the transducer-sensitive axis;

9.1.12. Statement of loading conditions under which the readouts are zeroed;

9.1.13. Loading conditions under which the reference calibration points are applicable;

9.1.14. Record of the on-board and external indicator outputs of each transducer output versus increasing and decreasing traction force and vertical load (force);

9.1.15. Statement of calibration values, linearity, and hysteresis characteristics for the transducer and its associated readout;

9.1.16. Correlation of external meter output with on-board meter or recorder output;

9.1.17. Report section for a second transducer, if applicable; and

9.1.18. Remainder of operating coefficient established in Section 8, ambient temperature range during the calibration; and notes on calibration procedures.

10. FREQUENCY OF CALIBRATION

10.1. It is recommended that the system be calibrated according to all sections of this specification at least once a year.

10.2. For a routine test to indicate normal system operations only, it may be sufficient to abbreviate the procedure in Section 8.

10.3. Calibration should be performed at least once a month according to Section 10.2.

10.4. Calibration should be performed whenever the measured friction is inconsistent with expected values for a given test site.

11. PRECISION AND BIAS

11.1. As a rule of thumb, instrumentation bias should be approximately ten times greater than the desired bias of the measurement. This would require the calibration to be made within 0.1 SN (skid number). To obtain this bias for skid testers in the mid-range of measurements (that is, SN = 40) and with a 4450-N (1000-lbf) vertical wheel load, the bias would have to be

±5 N (±1 lbf). Such an accuracy is difficult to obtain in practice, primarily because of the uncertain tire response. The recommended bias is 1 percent or better.

11.2. To obtain satisfactory test precision with a system so calibrated, it is recommended to conduct replicate tests. The preferred method for selecting the number of replicates is based on the desired precision and known performance of the test system. When replicate tests are conducted by experienced test crews and equipment that is in good condition, a precision of ±2 SN is readily achievable. Alternatively, a fixed number of replicates (such as recommended in T 242) may be used.

Standard Method of Test for

Prediction of Asphalt-Bound Pavement Layer Temperatures

AASHTO Designation: T 317-04 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Prediction of Asphalt-Bound Pavement Layer Temperatures

AASHTO Designation: T 317-04 (2009)

1. SCOPE

1.1. This test method provides a standard for measuring pavement surface temperature and predicting temperatures within the asphalt-bound layer(s) of a flexible pavement section. This test method provides a means of estimating the temperature at depth from the pavement surface temperature, the time of day, the previous day's high and low air temperatures, and the desired depth at which the temperature is to be estimated.

1.2. Deflection testing commonly involves the measurement of the pavement surface temperatures. This standard is based on temperature relationships developed as part of the Federal Highway Administration (FHWA) Long-Term Pavement Performance (LTPP) Seasonal Monitoring Program.

1.3. This test method is applicable for temperature predictions on flexible asphalt concrete (AC) and composite asphalt over portland cement concrete (AC/PCC) pavements.

1.4. *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 256, Pavement Deflection Measurements

2.2. *ASTM Standards*:

- D 4602, Standard Guide for Nondestructive Testing of Pavements Using Cyclic-Loading Dynamic Deflection Equipment
- D 4694, Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device
- D 4695, Standard Guide for General Pavement Deflection Measurements
- D 5858, Standard Guide for Calculating In Situ Equivalent Elastic Moduli of Pavement Materials Using Layered Elastic Theory

2.3. *Strategic Highway Research Program*:

- Manual for FWD Testing in the Long-Term Pavement Performance Study, *Operational Field Guidelines*, Version 2.0, SHRP, National Academy of Sciences, Washington, DC, February 1993

2.4. *Federal Highway Administration*:

- Temperature Predictions and Adjustment Factors for Asphalt Pavements, Report Number FHWA-RD-98-085

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *BELLS*—an acronym based on the initials of the four developers of the method: Baltzer, Ertman-Larsen, Lukanen, and Stubstad.

3.1.2. *depth*—the distance below the surface of the top layer of asphalt.

3.1.3. *one-day air temperature*—the average of the minimum and maximum air temperatures at the location of testing of the previous complete 24-hour day.

4. SUMMARY OF TEST METHOD

4.1. *Input Data Elements*:

4.1.1. *Infrared (IR) Temperature*—The exposed surface temperature of an asphalt pavement is measured, preferably with an infrared (IR) temperature-sensing device.

4.1.2. *Time of Day*—The time of day the temperature measurement takes place is recorded.

4.1.3. *One-Day Temperature*—The average 1-day air temperature of the previous complete 24-hour day is determined and recorded.

4.1.4. *Pavement Depth*—The depth at which an estimate of the asphalt layer temperature that is required is specified.

4.2. The input data elements are entered into a regression formula that predicts the temperature within the asphalt pavement at depth.

5. SIGNIFICANCE AND USE

5.1. Analysis of deflection data from asphalt pavements almost always requires that the deflections or analysis results be adjusted for the effects of temperature. Measuring the temperature at depth requires that a hole be drilled into the pavement, partially filled with fluid, and the temperature measured with hand-held devices. Alternatively, thermistors may be permanently installed at various locations. These processes are time consuming, resulting in a limited number of temperature measurements.

5.2. Current deflection testing equipment is often equipped with surface-temperature sensing devices, for example, an infrared thermometer that measures the surface temperature at every test location. To adequately adjust the deflection or deflection results for the effects of temperature, the temperature at some depth must be known.

5.3. Utilization of this method results in a significant savings in time over the conventional practice of manually drilling holes into the pavement, and it results in a significant increase in the volume of temperature data (one pavement temperature for each test point).

5.4. The BELLS temperature prediction model was based on temperature measurements made with surface temperature measurements between 0 and 40°C during the unfrozen times of the year. Application of BELLS outside of those conditions is not recommended. BELLS has been verified using the LTPP database at both mid-depth and third-depth temperature points. The use of BELLS to predict temperatures at depths shallower than the third point is not recommended.

6. APPARATUS

6.1. *Surface Temperature Measurement Device*:

6.1.1. The surface temperature measurement device can be an IR thermometer mounted on a deflection device, a hand-held IR thermometer, or a surface contact thermometer. The temperature measurement device should be calibrated according to the manufacturer's recommendations.

Note 1—The IR surface temperature is the most significant variable in the BELLS regression equation presented in Section 7.1.1. Thus, it is important that users verify the calibration of the surface temperature measurement device in the application of the equation.

7. CALCULATION

7.1. *BELLS Method*:

7.1.1. The BELLS method for production testing (called BELLS3 in other publications) has been derived based on temperature measurements taken on pavement surfaces that have been shaded for only a short time (less than 1 minute). The following equation is valid for approximately 30 seconds of shading:

$$T_d = 0.95 + 0.892*\mathrm{IR} + \{\log(d) - 1.25\}\{-0.448*\mathrm{IR} + 0.621*(1\text{-day}) + 1.83*\sin(\mathrm{hr}_{18} - 15.5)\} + 0.042*\mathrm{IR}*\sin(\mathrm{hr}_{18} - 13.5 \qquad (1)$$

where:

T_d = pavement temperature at depth d, °C;
IR = infrared surface temperature, °C;
log = base 10 logarithm;
d = depth at which asphalt temperature is to be predicted, mm;
1-day = average high and low air temperature, °C, for the day before the testing;
sin = sine function in 18-hour clock system, with 2π radians equal to one 18-hour cycle;
hr_{18} = time of day, in 24-hour system, but calculated using an 18-hour temperature rise and all cycle, as indicated in Sections 7.1.1 and 7.1.2.

7.1.2. When using the sin (hr18 – 15.5) decimal time function, only use times from 11:00 to 05:00 h. If the actual time is not within this time range, then calculate the sine as if the time is 11:00 h (where the sin = –1). If the time is between midnight and 05:00 h, add 24 to the actual decimal time. Then calculate as follows: If the time is 13:15, then in decimal form, 13.25 – 15.50 = –2.25; –2.25/18 = –0.125; –0.125 × 2π = –0.785 radians; sin (–0.785) = –0.707. [Note that an 18-hour sine function is assumed, with "flat" –1 sin segment between 05:00 and 11:00 h.]

Note 2—BELLS has been verified using the LTPP database at both mid-depth and third-depth temperature points. Since almost no difference exists in the regressions derived from the data at either depth, they were combined in deriving the BELLS equations.

7.2. *Alternate Calculation Method*:

7.2.1. Equation 1 can be calculated alternatively using degrees instead of radians and putting the sine function terms in a tabular form as shown below:

$$T_d = 0.95 + 0.892*\mathrm{IR} + \{\log(d) - 1.25\}*\{-0.44*\mathrm{IR} + 0.621*(1\text{-day}) + 1.83*A\} + 0.042*\mathrm{IR}*B \quad (2)$$

where:

A = dependent on time of day as in Table 1,

B = dependent on time of day as in Table 1,

sin = sine function – brackets contents { } are in degrees; (360 degrees equal to one 18-hour cycle).

Table 1—Values of *A* and *B* as Function of *h*

Time of Day*	*A*	*B*
$0.0 < h < 3.0$	Sin $\{(h + 24 - 15.5)*20\}$	Sin $\{(h + 24 - 13.5)*20\}$
$3.0 < h < 5.0$	Sin $\{(h + 24 - 15.5)*20\}$	–1
$5.0 < h < 9.0$	–1	–1
$9.0 < h < 11.0$	–1	Sin $\{(h - 13.5)*20\}$
$11.0 < h < 24.0$	Sin $\{(h - 15.5)*20\}$	Sin $\{(h - 13.5)*20\}$

* *h* = time of day in 24-hour format (military time) expressed as a decimal; i.e., 1:30 p.m. would be 1.5 + 12 or 13.5.

8. REPORT

8.1. The type of temperature measuring device, the measurement shading conditions, the time of measurement, the date of measurement, and the depth at which the temperature was calculated should be identified.

9. PRECISION AND BIAS

9.1. *Precision*:

9.1.1. The precision of the temperature estimation is described by the regression standard error of estimate. For the BELLS method for production testing (BELLS3), the regression standard estimate of error is ±1.9°C, based on an adjustment using the LTPP database for 30 seconds of shading.

9.2. *Bias*:

9.2.1. There was no means of measuring the bias during the development of the BELLS3 prediction equation.

10. KEYWORDS

10.1.1. Asphalt temperature; backcalculated moduli, Benkelman Beam; Dynaflect; Falling Weight Deflectometer; FWD; layer moduli; Road Rater; temperature correction.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE PROGRAM FOR CALCULATING THE PREDICTED ASPHALT TEMPERATURE BY THE BELLS METHOD

X1.1. *Explanation*:

X1.1.1. *Purpose*—The source code is presented to illustrate application of the temperature prediction equations, particularly the application of the 18-hour sine functions.

X1.1.2. *Language*—The source code is written in BASIC and can be run on a number of basic interpreters or compilers, or easily converted to other computer languages.

X1.2. *Source Code Listing*:

X1.2.1. Program to illustrate the implementation of the BELLS equation for routine testing with approximately 30 seconds of surface shade:

```
CLS
INPUT "Input Surface Temperature "; ir
INPUT "Input Hour of test "; hr
INPUT "Input Minutes past the hour "; min
INPUT "Input the depth for predicting the asphalt temperature "; d
INPUT "Input average air temperature for the day before the test date "; air
decimal.hrs = hr + min/60
IF decimal.hrs > 11 OR decimal.hrs < 5 THEN
IF decimal.hrs < 5 THEN decimal.hrs = decimal.hrs + 24
sine15.5 = SIN(2 * pi * (decimal.hrs – 15.5)/18)
ELSE
sine15.5 = –1
END IF
IF decimal.hrs > 9 OR decimal.hrs < 3 THEN
IF decimal.hrs < 3 THEN decimal.hrs = decimal.hrs + 24
sine13.5 = SIN(2 * pi * (decimal.hrs – 13.5)/18)
ELSE
sine13.5 = –1
```

```
END IF
td = 0.95 + .892 * ir
logdepth = LOG(d)/LOG(10) – 1.25
firstbracket = –0.448 * ir + 0.621 * air + 1.83 * sine15.5
last.term = 0.042 * ir * sine13.5
td = td + logdepth * firstbracket + last.term
```

Standard Method of Test for

Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test

AASHTO Designation: T 87-86 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test

AASHTO Designation: T 87-86 (2008)

1. SCOPE

1.1 This method describes the dry preparation of soil and soil-aggregate samples, as received from the field, for mechanical analysis, physical tests, moisture-density relations test, and other tests as may be desired.

1.2 This method provides qualitative information only; therefore, a precision statement is not applicable.

1.3 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 92, Determining the Shrinkage Factors of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 100, Specific Gravity of Soils
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 248, Reducing Samples of Aggregate to Testing Size

3. APPARATUS

3.1 The balance shall conform to the requirements of M 231, for the class of general purpose balance required for the principal sample mass of the sample being tested.

3.2 *Drying Apparatus*—Any suitable device capable of drying samples at a temperature not exceeding 60ºC (140ºF).

3.3 *Sieves*—A series of sieves of the following sizes: 19.0 mm ($^3/_4$ in.), 4.75 mm (No. 4), 2.00 mm (No. 10), 0.425 mm (No. 40) and others as required for preparing the sample for a specific test. The sieves shall conform to M 92.

Note 1—A 50-mm (2-in.) sieve is required if the sample includes particles retained on the 19.0-mm ($^3/_4$-in.) sieve, and it is desired that the sample for moisture-density relations (T 99 or T 180) contain material between 19.0-mm ($^3/_4$-in.) and 4.75-mm (No. 4) sieve size to represent the fraction between 50 and 19.0 mm (2 and $^3/_4$ in.).

3.4 *Pulverizing Apparatus*—Either a mortar and rubber-covered pestle or a mechanical device consisting of a power-driven, rubber-covered muller suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains.

Note 2—Other types of apparatus, such as a revolving drum into which the soil sample and rubber-covered rollers are placed and tumbled until soil aggregations are pulverized, are satisfactory if the aggregations of soil particles are broken up without reducing the size of the individual grains.

3.5 *Sample Splitter*—A suitable riffle sampler or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle sample splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also permitted.

Note 3—The procedure for proportional splitting is described in T 248.

4. SAMPLE SIZE

4.1 The amounts of soil material required to perform the individual tests are as follows:

4.1.1 *Particle Size Analysis of Soils (T 88)*—For the particle size analysis, material passing a 2.00-mm (No. 10) sieve is required in amounts equal to approximately 110 g for sandy soils and approximately 60 g for silty or clayey soils. A sufficient amount of material retained on either the 4.75-mm (No. 4) sieve or 2.00-mm (No. 10) sieve is required (Note 4) to obtain a representative gradation, and, depending on the maximum particle size, shall not be less than the amount shown in the following table:

Diameter of Largest Particle, mm (in.)	Approximate Minimum Mass of Portion, kg
9.5 (3/8)	0.5
25 (1)	2.0
50 (2)	4.0
75 (3)	5.0

Note 4—The material for coarse sieve analysis may be separated by either of two alternate methods, Section 5.2.1 (2.00-mm sieve) or Section 5.2.2 (4.75-mm sieve). When only a small percentage of the material will be retained on the 4.75-mm or 2.00-mm sieve, a considerable total mass of sample will be required to provide the minimum quantity shown in the above table; consequently, adherence to the minimum mass requirements in the above table may not be necessary if the material represented by the sample is not to be used in a base or subbase course, select borrow, or other item having a requirement for coarse aggregate.

4.1.2 *Specific Gravity (T 100)*—For the specific gravity test performed in conjunction with T 88, material passing the 2.00-mm (No. 10) sieve is required in the amounts (oven-dry) of at least 25 g when the volumetric flask is used and at least 10 g when the stoppered bottle is used.

4.1.3 *Physical Tests*—For the physical tests, material passing the 0.425-mm (No. 40) sieve is required in the total amount of at least 300 g, allocated approximately as follows:

Test (and AASHTO Designation)	Approximate Mass, g
Liquid limit (T 89)	100
Plastic limit (T 90)	20
Shrinkage factors (T 92)	30
Field moisture equivalent (T 93)	50
Check and referee tests	100

4.1.4 *Other Tests*—For quantity of material required for testing, refer to the specific method of test.

5. INITIAL PREPARATION OF TEST SAMPLES

5.1 The soil sample as received from the field shall be dried thoroughly in air or the drying apparatus at a temperature not exceeding 60ºC (140ºF). A representative test sample of the amount required to perform the desired tests (Section 3) shall then be obtained with the sampler, or by splitting or quartering. The aggregations of soil particles shall then be broken up in the pulverizing apparatus in such a way as to avoid reducing the natural size of individual particles.

Note 5—Samples dried in an oven or other drying apparatus at a temperature not exceeding 60ºC (140ºF) are considered to be air-dried.

5.2 The portion of the dried sample selected for particle-sized analysis and physical tests (including specific gravity) shall be weighed, and that mass recorded as the mass of total sample uncorrected for hygroscopic moisture. This portion shall then be separated into fractions by one of the following methods:

5.2.1 *Alternate Methods Using 2.00-mm (No. 10) Sieve*—The dried sample shall be separated into two fractions using a 2.00-mm sieve. The fraction retained on the sieve shall be ground with the pulverizing apparatus until the aggregations of soil particles are broken into separate grains. The ground soil shall then be separated into two fractions using the 2.00-mm sieve.

5.2.2 *Alternate Method Using 4.75-mm and 2.00-mm (Nos. 4 and 10) Sieves*—The dried sample shall first be separated into two fractions using a 4.75-mm sieve. The fraction retained on this sieve shall be ground with the pulverizing apparatus until the aggregation of soil particles are broken into separate grains, and again separated on the 4.75-mm sieve. The fraction passing the 4.75-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for the desired tests shall be obtained and weighed. This split-off portion shall then be separated on the 2.00-mm sieve, and processed as in Section 5.2.1. The material from the split-off fraction that is retained on the 2.00-mm sieve shall be weighed for later use in coarse sieve analysis computations.

6. TEST SAMPLE FOR PARTICLE SIZE ANALYSIS AND SPECIFIC GRAVITY

6.1 The fraction retained on the 2.00-mm (No. 10) sieve in Section 5.2.1 or that retained on the 4.75-mm (No. 4) sieve in Section 5.2.2, after the second sieving, shall be set aside for use in sieve analysis of the coarse material.

6.2 The fraction passing the 2.00-mm (No. 10) sieve in both sieving operations in Sections 5.2.1 or 5.2.2 shall be thoroughly mixed together and, by the use of the sampler or by splitting or quartering, representative portions having approximate masses as follows shall be obtained: (1) for the hydrometer analysis and sieve analysis of the fraction passing the 2.00-mm sieve, 110 g for sandy soil and 60 g for silty or clayey soils; and (2) for specific gravity, 25 g when the volumetric flask is to be used and 10 g when the stoppered bottle is to be used.

7. TEST SAMPLE FOR PHYSICAL TESTS

7.1 The remaining portion of the material passing the 2.00-mm (No. 10) sieve shall then be separated into two parts by means of a 0.425-mm (No. 40) sieve. The fraction retained on the 0.425-mm (No. 40) sieve shall be ground with the pulverizing apparatus in such a manner as to break up the aggregations without fracturing the individual grains. If the sample contains brittle particles, such as flakes of mica, fragments of sea shells, etc., the pulverizing operation shall be done carefully and with just enough pressure to free the finer material that adheres to the coarser particles. The ground soil shall then be separated into two fractions by means of the 0.425-mm (No. 40) sieve, and the material shall be reground as before. When repeated grinding produces only a small quantity of soil passing the 0.425-mm sieve, the material retained on the 0.425-mm sieve shall be discarded. The several fractions passing the 0.425-mm sieve obtained from the grinding and sieving operations just described shall be thoroughly mixed together and set aside for use in performing the physical tests.

8. TEST SAMPLE FOR THE MOISTURE-DENSITY RELATIONS

8.1 The portion of dried soil selected for the moisture-density relations test shall be separated by means of the required sieve as specified in Section 4.1.4. If necessary, the pulverizing apparatus shall be used to break up the soil aggregations retained on this sieve into separate grains. The ground soil shall then be separated into two fractions using the required sieve.

8.2 The fraction retained on the sieve after the second sieving shall be saved, if required. The fractions passing the required sieve in both sieve operations shall be thoroughly mixed and used for the moisture-density test.

9. PRECISION

9.1 Since this preparation for testing produces no numerical values, determination of the precision and accuracy is not applicable.

Standard Method of Test for

Particle Size Analysis of Soils

AASHTO Designation: T 88-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Particle Size Analysis of Soils

AASHTO Designation: T 88-10

1. SCOPE

1.1. This method describes a procedure for the quantitative determination of the distribution of particle sizes in soils.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- M 147, Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 100, Specific Gravity of Soils
- T 146, Wet Preparation of Disturbed Soil Samples for Test
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 100, Standard Specification for ASTM Hydrometers

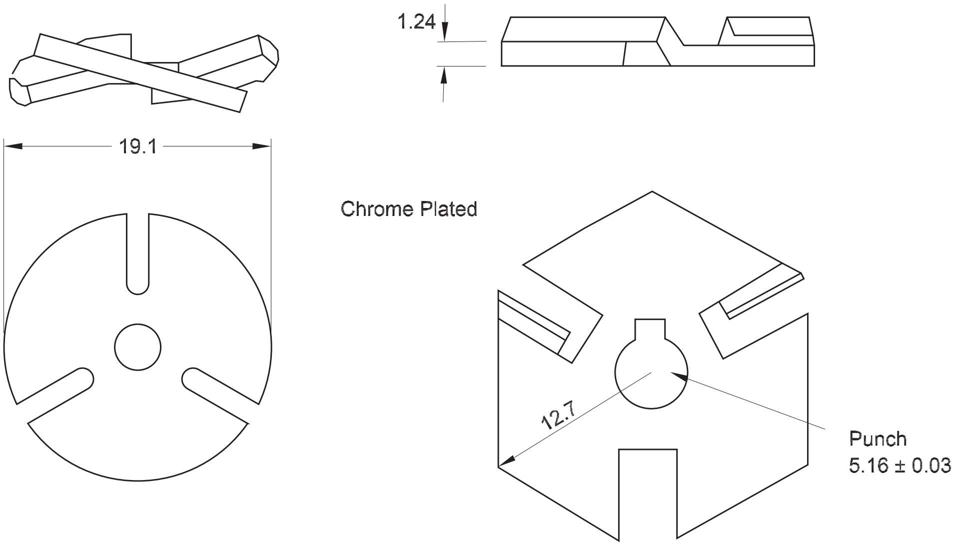
3. APPARATUS

3.1. *The apparatus shall consist of the following*:

3.1.1. *Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5ºC (230 ± 9ºF) for drying the sieve analysis samples.

3.1.2. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

3.1.3. *Stirring Apparatus*—A mechanically operated stirring apparatus consisting of an electric motor suitably mounted to turn a vertical shaft at a speed not less than 10,000 revolutions per minute without load, a replaceable stirring paddle made of metal, plastic, or hard rubber similar to one of the designs shown in Figure 1. The shaft shall be of such length that the stirring paddle will operate not less than 19.0 mm ($^3/_4$ in.) nor more than 38 mm (1.5 in.) above the bottom of the dispersion cup. A dispersion cup conforming to either of the designs shown in Figure 2.

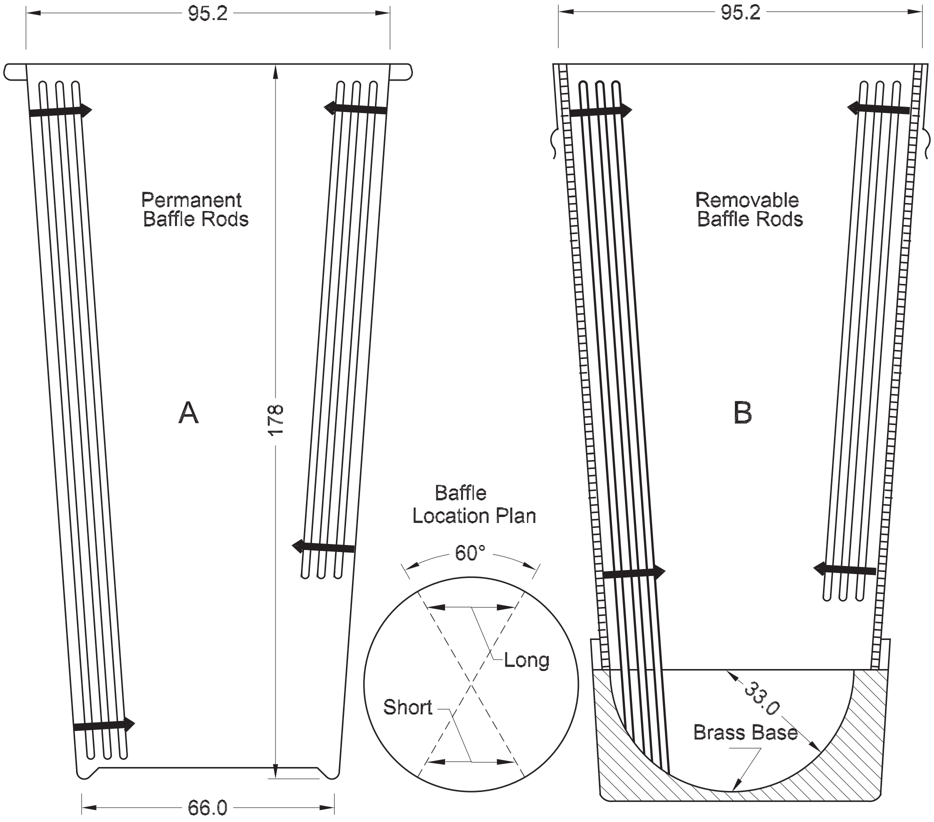


Dimensional Equivalents

mm	in.
19.1	$^3/_4$
12.7	$^1/_2$
5.16 ± 0.025	0.203 ± 0.001
1.24	0.049 (No. 18 BW Ga.)

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 1—Details of Stirring Paddles



Dimensional Equivalents

mm	in.
33.0	1.3
66.0	2.6
95.2	3.75
178	7.0

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 2—Dispersion Cups

3.1.3.1. *(Alternate B)*—An air-jet type dispersing device similar to either of the designs shown in Figure 3.

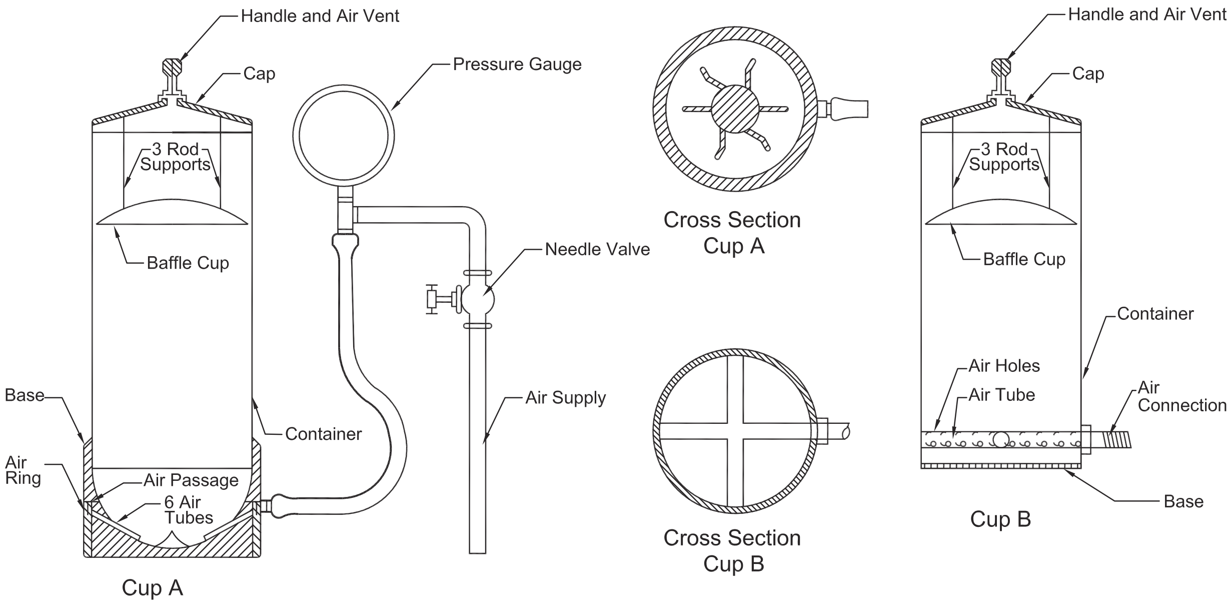


Figure 3—The Wintermyer Soil Dispersion Cups

Note 1—The amount of air required by an air-jet dispersion cup is of the order of 0.06 m^3/min (2 cfm); some small air compressors are not capable of supplying sufficient air to operate a cup.

Note 2—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

Note 3—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.1.4. *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per liter of suspension, and conforming to the requirements for hydrometers 151 H or 152 H in ASTM E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.1.5. *Sedimentation Cylinders*—A glass cylinder approximately 460 mm (18 in.) in height and 60 mm ($2^1/_2$ in.) in diameter and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000 mL mark is 360 ± 20 mm (14 ± 1.0 in.) from the bottom on the inside.

3.1.6. *Thermometer*—A calibrated thermometer readable to 0.5ºC (1ºF).

3.1.7. *Sieves*—A series of sieves of square mesh woven cloth, conforming to the requirements of M 92. The sieves normally required are as follows:

Standard Designation, mm	Alternate Designation
75	3 in.
50	2 in.
25	1 in.
9.25	$^3/_8$ in.
4.75	No. 4
2.00	No. 10
0.425	No. 40
0.075	No. 200

Note 4—The above sieves fulfill the requirements of M 145 and M 147. If desired, intermediate sieve sizes may be used in such sizes as:

Standard Designation, mm	Alternate Designation
75	3 in.
37.5	$1^1/_2$ in.
19	$^3/_4$ in.
9.5	$^3/_8$ in.
4.75	No. 4
2.36	No. 8
1.18	No. 16
0.60	No. 30
0.30	No. 50
0.15	No. 100
0.075	No. 200

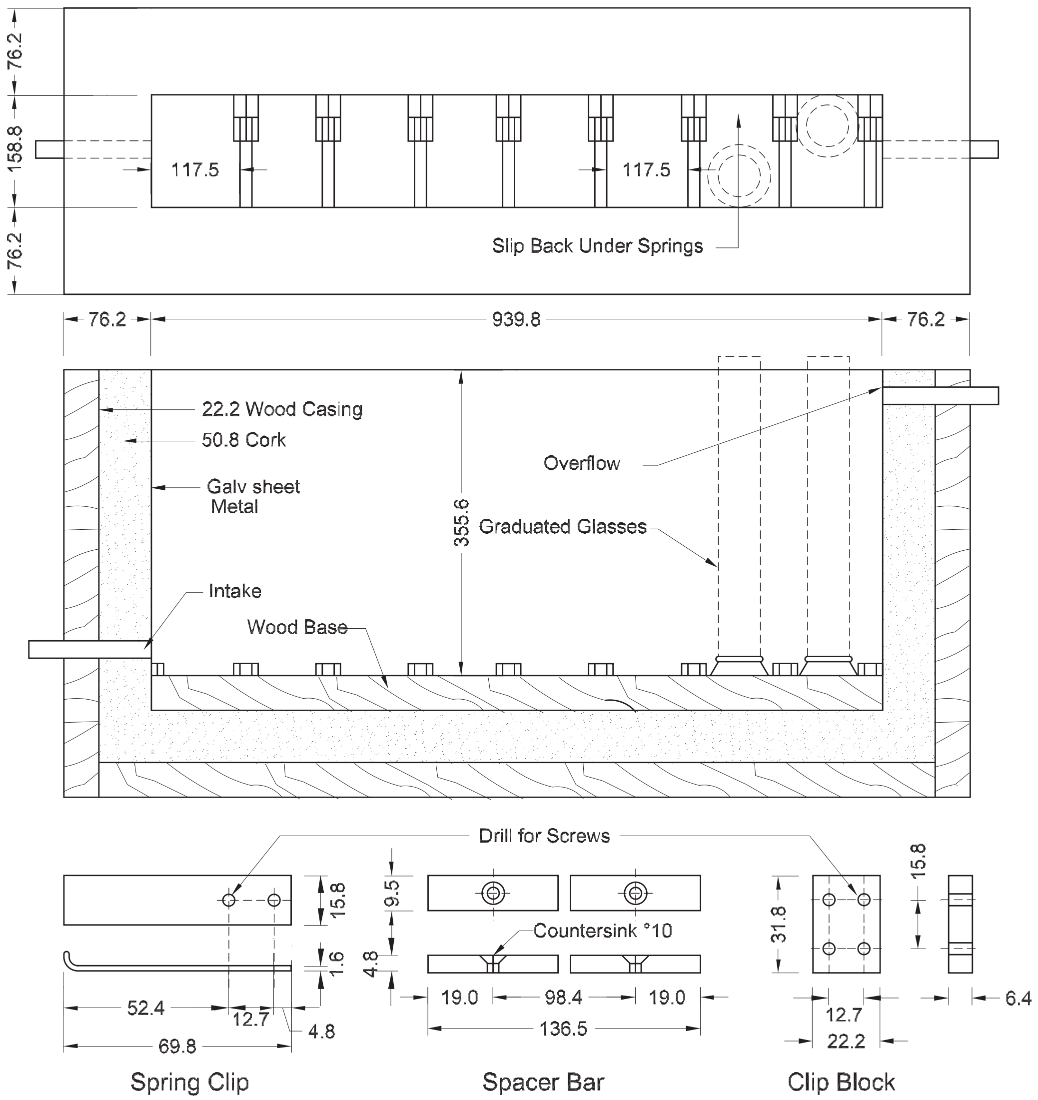
3.1.8. *Water Bath or Constant Temperature Room*—A water bath or constant temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water bath is an insulated tank that maintains the suspension at a convenient constant temperature as near 20ºC (68ºF) as the room and faucet-water temperature will permit. Such a device is illustrated in Figure 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary and subsequent reference to a constant temperature bath shall be interpreted as meaning either a water bath or a constant temperature room.

3.1.9. *Beaker*—A glass beaker having a capacity of at least 250 mL and not greater than 500 mL.

3.1.10. *Timing Device*—A watch or clock with a sweep second hand.

3.1.11. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

3.1.12. *Glass Rod*—Suitable for stirring the sample mixture.



Dimensional Equivalents

mm	in.	mm	in.
939.8	37	31.8	$1^{1}/_{4}$
355.6	14	22.2	$^{7}/_{8}$
158.8	$6^{1}/_{4}$	19.0	$^{3}/_{4}$
136.5	$5^{3}/_{8}$	15.8	$^{5}/_{8}$
117.5	$4^{5}/_{8}$	12.7	$^{1}/_{2}$
98.4	$3^{7}/_{8}$	9.5	$^{3}/_{8}$
76.2	3	6.4	$^{1}/_{4}$
69.8	$2^{3}/_{4}$	4.8	$^{3}/_{16}$
52.4	$2^{1}/_{16}$	1.6	$^{1}/_{16}$
50.8	2		

Note: All dimensions are in millimeters unless otherwise noted.

Figure 4—Tank for Maintaining Soil Suspension at Constant Temperature During Hydrometer Analysis

4. DISPERSING AGENT

4.1. A solution of sodium hexametaphosphate shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate per liter of solution.

4.1.1. Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersing action. Solutions shall be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions shall have the date of preparation marked on them.

5. GENERAL REQUIREMENTS FOR WEIGHING

5.1. The masses of subsamples and size fractions in the hydrometer analysis and hygroscopic moisture determination shall be determined to the nearest 0.01 g. The mass of the subsample for mechanical analysis of the fraction retained on the 4.75-mm sieve, the 2.00-mm sieve, or the 0.425-mm sieve for coarse sieve analysis, and each size fraction in the coarse sieve analysis, shall be determined to within 0.1 percent of the mass of the subsample. For example, a subsample with a mass of 1000 g, its size fractions in the coarse sieve analysis, must be weighed to the nearest gram.

6. SAMPLES

6.1. The test sample for particle size analysis shall be prepared in accordance with either T 87 for Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test, or T 146 for Wet Preparation of Disturbed Soil Samples for Test. The representative portion of the original air-dry sample selected for test shall be weighed. The mass of this sample shall be sufficient to yield quantities for particle size analysis as follows:

6.1.1. The minimum amount required of material retained on the 4.75-mm sieve, the 2.00-mm sieve, or the 0.425-mm sieve depends on the maximum particle size, but shall not be less than the amount shown in the following table:

Normal Size of Largest Particles Standard (Alternate)		Approximate Minimum Weight of Portion
mm	in.	kg
9.5	$^3/_8$	0.5
25	1	2
50	2	4
75	3	5

6.1.2. The size of the portion passing the 2.00-mm (No. 10) or 0.425-mm (No. 40) sieve shall be: (a) for the hydrometer test, approximately 100 g for sandy soil and approximately 50 g for silty or clayey soils, and (b) for hygroscopic moisture determination, at least 10 g.

6.2. The test sample selected in Section 5.1 shall be processed by one of the following methods:

6.2.1. *Alternate Method Using 4.75-mm and 2.00-mm (No. 4 and No. 10) Sieves*—After separating the test sample on the 4.75-mm sieve as described in Section 5.2.2 of T 87, the two fractions shall be weighed. A representative portion of the passing 4.75-mm sieve fraction adequate for mechanical analysis shall be selected and separated into two fractions using a 2.00-mm sieve. Each of these fractions shall be weighed and the subsamples for hydrometer analysis and hygroscopic moisture determination shall be obtained from the passing 2.00-mm sieve fraction by use of a riffle sampler or sample splitter, and either weighed immediately or placed in air-tight containers until tested.

6.2.2. *Alternate Method Using 2.00-mm (No. 10) Sieve*—The sample shall be separated on the 2.00-mm sieve as described in Section 5.2.1 of T 87. The portion retained on the 2.00-mm sieve after the second sieving shall be processed in accordance with Section 7, Sieve Analysis of Fraction Retained on 2.00-mm (No. 10) Sieve. The portion passing the 2.00-mm sieve in both sieving operations shall be weighed and prepared as described in Section 6.2 of T 87. Subsamples for hygroscopic moisture, hydrometer analysis, and sieve analysis shall be weighed immediately or placed in air-tight containers until tested.

6.2.3. *Alternate Method Using 0.425-mm (No. 40) Sieve*—The sample shall be processed as described in T 146, the portions retained on and passing the 0.425-mm sieve shall be weighed, and the subsamples for hydrometer analysis and hygroscopic moisture determination shall be obtained by use of a riffle sampler or sample splitter, and either weighed immediately or placed in air-tight containers until tested.

Note 4—Most laboratories prepare the sample in accordance with Section 5.2.1 of T 87, which provides for splitting the original sample on the 2.00-mm sieve. Hereafter in this method the triple designation, 4.75-mm, or 2.00-mm, or 0.425-mm sieve, is not used. When reference to the fraction retained or passing the 2.00-mm sieve is used, the 4.75-mm sieve is implied if the sample was processed in accordance with Section 6.2.1, and the 0.425-mm sieve is implied if the sample was processed in accordance with Section 6.2.3.

7. SIEVE ANALYSIS OF FRACTION RETAINED ON 2.00-MM (NO. 10) SIEVE

7.1. The portion of the sample retained on the 2.00-mm (No. 10) sieve shall be separated into a series of sizes by the use of the 75, 50, 25.0, 9.5, and 4.75-mm (3 in., 2 in., 1 in., $^3/_8$ in., and the No. 4) sieves, and using other sieves as may be needed depending on the sample or upon the specification for the material being tested. The 2.00-mm sieve shall be used if the sample was prepared in accordance with T 146.

7.2. The sieving operation shall be conducted by means of a lateral and vertical motion of the sieve, accomplished by jarring action so as to keep the sample moving continuously over the surface of the sieve. In no case shall fragments in the sample be turned or manipulated through the sieve by hand. Sieving shall be continued until not more than 1 percent by mass of the residue passes any sieve during 60 seconds. When sieving machines are used, their thoroughness of sieving shall be tested by comparison with hand methods of sieving as described in this paragraph.

7.3. The portion of the sample retained on each sieve shall be weighed and the mass recorded, although it shall be permissible to record the accumulated masses as the contents of each successive sieve are added to the fractions previously deposited on the scales pan.

8. DETERMINATION OF COMPOSITE CORRECTION FOR HYDROMETER READING

8.1. Equations for percentages of soil remaining in suspension, as given in Section 16.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

8.1.1. Both soil hydrometers are calibrated at 20ºC (68ºF); variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

8.1.2. Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

8.1.3. The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

8.2. For convenience, a graph or table of composite corrections for a series of 1-degree temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight line relationship between the two observed values.

8.3. Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the selected dispersing agent specified in Section 4. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151 H the composite correction is the difference between this reading and one; for hydrometer 152 H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before. (See Figure 5.)

9. HYGROSCOPIC MOISTURE

9.1. Determine the mass of the sample for the hygroscopic moisture determination. Dry the sample according to T 265, to determine the moisture content, and record the results.

10. DISPERSION OF SOIL SAMPLE

10.1. The approximately 100 or 50-g sample for hydrometer analysis shall be weighed, placed in a 250-mL beaker, covered with 125 mL of stock solution of the selected dispersing agent specified in Section 4, stirred thoroughly with a glass rod, and allowed to soak for a minimum of 12 hours. The contents of the beaker shall then be washed into one of the dispersion cups shown in Figure 2, distilled or demineralized water added until the cup is more than half full, and the contents dispersed for a period of 60 seconds in the mechanical stirring apparatus.

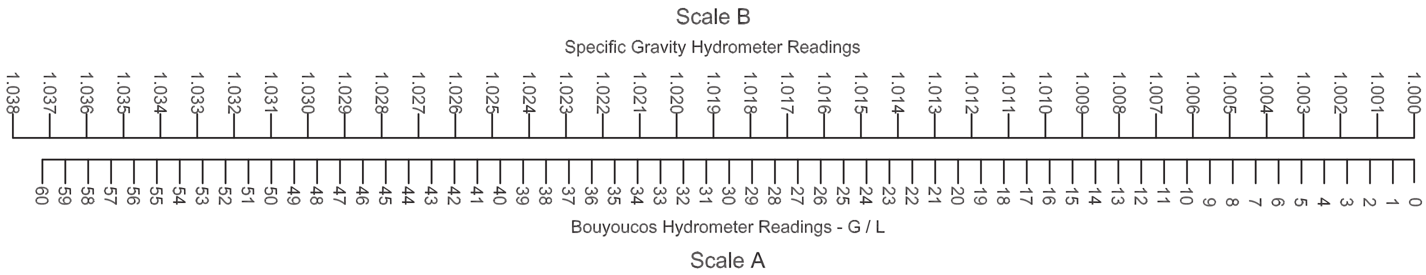
11. ALTERNATE METHOD FOR DISPERSION

11.1. The approximately 100 or 50-g sample for hydrometer analysis shall be weighed, placed in a 250-mL beaker, covered with 125 mL of the stock solution of the selected dispersing agent specified in Section 4, stirred thoroughly with a glass rod, and allowed to soak for a minimum of 12 hours.

11.2. The air-jet dispersion apparatus shall be assembled as shown in Figure 3 without the cover cap in place. The needle valve controlling the line pressure shall be opened until the pressure gauge indicates 6.9-kPa (1-psi) air pressure. This initial air pressure is required to prevent the soil-water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup. After the apparatus is adjusted, the soil-water mixture shall be transferred from the beaker to the dispersion cup, using a wash bottle to assist in the transfer operation.

11.3. The volume of the soil-water mixture in the dispersion cup shall not exceed 250 mL. The cover containing the baffle plate shall be placed upon the dispersion cup and the needle valve opened until the pressure gauge reads 138 kPa (20 psi). The soil-water mixture shall be dispersed for 5, 10, or 15 minutes depending upon the plasticity index of the soil. Soils with a PI of five or less shall be dispersed for 5 minutes; soil with a PI between 6 and 20 for 10 minutes; and soils with a PI greater than 20 for 15 minutes. Soils containing large percentages of mica need be dispersed for 60 seconds only.

11.4. After the dispersion period is completed, the needle valve shall be closed until the pressure gauge indicates 6.9 kPa (1 psi). The cover shall be removed and all adhering soil particles washed back into the dispersion cup. The soil water suspension shall then be washed into the 1000-mL glass graduate and the needle valve closed.



The specific gravity scale (SP. G.) shall be calibrated to read 1.000 at 68° F and it shall extend beyond the limits shown, so as to read from 0.995 to 1.038. The grams per liter scale (G/L) shall be extended 5 G/L above zero (1.000 SP. G.) and down to 60 G/L. The bulb shall be symmetrical above and below the middle diameter, and shall be blown into a mold to assure uniformity of product.

* The diameter of the stem may be varied to adjust the length of the scale specified but the stem shall be uniform in diameter from top to bottom.
The accuracy of the scale shall be ± 1 scale division. Distributed uniformly over the scale length.

Hydrometer equipped with Scale B shall be identified as No. 151 H.

Hydrometer equipped with Scale A shall be identified as No. 152 H.

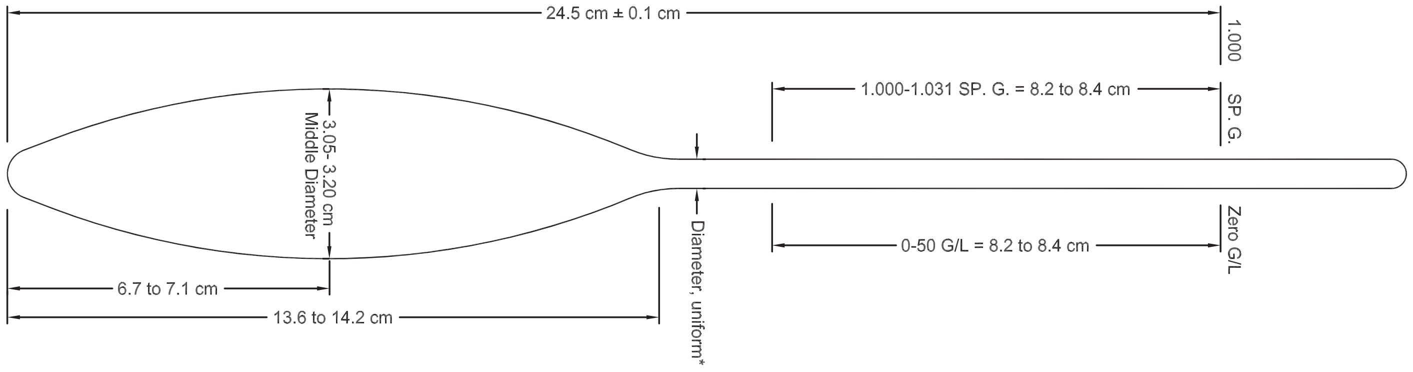


Figure 5—Hydrometer

12. HYDROMETER TEST

12.1. After dispersion, the mixture shall be transferred to the glass graduate and distilled or demineralized water having the same temperature as the constant temperature bath added until the mixture attains a volume of 1000 mL. The graduate containing the soil suspension shall then be placed in the constant temperature bath. Remove the graduate after the soil suspension attains the temperature of the bath. Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 60 seconds to complete the agitation of the slurry.

Note 5—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

Note 6—Upon completion of the agitation period, if necessary, any material clinging to the inside walls of the top of the cylinder may be rinsed into the suspension with a small amount of water.

12.2. At the conclusion of this shaking, the time shall be recorded, the graduate placed in the bath, and readings taken with the hydrometer at the end of 120 seconds. The hydrometer shall be read at the top of the meniscus formed by the suspension around its stem. The hydrometer shall float freely and not touch the wall of the graduate or cylinder. If hydrometer with scale A is used, it shall be read to the nearest 0.5 g/L. Scale B shall be read to the nearest 0.0005 specific gravity. Subsequent readings shall be taken at intervals of 5, 15, 30, 60, 250, and 1440 minutes after the beginning of sedimentation. Readings of the thermometer placed in the soil suspension shall be made immediately following each hydrometer reading and recorded.

12.3. After each reading the hydrometer shall be very carefully removed from the soil suspension and placed with a spinning motion in a graduate of clean water. About 25 or 30 seconds before the time for a reading, it shall be taken from the clear water and slowly immersed in the soil suspension to assure that it comes to rest before the appointed reading time.

13. SIEVE ANALYSIS

13.1. At the conclusion of the final reading of the hydrometer, the suspension shall be washed on a 0.075-mm (No. 200) sieve. That fraction retained on the 0.075-mm sieve shall be dried in an oven at 110 ± 5ºC (230 ± 9ºF) and a sieve analysis made using the 0.425-mm and 0.075-mm sieves and such other sieves as may be required by the material under test.

Note 7—Following washing of the sample and flushing of any materials retained on the 75-µm (No. 200) sieve back into the container, no water should be decanted from the container except through the 75-µm (No. 200) sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

CALCULATIONS

14. PERCENTAGE OF HYGROSCOPIC MOISTURE

14.1. The hygroscopic moisture shall be expressed as a percentage of the mass of the oven-dried soil and shall be determined as follows:

$$\text{Percentage of hygroscopic moisture} = \frac{W - W_1}{W_1} \times 100 \quad (1)$$

where:

W = mass of air-dried soil, and

W_1 = mass of oven-dried soil.

To correct the mass of the air-dried sample for hygroscopic moisture, the given value shall be multiplied by the expression:

$$\frac{100}{100 + \text{percentage of hygroscopic moisture}} \quad (2)$$

14.2. Calculate the percentage of moisture to the nearest 0.001 as described in Section 14.1.

15. COARSE MATERIAL

15.1. The percentage of coarse material shall be calculated from the masses of the fractions recorded during the sieving of the material retained on the 2.00-mm sieve, in accordance with Section 7.3, and the total mass recorded in Section 6.1. The calculations shall be made as follows:

15.1.1. From the mass of the air-dried sample, obtained in Section 6.1, subtract the mass of the fraction retained on the 2.00-mm sieve. The difference is assumed to equal the mass of the air-dried fraction passing the 2.00-mm sieve (Note 5).

15.1.2. Correct the mass of the fraction passing the 2.00-mm sieve for hygroscopic moisture, determined in Section 14.1.

15.1.3. To the corrected mass obtained in Section 15.1.2, add the mass of the fraction retained on the 2.00-mm sieve to obtain the mass of the total test sample corrected for hygroscopic moisture.

15.1.4. The fractions retained on the 2.00-mm and coarser sieves shall be expressed as percentages of the corrected mass obtained in Section 15.1.3.

Note 8—According to this assumption, no hygroscopic moisture is contained in the air-dried particles retained on the 2.00-mm sieve when as a matter of fact a small percentage of moisture may be present in this fraction. This amount of moisture, compared with that held in the pores of the fraction passing the 2.00-mm sieve, is relatively small. Therefore, any error produced by the assumption as stated may be considered negligible in amount.

Note 9—Somewhat different computations are required when the test sample is processed in accordance with Section 6.2.1 (Alternate Method Using 4.75-mm and 2.00-mm sieves). In Section 15.1, substitute the 4.75-mm sieve for the 2.00-mm sieve. The percentage passing the 2.00-mm sieve shall be calculated as follows: (1) correct the mass of the test fractions passing the 4.75-mm and 2.00-mm sieves for hygroscopic moisture; (2) divide the dry mass of the fraction passing the 2.00-mm sieve by the dry mass of the subsample passing the 4.75-mm sieve, and multiply this value by 100, giving the percent passing the 2.00-mm sieve in the selected subsample (Section 6.2.1); and (3) multiply this percentage by the percentage of the total sample passing the 4.75-mm sieve, to give the percentage passing the 2.00-mm sieve in the total sample.

16. PERCENTAGE OF SOIL IN SUSPENSION

16.1. Hydrometer readings shall be corrected by applying the approximate composite correction as determined by Section 8 to account for the dispersing agent used, temperature of the suspension, and height of the meniscus on the stem of the hydrometer.

16.2. The percentage of the dispersed soil in suspension represented by different corrected hydrometer readings depends upon both the amount and the specific gravity of the soil dispersed. The percentage of dispersed soil remaining in suspension shall be calculated as follows:

For hydrometer 152 H

$$P = \frac{Ra}{w} \times 100 \qquad (3)$$

For hydrometer 151 H

$$P = \frac{1606\left(R - 1\right) a}{w} \times 100 \qquad (4)$$

where:

P = percentage of originally dispersed soil remaining in suspension,

R = corrected hydrometer reading,

w = mass in grams of soil originally dispersed minus the hygroscopic moisture, and

a = constant depending on the density of the suspension.

For an assumed value of G for the specific gravity of the soil, and a water density of 1.000 at 20.0ºC (68ºF), the value of "a" may be obtained by the formula:

$$a = \frac{2.6500 - 1.000}{2.6500} \times \frac{G}{G - 1.000}$$

The values of "a," given to two decimal places, are shown in Table 1.

Table 1—Values of *a*, for Different Specific Gravities

Specific Gravity, *G*	Constant, *a*
2.95	0.94
2.85	0.96
2.75	0.98
2.65	1.00
2.55	1.02
2.45	1.05
2.35	1.08

16.2.1. It is sufficiently accurate for ordinary tests to select the constant for the specific gravity nearest to that of the particular soil tested.

16.3. To convert the percentages of soil in suspension to percentages of the total test sample including the fraction retained on the 2.00-mm (No. 10) sieve, the percentage of originally dispersed soil remaining in suspension shall be multiplied by the expression:

$$\frac{100 - \text{the percentage retained on 2.00-mm sieve}}{100} \qquad (5)$$

17. DIAMETER OF SOIL PARTICLES IN SUSPENSION

17.1. The maximum diameter, *d*, of the particles in suspension, corresponding to the percentage indicated by a given hydrometer reading, shall be calculated by the use of Stokes' law.

According to Stokes' law:

$$d = \sqrt{\frac{30\, nL}{980\left(G - G_1\right) T}} \qquad (6)$$

where:

d = maximum grain diameter in millimeters;

n = coefficient of viscosity of the suspending medium (in this case water) in Pa·s. Varies with changes in temperature of the suspending medium;

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, mm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (see Table 2).);

T = interval of time from beginning of sedimentation to the taking of the reading, min;

G = specific gravity of soil particles; and

G_1 = specific gravity of the suspending medium (approximately 1.0 for water).

Note 10—As Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

Table 2—Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes[a]

Hydrometer 151 H		Hydrometer 152 H			
Actual Hydrometer Reading	Effective Depth, *L*, mm	Actual Hydrometer Reading	Effective Depth, *L*, mm	Actual Hydrometer Reading	Effective Depth, *L*, mm
1.000	163	0	163	31	112
1.001	160	1	161	32	111
1.002	158	2	160	33	109
1.003	155	3	158	34	107
1.004	152	4	156	35	106
1.005	150	5	155		
1.006	147	6	153	36	104
1.007	144	7	152	37	102
1.008	142	8	150	38	101
1.009	139	9	148	39	99
1.010	137	10	147	40	97
1.011	134	11	145	41	96
1.012	131	12	143	42	94
1.013	129	13	142	43	92
1.014	126	14	140	44	91
1.015	123	15	138	45	89
1.016	121	16	137	46	88
1.017	118	17	135	47	86
1.018	115	18	133	48	84
1.019	113	19	132	49	83
1.020	110	20	130	50	81
1.021	107	21	129	51	79
1.022	105	22	127	52	78
1.023	102	23	125	53	76
1.024	100	24	124	54	74
1.025	97	25	122	55	73
1.026	94	26	120	56	71
1.027	92	27	119	57	70
1.028	89	28	117	58	68
1.029	86	29	115	59	66
1.030	84	30	114	60	65
1.031	81				
1.032	78				
1.033	76				
1.034	73				
1.035	70				
1.036	68				
1.037	65				
1.038	62				

[a] Values of effective depth are calculated from the equation:

$$L = L_1 + {}^{1}\!/_{2}[L_2 - (V_B/A)] \quad (7)$$

where:

L = effective depth, mm;

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, mm;

L_2 = overall length of hydrometer bulb, mm;

V_B = volume of hydrometer bulb, mm^3; and

A = cross-sectional area of sedimentation cylinder, mm^2.

For both hydrometers, 151 H and 152 H:

L_2 = 140 mm

V_B = 67000 mm^3

A = 2780 mm^2

For hydrometer 151 H:

L_1 = 105 mm for a reading of 1.000

L_2 = 23 mm for a reading of 1.031

For hydrometer 152 H:

L_1 = 105 mm for a reading of 0 g/L

L_2 = 23 mm for a reading of 50 g/L

17.2. For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{\frac{L}{T}} \tag{8}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K may not change for a series of readings constituting a test, while values of L and T do vary.

Table 3—Values of *K* for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature deg C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.004838	0.004759	0.004683	0.004607	0.004538	0.004471	0.004408	0.004345	0.004288
17	0.004778	0.004699	0.004623	0.004551	0.004481	0.004415	0.004351	0.004288	0.004231
18	0.004718	0.004639	0.004563	0.004494	0.004424	0.004358	0.004298	0.004234	0.004177
19	0.004661	0.004582	0.004506	0.004437	0.004370	0.004304	0.004244	0.004184	0.004127
20	0.004604	0.004525	0.004452	0.004383	0.004317	0.004250	0.004190	0.004133	0.004076
21	0.004547	0.004471	0.004399	0.004329	0.004263	0.004200	0.004139	0.004083	0.004026
22	0.004494	0.004418	0.004345	0.004279	0.004212	0.004149	0.004092	0.004035	0.003978
23	0.004440	0.004367	0.004294	0.004228	0.004165	0.004101	0.004045	0.003988	0.003931
24	0.004389	0.004317	0.004244	0.004177	0.004114	0.004054	0.003997	0.003940	0.003886
25	0.004339	0.004266	0.004196	0.004130	0.004067	0.004007	0.003950	0.003896	0.003842
26	0.004291	0.004218	0.004149	0.004083	0.004022	0.003962	0.003905	0.003852	0.003798
27	0.004244	0.004171	0.004101	0.004038	0.003978	0.003918	0.003861	0.003807	0.003757
28	0.004196	0.004124	0.004057	0.003997	0.003934	0.003875	0.003820	0.003766	0.003716
29	0.004149	0.004079	0.004013	0.003950	0.003890	0.003833	0.003779	0.003725	0.003675
30	0.004105	0.004035	0.003972	0.003909	0.003848	0.003792	0.003738	0.003684	0.003633

18. FINE SIEVE ANALYSIS

18.1. The percentage of the dispersed soil sample retained on each of the sieves in the sieve analysis of the material washed on the 0.075-mm (No. 200) sieve shall be obtained by dividing the mass of fraction retained on each sieve by the oven-dry mass of the dispersed soil and multiplying by 100.

18.2. The percentages of the total test sample, including the fraction retained on the 2.00-mm (No. 10) sieve, shall be obtained by multiplying these values by the expression:

$$\frac{100 - \text{the percentage retained on 2.00-mm sieve}}{100}$$

19. PLOTTING

19.1. The accumulated percentages of grains of different diameters shall be plotted on semilogarithmic paper to obtain a "grain size accumulation curve," such as that shown in Figure 6.

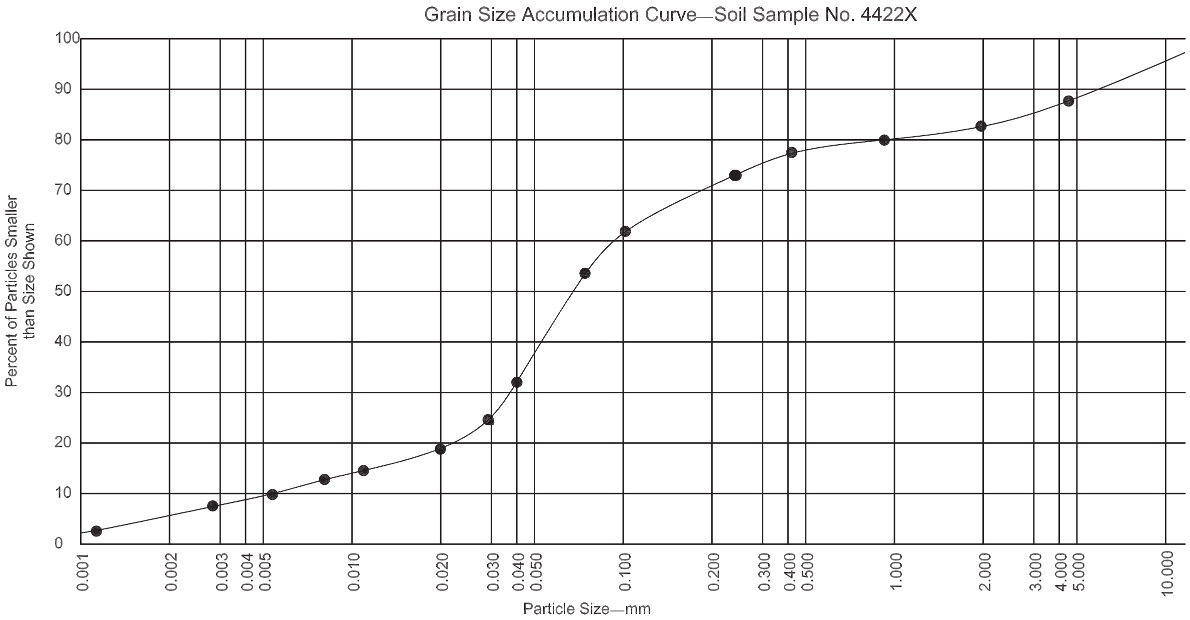


Figure 6—Grain Diameter Accumulation Curve for Soil Sample No. 4422X

20. REPORT

20.1. The results, read from the accumulation curve, shall be reported as follows:

20.1.1. Particles larger than 2-mm percent;

20.1.2. Coarse sand, 2.0 to 0.42-mm percent;

20.1.3. Fine sand, 0.42 to 0.074-mm percent;

20.1.4. Silt, 0.074 to 0.002-mm percent;

20.1.5. Clay, smaller than 0.002-mm percent; and

20.1.6. Colloids, smaller than 0.001-mm percent.

20.2. The results of complete mechanical analyses furnished by the combined sieve and hydrometer analysis shall be reported as follows:

Sieve Analysis		
Sieve Size		
Standard, mm	Alternate	Percent Passing
75	3 in.	
50	2 in.	
25	1 in.	
4.75	No. 4	
2.00	No. 10	
0.425	No. 40	
0.075	No. 200	

Hydrometer Analysis	
Smaller Than:	Percent
.02 mm	
.002 mm	
.001 mm	

For materials examined for any particular type of work or purpose, only such fractions shall be reported as are included in the specifications or other requirements for the work or purpose.

20.3. Report the Sieve Analysis to the nearest 0.1 percent passing.

20.4. Report the Hydrometer Analysis to the nearest 0.1 percent smaller than.

21. PRECISION

21.1. Criteria for judging the acceptability of the particle size analysis of soils is as follows:

Note 11—Colloids (smaller than 0.001 mm) are not normally required. However, if it is desired to obtain this size, it will then be necessary to extend the reading time to a minimum of 2880 minutes.

Note 12—The figures in Column 2 are the standard deviations that have been found to be appropriate for the tests described in Column 1. The figures in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

Table 4—Single-Operator Precision

Single-Operator Precision:

Test Performed	Standard Deviation[a]	Acceptable Range of Two Results[a]
Hygroscopic Moisture in Percent Moisture:		
4.75 mm (No. 4)	0.15	0.4
2.00 mm (No. 10)	0.21	0.6
Sieve Analysis in Percent Passing:		
2.00 mm (No. 10)	0.66	1.9
0.425 mm (No. 40)	1.07	3.0
0.075 mm (No. 200)	1.19	3.4
Hydrometer Analysis in Percent Smaller Than:		
0.02 mm	1.98	5.6
0.002 mm	1.34	3.8
0.001 mm	1.45	4.1

Multilaboratory Precision:

Test Performed	Standard Deviation[a]	Acceptable Range of Two Results[a]
Hygroscopic Moisture in Percent Moisture:		
4.75 mm (No. 4)	0.89	2.5
2.00 mm (No. 10)	0.88	2.4
Sieve Analysis in Percent Passing:		
2.00 mm (No. 10)	1.39	3.9
0.425 mm (No. 40)	1.98	5.6
0.075 mm (No. 200)	2.31	.5
Hydrometer Analysis in Percent Smaller Than:		
0.02 mm	4.32	12.2
0.002 mm	3.19	9.0
0.001 mm	3.16	8.9

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

Standard Method of Test for

Determining the Liquid Limit of Soils

AASHTO Designation: T 89-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Liquid Limit of Soils

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1. SCOPE

1.1. The liquid limit of a soil is that water content, as determined in accordance with the following procedure, at which the soil passes from a plastic to a liquid state.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 87, Dry Preparation of Disturbed Soil and Soil–Aggregate Samples for Test
- T 146, Wet Preparation of Disturbed Soil Samples for Test
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standard*:

- D 4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

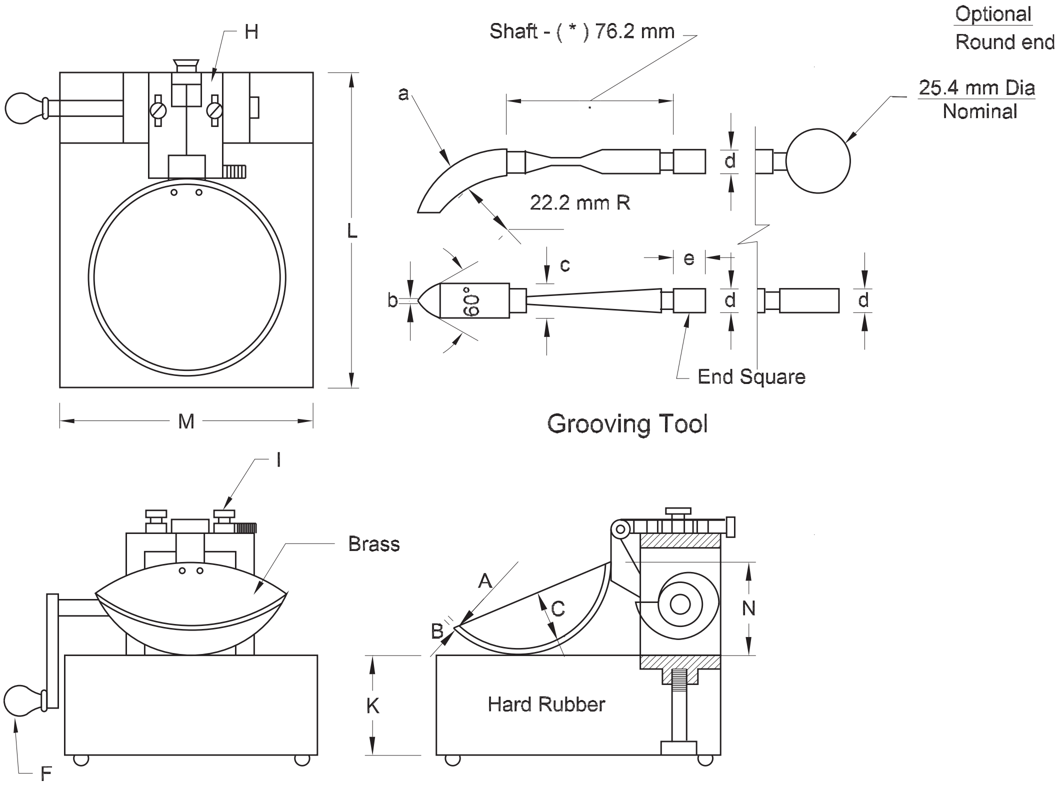
3. APPARATUS

3.1. *Dish*—A porcelain dish, preferably unglazed, or similar mixing dish, about 115 mm in diameter.

3.2. *Spatula*—A spatula or pill knife having a blade about 75 mm to 100 mm in length and about 20 mm in width.

3.3. *Liquid Limit Device*:

3.3.1. *Manually Operated*—A device consisting of a brass dish and carriage, constructed according to the plan and dimensions shown in Figure 1 (See Note 1.).



	Liquid Limit Device							Grooving Tool				
	Cup Assembly				Base			Curved End			Gauge	
Dimension	A	B	C	N	K	L	M	a	b	c	d	*e
Description	Radius of Cup	Thickness of Cup	Depth of Cup	Cup at Cam Follower to Base	Thickness	Length	Width	Thickness	Cutting Edge	Width	Depth	Length
Metric, mm	54	2.0	27	47	50	150	125	10.0	2.0	13.5	10.0	15.9
Tolerance, mm	2	0.1	1	1.5	5	5	5	0.1	0.1	0.1	0.2	—

Note: Plate "H" may be designed for using one (1) securing screw (I).
An additional wear tolerance of 0.1 mm shall be allowed for dimension "b" for used grooving tools.
Feet for base shall be of resilient material.
(*) Nominal dimensions.
All tolerances specified are plus or minus (±) except as noted above.

Figure 1—Manual Liquid Limit Device

3.3.2. *Mechanically Operated*—A motorized device equipped to produce the rise and rate of shocks to a brass cup as described in Sections 5.2 and 6.3 of this procedure, respectively. The cup and the critical dimensions of the device shall conform to those shown in Figure 1 of this procedure. The device shall give the same liquid limit values as obtained with the manually operated device (Note 1).

Note 1—The base of the liquid limit device should have a resilience of at least 80 percent and not more than 90 percent when determined in accordance with the procedure given in the Appendix.

3.4. *Grooving Tool*:

3.4.1. *Curved Grooving Tool*—A grooving tool conforming to the critical dimensions shown in Figure 1. The gauge need not be part of the tool.

3.4.2. *Flat Grooving Tool (Alternate)*—A grooving tool made of plastic or noncorroding metal conforming to the critical dimensions shown in ASTM D 4318, Figure 2. The gauge need not be part of the tool (Note 2).

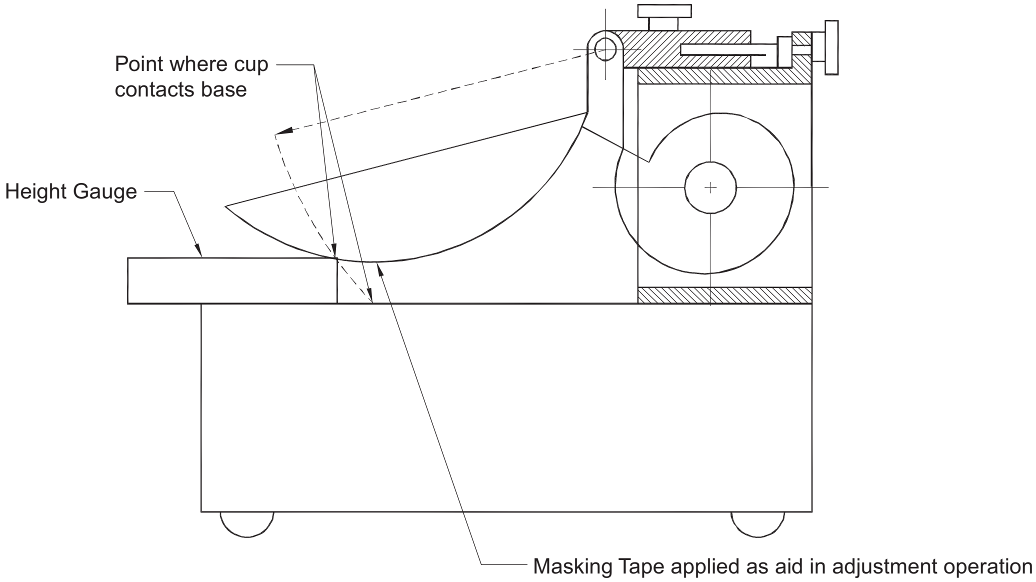


Figure 2—Calibration for Height of Drop

Note 2—The flat grooving tool should not be used interchangeably with the curved grooving tool. There are some data that indicate that the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

3.5. *Gauge*—A gauge, whether attached to the grooving tool or separate, conforming to the critical dimension "d" shown in Figure 1 of this method or "K" in Figure 2 of ASTM D 4318, and may be, if separate, a metal bar 10.0 ± 0.2 mm thick and approximately 50 mm long.

3.6. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

3.7. *Balance*—The balance shall have sufficient capacity and conform to M 231, Class G 1.

3.8. *Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5ºC for drying moisture samples.

METHOD A

4. SAMPLE

4.1. A sample with a mass of about 100 g shall be taken from the thoroughly mixed portion of the material passing the 0.425-mm sieve that has been obtained in accordance with T 87 or T 146; for structural analysis use T 146, Method B.

5. ADJUSTMENT OF LIQUID LIMIT DEVICE

5.1. The Liquid Limit Device shall be inspected to determine that the device is in good working order; that the pin connecting the cup is not worn sufficiently to permit side play; that the screws connecting the cup to the hanger arm are tight; that the points of contact on the cup and base are not excessively worn; that the lip of the cup is not excessively worn; and that a groove has not been worn in the cup through long usage. The grooving tool shall be inspected to determine that the critical dimensions are as shown in Figure 1 of this method or ASTM D 4318, Figure 2.

Note 3—Wear is considered excessive when the point of contact on the cup or base exceeds approximately 13 mm in diameter, or when any point on the rim of the cup is worn to approximately $^1/_2$ the original thickness. Although a slight groove in the center of the cup is noticeable, it is not objectionable. If the groove becomes pronounced before other signs of wear appear, the cup should be considered excessively worn. Excessively worn cups shall be replaced. A base that is excessively worn may be refinished as long as the thickness does not exceed the tolerance shown in Figure 1 by more than –2.5 mm and the distance between the cup at the cam follower and the base is maintained within the tolerances specified in Figure 1.

5.2. Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10.0 ± 0.2 mm. See Figure 2 for proper location of the gauge relative to the cup during adjustment.

Note 4—A convenient procedure for adjusting the height of drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gauge under the cup from the front, and observe whether the gauge contacts the cup or the tape. See Figure 2. If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at two revolutions per second while holding the gauge in position against the tape and cup. If a ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from the gauge, readjust the height of drop. If the cup rocks on the gauge during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

6. PROCEDURE USING THE CURVED GROOVING TOOL

6.1. The soil sample shall be placed in the mixing dish and thoroughly mixed with 15 to 20 mL of distilled or demineralized water by alternately and repeatedly stirring, kneading, and chopping with a spatula. Further additions of water shall be made in increments of 1 to 3 mL. Each increment of water shall be thoroughly mixed with the soil as previously described before another increment of water is added. Once testing has begun, no additional dry soil should be added to the moistened soil. The cup of the Liquid Limit Device shall not be used for mixing soil and water. If too much moisture has been added to the sample, the sample shall either be discarded, or mixed and kneaded until natural evaporation lowers the closure point into an acceptable range.

Note 5—Some soils are slow to absorb water; therefore, it is possible to add the increments of water so fast that a false liquid limit value is obtained. This can be avoided if more mixing and/or time is allowed. Tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water. However, referee or disputed tests shall be performed using distilled or demineralized water.

6.2. When sufficient water has been thoroughly mixed with the soil to form a uniform mass of stiff consistency, a sufficient quantity of this mixture shall be placed in the cup above the spot where the cup rests on the base and shall be squeezed and spread with the spatula to level and at the same time trimmed to a depth of 10 mm at the point of maximum thickness. As few strokes of the spatula as possible shall be used, care being taken to prevent the entrapment of air bubbles within the mass. The excess soil shall be returned to the mixing dish and covered to retain the moisture in the sample. The soil in the cup of the device shall be divided by a firm stroke of the grooving tool along the diameter through the centerline of the cam follower so that a clean sharp groove of the proper dimensions will be formed as shown in Figure 3. To avoid tearing of the sides of the groove or slipping of the soil cake on the cup, up to six strokes from front to back or from back to front counting as one stroke, shall be permitted. The depth of the groove should be increased with each stroke and only the last stroke should scrape the bottom of the cup.

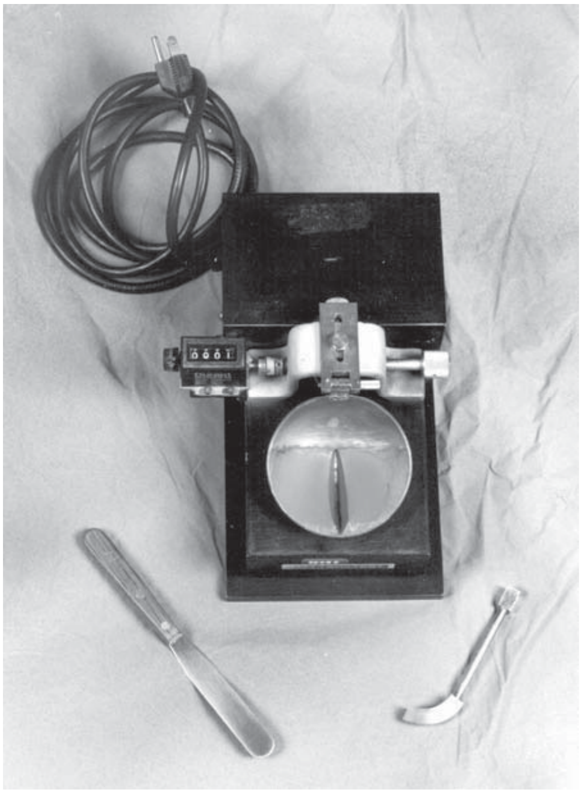


Figure 3—Liquid Limit Device with Soil Sample in Place

6.3. The cup containing the sample prepared as described in Section 6.2 shall be lifted and dropped by turning the crank F at the rate of approximately two revolutions per second until the two sides of the sample come in contact at the bottom of the groove along a distance of about 13 mm. The number of shocks required to close the groove this distance shall be recorded. The base of the machine shall not be held with the free hand while the crank F is turned.

Note 6—Some soils tend to slide on the surface of the cup instead of flowing. If this occurs, more water should be added to the sample and remixed, then the soil–water mixture placed in the cup, a groove cut with the grooving tool and Section 6.2 repeated. If the soil continues to slide on the cup at a lesser number of blows than 25, the test is not applicable and a note should be made that the liquid limit could not be determined.

6.4. A slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, shall be removed and placed in a suitable container. The soil in the container shall be dried in accordance with T 265 to determine the moisture content, and the results recorded.

6.5. The soil remaining in the cup shall be transferred to the mixing dish. The cup and grooving tool shall then be washed and dried in preparation for the next trial.

6.6. Repeat the foregoing operations, adding sufficient water to bring the soil to a more fluid condition. Obtain the first sample in the range of 25 to 35 shocks, the second sample in the range of 20 to 30 shocks, and the third sample in the range of 15 to 25 shocks. The range of the three determinations shall be at least 10 shocks.

7. ALTERNATE PROCEDURE USING THE FLAT GROOVING TOOL

7.1. The procedure shall be the same as prescribed in Sections 6.1 through 6.6, except for the procedure in Section 6.2 for forming the groove. Form a groove in the soil pat in accordance with Section 11.2 of ASTM D 4318.

8. CALCULATION

8.1. The water content of the soil shall be expressed as the moisture content in percentage of the mass of the oven-dried soil and shall be calculated as follows:

$$\text{Percentage moisture} = \frac{\text{mass of water}}{\text{mass of oven-dried soil}} \times 100 \qquad (1)$$

8.1.1. Calculate the percentage of moisture to the nearest whole percent.

9. PREPARATION OF FLOW CURVE

9.1. A “flow curve” representing the relation between moisture content and corresponding number of shocks shall be plotted on a semi-logarithmic graph with the moisture contents as abscissae on the arithmetical scale, and the number of shocks as ordinates on the logarithmic scale. The flow curve shall be a straight line drawn as nearly as possible through the three or more plotted points.

10. LIQUID LIMIT

10.1. The moisture content corresponding to the intersection of the flow curve with the 25 shock ordinate shall be taken as the liquid limit of the soil. Report this value to the nearest whole number.

METHOD B

11. SAMPLE

11.1. A sample with a mass of about 50 g shall be taken as described in Section 4.1.

12. PROCEDURE

12.1. Using the curved grooving tool (Section 6) or the flat grooving tool (Section 7) the procedure shall be the same as prescribed in Sections 6.1 through 6.5 except that the initial amount of water to be added in accordance with Section 6.1 shall be approximately 8 to 10 mL and the moisture sample taken in accordance with Section 6.4 shall be taken only for the accepted trial.

12.2. For accuracy equal to that obtained by the standard three-point method, the accepted number of blows for groove closure shall be restricted to between 22 and 28 blows. After obtaining a preliminary closure in the acceptable blow range, immediately return the soil remaining in the cup to the mixing dish and, without adding any additional water, repeat as directed in Sections 6.2 and 6.3. If the second closure occurs in the acceptable range (22 to 28, inclusive) and the second closure is within two (2) blows of the first closure, secure a water content specimen as directed in Section 6.4.

12.3. Groove closures between 15 and 40 blows may be accepted if variations of ±5 percent of the true liquid limit are tolerable.

13. CALCULATION

13.1. The water content of the soil at the time of the accepted closure shall be calculated in accordance with Section 8.1.

14. LIQUID LIMIT

14.1. The liquid limit shall be determined by one of the following methods: the nomograph, Figure 4; the correction factor method, Table 1; or by any other method of calculation that produces equally accurate liquid limit values. The standard three-point method shall be used as a referee test to settle all controversies.

14.2. The key in Figure 4 illustrates the use of the nomograph (mean slope).

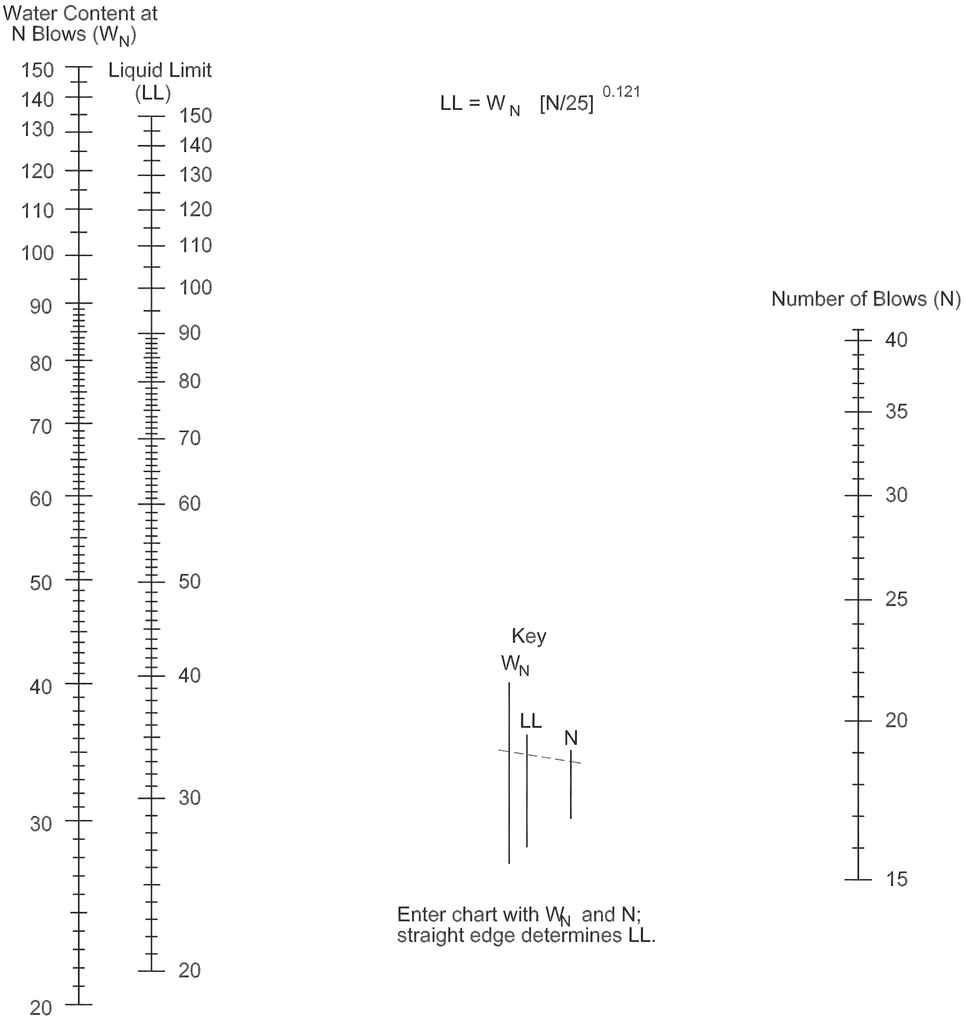


Figure 4—Nomographic Chart Developed by the Waterways Experiment Station, Corps of Engineers, U.S. Army, to Determine Liquid Limit Using Mean Slope Method

14.3. The correction factor method, Table 1, uses the moisture content of the liquid limit sample multiplied by a factor (k) of the second closure blow count. Figure 5 was developed for the Calculation of the Liquid Limit.

$$LL = W_N(N/25)^{0.121} \tag{2}$$

or

$$LL = kW_N \tag{3}$$

where:

N = number of blows causing closure of the groove at water content,

LL = Liquid limit corrected for closure at 25 blows,

W_N = water content, and

k = factor given in Table 1.

Table 1—Factors for Obtaining Liquid Limit from Water Content and Number of Blows Causing Closure of the Groove

Number of Blows, *N*	Factor for Liquid Limit, *k*
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014

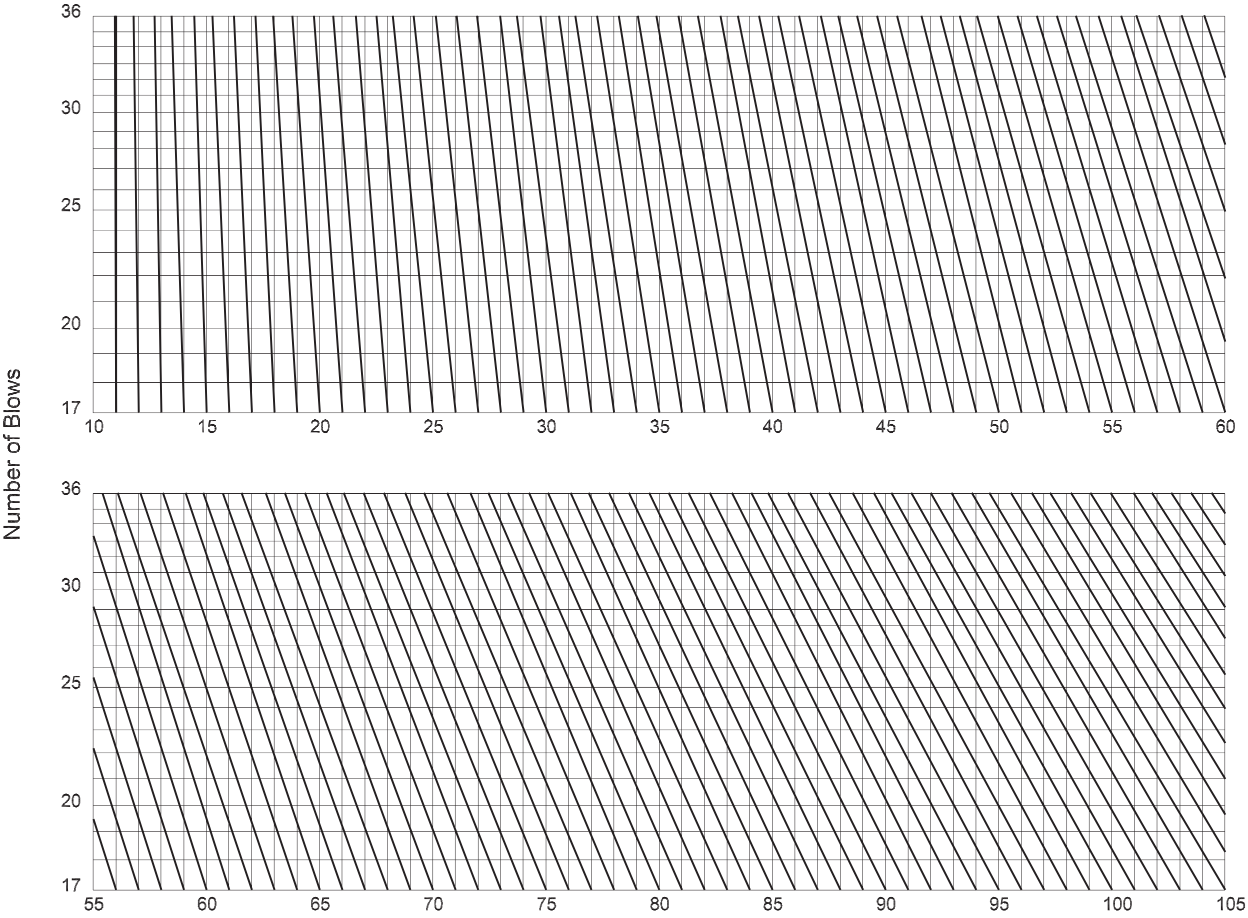


Figure 5—Chart Developed by Washington State Highway Department for the Calculation of the Liquid Limit

CHECK OR REFEREE TESTS

15. METHOD TO BE USED

15.1. Method A, using the curved grooving tool procedure (Section 6), shall be used in making check or referee tests. The results of liquid limit tests are influenced by:

15.1.1. The time required to make the test;

15.1.2. The moisture content at which the test is begun; and

15.1.3. The addition of dry soil to the seasoned sample.

16. PROCEDURE

16.1. Therefore, in making the liquid limit test for check or referee purposes, the following time schedule shall be used:

16.1.1. *Mixing of soil with water*—5 to 10 minutes, the longer period being used for the more plastic soils;

16.1.2. *Seasoning in the humidifier*—30 minutes;

16.1.3. *Remixing before placing in the brass cup*—add 1 mL of water and mix for 1 minute;

16.1.4. *Placing in the brass cup and testing*—3 minutes; and

16.1.5. *Adding water and remixing*—3 minutes.

16.2. No trial requiring more than 35 blows or fewer than 15 blows shall be recorded. In no case shall dried soil be added to the seasoned soil being tested.

17. PRECISION STATEMENT

17.1. This precision statement applies to soils having a liquid limit range from 21 to 67.

17.2. *Repeatability (Single Operator)*—Two results obtained by the same operator on the same sample in the same laboratory using the same apparatus, and on different days, should be considered suspect if they differ by more than 7 percent of their mean.

17.3. *Reproducibility (Multilaboratory)*—Two results obtained by different operators in different laboratories should be considered suspect if they differ from each other by more than 13 percent of their mean.

APPENDIX—RESILIENCE TEST

(Nonmandatory Information)

X1. MEASURING THE RESILIENCE OF LIQUID LIMIT DEVICE BASES

X1.1. A device for measuring the resilience of liquid limit device bases is shown in Figure X1.1 and Table X1.1. The device consists of a clear acrylic plastic tube and cap, an 8-mm diameter polished steel ball, and a small bar magnet. The cylinder may be cemented to the cap or threaded as shown. The small bar magnet is held in the recess of the cap, and the steel ball is fixed into the recess in the underside of the cap with the bar magnet. The cylinder is then turned upright and placed on the top surface of the base to be tested. Hold the tube lightly against the liquid limit device base with one hand, and release the ball by pulling the magnet out of the cap. Use the scale markings on the outside of the cylinder to determine the highest point reached by the bottom of the ball. Repeat the drop at least three times, placing the tester in a different location for each drop. The average rebound of the steel ball, expressed as a percent of the total drop, equals the resilience of the liquid limit device base. Tests should be conducted at room temperature.

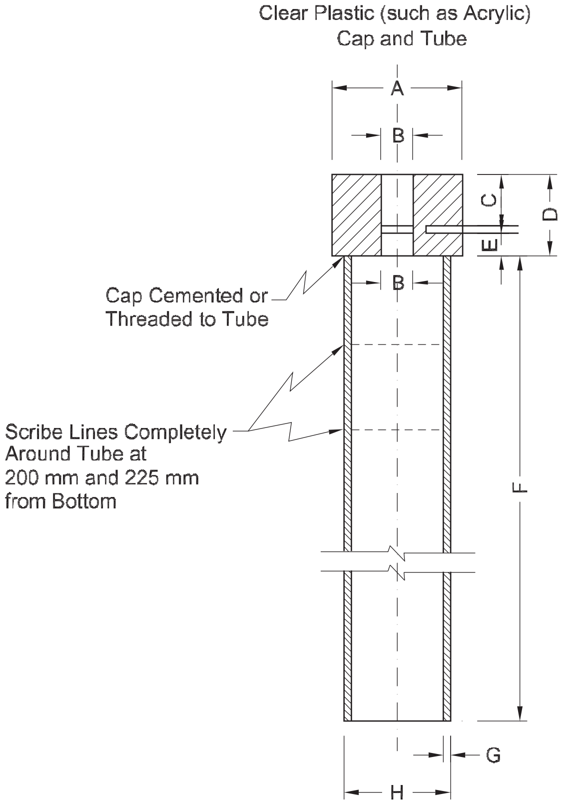


Figure X1.1—Resilience Tester

Table X1.1—Table of Measurements for Resilience Tester[a]

Dimension	Description	Metric, mm
A	Diam. of Cap	38.0[b]
B	Diam. of Hole	9.0[b]
C	Depth of Hole	18.0[b]
D	Height of Cap	25.5[b]
E	Depth of Hole	8.0
F	Length of Tube	250.0
G	Wall Thickness	3.2[b]
H	O.D. of Tube	31.8[b]
Scribed lines from bottom	Upper 90%	225.0
	Lower 80%	200.0

[a] Tube stands plumb.

[b] These dimensions are not critical in the performance of the test.

Standard Method of Test for

Determining the Plastic Limit and Plasticity Index of Soils

AASHTO Designation: T 90-00 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Plastic Limit and Plasticity Index of Soils

AASHTO Designation: T 90-00 (2008)

1. SCOPE

1.1. The plastic limit of a soil is the lowest water content determined in accordance with the following procedure at which the soil remains plastic. The plasticity index of a soil is the range in water content, expressed as a percentage of the mass of the oven-dried soil, within which the material is in a plastic state. It is the numerical difference between the liquid limit and plastic limit of the soil.

1.2. The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.3. The Hand Rolling Method shall be the referee procedure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 87, Dry Preparation of Disturbed Soil and Soil–Aggregate Samples for Test
- T 89, Determining the Liquid Limit of Soils
- T 146, Wet Preparation of Disturbed Soil Samples for Test
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *Dish*—A porcelain evaporating dish or similar mixing dish about 115 mm in diameter.

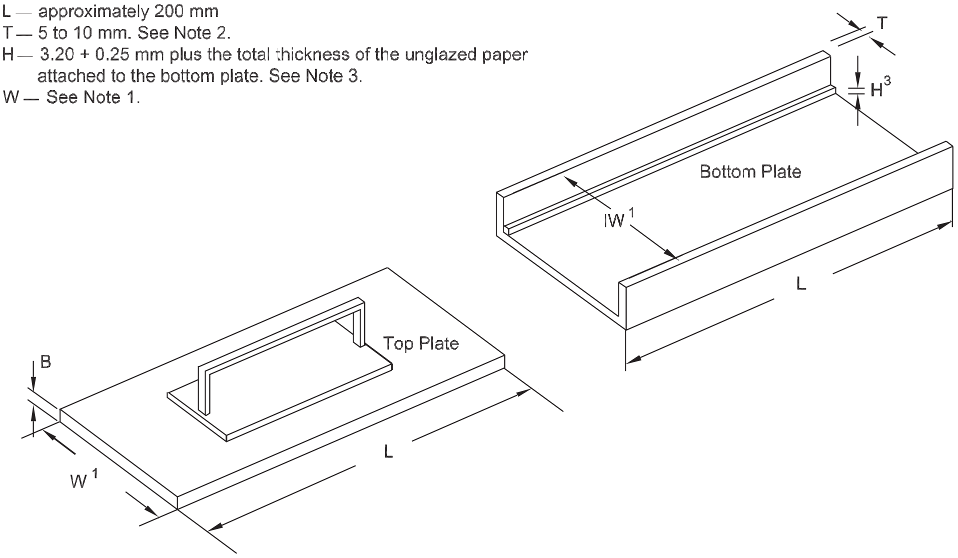
3.2. *Spatula*—A spatula or pill knife having a blade about 75 mm in length and about 20 mm in width.

3.3. *Surface for Rolling*—A ground glass plate or piece of smooth, unglazed paper on which to roll the sample.

3.4. *Plastic Limit Rolling Device*[1,2] (optional)—A device made of acrylic conforming to the dimensions shown in Figure 1.

Dimensions:

IW — approximately 100 mm
L — approximately 200 mm
T — 5 to 10 mm. See Note 2.
H — 3.20 + 0.25 mm plus the total thickness of the unglazed paper attached to the bottom plate. See Note 3.
W — See Note 1.



Notes:

1. The tolerance between the width of the top plate (W) and the inside width of the bottom plate (IW) shall be such that the top plate slides freely on the rails without wobbling.
2. The top plate shall be rigid enough so that the thickness of the soil threads is not influenced by flexure of the top plate.
3. The width of the side rails shall be between 3 and 6 mm.

Figure 1—Plastic Limit Rolling Device

3.5. *Paper for Rolling Device*—Unglazed paper that does not add foreign matter (fibers, paper fragments, etc.) to the soil during the rolling process. Such paper shall be attached to the top and bottom plates of the device either by a spray-on adhesive or by a self-adhesive backing.

Note 1—Take special care to remove the adhesive that remains on the plastic limit rolling device after testing. Repeated tests without such removal will result in a buildup of the residual adhesive and a decreased soil thread diameter.

3.6. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

3.7. *Balance*—The balance shall have sufficient capacity and conform to M 231, Class G 1.

3.8. *Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5ºC for drying samples.

4. SAMPLE

4.1. If the plastic limit only is required, take a quantity of soil with a mass of about 20 g from the thoroughly mixed portion of the material passing the 0.425-mm sieve, obtained in accordance with T 87 or T 146. Place the air-dried soil in a mixing dish and thoroughly mix with distilled or demineralized water until the mass becomes plastic enough to be easily shaped into a ball. Take a portion of this ball with a mass of about 8 g for the test sample.

Note 2—Tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water. However, referee or disputed tests shall be performed using distilled or demineralized water.

4.2. If both the liquid and plastic limits are required, take a test sample with a mass of about 8 g from the thoroughly wet and mixed portion of the soil prepared in accordance with T 89. Take the sample at any stage of the mixing process at which the mass becomes plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed. If the sample is taken before completion of the liquid limit test, set it aside and allow to season in air until the liquid limit test has been completed. If the sample taken during the liquid limit test is too dry to permit rolling to a 3-mm thread, add more water and remix.

5. PROCEDURE

5.1. Select a 1.5- to 2.0-g portion from the mass of soil taken in accordance with Section 4. Form the selected portion into an ellipsoidal mass.

5.2. Use one of the following methods to roll the soil mass into a 3-mm diameter thread at a rate of 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position again.

5.2.1. *Hand Rolling Method*—Roll the mass between the palm or fingers and the ground-glass plate (or a piece of paper laying on a smooth horizontal surface) with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The thread shall be further deformed on each stroke so that its diameter reaches 3 mm, taking no more than 2 minutes. The amount of hand or finger pressure required will vary greatly, according to the soil. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

5.2.2. *Alternate Procedure, Plastic Limit Device Method*—Place the soil mass on the bottom plate. Place the top plate in contact with the soil mass. Simultaneously apply a slight downward force and back and forth motion to the top plate so the plate comes in contact with the side rails within 2 minutes. During this rolling process, do not allow the soil thread to contact the side rails.

Note 3—In most cases, more than one soil mass (thread) can be rolled simultaneously in the plastic limit rolling device.

5.3. When the diameter of the thread becomes 3 mm, break the thread into six or eight pieces. Squeeze the pieces together between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape and then reroll. Continue this alternate rolling to a thread 3 mm in diameter, gathering together, kneading, and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the thread has a diameter greater than 3 mm. This shall be considered a satisfactory end point, provided the solid has been previously rolled into a thread 3 mm in diameter. The crumbling will manifest itself differently with various types of soil. Some soils fall apart in numerous small aggregations of particles; others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally the thread falls apart in many small platy particles. Heavy clay soils require much pressure to deform the thread, particularly as they approach the plastic limit, and finally, the thread breaks into a series of barrel-shaped segments each about 6 to 9 mm in length. At no time shall the operator attempt to produce failure at exactly 3-mm diameter by allowing the thread to reach 3 mm, then reducing the rate of rolling or the hand pressure, or both, and continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal-shaped mass nearer to the required 3-mm final diameter.

5.4. Gather the portions of the crumbled soil together and place in a weighed container. Immediately cover the container.

5.5. Repeat the operations described in Sections 5.1 through 5.4 until the 8-g specimen is completely tested. Determine the moisture content of the soil in the containers in accordance with T 265, and record the results.

6. CALCULATIONS

6.1. Calculate the plastic limit, expressed as the water content in percentage of the mass of the oven-dry soil, as follows:

$$\text{Plastic Limit} = \frac{\text{mass of water}}{\text{mass of oven-dry soil}} \times 100 \qquad (1)$$

Report the plastic limit to the nearest whole number.

6.2. Calculate the plasticity index of a soil as the difference between its liquid limit and its plastic limit, as follows:

$$\text{Plasticity Index} = \text{liquid limit} - \text{plastic limit} \qquad (2)$$

6.3. Report the difference calculated as indicated in Section 6.2 as the plasticity index, except under the following conditions:

6.3.1. When the liquid limit or plastic limit cannot be determined, report the plasticity index as NP (non-plastic).

6.3.2. When the plastic limit is equal to, or greater than, the liquid limit, report the plasticity index as NP.

7. PRECISION STATEMENT

7.1. This precision statement applies to soils with a plastic limit range between 15 and 32, tested using the hand rolling method.

7.2. *Repeatability (Single Operator)*—Two results obtained by the same operator on the same sample in the same laboratory using the same apparatus should be considered suspect if they differ by more than 10 percent of their mean.

7.3. *Reproducibility (Multilaboratory)*—Two results obtained by different operators in different laboratories should be considered suspect if they differ from each other by more than 18 percent of their mean.

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[1] The plastic limit-rolling device is covered by a patent (U.S. Patent No. 5,027,660). Interested parties are invited to submit information regarding the identification of an alternative(s) to this patent to AASHTO Headquarters. Your comments will receive careful consideration at a meeting of AASHTO Technical Section 1a on Soil Materials Tests.

[2] Bobrowski, L. J., Jr. and D. M. Griekspoor, "Determination of the Plastic Limit of a Soil by Means of a Rolling Device," *Geotechnical Testing Journal*, GTJODJ, Vol. 15, No. 3, September 1992, *pp*. 284–287.

Standard Method of Test for

Determining the Shrinkage Factors of Soils

AASHTO Designation: T 92-97 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining the Shrinkage Factors of Soils

AASHTO Designation: T 92-97 (2009)

1. SCOPE

1.1. This procedure furnishes data from which the following soil characteristics may be calculated: (a) shrinkage limit, (b) shrinkage ratio, (c) volumetric change, and (d) lineal shrinkage.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit'' in the last right-hand place of figures used in expressing the limited value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

1.5. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

DETERMINATION OF THE VOLUMETRIC SHRINKAGE

2. APPARATUS

2.1. The apparatus shall consist of the following:

2.1.1. *Dishes*:

2.1.1.1. A porcelain evaporating dish, or similar mixing dish, about 115-mm ($4^1/_2$-in.) in diameter.

2.1.1.2. A porcelain evaporating dish about 150 mm (6 in.) in diameter.

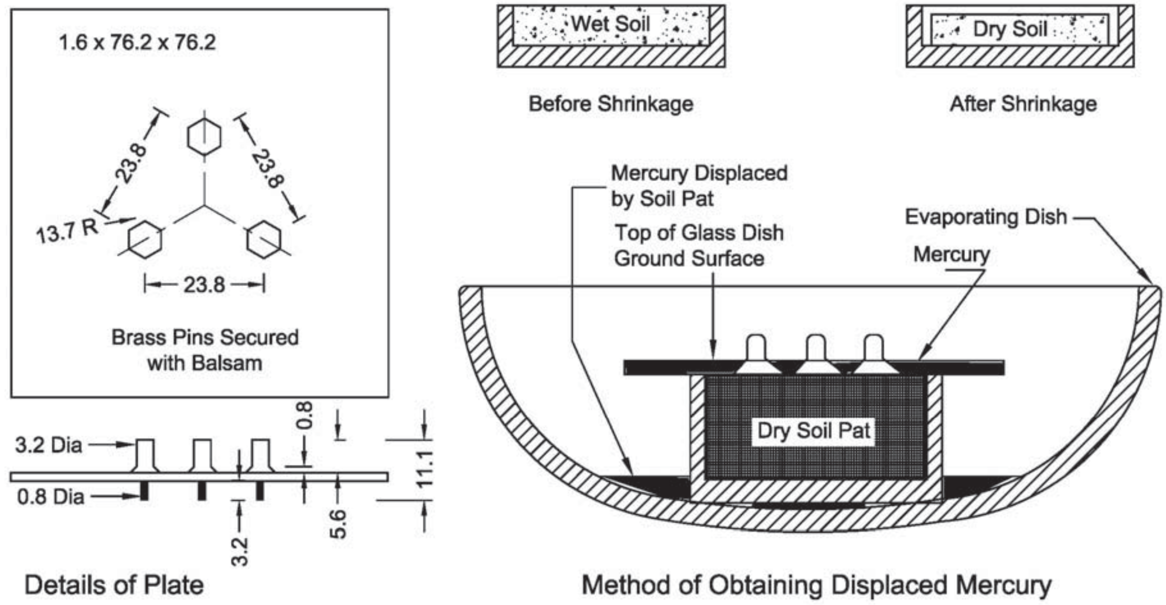
2.1.2. *Spatula*—A spatula or pill knife having a blade about 75 mm (3 in.) long and about 20 mm ($^3/_4$ in.) wide.

2.1.3. *Milk Dish*—A porcelain or Monel metal milk dish having a flat bottom and being about 45 mm ($1^3/_4$ in.) in diameter by about 12.7 mm ($^1/_2$ in.) high.

2.1.4. *Straightedge*—A steel straightedge 100 mm (4 in.) or more in length.

2.1.5. *Glass Cup*—A glass cup about 50 mm (2 in.) in diameter by 25 mm (1 in.) high, the top rim of which is ground smooth and parallel with its base.

2.1.6. *Transparent Plate*—A transparent plate with three metal prongs for immersing the soil pat in mercury as shown in Figure 1.



Dimensional Equivalents	
mm	in.
0.8	1/32
1.6	1/16
3.2	1/8
5.6	7/32
11.1	7/16
13.7	0.54
23.8	15/16
76.2	3

Note: All dimensions shown in millimeters unless otherwise noted.

Figure 1—Apparatus for Determining the Shrinkage Factors of Subgrade Soils

2.1.7. *Glass Graduate*—A glass graduate having a capacity of 25 mL and graduated to 0.2 mL.

2.1.8. *Balance*—The balance shall have sufficient capacity and conform to M 231, Class G 1.

2.1.9. *Mercury*—Sufficient mercury to fill the glass cup to overflowing.

2.1.10. *Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5ºC (230 ± 9ºF) for drying soil samples.

3. SAMPLE

3.1. A sample with a mass of about 30 g shall be taken from the thoroughly mixed portion of the material passing the 0.425-mm (No. 40) sieve prepared in accordance with the Standard Method of Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test (T 87), or the Standard Method of Wet Preparation of Disturbed Soil Samples for Test (T 146).

4. PROCEDURE

4.1. The sample shall be placed in the 115-mm ($4^1/_2$-in.) mixing dish and thoroughly mixed with water in amount sufficient to fill the soil voids completely and to make the soil pasty enough to be readily worked into the milk dish without inclusion of air bubbles. The amount of water required to produce the desired consistency in friable soils is equal to or slightly greater than the liquid limit, and the amount necessary to produce the desired consistency in plastic soils may exceed the liquid limit by as much as 10 percent.

4.2. The inside of the milk dish shall be coated with a thin layer of vaseline or some other heavy grease to prevent the adhesion of the soil to the dish. An amount of the wetted soil equal to about one-third of the volume of the milk dish shall be placed in the center of the dish, and the soil shall be caused to flow to the edges by tapping the dish on the firm surface cushioned by several layers of blotting paper or similar material. An amount of soil, approximately equal to the first portion, shall be added and the dish tapped until the soil is thoroughly compacted and all included air has been brought to the surface. More soil shall be added and the tapping continued until the dish is completely filled and excess soil stands out about its edge. The excess soil shall then be struck off with a straightedge and all soil adhering to the outside of the dish shall be wiped off.

4.3. The dish when filled, struck off, and wiped clean shall be weighed immediately and the mass recorded as the mass of dish and wet soil. The soil pat shall be allowed to dry at room temperature until the color of the pat turns from dark to light. It shall then be oven-dried to constant mass at 110 ± 5ºC (230 ± 9ºF) and the mass recorded as the mass of dish and dry soil. The mass of the empty dish shall be determined and recorded. The capacity of the dish in mL, which is also the volume of the wet soil pat, shall be determined by filling the dish to overflowing with mercury, removing the excess by pressing a glass plate firmly over the top of the dish, and measuring the volume of the mercury held in the dish in the glass graduate. The volume of the mercury shall be determined by the value at the top of the meniscus. Alternatively, determine the volume of the dish by weighing the mercury held in the dish to the nearest 0.1 g and calculate the volume in mL using the formula $V = M/D$, where M = mass of displaced mercury in grams and D = 13.5 g/mL (the density of mercury). This volume shall be recorded as the volume of the wet soil pat, V.

4.4. The volume of the dry soil pat shall be determined by removing the pat from the milk dish and immersing it in the glass cup full of mercury in the following manner:

4.4.1. The glass cup shall be filled to overflowing with mercury and the excess mercury shall be removed by pressing the glass plate with the three prongs (Figure 1) firmly over the top of the cup. Any mercury that may be adhering to the outside of the cup shall be carefully wiped off. The cup filled with mercury shall be placed in the 150-mm (6-in.) evaporating dish and the soil pat shall be placed on the surface of the mercury. The pat shall then be carefully forced under the mercury by means of the glass plate with the three prongs (Figure 1) and the plate shall be pressed firmly over the top of the cup. It is essential that no air be trapped under the soil pat. Determine the volume in mL of the dry soil pat, V_o, by measuring the mercury so displaced in the glass graduate or by determining the mass of the mercury to the nearest 0.1 g and calculating the volume in mL using the formula $V_o = M/D$, where, M = mass of mercury in grams and D = 13.5 g/mL (density of mercury).

5. CALCULATION OF WATER CONTENT

5.1. The water content of the soil at the time it was placed in the dish expressed as a percentage of the dry mass of the soil shall be calculated as follows:

$$w = \frac{W - W_o}{W_o} \times 100 \qquad (1)$$

where:

w = water content of the soil when placed in the dish,

W = mass of wet soil obtained by subtracting the mass of the shrinkage dish from the mass of the dish and wet pat, and

W_o = mass of dry soil pat obtained by subtracting the mass of the shrinkage dish from the mass of the dish and dry pat.

5.1.1. Calculate the water content to the nearest 0.1 percent.

6. CALCULATION OF THE SHRINKAGE LIMIT

6.1. *Definition*:

6.1.1. The shrinkage limit of a soil is defined as the maximum calculated water content, at which a reduction in water content will not cause a decrease in the volume of the soil mass.

6.2. *Calculation*:

6.2.1. The shrinkage limit, S, shall be calculated from the data obtained in the volumetric shrinkage determination by the following formula:

$$S = w - \frac{V - V_o}{W} \times 100 \qquad (2)$$

where:

S = shrinkage limit;

w = water content of wet soil, in percentage of the mass of oven-dried soil;

V = volume of wet soil pat;

V_o = volume of oven-dried soil pat; and

W = mass of oven-dried soil pat.

6.2.1.1. Calculate the shrinkage limit to the nearest 0.1 percent.

6.3. *Optional Method*:

6.3.1. When both the true specific gravity, G, and the shrinkage ratio, R, are known, the shrinkage limit may be calculated from the following formula:

$$S = \left(1/R - 1/G\right) \times 100 \qquad (3)$$

7. CALCULATION OF THE SHRINKAGE RATIO

7.1. *Definition*:

7.1.1. The shrinkage ratio of a soil is the ratio between a given volume change and the corresponding change in water content above the shrinkage limit.

7.2. *Calculation*:

7.2.1. The shrinkage ratio, *R,* shall be calculated from the data obtained in the volumetric shrinkage determination by the following formula:

$$R = \frac{W_o}{V_o} \qquad (4)$$

7.2.1.1. Calculate the shrinkage ratio to the nearest 0.1.

8. CALCULATION OF THE VOLUMETRIC CHANGE

8.1. *Definition*:

8.1.1. The volumetric change of a soil is the decrease in volume of the soil mass when the water content is reduced from a given percentage to the shrinkage limit.

8.2. *Calculation*:

8.2.1. The volumetric change, *VC,* shall be calculated from the data obtained from the volumetric shrinkage determination by the following formula:

$$VC = \left(w_1 - S\right)R \qquad (5)$$

where:

VC = the volumetric change, and

w_1 = a given water content.

8.2.1.1. Calculate the volumetric change to the nearest 0.1 percent.

9. CALCULATION OF THE LINEAL SHRINKAGE

9.1. *Definition*:

9.1.1. The lineal shrinkage of a soil is defined as the decrease in one dimension of the soil mass when the water content is reduced from a given percentage to the shrinkage limit.

9.1.2. The lineal shrinkage, *LS,* shall be obtained either by means of the formula:

$$LS = 100\left(1 - \sqrt[3]{\frac{100}{VC + 100}}\right) \qquad (6)$$

or by means of the curve in Figure 2, which represents this relation.

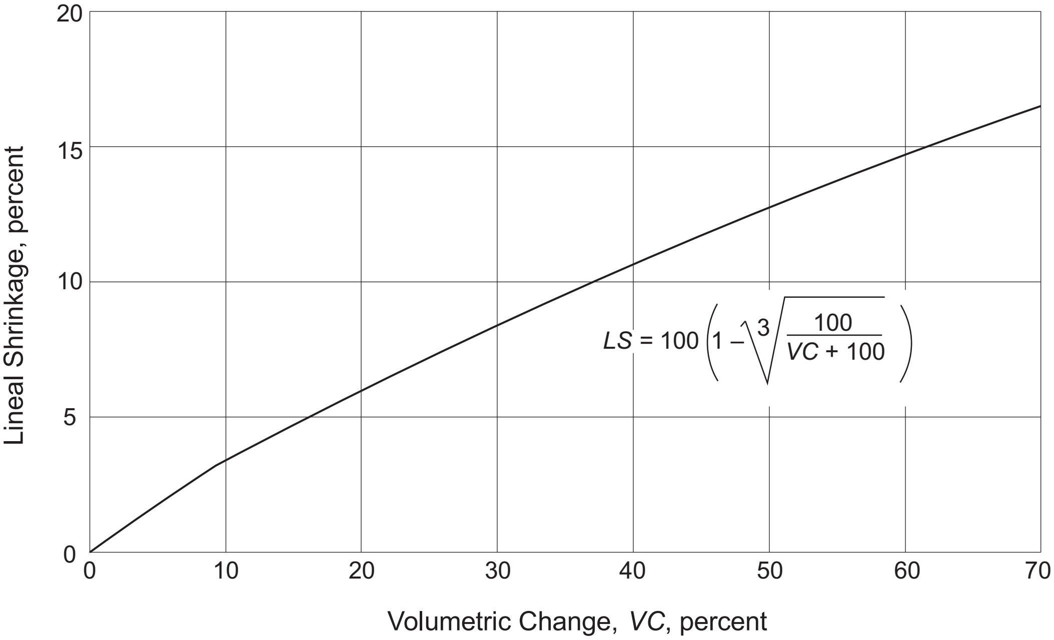


Figure 2—Relation between Volumetric Change and Lineal Shrinkage

9.1.2.1. Determine the lineal shrinkage to the nearest whole percent.

10. PRECISION

10.1. Criteria for judging the shrinkage factors of soils are as follows:

Note 1—The figures in Column 2 are the standard deviations that have been found to be appropriate for the tests described in Column 1. The figures in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

10.1.1. *Single-Operator Precision*:

Table 1—Single-Operator Precision

	Type of Test	Standard Deviation[a]	Acceptable Range of Two Results[a]
10.1.1.1	Water Content	no data	no data
10.1.1.2	Shrinkage Limit	0.91	2.6
10.1.1.3	Shrinkage Ratio	0.020	0.06
10.1.1.4	Volumetric Change	no data	no data
10.1.1.5	Lineal Shrinkage	no data	no data

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

10.1.2. *Multilaboratory Precision*:

Table 2—Multilaboratory Precision

	Type of Test	Standard Deviation[a]	Acceptable Range of Two Results[a]
10.1.2.1	Water Content	no data	no data
10.1.2.2	Shrinkage Limit	2.42	6.8
10.1.2.3	Shrinkage Ratio	0.055	0.16
10.1.2.4	Volumetric Change	no data	no data
10.1.2.5	Lineal Shrinkage	no data	no data

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

Standard Method of Test for

Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

AASHTO Designation: T 99-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

AASHTO Designation: T 99-10

1. SCOPE

1.1. These methods of test are intended for determining the relation between the moisture content and density of soils compacted in a mold of a given size with a 2.5-kg (5.5-lb) rammer dropped from a height of 305 mm (12 in.). Four alternate procedures are provided as follows:

- *Method A*—A 101.60-mm (4-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 4 and 5.
- *Method B*—A 152.40-mm (6-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 6 and 7.
- *Method C*—A 101.60-mm (4-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections 8 and 9.
- *Method D*—A 152.40-mm (6-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections 10 and 11.

1.2. The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Method A shall govern.

1.3. This test method applies to soil mixtures that have 40 percent or less retained on the 4.75 mm-(No. 4) sieve, when Method A or B is used and 30 percent or less retained on the 19.0-mm ($^3/_4$-in.) sieve, when Method C or D is used. The material retained on these sieves shall be defined as oversized particles (coarse particles).

1.4. If the test specimen contains oversize particles, and the test specimen is used for field density compaction control, corrections must be made according to T 224 to compare the total field density with the compacted specimen density. The person or agency specifying this method shall specify a minimum percentage of oversize particles below which correction for oversize need not be applied. If no minimum percentage is specified, correction shall be applied to samples with more than 5 percent by mass of oversize particles.

1.5. If the specified oversized maximum tolerances are exceeded, other methods of compaction control must be used.

Note 1—One method for the design and control of the compaction of such soils is to use a test fill to determine the required degree of compaction and a method to obtain that compaction. Then use a method specification to control the compaction by specifying the type and size of compaction equipment, the lift thickness, and the number of passes.

1.6. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit” in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.7. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 224, Correction for Coarse Particles in the Soil Compaction Test
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- D 2168, Standard Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

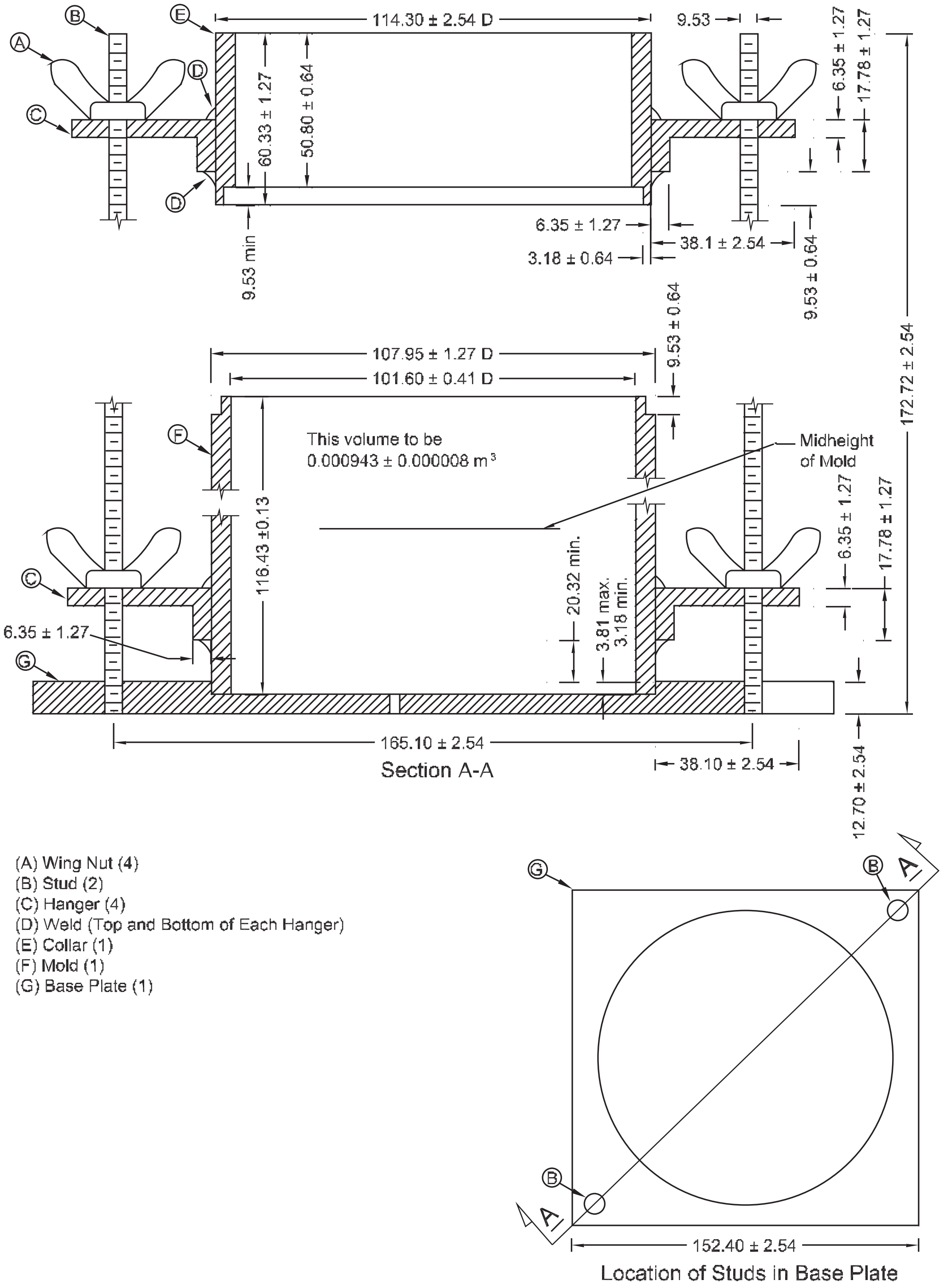
3.1. *Molds*—The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in Sections 3.1.1, 3.1.2, and Figures 1 and 2. They shall have a detachable collar assembly approximately 60 mm (2.375 in.) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired height and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material (Note 2). The base plate shall be plane to 0.005 in. as shown in Figures 1 and 2.

Note 2—Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection, when alternate types of molds are used.

3.1.1. A 101.6-mm (4-in.) mold having a capacity of 0.000943 ± 0.000008 m^3 ($^1/_{30}$ (0.0333) ± 0.0003 ft^3) with an internal diameter of 101.60 ± 0.41 mm (4.000 ± 0.016 in.) and a height of 116.43 ± 0.13 mm (4.584 ± 0.005 in.) (Figure 1).

3.1.2. A 152.4-mm (6-in.) mold having a capacity of 0.002124 ± 0.000021 m^3 ($^1/_{13.33}$ (0.07500) ± 0.00075 ft^3) with an internal diameter of 152.40 ± 0.66 mm (6.000 ± 0.026 in.) and a height of 116.43 ± 0.13 mm (4.584 ± 0.005 in.) (Figure 2).

3.1.3. *Molds Out of Tolerance Due to Use*—A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with T 19M/T 19 for Unit Mass of Aggregate, is used in the calculations.

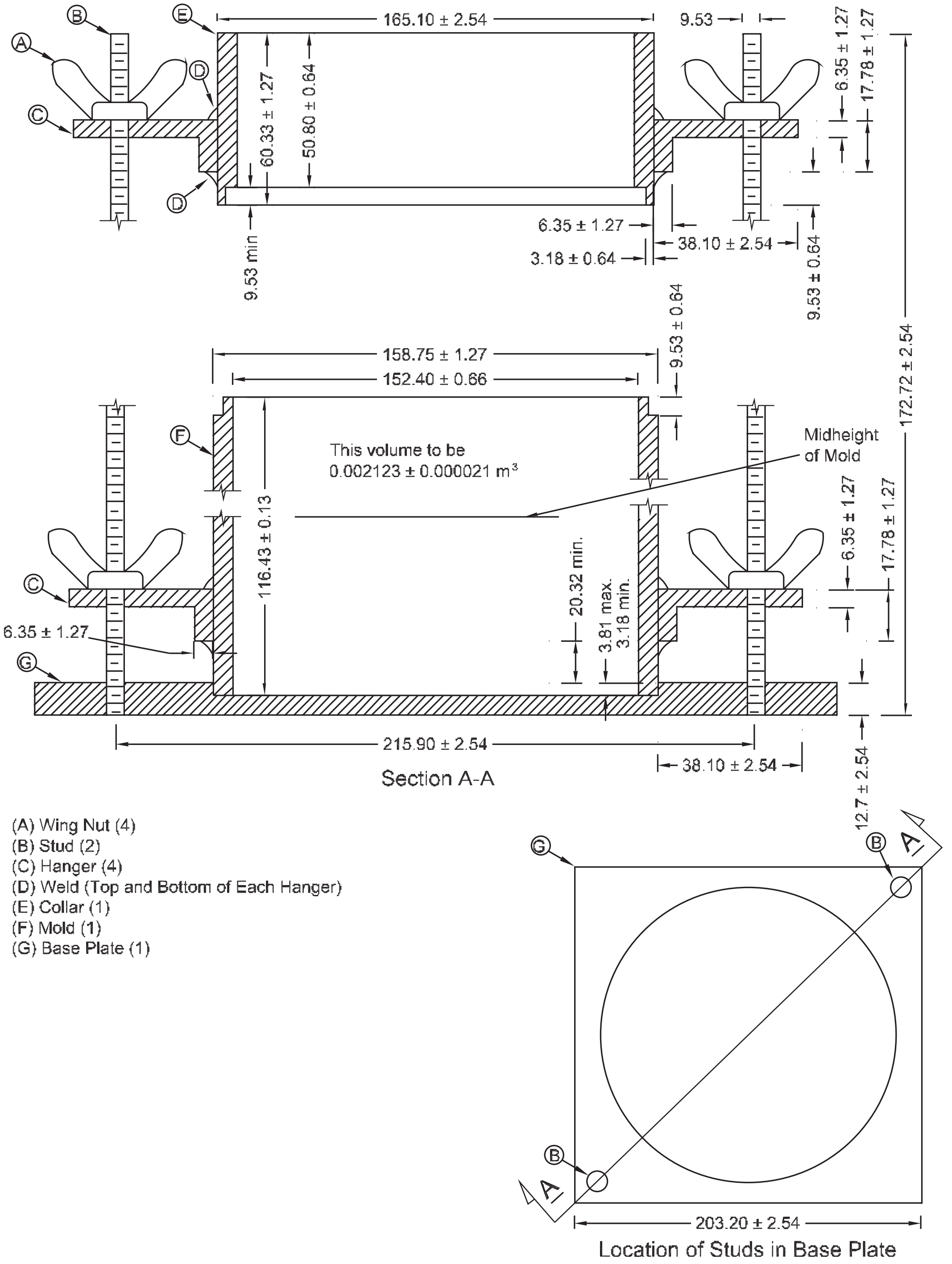


Notes: 1. All dimensions shown in millimeters unless otherwise noted.

2. Hanger on the mold portion only cannot extend above the midheight line.

3. Figure 1 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).

Figure 1—Cylindrical Mold and Base Plate (101.6-mm Mold)



(A) Wing Nut (4)
(B) Stud (2)
(C) Hanger (4)
(D) Weld (Top and Bottom of Each Hanger)
(E) Collar (1)
(F) Mold (1)
(G) Base Plate (1)

Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Hanger on the mold portion only cannot extend above the midheight line.
3. Figure 2 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).

Figure 2—Cylindrical Mold and Base Plate (152.4-mm Mold)

Table 1—Dimensional Equivalents for Figure 1

mm	in.	Mm	in.
3.18 ± 0.64	0.125 ± 0.025	50.80 ± 0.64	2.000 ± 0.025
3.81	0.150	60.33 ± 1.27	2.375 ± 0.050
6.35 ± 1.27	0.250 ± 0.050	101.60 ± 0.41	4.000 ± 0.016
7.62	0.300	107.95 ± 1.27	4.250 ± 0.050
9.53 ± 0.64	0.375 ± 0.025	114.30 ± 2.54	4.500 ± 0.100
12.70 ± 2.54	0.500 ± 0.100	116.43 ± 0.13	4.584 ± 0.005
17.78 ± 1.27	0.700 ± 0.050	152.40 ± 2.54	6.000 ± 0.100
20.32	0.800	165.10 ± 2.54	6.500 ± 0.100
38.10 ± 2.54	1.500 ± 0.100	172.72 ± 2.54	6.800 ± 0.100
0.000943 ± 0.000008 m^3	1/30 ± 0.0003 ft^3		

Table 2—Dimensional Equivalents for Figure 2

mm	in.	Mm	in.
3.18 ± 0.64	0.125 ± 0.025	50.80 ± 0.64	2.000 ± 0.025
3.81	0.150	60.33 ± 1.27	2.375 ± 0.050
6.35 ± 1.27	0.250 ± 0.050	116.43 ± 0.13	4.584 ± 0.005
7.62	0.300	152.40 ± 0.66	6.000 ± 0.026
9.53 ± 0.64	0.375 ± 0.025	158.75 ± 1.27	6.250 ± 0.050
12.70 ± 2.54	0.500 ± 0.100	165.10 ± 2.54	6.500 ± 0.100
17.78 ± 1.27	0.700 ± 0.050	172.72 ± 2.54	6.800 ± 0.100
20.32	0.800	203.23 ± 2.54	8.000 ± 0.100
38.10 ± 2.54	1.500 ± 0.100	215.90 ± 2.54	8.500 ± 0.100
0.002124 ± 0.000021 m^3	1/13.33 ± 0.00075 ft^3		

3.2. *Rammer*:

3.2.1. *Manually Operated*—Metal rammer with a mass of 2.495 ± 0.009 kg (5.5 ± 0.02 lb), and having a flat circular face of 50.80-mm (2.000-in.) diameter with a manufacturing tolerance of ± 0.25 mm (0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of 305 ± 2 mm (12.00 ± 0.06 in.) above the elevation of the soil. The guide-sleeve shall have at least four vent holes, no smaller than 9.5-mm ($^3/_8$-in.) diameter spaced approximately 90 degrees (1.57 rad) apart and approximately 19 mm ($^3/_4$ in.) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2. *Mechanically Operated*—A metal rammer that is equipped with a device to control the height of drop to a free fall of 305 ± 2 mm (12.00 ± 0.06 in.) above the elevation of the soil and uniformly distributes such drops to the soil surface (Note 3). The rammer shall have a mass of 2.495 ± 0.009 kg (5.5 ± 0.02 lb), and have a flat circular face of 50.80-mm (2.000-in.) diameter with a manufactured tolerance of ± 0.25 mm (0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The mechanical rammer shall be calibrated by ASTM D 2168.

Note 3—It may be impractical to adjust the mechanical apparatus so the free fall is 305 mm (12 in.) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 305-mm drop is determined. Subsequent blows on the layer of soil being compacted may all be applied by dropping the rammer from a height of 305 mm above the initial-setting elevation; or, when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have a rammer free fall of 305 mm measured from the elevation of the soil as compacted by the previous blow. A more detailed calibration procedure for laboratory mechanical-rammer soil compactors can be found in ASTM D 2168.

3.2.3. *Rammer Face*—The circular face rammer shall be used, but a sector face may be used as an alternative, provided the report shall indicate type of face used other than the 50.8-mm (2-in.) circular face, and it shall have an area equal to that of the circular face rammer.

3.3. *Sample Extruder (for Solid-Walled Molds Only)*—A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

3.4. *Balances and Scales*—A balance or scale conforming to the requirements of M 231, Class G 20. Also, a balance conforming to the requirements of M 231, Class G 2.

Note 4—The capacity of the metric balance or scale should be approximately 11.5 kg when used to weigh the 152.40-mm (6-in.) mold and compacted, moist soil; however, when the 101.60-mm (4-in.) mold is used, a balance or scale of lesser capacity than the 11.5 kg may be used, if the sensitivity and readability is 5 g.

3.5. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF) for drying moisture samples.

3.6. *Straightedge*—A hardened-steel straightedge at least 250 mm (10 in.) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.250 mm per 250 mm (0.01 in. per 10 in.) (0.1 percent) of length within the portion used for trimming the soil (Note 5).

Note 5—The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.250 mm per 250 mm (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil with the cutting edge will cause a concave soil surface.

3.7. *Sieves*—50-mm (2-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves conforming to the requirements of M 92.

3.8. *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

METHOD A

4. SAMPLE

4.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

4.2. Sieve an adequate quantity of the representative pulverized soil over the 4.75-mm (No. 4) sieve. Discard the coarse material, if any, retained on the 4.75-mm (No. 4) sieve.

4.3. Select a representative sample, with a mass of approximately 3 kg (7 lb) or more, of the soil prepared as described in Sections 4.1 and 4.2.

Note 6—When developing a compaction curve for free-draining soils, such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content sample from the mixing bowl may be preferred to determine the amount of moisture available for compaction.

5. PROCEDURE

5.1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

5.2. Form a specimen by compacting the prepared soil in the 101.60-mm (4-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5 in.). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 50 mm (2 in.). Following compaction of each of the first two layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed using a knife or other suitable device and evenly distributed on top of the layer. Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm (12 in.) above the elevation of the soil when a sleeve-type rammer is used, or from 305 mm above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process (Note 7).

Note 7—Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: a block of concrete, with a mass not less than 90 kg (200 lb), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as are found in concrete box culverts, bridges, and pavements.

5.2.1. Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and determine the mass of the mold and moist soil in kilograms to the nearest five grams, or determine the mass in pounds to the nearest 0.01 pounds. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

5.3. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces (Figure 3) and weigh immediately. Determine the moisture content in accordance with T 265 and record the results.

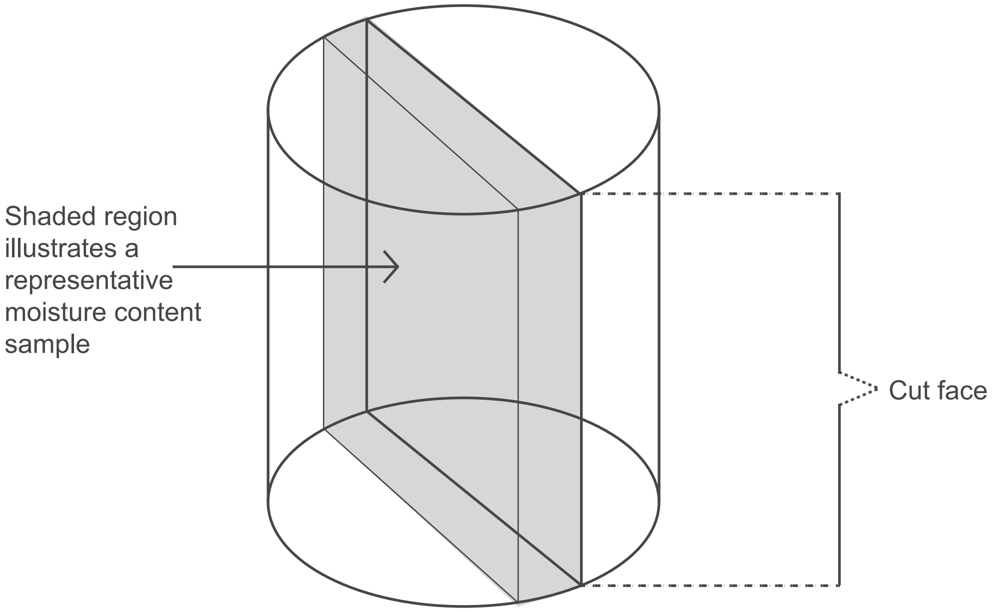


Figure 3—Representative Moisture Content Sample Selection

5.4. Thoroughly break up the remaining portion of the molded specimen until it will pass through a 4.75-mm (No. 4) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil 1 to 2 percentage points (water content increments should not exceed 2.5 percent except when heavy clay soils or organic soils exhibiting flat elongated curves are encountered; the water content increments may be increased to a maximum of 4 percent) and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass, W_1, per cubic meter (cubic foot) of the compacted soil (Note 8).

Note 8—In instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, and in cases where the soil is a heavy-textured clayey material into which it is difficult to incorporate water, a separate and new sample shall be used in each compaction test. In these cases, separate samples shall be thoroughly mixed with amounts of water sufficient to cause the moisture contents of the samples to vary by approximately two percentage points. The moisture points selected shall bracket the optimum moisture content, thus providing samples that, when compacted, will increase in mass to the maximum density and then decrease in mass. The samples of soil-water mixtures shall be placed in covered containers and allowed to stand for not less than 12 hours before making the moisture-density test.

5.4.1. In instances where the soil material is fragile in character and will be reduced significantly in grain size by repeated compaction, a separate and new sample shall be used in each compaction test.

METHOD B

6. SAMPLE

6.1. Select the representative sample in accordance with Section 4.3, except that it shall have a mass of approximately 7 kg (16 lb).

7. PROCEDURE

7.1. Follow the same procedure as described for Method A in Section 5, except for the following: Form a specimen by compacting the prepared soil in the 152.4-mm (6-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5 in.), each layer being compacted by 56 uniformly distributed blows from the rammer. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

METHOD C

8. SAMPLE

8.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

8.2. Sieve an adequate quantity of the representative pulverized soil over the 19.0-mm sieve. Discard the coarse material, if any, retained on the 19.0-mm sieve (Note 9).

Note 9—The discarded coarse material may be utilized in T 224.

8.3. Select a representative sample, having a mass of approximately 5 kg (11 lb) or more, of the soil prepared as described in Sections 8.1 and 8.2.

9. PROCEDURE

9.1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

9.2. Form a specimen by compacting the prepared soil in the 101.60-mm (4-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5 in.). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or a similar device having a face diameter of approximately 50 mm (2 in.). Following compaction of each of the first two layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed using a knife or other suitable device and evenly distributed on top of the layer. Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm (12 in.) above the elevation of the soil when a sleeve-type rammer is used, or from 305 mm (12 in.) above the approximate elevation of each finely compacted layer when a stationary mounted-type rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation (Note 7).

9.2.1. Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Holes developed in the surface by removal of coarse material shall be patched with smaller-sized material. Determine the mass of the mold and moist soil in kilograms to the nearest five grams, or determine the mass in pounds to the nearest 0.01 pounds. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

9.3. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces and weigh immediately. Determine the moisture content in accordance with T 265 and record the results.

9.4. Thoroughly break up the remainder of the material until it will pass through a 19.0-mm sieve and 90 percent of the soil aggregations will pass a 4.75-mm sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass, W_1, per cubic meter (cubic foot) of compacted soil (Note 8).

METHOD D

10. SAMPLE

10.1. Select the representative sample in accordance with Section 8.3 except that it shall have a mass of approximately 11 kg (25 lb).

11. PROCEDURE

11.1. Follow the same procedure as described for Method C in Section 9, except for the following: Form a specimen by compacting the prepared soil in the 152.4-mm (6-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5 in.), each layer being compacted by 56 uniformly distributed blows from the rammer. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

CALCULATIONS AND REPORT

12. CALCULATIONS

12.1. The mold factor can be related to the volume of the mold as follows:

$$F = 1 / V \tag{1}$$

where:

F = mold factor; and
V = volume of mold.

12.2. The wet density can be determined using the mold factor. For masses recorded in kilograms, the unit of wet density is kilograms per cubic meter of compacted soil. For masses recorded in pounds, the unit of wet density is pounds per cubic foot of compacted soil.

$$W_1 = (A - B) \times F \tag{2}$$

where:

A = mass of compacted specimen and mold;
B = mass of mold;
F = mold factor as given in Table 3; and
W_1 = wet density.

Table 3—Mold Factors for Molds in Compliance with Sections 3.1.1 or 3.1.2

	Mold Factor	
Method	For masses recorded in kilograms	For masses recorded in pounds
A	1060	30
B	471	13.3
C	1060	30
D	471	13.3

For used molds in compliance with Section 3.1.3, determine the mold factor in accordance with Section 3.1.3 and Equation 1.

12.3. Alternatively, the wet density can be determined using the mold volume. For masses recorded in kilograms, the unit of wet density is kilograms per cubic meter of compacted soil. For masses recorded in pounds, the unit of wet density is pounds per cubic foot of compacted soil.

$$W_1 = (A - B)/V \tag{3}$$

where:

V = mold volume as given in Section 3.1.1 for Methods A and C, or Section 3.1.2 for Methods B and D. For used molds in compliance with Section 3.1.3, determine the mold volume in accordance with Section 3.1.3.

12.4. The dry density is related to the wet density as follows:

$$W = \frac{W_1}{w + 100} \times 100 \tag{4}$$

where:

w = moisture content (percent) of the specimen, as determined by T 265; and

W = dry density, in kilograms per cubic meter of compacted soil, or pounds per cubic foot of compacted soil.

13. MOISTURE-DENSITY RELATIONSHIP

13.1. The calculations in Section 12 shall be made to determine the wet density (unit mass) and oven-dry density (unit mass) in kilograms per cubic meter or pounds per cubic foot of the compacted samples. The oven-dry densities of the soil shall be plotted as ordinates, and the corresponding moisture content as abscissas.

13.2. *Optimum Moisture Content*—When the densities and corresponding moisture contents for the soil have been determined and plotted as indicated in Section 13.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture content" of the soil under the above compaction.

13.3. *Maximum Density*—The oven-dry density in kilograms per cubic meter or pounds per cubic foot of the soil at optimum moisture content shall be termed "maximum density" under the above compaction.

14. REPORT

14.1. The report shall include the following:

14.1.1. The method used (Method A, B, C, or D).

14.1.2. The optimum moisture content, as a percentage, to the nearest whole number.

14.1.3. The maximum density in kilograms per cubic meter to the nearest 10 kg/m^3 or in pounds per cubic foot, to the nearest whole number.

14.1.4. Type of face if other than 50.8 mm (2 in.) circular.

15. PRECISION STATEMENT

15.1. *Repeatability (Single Operator)*—Two results obtained by the same operation on the same sample in the same laboratory using the same apparatus and on different days should be considered suspect if they differ by more than 10 percent of their mean for optimum moisture content and 35 kg/m^3 (2.2 lb/ft^3) for maximum density.

15.2. *Reproducibility (Multilaboratory)*—Two results obtained by different operators in different laboratories should be considered suspect if they differ by more than 15 percent of their mean for optimum moisture and 72 kg/m^3 (4.5 lb/ft^3) for maximum density.

Standard Method of Test for

Specific Gravity of Soils

AASHTO Designation: T 100-06[1]
ASTM Designation: D 854-00

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Specific Gravity of Soils

AASHTO Designation: T 100-06[1]
ASTM Designation: D 854-00

1. SCOPE

1.1. This method covers determination of the specific gravity of soils by means of a pycnometer. When the soil is composed of particles larger than the 4.75-mm (No. 4) sieve, the method outlined in T 85 shall be followed. When the soil is composed of particles both larger and smaller than the 4.75-mm sieve, the sample shall be separated on the 4.75-mm sieve and the appropriate test method used on each portion. The specific gravity value for the soil shall be the weighted average of the two values (Note 1). When the specific gravity value is to be used in calculations in connection with the hydrometer portion of AASHTO T 88, Particle Size Analysis of Soils, it is intended that the specific gravity test be made on that portion of the soil that passes the 2.00-mm (No. 10) sieve.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

Note 1—The weighted average specific gravity should be calculated using the following equation:

$$G_{\text{avg}} = \frac{1}{\dfrac{R_1}{100G_1} + \dfrac{P_1}{100G_2}} \qquad (1)$$

where:

G_{avg} = weighted average specific gravity of soils composed of particles larger and smaller than the 4.75-mm (No. 4) sieve,

R_1 = percent of soil particles retained on the 4.75-mm sieve,

P_1 = percent of soil particles passing the 4.75-mm sieve,

G_1 = apparent specific gravity of soil particles retained on the 4.75-mm sieve as determined by AASHTO T 85, and

G_2 = specific gravity of soil particles passing the 4.75-mm sieve as determined by this test method.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- M 231, Weighing Devices Used in the Testing of Materials
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 88, Particle Size Analysis of Soils

2.2. *ASTM Standards*:

- C 127, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 4753, Standard Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
- D 6026, Standard Practice for Using Significant Digits in Geotechnical Data
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. DEFINITION

3.1. *specific gravity*—The ratio of the mass of a unit volume of a material at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature (per Definition, E 1547).

4. SIGNIFICANCE AND USE

4.1. The specific gravity of a soil is used in almost every equation expressing the phase relationship of air, water, and solids in a given volume of material.

4.2. The term *solid particles*, as used in geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not very soluble in water. Therefore, the specific gravity of materials containing extraneous matter (such as cement, lime, etc.), water-soluble matter (such as sodium chloride), and soils containing matter with a specific gravity of less than one, typically require special treatment or a qualified definition of specific gravity.

5. APPARATUS

5.1. *The apparatus shall consist of the following*:

5.1.1. *Pycnometer*—Either a volumetric flask having a capacity of at least 100 mL or a stoppered bottle having a capacity of at least 50 mL (Note 2). The stopper shall be of the same material as the bottle, and of such size and shape that it can be easily inserted to a fixed depth in the neck of the bottle, and shall have a small hole through its center to permit the emission of air and surplus water.

Note 2—The use of either the volumetric flask or the stoppered bottle is a matter of individual preference, but in general, the flask should be used when a larger sample than can be used in the stoppered bottle is needed due to maximum grain size of the sample. A 500 mL flask is required for samples of clayey soils containing their natural moisture content. (See Section 8.2.)

5.1.2. *Balance*—Either an M 231, Class G 1 balance for use with the volumetric flask, or an M 231, Class B balance for use with the stoppered bottle.

5.1.3. *Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110º ± 5ºC (230 ± 9ºF).

5.1.4. *Thermometer*—Capable of measuring the temperature range within which the test is being performed, graduated in a 0.5ºC (1.0ºF) division scale and meeting the requirements of ASTM E 1 or any other thermometric device of equal accuracy, precision, and sensitivity.

6. GENERAL REQUIREMENTS FOR WEIGHING

6.1. When the volumetric flask is used in the specific gravity determination, all masses shall be determined to the nearest 0.01 g. When the stoppered bottle is used in the specific gravity determination, all masses shall be determined to the nearest 0.001 g.

7. CALIBRATION OF PYCNOMETER

7.1. The pycnometer shall be cleaned, dried, weighed, and the mass recorded. The pycnometer shall be filled with distilled water (Note 3) essentially at room temperature. The mass of the pycnometer and water, W_a, shall be determined and recorded. A thermometer shall be inserted in the water and its temperature, T_i, determined to the nearest whole degree.

Note 3—Kerosene is a better wetting agent than water for most soils and may be used in place of distilled water for oven-dried samples.

7.2. A table of values of mass W_a shall be prepared for a series of temperatures that are likely to prevail when the mass W_b of the pycnometer, sample, and water is determined at the end of testing (Note 4). These values of W_a shall be calculated as follows:

$$W_a\left(\text{at } T_x\right) = \left(\text{density of water at } T_x / \text{density of water at } T_i\right) \times \left(W_a\left(\text{at } T_i\right) - W_f\right) + W_f \tag{2}$$

where:

W_a = mass of pycnometer and water, in grams;

W_f = mass of pycnometer, in grams;

T_i = observed temperature of water, in degrees Celsius; and

T_x = any other desired temperature, in degrees Celsius.

Note 4—This method provides a procedure that is most convenient for laboratories making many determinations with the same pycnometer. It is equally applicable to a single determination. Bringing the pycnometer and contents to some designated temperature when masses W_a and W_b are taken requires considerable time. It is much more convenient to prepare a table of masses W_a for various temperatures likely to prevail when masses W_b (see Section 9.3) are taken. It is important that masses W_a and W_b be based on water at the same temperature. Values for the relative density of water at temperatures from 18 to 30ºC are given in Table 1.

Table 1—Relative Density of Water and Correction Factor *K* for Various Temperatures

Temperatures, ºC	Relative Density of Water	Correction Factor *K*
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9965451	0.9983
28	0.9962652	0.9980
29	0.9959761	0.9977
30	0.9956780	0.9974

8. SAMPLE

8.1. The soil to be used in the specific gravity test may contain its natural moisture or be oven-dried. The mass of the test sample on an oven-dry basis shall be at least 25 g when the volumetric flask is to be used, and at least 10 g when the stoppered bottle is to be used.

8.2. *Samples Containing Natural Moisture*—When the sample contains its natural moisture, the mass of the soil, W_o, on an oven-dry basis shall be determined at the end of the test by evaporating the water in an oven maintained at 110º ± 5ºC (230 ± 9ºF) (Note 5). Samples of clay soils containing their natural moisture content shall be dispersed in distilled water before placing in a 500 mL flask, using the dispersing equipment specified in T 88 (Note 6).

8.3. *Oven-Dried Samples*—When an oven-dried sample is to be used, the sample shall be dried for at least 12 hours, or to constant mass, in an oven maintained at 110º ± 5ºC (230 ± 9ºF) (Note 5), cooled to room temperature, then weighed and transferred to the pycnometer or transferred to the pycnometer and then weighed. Distilled water shall be added into the pycnometer in an amount that will provide complete sample coverage. The sample shall then soak for at least 12 hours.

Note 5—Drying of certain soils at 110ºC may bring about loss of moisture of composition or hydration, and in such cases drying shall be done, if desired, in reduced air pressure and at a lower temperature.

Note 6—The minimum volume of slurry that can be prepared by the dispersing equipment specified in T 88 is such that a 500-mL flask is needed as the pycnometer.

9. PROCEDURE

9.1. The sample as prepared in Section 8 shall have distilled water added to a level that will cover the soil to a maximum of about three-fourths full in the volumetric flask, or about one-half full in the stoppered bottle (Note 7).

9.2. Remove entrapped air by either of the following methods: (1) subject the contents to a partial vacuum of 13.33 kPa (100 mm Hg) or less absolute pressure or (2) boil gently for at least 10 min., while occasionally rolling the pycnometer to assist in the removal of the air. Subjection of the contents to reduced air pressure may be done either by connecting the pycnometer directly to an aspirator or vacuum pump, or by use of a bell jar. Some soils boil violently when subjected to reduced air pressure. It will be necessary in those cases to reduce the air pressure at a slower rate or to use a larger flask (Note 8). Samples that are heated shall be cooled to room temperature.

Note 7—If the vacuum method of air removal is used, the required amount of distilled water may be added in layers, with each layer being subjected to the vacuum until the sample ceases to release air.

Note 8—When using a partial vacuum, agitate the flask gently at intervals during the evacuation process. (A) Samples containing natural moisture with high plasticity may require 6 to 8 hours to remove air; samples with low plasticity may require 4 to 6 hours to remove air. (B) Oven-dried samples may require 2 to 4 hours to remove air.

9.3. Fill the pycnometer with distilled water to its calibrated capacity and then clean the outside and dry with a clean, dry cloth. Determine the mass of the pycnometer and contents, W_b, and the temperature in degrees Celsius, T_x, of the contents as described in Section 7.

10. CALCULATION AND REPORT

10.1. Calculate the specific gravity of the soil, based on water at a temperature T_x, as follows:

$$\text{Specific Gravity, } T_x / T_x = W_o / \left[W_o + \left(W_a - W_b \right) \right] \tag{3}$$

where:

T_x = temperature of the contents of the pycnometer when mass W_b was determined, in degrees Celsius;

W_o = mass of sample of oven-dried soil in grams;

W_a = mass of pycnometer filled with water at temperature T_x (Note 9), in grams; and

W_b = mass of pycnometer filled with water and soil at temperature T_x, in grams.

Note 9—This value shall be taken from the table of values of W_a, prepared in accordance with Section 7.2, for the temperature prevailing when mass W_b was taken.

10.2. Unless otherwise required, specific gravity values reported shall be based on water at 20ºC. The value based on water at 20ºC shall be calculated from the value based on water at the observed temperature T_x, as follows:

$$\text{Specific Gravity, } T_x / 20°\text{C} = K \times \text{ Specific Gravity, } T_x / T_x \tag{4}$$

where:

K = a number found by dividing the relative density of water at temperature T_x by the relative density of water at 20ºC. Values for a range of temperatures are given in Table 1.

10.3. When it is desired to report the specific gravity value based on water at 4ºC, such a specific gravity value may be calculated by multiplying the specific gravity value at temperature T_x by the relative density of water at temperature T_x.

10.4. When any portion of the original sample of soil is eliminated in the preparation of the test sample, the portion on which the test has been made shall be reported.

10.5. When using the volumetric flask to determine specific gravities, report results to at least the nearest 0.01.

10.6. When using the stoppered bottle to determine specific gravities, report results to at least the nearest 0.001.

11. PRECISION AND BIAS

11.1. Criteria for judging the acceptability of specific gravity test results obtained by this test method on material passing the 4.75-mm (No. 4) or 2.00-mm (No. 10) sieve are given in Table 2 (see Note 10):

Table 2—Specific Gravity Test Results

Material and Type Index	Standard Deviation[a]		Acceptable Range of Two Results (Percent of Mean)[a]	
	ASTM[b] Passing 4.75 mm (No. 4)	AASHTO[c] Passing 2.00 mm (No. 10)	ASTM[b] Passing 4.75 mm (No. 4)	AASHTO[c] Passing 2.00 mm (No. 10)
Single-Operator precision:				
Cohesive soils	0.021	0.02	0.06	0.05
Noncohesive soils	[d]	[d]	[d]	[d]
Multilaboratory precision:				
Cohesive soils	0.056	0.04	0.16	0.11
Noncohesive soils	[d]	[d]	[d]	[d]

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670 for Preparing Precision Statements for Test Methods for Construction Materials.

[b] These numbers represent standard deviation values assigned by ASTM Committee on Materials.

[c] These numbers represent standard deviation values assigned by AASHTO Subcommittee on Materials.

[d] Criteria for assigning standard deviation values for noncohesive soils are not available at the present time.

Note 10—The figures given in Column 2 are the standard deviations that have been found to be appropriate for the materials described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

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[1] Except for the requirements given for the thermometer, reporting accuracy, minimum sampling size and weighing, and our deletion of the desiccator, this method is the same as ASTM D 854-00.

Standard Method of Test for

Moisture-Density Relations of Soil-Cement Mixtures

AASHTO Designation: T 134-05 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Moisture-Density Relations of Soil-Cement Mixtures

AASHTO Designation: T 134-05 (2009)

1. SCOPE

1.1. These methods of test are intended for determining the relation between moisture content and density of soil-cement mixtures when compacted before cement hydration as prescribed.

1.2. A 944-cm^3 (1/30-ft^3) mold and a 2.5-kg (5.5-lb) rammer dropped from a height of 305 mm (12 in.) are used and two methods, depending on soil gradation, are covered, as follows:

- *Method A*—Soil material passing a 4.75-mm (No. 4) sieve. This method shall be used when 100 percent of the soil sample passes the 4.75-mm (No. 4) sieve.
- *Method B*—Soil material passing a 19.0-mm ($^3/_4$-in.) sieve. This method shall be used when part of the soil sample is retained on the 4.75-mm (No. 4) sieve.

1.3. This test method applies to soil-cement mixtures that have 30 percent or less retained on the 19.0-mm ($^3/_4$-in.) sieve, when Method B is used. The material retained on these sieves shall be defined as oversized particles (coarse particles).

1.4. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- M 240, Blended Hydraulic Cement
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 224, Correction for Coarse Particles in the Soil Compaction Test
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- D 2168, Standard Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *Molds*—The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in Table 1. They shall have a detachable collar assembly approximately 60 mm (2.375 in.) in height to permit preparation of compacted specimens of soil-cement mixtures of the desired weight and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material (Figure 1).

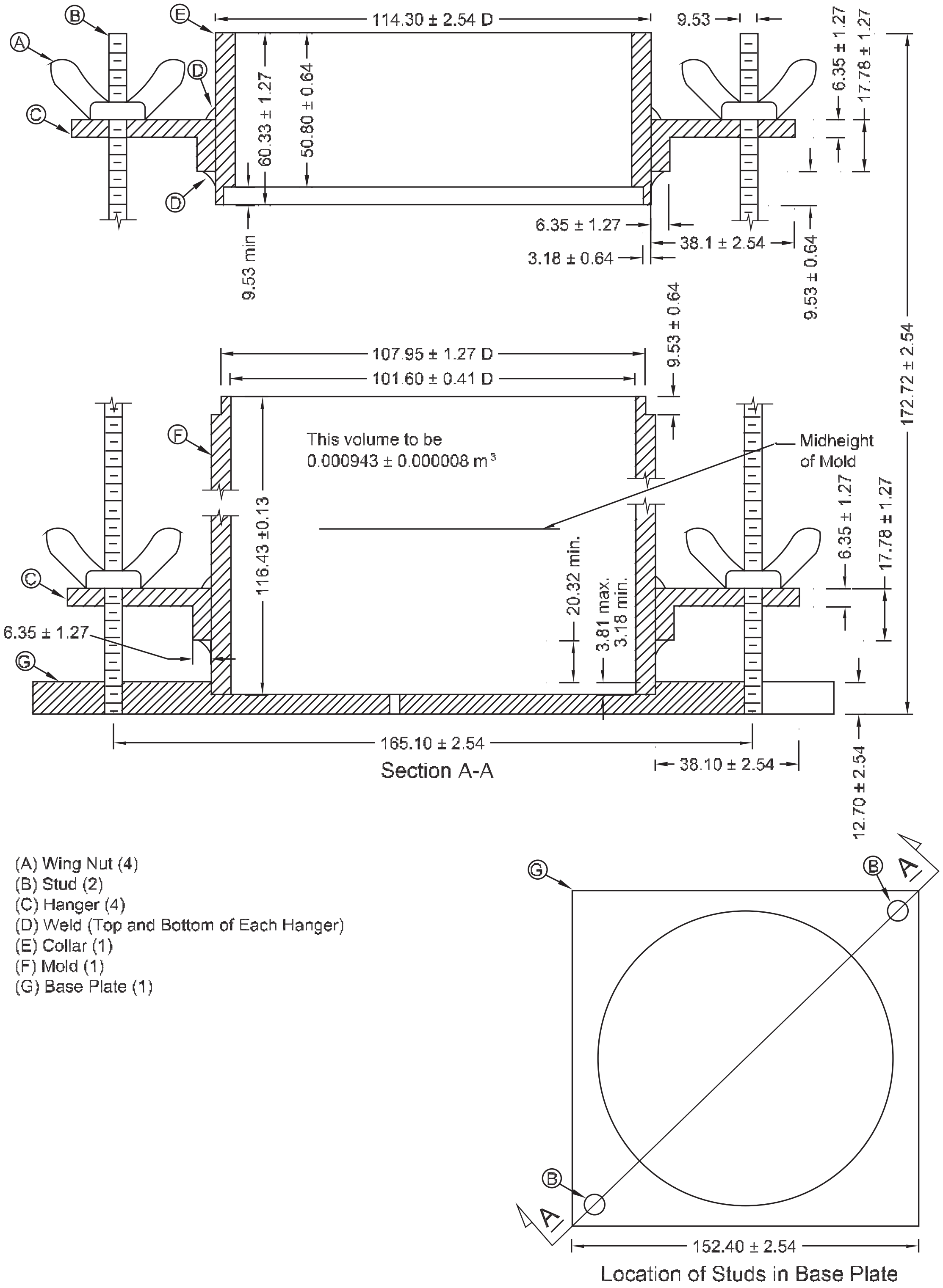
Note 1—Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection, when alternate types of molds are used.

3.2. A 101.6-mm (4-in.) mold having a capacity of 0.000943 ± 0.000008 m^3 ($^1/_{30}$ (0.0333) ± 0.0003 ft^3) with an internal diameter of 101.60 ± 0.41 mm (4.000 ± 0.016 in.) and a height of 116.43 ± 0.13 mm (4.584 ± 0.005 in.) (Figure 1).

3.3. *Molds Out of Tolerance Due to Use*—A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with T 19M/T 19, for Unit Mass of Aggregate, is used in the calculations.

Table 1—Dimensional Equivalents for Figure 1

mm	in.	mm	in.
3.18 ± 0.64	0.125 ± 0.025	50.80 ± 0.64	2.000 ± 0.025
3.81	0.150	60.33 ± 1.27	2.375 ± 0.050
6.35 ± 1.27	0.250 ± 0.050	101.60 ± 0.41	4.000 ± 0.016
7.62	0.300	107.95 ± 1.27	4.250 ± 0.050
9.53 ± 0.64	0.375 ± 0.025	114.30 ± 2.54	4.500 ± 0.100
12.70 ± 2.54	0.500 ± 0.100	116.43 ± 0.13	4.584 ± 0.005
17.78 ± 1.27	0.700 ± 0.050	152.40 ± 2.54	6.000 ± 0.100
20.32	0.800	165.10 ± 2.54	6.500 ± 0.100
38.10 ± 2.54	1.500 ± 0.100	172.72 ± 2.54	6.800 ± 0.100
0.000943 ± 0.000008 m^3	$^1/_{30}$ ± 0.0003 ft^3		



Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Hanger on the mold portion only cannot extend above the midheight line.
3. Figure 1 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).
4. Not to scale.

Figure 1—Cylindrical Mold and Base Plate (101.6-mm Mold)

3.4. *Rammer*:

3.4.1. *Manually Operated*—Metal rammer with a mass of 2.495 ± 0.009 kg (5.5 ± 0.02 lb), and having a flat circular face of 50.80-mm (2.000-in.) diameter with a manufacturing tolerance of ± 0.25 mm (0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of 305 ± 2 mm (12.00 ± 0.06 in.) above the elevation of the soil. The guide-sleeve shall have at least four vent holes, no smaller than 9.5-mm ($^3/_8$-in.) diameter spaced approximately 90 degrees (1.57 radius) apart and approximately 19 mm ($^3/_4$ in.) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.4.2. *Mechanically Operated*—A metal rammer that is equipped with a device to control the height of drop to a free fall of 305 ± 2 mm (12.00 ± 0.06 in.) above the elevation of the soil and uniformly distributes such drops to the soil surface (Note 2). The rammer shall have a mass of 2.495 ± 0.009 kg (5.5 ± 0.02 lb), and have a flat circular face of 50.80-mm (2.000-in.) diameter with a manufactured tolerance of ± 0.25 mm (0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.).

Note 2—The rammer apparatus shall be calibrated with several soil-cement mixtures and the mass of the rammer adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. It may be impractical to adjust the mechanical apparatus so the free fall is 305 mm (12 in.) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 305-mm (12-in.) drop is determined. Subsequent blows on the layer of soil-cement may all be applied by dropping the rammer from a height of 305 mm (12 in.) above the initial-setting elevation, or when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have rammer free fall of 305 mm (12 in.) measured from the elevation of the soil-cement as compacted by the previous blow.

3.4.3. *Rammer Face*—The circular face rammer shall be used, but a sector face may be used as an alternative, provided the report shall indicate type of face used other than the 50.8-mm (2-in.) circular face and it shall have an area equal to that of the circular face rammer.

3.5. *Sample Extruder*—A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold. Not required when a split-type mold is used.

3.6. *Balances and Scales*—A balance or scale conforming to the requirements of M 231, Class G 20. Also, a balance conforming to the requirements of M 231, Class G 2.

3.7. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF) for drying moisture samples.

3.8. *Straightedge*—A hardened-steel straightedge at least 254 mm (10 in.) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.250 mm per 250 mm (0.01 in. per 10 in.) (0.1 percent) of length within the portion used for trimming the soil (Note 3).

Note 3—The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.250 mm per 250 mm (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil with the cutting edge will cause a concave soil surface.

3.9. *Sieves*—75-mm (3-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves conforming to the requirements of M 92.

3.10. *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with cement and with increments of water.

3.11. *Container*—A flat, round pan for moisture absorption by soil-cement mixtures, about 305 mm (12 in.) in diameter and 50 mm (2 in.) deep.

3.12. *Moisture Containers*—Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

3.13. *Butcher Knife*—A butcher knife approximately 250 mm (10 in.) in length for trimming the top of the specimens.

METHOD A

4. SAMPLE

4.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF). Then thoroughly break up the aggregations to pass the 4.75-mm (No. 4) sieve, in such a manner as to avoid reducing the natural size of individual particles.

4.2. Select a representative sample, with a mass of approximately 2.7 kg (6 lb) or more, of the soil prepared as described in Section 4.1.

5. PROCEDURE

5.1. Add to the soil the required amount of cement conforming to M 85 or M 240. Mix the cement and soil thoroughly to a uniform color.

5.2. When needed, add sufficient potable water to dampen the mixture to approximately four to six percentage points below optimum moisture content and mix thoroughly. At this moisture content, plastic soils, tightly squeezed in the palm of the hand, will form a cast that will fracture with only slight pressure applied by the thumb and fingertips; nonplastic soils will bulk noticeably.

5.3. When the soil is a heavy textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of 50 mm (2 in.) using the rammer described in Section 3.2 or a similar hand tamper. Cover and allow to stand for not less than 5 minutes but not more than 10 minutes to aid dispersion of the moisture and to permit more complete absorption by the soil-cement.

5.4. After the absorption period, thoroughly break up the mixture, without reducing the natural size of individual particles, until it will pass a 4.75-mm (No. 4) sieve, and then remix.

5.5. Form a specimen by compacting the prepared soil-cement mixture in the mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 130 mm (5 in.). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm (12 in.) above the elevation of the soil-cement when a sleeve-type rammer is used, or from 305 mm (12 in.) above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process (Note 4).

Note 4—Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: a block of concrete, with a mass not less than 90 kg (200 lb), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges, and pavements.

5.6. Following compaction, remove the extension collar, carefully trim the compacted soil-cement mixture even with the top of the mold by means of the knife and straightedge, and determine the mass of the mold and moist soil in kilograms to the nearest five grams, or determine the mass in pounds to the nearest 0.01 pounds. For molds conforming to tolerances given in Table 1 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 1060, and record the result as the wet density, W_1, in kilograms per cubic meter, of compacted soil. For molds conforming to tolerances given in Table 1 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, W_1, in pounds per cubic foot, of compacted soil. For used molds out of tolerance by not more than 50 percent (Table 1), use the factor for the mold as determined in accordance with Calibration of Measure in T 19M/T 19.

5.7. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, weighing not less than 100 g, from the full height of one of the cut faces, weigh immediately, and dry in accordance with T 265, to determine the moisture content, and record the results.

5.8. Thoroughly break up the remaining portion of the molded specimen until it will pass a 4.75-mm (No. 4) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil one to two percentage points and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass, W_1, per cubic meter (cubic foot), of the compacted soil-cement mixture (Note 5).

Note 5—In instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction a separate and new sample shall be used in each compaction test.

Note 6—To minimize the effect of cement hydration, perform the test expeditiously and continuously to completion.

METHOD B

6. SAMPLE

6.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles. Prepare the sample for testing by segregating the material retained on a 4.75-mm (No. 4) sieve and breaking up the remaining soil aggregations to pass the 4.75-mm (No. 4) sieve in such a manner as to avoid reducing the natural size of the individual particles.

6.2. Sieve the prepared soil over the 75-mm (3-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves. Discard the material retained on the 75-mm (3-in.) sieve. Determine the percentage of material, by oven-dry mass, retained on the 19.0-mm ($^3/_4$-in.) and 4.75-mm (No. 4) sieves.

6.3. Saturate the aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve by soaking in potable water; surface dry the material as required for later testing.

Note 7—Most soil-cement construction specifications covering soil gradation limit maximum size material to 75-mm (3-in.) or less.

6.4. Select and maintain separate representative samples of soil passing the 4.75-mm (No. 4) sieve and of saturated, surface dry aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve so that the total sample will weigh approximately 4.99 kg (11 lb) or more. The percentage, by oven-dry mass, of aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve shall be the same as the percentage passing the 75-mm (3-in.) sieve and retained on the 4.75-mm (No. 4) sieve in the original sample.

7. PROCEDURE

7.1. Add to the portion of the soil sample passing the 4.75-mm (No. 4) sieve the amount of cement conforming to Specification M 85 or Specification M 240, required for the total sample specified in Section 6.4. Mix the cement and soil thoroughly to a uniform color.

7.2. When needed, add water to this soil-cement mixture and facilitate moisture dispersion as described for Method A in Sections 5.2 to 5.4. After this preparation, add the saturated, surface-dry aggregate to the soil-cement mixture passing the 4.75-mm (No. 4) sieve and mix thoroughly.

7.3. Form a specimen by compacting the prepared soil-cement mixture in the mold (with collar attached) and trim and weigh the compacted specimen as described for Method A in Sections 5.5 and 5.6. Holes developed in the surface by removal of coarse material shall be patched with smaller sized material.

7.4. Remove the material from the mold and take a sample for determining the moisture content as described for Method A in Section 5.7, except the sample shall weigh not less than 500 g.

7.5. Thoroughly break up the remainder of the material as before until it will pass a 19.0-mm ($^3/_4$-in.) sieve and 90 percent of the soil aggregations will pass a 4.75-mm (No. 4) sieve as judged by eye, and add to the remaining portion of the sample being tested.

7.6. Add water in sufficient amounts to increase the moisture content of the soil-cement mixture by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass, W_1, per cubic meter (cubic foot) of compacted soil (Notes 5 and 6).

CALCULATIONS AND REPORT

8. CALCULATIONS

8.1. Calculate the moisture content and the dry unit mass of the soil-cement mixture as compacted for each trial, as follows:

$$w = \frac{A - B}{B - C} \times 100 \tag{1}$$

and

$$W = \frac{W_1}{w + 100} \times 100 \tag{2}$$

where:

w = percentage of moisture in the specimen, based on oven-dry mass of soil-cement;

A = mass of container and wet soil-cement;

B = mass of container and oven-dry soil-cement;

C = mass of moisture container;

W = dry unit mass of compacted soil-cement, in kilograms per cubic meter, or pounds per cubic foot; and

W_1 = wet unit mass of compacted soil-cement, in kilograms per cubic meter, or pounds per cubic foot.

9. MOISTURE-DENSITY RELATIONSHIP

9.1. The calculations in Section 8 shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in kilograms per cubic meter or pounds per cubic foot of the compacted soil-cement samples. The oven-dry densities (unit mass) of the soil-cement mixture shall be plotted as ordinates and the corresponding moisture content as abscissas.

9.2. *Optimum Moisture Content*—When the densities and corresponding moisture contents for the soil-cement mixture have been determined and plotted as indicated in Section 9.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture content" of the soil-cement mixture under the compaction prescribed in these methods.

9.3. *Maximum Density*—The oven-dry density in kilograms per cubic meter or pounds per cubic foot of the soil-cement mixture at optimum moisture content shall be termed "maximum density" under the compaction prescribed in these methods.

10. REPORT

10.1. The report shall include the following:

10.1.1. The method used (Method A or B).

10.1.2. The optimum moisture content, as a percentage, to the nearest whole number.

10.1.3. The maximum density in kilograms per cubic meter to the nearest 10 kg/m^3 or in pounds per cubic foot to the nearest whole number.

10.1.4. Type of rammer face if other than 50.8-mm (2-in.) circular.

11. PRECISION STATEMENT

11.1. Precision of this test method has not yet been established.

Standard Method of Test for

Wetting-and-Drying Test of Compacted Soil-Cement Mixtures

AASHTO Designation: T 135-97 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Wetting-and-Drying Test of Compacted Soil-Cement Mixtures

AASHTO Designation: T 135-97 (2009)

1. SCOPE

1.1. These methods of test cover procedures for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by the repeated wetting and drying of hardened soil-cement specimens. The specimens are compacted in a mold, before cement hydration, to maximum density at optimum moisture content using the compaction procedure described in T 134.

1.2. Two methods, depending on soil gradation, are covered for preparation of material for molding specimens and for molding specimens as follows:

1.2.1. *Method A*—Using soil material passing the 4.75-mm (No. 4) sieve. This method shall be used when 100 percent of the soil samples passes the 4.75-mm (No. 4) sieve. See Sections 4 to 6.

1.2.2. *Method B*—Using soil material passing the 19.0-mm ($^{3}/_{4}$-in.) sieve. This method shall be used when part of the soil sample is retained on the 4.75-mm (No. 4) sieve. See Sections 7 to 9.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- M 240, Blended Hydraulic Cement
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 134, Moisture-Density Relations of Soil-Cement Mixtures
- T 265, Laboratory Determination of Moisture Content of Soils

3. APPARATUS

3.1. *Molds 101.6 mm (4 in.), Rammer, Sample Extruder, and Straightedge*—As specified in T 99.

3.2. Both scales and balances shall meet the requirements of M 231. A balance or scale having a capacity of at least 11.5 kg (25.4 lb) and conforming to the requirements for a G 20 class scale and a balance of at least 1 kg (2 lb) capacity and conforming to the requirements of a G 2 class scale.

3.3. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining temperatures of 110 ± 5ºC (230 ± 9ºF).

3.4. *Moist Room*—A moist room or suitable covered container capable of maintaining a temperature of 21 ± 1.7ºC (70 ± 3ºF) and a relative humidity of 100 percent for seven-day storage of compacted specimens.

3.5. *Water Bath*—Suitable tank for submerging compacted specimens in water at room temperature.

3.6. *Wire Scratch Brush*—A wire scratch brush made of 50 by 1.6 mm (2 by $^1/_{16}$ in.) flat No. 26 gauge wire bristles assembled in 50 groups of 10 bristles each and mounted to form five longitudinal rows and 10 transverse rows of bristles on a 191 by 64 mm ($7^1/_2$ by $2^1/_2$ in.) hardwood block.

3.7. *Sieves*—75-mm (3-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves conforming to the requirements of M 92.

3.8. *Mixing Tools*—Miscellaneous tools such as a mixing pan and trowel, or a suitable mechanical device, for thoroughly mixing the soil with cement and water.

3.9. *Butcher Knife*—A butcher knife approximately 254 mm (10 in.) in length for trimming the top of the specimens.

3.10. *Scarifier*—A six-pronged ice pick or similar apparatus to remove the smooth compaction plane at the top of the first and second layers of the specimen.

3.11. *Container*—A flat, round pan for moisture absorption by soil-cement mixtures, about 305 mm (12 in.) in diameter and 50 mm (2 in.) deep.

3.12. *Measuring Device*—A measuring device suitable for accurately measuring the heights and diameters of test specimens to the nearest 0.25 mm (0.01 in.).

3.13. *Pans and Carriers*—Suitable pans for handling materials and carriers or trays for handling test specimens.

3.14. *Graduate*—A graduated cylinder of 250-mL capacity for measuring water.

3.15. *Moisture Content Container*—As specified in T 265.

METHOD A—USING SOIL MATERIAL PASSING A 4.75-MM (NO. 4) SIEVE

4. PREPARATION OF MATERIAL FOR MOLDING SPECIMENS

4.1. Prepare the soil sample in accordance with the procedure described in Method A of T 134.

4.2. Select a sufficient quantity of the soil prepared as described in T 134 to provide two compacted specimens at the required moisture contents. (See Note 1.)

Note 1—*Optional*: Usually only one specimen (identified as No. 2) is required for routine testing. The other specimen (identified as No. 1) is made for research work and for testing unusual soils.

4.3. Add to the soil the required amount of cement conforming to M 85 or M 240. Mix the soil and cement thoroughly until the color of the mixture is uniform.

4.4. Add sufficient potable water to raise the soil-cement mixture to optimum moisture content at the time of compaction and mix thoroughly. When the soil used is a heavy textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of about 51 mm (2 in.) using the rammer described in T 99 or a similar hand tamper; cover; and allow to stand for not less than 5 minutes but not more than 10 minutes to aid dispersion of the moisture and to permit more complete absorption by the soil-cement. After the absorption period, thoroughly break up the mixture, without reducing the material size of individual particles, until it will pass a 4.75-mm (No. 4) sieve as judged by eye, and then remix.

5. MOLDING SPECIMENS

5.1. Form a specimen by immediately compacting the soil-cement mixture in the mold, with the collar attached and later trimming the specimen in the same manner as directed in T 134, and in addition scarify the tops of the first and second layers to remove smooth compaction planes before placing and compacting the succeeding layers. This scarification shall form grooves at right angles to each other, approximately 3 mm ($^1/_8$ in.) in width and 6.4 mm ($^1/_4$ in.) in depth and approximately 6.4 mm ($^1/_4$ in.) apart. During compaction, take from the batch a representative sample of the soil-cement mixture having a mass of not less than 100 g. Determine the mass immediately and dry in accordance with T 265. Calculate the percentage of moisture content as prescribed in Section 7 of T 134 to check against design moisture content.

5.2. Determine the mass of the compacted specimen and mold, remove the specimen from the mold, weigh the oven-dry mass in kilograms, and calculate the dry density in kilograms per cubic meter (pounds per cubic foot) to check against the design density.

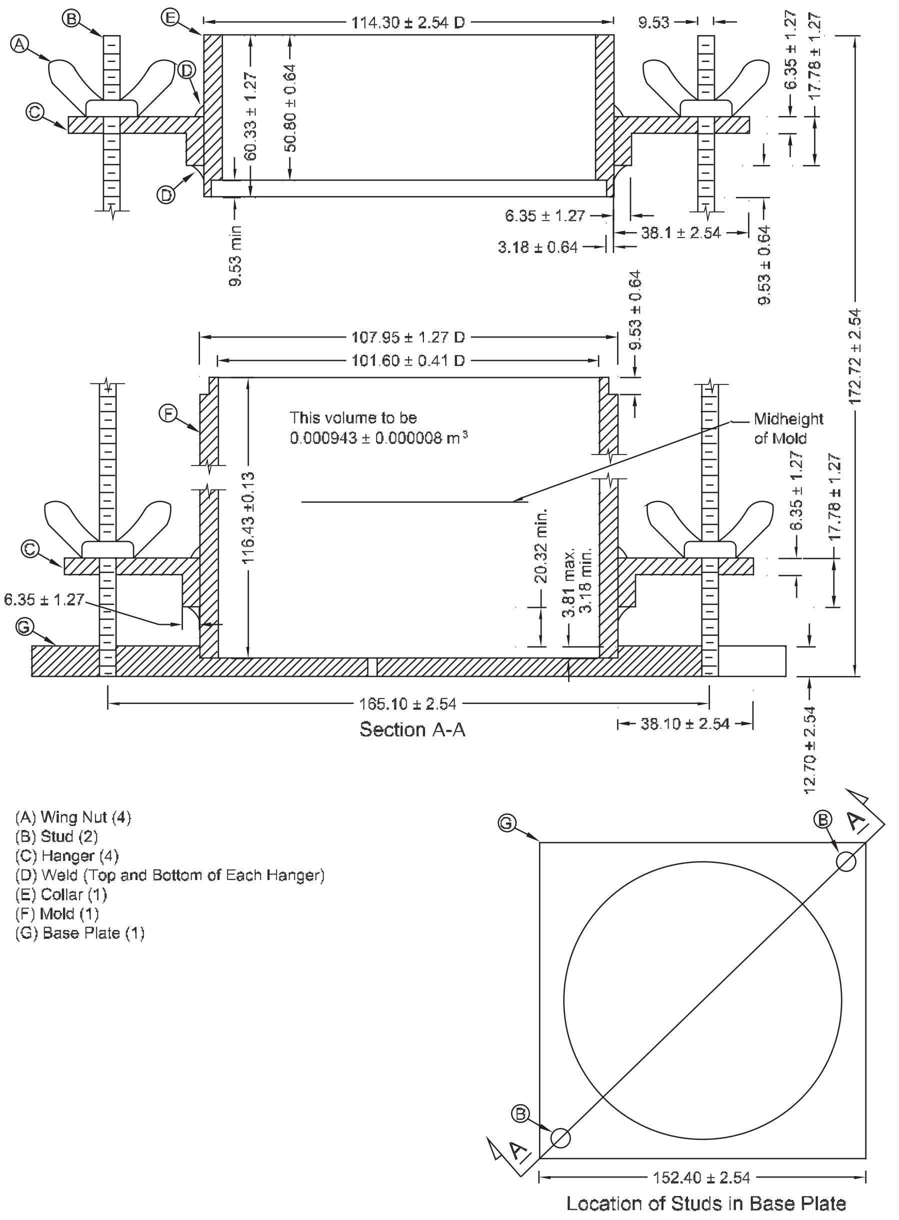
5.3. Identify the specimen on a metal tag (or other suitable device) as No. 1 (Note 3) together with other needed identification marks and use to obtain data on moisture and volume changes during the test.

5.4. Form a second specimen as rapidly as possible and determine the percentage of moisture content and oven-dry mass as described in Sections 5.1 and 5.2. Identify this specimen as No. 2, together with other needed identification marks, and use to obtain data on soil-cement losses during the test.

5.5. Determine the average diameter and height of the No. 1 specimen and calculate its volume.

5.6. Place the specimens on suitable carriers in the moist room and protect them from free water for a period of seven days. Determine the mass and measure the No. 1 specimen at the end of the seven-day storage period to provide data for calculating its moisture content and volume. (See Note 2.)

Note 2—It is important that all height and diameter measurements be accurate to within 0.25 mm (0.01 in.) and be taken at the same points on the specimen at all times.



Dimensional Equivalents

mm	in.	mm	in.	mm	in.
3.18 ± 0.64	(0.125 ± 0.025)	17.78 ± 1.27	(0.700 ± 0.050)	107.95 ± 1.27	(4.250 ± 0.050)
3.81	(0.150)	20.32	(0.800)	114.30 ± 2.54	(4.500 ± 0.100)
6.35 ± 1.27	(0.250 ± 0.050)	38.10 ± 2.54	(1.500 ± 0.100)	116.43 ± 0.13	(4.584 ± 0.005)
7.62	(0.300)	50.80 ± 0.64	(2.000 ± 0.025)	152.40 ± 2.54	(6.000 ± 0.100)
9.53 ± 0.64	(0.375 ± 0.025)	60.33 ± 1.27	(2.375 ± 0.050)	165.10 ± 2.54	(6.500 ± 0.100)
12.70 ± 2.54	(0.500 ± 0.100)	101.60 ± 0.41	(4.000 ± 0.016)	172.72 ± 2.54	(6.800 ± 0.100)

0.000943 ± 0.000008 m^3 (1/30 ± 0.0003 ft^3)

Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Hanger on the mold portion only cannot extend above the midheight line.
3. Figure 1 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).
4. Not to scale.

Figure 1—Cylindrical Mold and Base Plate (101.6 mm Mold)

6. PROCEDURE

6.1. At the end of the storage in the moist room, submerge the specimens in potable water at room temperature for a period of 5 hours. Blot, weigh, and measure the No. 1 specimen (volume and moisture change specimen).

6.2. Place both specimens in an oven at 71 ± 3ºC (160 ± 5ºF) for 42 hours and remove. Determine the mass and measure the No. 1 specimen. Give specimen No. 2 (soil-cement loss specimen) two firm strokes on all areas with the wire scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. Apply these strokes to the full height and width of the specimen with a firm stroke corresponding to approximately 13.3 N (3 lb). (See Note 3.) Eighteen to 20 vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.

Note 3—This pressure is measured as follows: Clamp a specimen in a vertical position on the edge of a platform scale and zero the scale. Apply vertical brushing strokes to the specimen and note the force necessary to register approximately 13.3 N (3 lbf).

6.3. The procedures described in Sections 6.1 and 6.2 constitute one cycle (48 hours) of wetting and drying. Again submerge the specimens in water and continue the procedure for 12 cycles. (See Note 4.) The No. 1 specimen may be discontinued prior to 12 cycles should the measurements become inaccurate due to soil-cement loss of the specimen. (See Note 5.)

Note 4—Mass determinations of specimen No. 2 before and after brushing are usually made at the end of each cycle when conducting research and making special investigations.

Note 5—If it is not possible to run the cycles continuously because of Sundays, holidays, or for any other reason, hold the specimens in the oven during the layover period if possible.

6.4. After 12 cycles of test, dry the specimens in accordance with T 265, Section 5, and weigh to determine the oven-dry mass of the specimens.

6.5. The data collected will permit calculations of volume and moisture changes of specimen No. 1 and the soil-cement losses of specimen No. 2 after the prescribed 12 cycles of test.

METHOD B—USING MATERIAL PASSING A 19.0-MM ($^3/_4$-IN.) SIEVE

7. PREPARATION OF MATERIAL FOR MOLDING SPECIMENS

7.1. Prepare the soil sample in accordance with Method B (Section 5) of T 134.

7.2. Select and maintain separate representative samples of soil passing the 4.75-mm sieve (No. 4) and of saturated, surface-dry aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve so that the total sample will be enough to provide (Note 1) compacted specimens and required moisture samples. The percentage, by oven-dry mass, of aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve shall be the same as the percentage passing the 75-mm (3-in.) sieve and retained on the 4.75-mm (No. 4) sieve in the original sample.

7.3. Add to the sample passing the 4.75-mm (No. 4) sieve the required amount of cement conforming to M 85 or M 240 required for the total sample specified in Section 7.2. Mix the soil and cement thoroughly until the color of the mixture is uniform.

7.4. Add to the sample passing the 4.75-mm (No. 4) sieve sufficient water to raise the total soil-cement mixture prescribed in Section 7.2 to optimum moisture content at time of compaction and facilitate moisture dispersion as described for Method A in Section 4.4.

7.5. After preparation of the mixture as described in Sections 7.1 to 7.4, add the saturated, surface-dry aggregate to the mixture and mix thoroughly.

8. MOLDING SPECIMENS

8.1. Form a specimen by immediately compacting the soil-cement mixture in the mold (with the collar attached) and later trimming the specimen in accordance with Section 6.2 of T 134; and in addition, as the mixture for each layer is placed in the mold, spade along the inside of the mold with a butcher knife before compaction to obtain uniform distribution of the material retained on the 4.75-mm sieve and scarify the tops of the first and second layers as described in Section 5.1 of this method. During compaction, take from the batch a representative sample of the soil-cement mixture having a mass of not less than 500 g, determine the mass immediately, and dry in accordance with T 265, Section 5, to determine the moisture content to check against design moisture content. Form a second specimen as rapidly as possible in the same manner.

8.2. Determine the mass of each compacted specimen with mold, remove the specimen from the mold, weigh the oven-dry mass, and calculate the dry density to check against the design density, identify and measure the No. 1 specimen (Note 1), place in the moist room, and measure the No. 1 specimen again at the end of the seven-day storage period as described in Sections 5.2 to 5.6. (See Note 2.)

9. PROCEDURE

9.1. Proceed as directed in Section 6.

CALCULATIONS AND REPORT

10. CALCULATIONS

10.1. Calculate the volume and moisture changes and the soil-cement losses of the specimens as follows:

10.1.1. Calculate the difference between the volume of specimen No. 1 at the time of molding and subsequent volumes as a percentage of the original volume.

10.1.2. Calculate the moisture content of specimen No. 1 at the time of molding and subsequent moisture contents as a percentage of the original oven-dry mass of the specimen.

10.1.3. Correct the oven-dry mass of specimen No. 2 as obtained in Section 6.4 for water that has reacted with the cement and soil during the test and is retained in the specimen at 110ºC (230º F), as follows:

$$\text{Corrected Oven-Dry Mass} = \frac{A}{B} \times 100 \qquad (1)$$

where:

A = oven-dry mass after drying at 110ºC (230ºF), and

B = percentage of water retained in specimen, plus 100.

The percentage of water retained in specimen No. 2 after drying at 110ºC (230ºF) for use in the above formula can be assumed to be equal to the water retained in specimen No. 1. When No. 1 specimens are not molded, the foregoing data are not available and the average values prescribed in Table 2 are used.

Table 1—Average Values

Soil Classification (AASHTO Designation M 145)	Average Water Retained After Drying at 110°C, Mass Percent
A-1, A-3	1.5
A-2	2.5
A-4, A-5	3.0
A-6, A-7	3.5

10.1.4. Calculate the soil-cement loss of specimen No. 2 as a percentage of the original oven-dry mass of the specimen as follows:

$$\text{Soil-Cement Loss, Percent} = \frac{A}{B} \times 100 \tag{2}$$

where:

A = original calculated oven-dry mass minus final corrected oven-dry mass, and

B = original calculated oven-dry mass.

11. REPORT

11.1. The report shall include the following:

11.1.1. The designed optimum moisture content and maximum density of the molded specimens;

11.1.2. The moisture content and density obtained in molded specimens (See Note 6);

Note 6—Good laboratory practice permits the following tolerances between design factors and those obtained in the molded specimens:

- Moisture content, ±1 percentage point
- Density, ±48 kg/m^3 (3 lb/ft^3)

11.1.3. The designed cement content, in percent, of the molded specimens;

11.1.4. The cement content, in percent, obtained in molded specimens;

11.1.5. The maximum volume change, in percent, and maximum moisture content during test of specimen No. 1; and

11.1.6. The soil-cement loss, in percent, of specimen No. 2.

Standard Method of Test for

Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures

AASHTO Designation: T 136-97 (2009)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures

AASHTO Designation: T 136-97 (2009)

1. SCOPE

1.1. These methods cover procedures for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by the repeated freezing and thawing of hardened soil-cement specimens. The specimens are compacted in a mold, before cement hydration, to maximum density at optimum moisture content using the compaction procedure described in T 134.

1.2. Two methods depending on soil gradation are covered for preparation of material for molding specimens and molding specimens as follows:

1.2.1. *Method A*—Using soil material passing the 4.75-mm (No. 4) sieve. This method shall be used when 100 percent of the soil sample passes the 4.75-mm (No. 4) sieve. (See Sections 4 to 6.)

1.2.2. *Method B*—Using soil material passing the 19.0-mm ($^3/_4$-in.) sieve. This method shall be used when part of the soil sample is retained on 4.75-mm sieve. (See Sections 7 to 9.)

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- M 240, Blended Hydraulic Cement
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 134, Moisture-Density Relations of Soil-Cement Mixtures
- T 265, Laboratory Determination of Moisture Content of Soils

3. APPARATUS

3.1. *Molds 101.6 mm (4 in.), Rammer, Sample Extruder, and Straightedge*—As specified in T 99.

3.2. Both scales and balances shall meet the requirements of M 231. A balance or scale having a capacity of at least 11.5 kg (25.4 lb) and conforming to the requirements for a G 20 class scale and a balance of at least 1-kg (2-lb) capacity and conforming to the requirements of a G 2 class scale.

3.3. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF) for drying moisture samples.

3.4. *Freezing Cabinet*—A freezing cabinet capable of maintaining temperatures of –23ºC (–10ºF) or lower.

3.5. *Moist Room*—A moist room or suitable covered container capable of maintaining a temperature of 21.0 ± 1.7ºC (70 ± 3ºF) and a relative humidity of 100 percent for seven-day storage of compacted specimens and for thawing frozen specimens.

3.6. *Wire Scratch Brush*—A wire scratch brush made of 50 by 1.6 mm (2 by $^1/_{16}$ in.) flat No. 26 gauge wire bristles assembled in 50 groups of 10 bristles each and mounted to form five longitudinal rows and 10 transverse rows of bristles on a 190 by 65 mm ($7^1/_2$ by $2^1/_2$ in.) hardwood block.

3.7. *Sieves*—75-mm (3-in.), 19.0-mm ($^3/_4$-in.), 4.75-mm (No. 4) sieves conforming to the requirements of M 92.

3.8. *Mixing Tools*—Miscellaneous tools such as mixing pan, and trowel, or a suitable mechanical device for thoroughly mixing the soil with cement and water.

3.9. *Butcher Knife*—A butcher knife approximately 254 mm (10 in.) in length for trimming the top of the specimens.

3.10. *Scarifier*—A six-pronged ice pick or similar apparatus to remove the smooth compaction plane at the top of the first and second layers of the specimen.

3.11. *Container*—A flat, round pan, for moisture absorption by soil-cement mixtures about 305 mm (12 in.) in diameter and 50 mm (2 in.) deep.

3.12. *Measuring Device*—A measuring device suitable for accurately measuring the heights and diameters of test specimens to the nearest 0.25 mm (0.01 in.).

3.13. *Pans and Carriers*—Suitable pans for handling materials and carriers or trays for handling test specimens.

3.14. *Absorptive Pads*—6.4-mm ($^1/_4$-in.) thick felt pads, blotters, or similar absorptive material for placing between specimens and specimen carriers.

3.15. *Graduate*—A graduated cylinder of 250-mL capacity for measuring water.

3.16. *Moisture Content Containers*—As specified in T 265.

METHOD A—USING SOIL MATERIAL PASSING A 4.75-MM (NO. 4) SIEVE

4. PREPARATION OF MATERIAL FOR MOLDING SPECIMENS

4.1. Prepare the soil sample in accordance with Method A of T 134.

4.2. Select a sufficient quantity of the soil prepared as described in T 134 to provide two compacted specimens and required moisture samples. (See Note 1.)

Note 1—*Optional*: Usually only one specimen (identified as No. 2) is required for routine testing. The other specimen (identified as No. 1) is made for research work and for testing unusual soils.

4.3. Add to the soil the required amount of cement conforming to M 85 or M 240. Mix the soil and cement thoroughly until the color of the mixture is uniform.

4.4. Add sufficient potable water to raise the soil-cement mixture to optimum moisture content at time of compaction and mix thoroughly. When the soil used is a heavy-textured, clayey material, compact the mixture of soil, cement, and water in a container to a depth of about 50 mm (2 in.) using the rammer described in T 99 or similar hand tamper; cover; and allow to stand for not less than 5 minutes but not more than 10 minutes to aid dispersion of the moisture and to permit more complete absorption by the soil-cement. After the absorption period, thoroughly break up the mixture, without reducing the natural size of individual particles, until it will pass a 4.75-mm (No. 4) sieve, as judged by eye, and then remix.

5. MOLDING SPECIMENS

5.1. Form a specimen by immediately compacting the soil-cement mixture in the mold, with the collar attached, and later trimming the specimen in the same manner as directed in T 134, and in addition scarify the tops of the first and second layers to remove smooth compaction planes before placing and compacting the succeeding layers. This scarification shall form grooves at right angles to each other, approximately 3 mm ($^1/_8$ in.) in width and 3 mm ($^1/_8$ in.) in depth and approximately 6 mm ($^1/_4$ in.) apart. During compaction, take from the batch a representative sample of the soil-cement mixture, having a mass of not less than 100 g. Determine the mass immediately and dry in accordance with T 265. Calculate the percentage of moisture as directed in T 134 to check against design moisture content.

5.2. Determine the mass of the compacted specimen and mold, remove the specimen from the mold, and calculate the oven-dry mass of each specimen in kilograms per cubic meter (lb/ft^3) to check against design density.

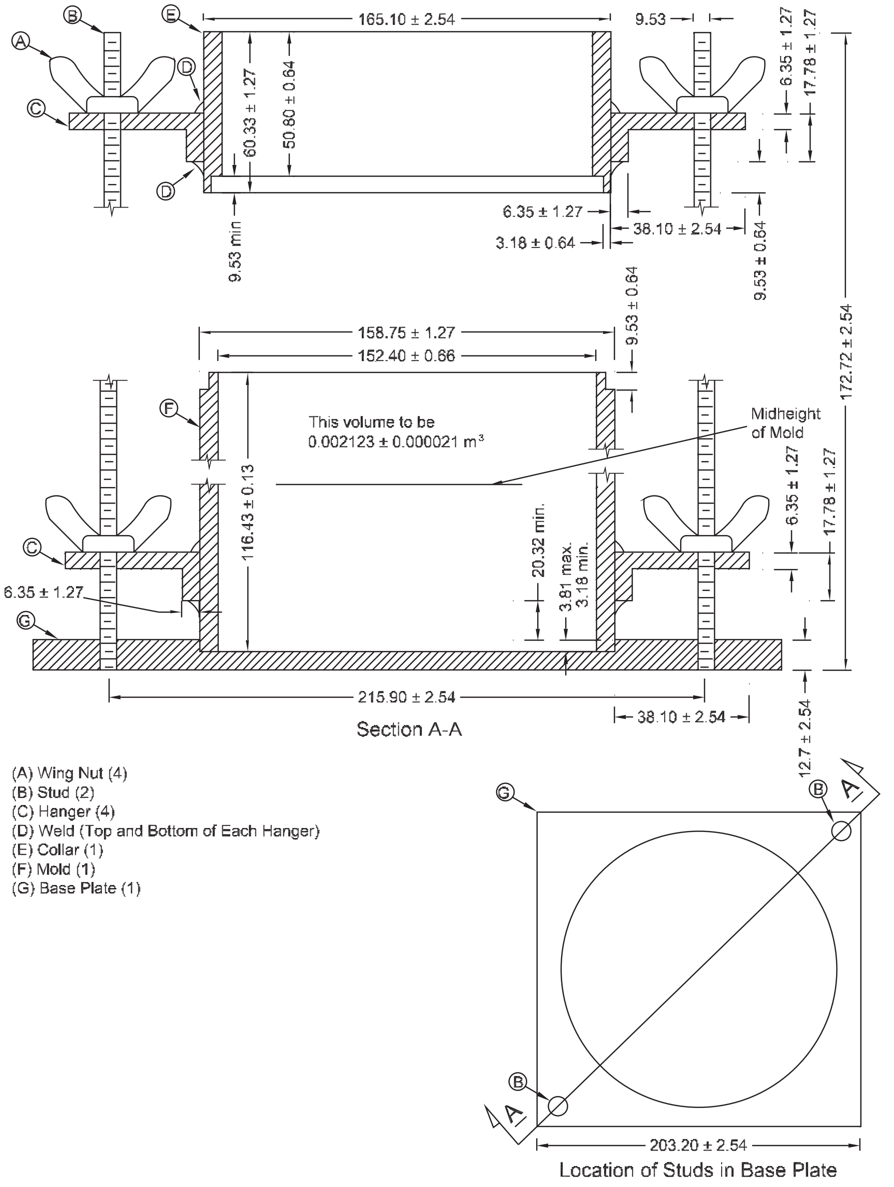
5.3. Identify the specimen on a metal tag (or other suitable device) as No. 1 (Note 3) together with other needed identification marks and use to obtain data on moisture and volume changes during the test.

5.4. Form a second specimen as rapidly as possible and determine the percentage of moisture and oven-dry mass as described in Sections 5.1 and 5.2. Identify this specimen as No. 2, together with other needed identification marks, and use to obtain data on soil-cement losses during the test.

5.5. Determine the average diameter and height of the No. 1 specimen and calculate its volume.

5.6. Place the specimens on suitable carriers in the moist room and protect them from free water for a period of seven days. Determine the mass and measure the No. 1 specimen at the end of the seven-day storage period to provide data for calculating its moisture content and volume. (See Note 2.)

Note 2—It is important that all height and diameter measurements be accurate to within 0.25 mm, (0.01 in.) and be taken at the same points on the specimen at all times.



Dimensional Equivalents

mm	in.	mm	in.	mm	in.
3.18 ± 0.64	(0.125 ± 0.025)	17.78 ± 1.27	(0.700 ± 0.050)	107.95 ± 1.27	(4.250 ± 0.050)
3.81	(0.150)	20.32	(0.800)	114.30 ± 2.54	(4.500 ± 0.100)
6.35 ± 1.27	(0.250 ± 0.050)	38.10 ± 2.54	(1.500 ± 0.100)	116.43 ± 0.13	(4.584 ± 0.005)
7.62	(0.300)	50.80 ± 0.64	(2.000 ± 0.025)	152.40 ± 2.54	(6.000 ± 0.100)
9.53 ± 0.64	(0.375 ± 0.025)	60.33 ± 1.27	(2.375 ± 0.050)	165.10 ± 2.54	(6.500 ± 0.100)
12.70 ± 2.54	(0.500 ± 0.100)	101.60 ± 0.41	(4.000 ± 0.016)	172.72 ± 2.54	(6.800 ± 0.100)

0.000943 ± 0.00008 m^3 (1/30 ± 0.0003 ft^3)

Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Hanger on the mold portion only cannot extend above the midheight line.
3. Figure 1 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).
4. Not to scale.

Figure 1—Cylindrical Mold and Base Plate (101.6-mm Mold)

6. PROCEDURE

6.1. At the end of the storage in the moist room, place water-saturated felt pads about 6.4 mm ($^1/_4$ in.) thick, blotters, or similar absorptive material between the specimens and the carriers, and place the assembly in a freezing cabinet having a constant temperature not warmer than –23ºC (–10ºF) for 24 hours and remove. Determine the mass and measure the No. 1 specimen (volume and moisture change specimen).

6.2. Place the assembly in the moist room or suitable covered container having a temperature of 21.0 ± 1.7ºC (70 ± 3ºF) and a relative humidity of 100 percent for 23 hours and remove. Free potable water shall be made available to the absorbent pads under the specimens to permit the specimens to absorb water by capillary action during the thawing period. Determine the mass and measure the No. 1 specimen. Give specimen No. 2 (soil-cement loss specimen) two firm strokes on all areas with the wire scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. Apply these strokes to the full height and width of the specimen with a firm stroke corresponding to approximately 13.3 N (3 lbf). (See Note 3.) Eighteen to 20 vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end. After being brushed, the specimens shall be turned over end for end before they are replaced on the water-saturated pads.

Note 3—This pressure is measured as follows: clamp a specimen in a vertical position on the edge of a platform scale and zero the scale. Apply vertical brushing strokes to the specimen and note the force necessary to register approximately 13.3 N (3 lbf).

6.3. The procedures described in Sections 6.1 and 6.2 constitute one cycle (48 h) of freezing and thawing. Again place the specimens in the freezing cabinet and continue the procedure for 12 cycles. (See Note 4.) The No. 1 specimen may be discontinued prior to 12 cycles should the measurements become inaccurate due to soil-cement loss of the specimen. (See Note 5.)

Note 4—Mass determinations of specimen No. 2 before and after brushing are usually made at the end of each cycle when conducting research and making special investigations. Some specimens made of silty and clayey soils tend to scale on sides and ends particularly after about the sixth cycle of test. This scale shall be removed with a sharp-pointed instrument such as an ice pick, since the regular brushing may not be effective.

Note 5—If it is not possible to run the cycles continuously because of Sundays, holidays, or for any other reason, the specimens shall be held in the freezing cabinet during the layover period if possible.

6.4. After 12 cycles of test, dry the specimens in accordance with T 265, Section 5, and weigh to determine the oven-dry mass of the specimens.

6.5. The data collected will permit calculations of volume and moisture changes of specimen No. 1 and the soil-cement losses of specimen No. 2 after the prescribed 12 cycles of test.

METHOD B—USING MATERIAL PASSING A 19.0-MM ($^3/_4$-IN.) SIEVE

7. PREPARATION OF MATERIAL FOR MOLDING SPECIMENS

7.1. Prepare the soil sample in accordance with Method B of T 134.

7.2. Select and maintain separate representative samples of soil passing the 4.75-mm (No. 4) sieve and of saturated, surface-dry aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve so that the total sample will be enough to provide two (Note 1) compacted specimens and required moisture samples. The percentage, by oven-dry mass, of aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve shall be the same as the percentage passing the 75-mm (3-in.) sieve and retained on the 4.75-mm (No. 4) sieve in the original sample.

7.3. Add to the sample passing the 4.75-mm (No. 4) sieve the required amount of cement conforming to M 85 or M 240. Mix the soil and cement thoroughly until the color of the mixture is uniform.

7.4. Add to the sample passing the 4.75-mm (No. 4) sieve sufficient water to raise the total soil-cement mixture specified in Section 7.2 to optimum moisture content at time of compaction and facilitate moisture dispersion as described for Method A in Section 4.4.

7.5. After preparation of the mixture as described in Sections 7.1 to 7.4, add the saturated, surface-dry aggregate to the mixture and mix thoroughly.

8. MOLDING SPECIMENS

8.1. Form a specimen by immediately compacting the soil-cement mixture in the mold (with the collar attached) and later trimming the specimen in accordance with T 134. In addition, as the mixture for each layer is placed in the mold, spade along the inside of the mold with a butcher knife before compaction to obtain uniform distribution of the material retained on the 4.75-mm (No. 4) sieve and scarify the tops of the first and second layers as described in Section 5.1 of this method. During compaction, take from the batch a representative sample of the soil-cement mixture having a mass of not less than 500 g, determine the mass immediately, and dry in accordance with T 265 to determine the moisture content to check against design moisture content. Form a second specimen as rapidly as possible in the same manner.

8.2. Determine the mass of each compacted specimen to check against design density, identify, measure the No. 1 specimen (Note 1), place in the moist room, and measure the No. 1 specimen again at the end of the seven-day storage period as described in Sections 5.2 to 5.6. (See Note 2.)

9. PROCEDURE

9.1. Proceed as directed in Section 6.

CALCULATIONS AND REPORT

10. CALCULATIONS

10.1. Calculate the volume and moisture changes and the soil-cement losses of the specimens as follows:

10.1.1. Calculate the difference between the volume of specimen No. 1 at the time of molding and subsequent volumes as a percentage of the original volume.

10.1.2. Calculate the moisture content of specimen No. 1 at the time of molding and subsequent moisture contents as a percentage of the original oven-dry mass of the specimen.

10.1.3. Correct the oven-dry mass of specimen No. 2 as obtained in Section 6.4 for water that has reacted with the cement and soil during the test and is retained in the specimen at 110ºC (230ºF) as follows:

$$\text{Corrected Oven-Dry Mass} = \frac{A}{B} \times 100 \quad (1)$$

where:

A = oven-dry mass after drying at 110ºC (230ºF), and

B = percentage of water retained in specimen, plus 100.

The percentage of water retained in specimen No. 2 after drying at 110ºC (230ºF) for use in the above formula can be assumed to be equal to the water retained in specimen No. 1. When No. 1 specimens are not molded, the foregoing data are not available and the average values prescribed in Table 2 are used.

Table 1—Average Values

Soil Classification (AASHTO Designation M 145)	Average Water Retained After Drying at 110°C, Mass Percent
A-1, A-3	1.5
A-2	2.5
A-4, A-5	3.0
A-6, A-7	3.5

10.1.4. Calculate the soil-cement loss of specimen No. 2 as a percentage of the original oven-dry mass of the specimen as follows:

$$\text{Soil-Cement Loss, Percent} = \frac{A}{B} \times 100 \quad (2)$$

where:

A = original calculated oven-dry mass minus final corrected oven-dry mass, and

B = original calculated oven-dry mass.

11. REPORT

11.1. The report shall include the following:

11.1.1. The designed optimum moisture and maximum density of the molded specimens;

11.1.2. The moisture content and density obtained in molded specimens (Note 6);

Note 6—Good laboratory practice permits the following tolerances between design factors and those obtained in the molded specimens:

- Moisture content, ±1 percentage point
- Density, ±48 kg/m^3 (3 lb/ft^3)

11.1.3. The designed cement content, in percent, of the molded specimens;

11.1.4. The cement content, in percent, obtained in molded specimens;

11.1.5. The maximum volume change, in percent, and maximum moisture content during test of specimen No. 1; and

11.1.6. The soil-cement loss, in percent, of specimen No. 2.

Standard Method of Test for

Wet Preparation of Disturbed Soil Samples for Test

AASHTO Designation: T 146-96 (2008)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Wet Preparation of Disturbed Soil Samples for Test

AASHTO Designation: T 146-96 (2008)

1. SCOPE

1.1. These methods of test cover the wet preparation of soil samples, as received from the field, for mechanical analysis and the determination of soil constants.

1.2. Method A provides for drying the field samples at a temperature not exceeding 60ºC (140ºF), making a wet separation on the 0.425-mm (No. 40) sieve and drying to a temperature not exceeding 60ºC (140ºF). Method B provides that the field sample shall be kept at a moisture content equal to or greater than the natural moisture content. Samples of such soil should be shipped to the laboratory in sealed containers and not allowed to dry out before testing. If no procedure is specified, Method A shall govern.

1.3. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.4. The values stated in SI units are to be regarded as the standard.

2. SIZE OF SAMPLE

2.1. Moist samples having the dry masses designated for physical tests described in T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test, shall be obtained.

3. APPARATUS

3.1. The apparatus shall consist of that listed in Section 2 of T 87, and the following:

3.1.1. *Drying Apparatus*—A thermostatically controlled drying oven for use at 110 ± 5ºC (230 ± 9ºF) and a suitable device capable of drying samples at a temperature not exceeding 60ºC (140ºF).

3.1.2. *Filter Funnels or Candles (Optional)*—Buchner funnels 254 mm (10 in.) in diameter and filter paper or filter candles.

3.1.3. *Miscellaneous Equipment*—Pans 300 mm (12 in.) in diameter by 75 mm (3 in.) in depth or other suitable containers that can accommodate a 203-mm (8 in.) diameter sieve for collecting the wash water; a suitable container that will prevent loss of moisture during storage of the moist test sample.

METHOD A

4. PROCEDURE

4.1. The soil sample as received from the field shall be dried thoroughly in air, in a warming oven whose temperature is not above 60ºC (140ºF), or by means of a device that will not raise the temperature of the samples above 60ºC (140ºF). The aggregations shall then be thoroughly broken up in the mortar with a rubber-covered pestle or suitable mechanical device in such a way as to avoid reducing the natural size of individual particles. A representative test sample of the amount required to perform the desired tests shall then be selected by the method of quartering or by the use of a sampler.

4.2. The portion of the air-dried sample selected for the purpose of mechanical analysis and physical tests shall be weighed and the mass recorded as the mass of the total sample uncorrected for hygroscopic moisture. The test sample shall then be separated into two portions by means of a 0.425-mm sieve. The material passing the 0.425-mm sieve shall be set aside for later recombination with additional material as described in Sections 4.3 to 4.7.

4.3. The material retained on the 0.425-mm sieve shall be placed in a pan, covered with water, and allowed to soak for a period of 2 to 24 hours until the particle aggregations have become soft and broken down.

4.4. After soaking, the material shall be washed on a 0.425-mm sieve in the following manner: The empty 0.425-mm sieve shall be set in the bottom of a pan and the liquid from the sample poured into it. Enough additional water shall be added to bring the level of the water in the pan approximately 13 mm ($^1/_2$ in.) above the mesh of the sieve. A portion of the soaked material not to exceed 0.45 kg (one lb) in mass shall be placed in the water on the 0.425-mm sieve and stirred by hand at the same time the sieve is agitated up and down. If the material retained on the 0.425-mm sieve contains lumps that have not slaked or disintegrated, but which can be crumbled or mashed between the thumb and finger so as to pass the 0.425-mm sieve, such lumps shall be broken and washed through the sieve into the pan. After all lumps have been broken up, the sieve shall be held above the soil and water in the pan and the material remaining on the sieve shall be washed with a small amount of clean water. The washed material retained on the 0.425-mm sieve shall be transferred to a clean pan.

4.5. Another increment of the soaked material, not exceeding 0.5 kg (one lb) in mass shall be placed on the 0.425-mm sieve and washed as described in Section 4.4. This procedure shall be repeated until all of the soaked sample has been washed.

4.6. The material retained on the 0.425-mm sieve shall be dried and dry-sieved on the 0.425-mm sieve. The material passing the 0.425-mm sieve in this operation shall be added to the material passing the 0.425-mm sieve obtained by the procedure described in Section 4.2. The material retained on the 0.425-mm sieve shall be set aside for use in the mechanical analysis of the coarse material.

4.7. After all the soaked material has been washed, the pan containing the wash water shall be set aside and not disturbed for a period of several hours until all of the soil particles have settled to the bottom of the pan and the water above the soil is clear (Note 1). As much of the clear water as possible shall then be decanted or siphoned off. The soil remaining in the pan shall be dried at a temperature not exceeding 60ºC (140ºF). The dried soil shall be ground in the mortar with a rubber-covered pestle or suitable mechanical device and combined with the material passing the 0.425-mm sieve obtained by the procedures described in Sections 4.2 and 4.6.

Note 1—In some instances, the wash water will not become clear in a reasonable length of time, in which case the entire volume must be evaporated.

4.7.1. *(Alternate Section 4.7)*—After all of the soaked material has been washed, the wash water and material passing the 0.425-mm sieve shall be filtered on one or more Buchner funnels that have previously been fitted with filter paper. Vacuum shall be applied to the lower end of the Buchner funnels to speed up the filtering process. After filtering, the soil shall be removed from the filter, the filter paper stripped from the damp soil, and the soil dried at a temperature not exceeding 60ºC (140ºF). The dried soil shall be ground in the mortar with a rubber-covered pestle or suitable mechanical device and combined with the material passing the 0.425-mm sieve obtained by the procedures described in Sections 4.2 and 4.6.

5. TEST SAMPLE FOR MECHANICAL ANALYSIS AND SOIL CONSTANTS

5.1. The fractions passing the 0.425-mm sieve obtained as described in Sections 4.2, 4.6, and 4.7 shall be thoroughly mixed. A portion with a mass of approximately 60 g for silt and clay soils shall be selected for mechanical analysis. The remaining portion of the material passing the 0.425-mm sieve shall be used for the determination of the soil characteristics.

METHOD B

6. PROCEDURE

6.1. For rapid mechanical analysis results based on dry mass of the original material, select and weigh a representative portion of the material for oven-dried moisture determination. Determine the moisture content at 110 ± 5ºC (230 ± 9ºF).

6.1.1. Select a representative portion of the moist sample estimated to contain sufficient particles passing the 0.425-mm (No. 40) sieve to make the required tests for determination of soil constants. Soak this selected portion of the moist sample in water until the particle aggregations become soft (Note 2). Samples obviously containing only particles passing the 0.425-mm (No. 40) sieve may be used in the tests to determine soil constants without first washing on the 0.425-mm (No. 40) sieve.

Note 2—In some areas it is possible that the cations of salts present in the tap water may exchange with the natural cations in the soil and alter significantly the values of the soil constants should tap water be used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. The soaking and washing operation will remove soluble salts contained in the soil. When soluble salts are present in the soil, the wash water should be saved and evaporated, and the salts returned to the soil sample.

6.2. After soaking, wash the material on a 0.425-mm (No. 40) sieve in the following manner: Place an empty 0.425-mm (No. 40) sieve on the bottom of a clean pan and pour the water from the soaked sample (Note 3) onto the sieve. Add sufficient water to bring the level approximately 13 mm ($^1/_2$ in.) above the mesh of the sieve. Transfer the soaked material to the sieve in workable increments, stirring each increment with the fingers while agitating the sieve up and down. Crumble or mash any lumps that have not slaked, using the thumb and fingers. Raise the sieve above the water in the pan and complete the washing operation using a small amount of clean water. Discard the washed material on the sieve before placing another increment of soaked material on the sieve.

Note 3—In cases where heavy clays are incurred it may be advantageous to use a mechanical stirrer to form a slurry that will more readily pass the 0.425-mm (No. 40) sieve.

6.3. Set aside the pan containing the washings for a period of several hours or until the water above the particles is clear. Decant, pipet, or siphon off as much of the clear water as possible (Note 1).

6.4. Alternatively, after all the soaked material has been washed, remove most of the water by filtering the wash water on one or more Buchner funnels fitted with a filter paper or by using filter candles. Remove the moist soil from the filter paper or filter candles, and combine with the sediment remaining in the pan.

6.5. Reduce the moisture content of the material passing the 0.425-mm (No. 40) sieve until the mass reaches a putty-like consistency (such as 30 to 35 drops of the cup in the liquid limit test) but never below the natural moisture content. Reduction of moisture content may be accomplished by exposure to air at ordinary room temperature, by heating in an oven at a temperature not exceeding 110ºC (230ºF), by boiling, by filtering on a Buchner funnel, or by use of filter candles. During evaporation and cooling, stir the sample often enough to prevent overdrying of the fringes and soil pinnacles on the surface. Cool the heated samples to normal room temperature before testing. For soil samples containing soluble salts, use a method of water reduction that will not eliminate the soluble salts from the test sample. Protect the prepared sample, in a moisture-tight container, from further drying until all required tests have been performed.

7. PRECISION

7.1. Since this preparation for tests produces no numerical values, determination of the precision and accuracy is not applicable.

Standard Method of Test for

Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test

AASHTO Designation: T 176-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test

AASHTO Designation: T 176-08

1. SCOPE

1.1 This test is intended to serve as a rapid test to show the relative proportions of fine dust or claylike material in soils or graded aggregates.

1.2 The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2 *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. SIGNIFICANCE AND USE

3.1 This test method is used to determine the proportion of detrimental fines in the portion passing the 4.75-mm (No. 4) sieve of soils or graded aggregates.

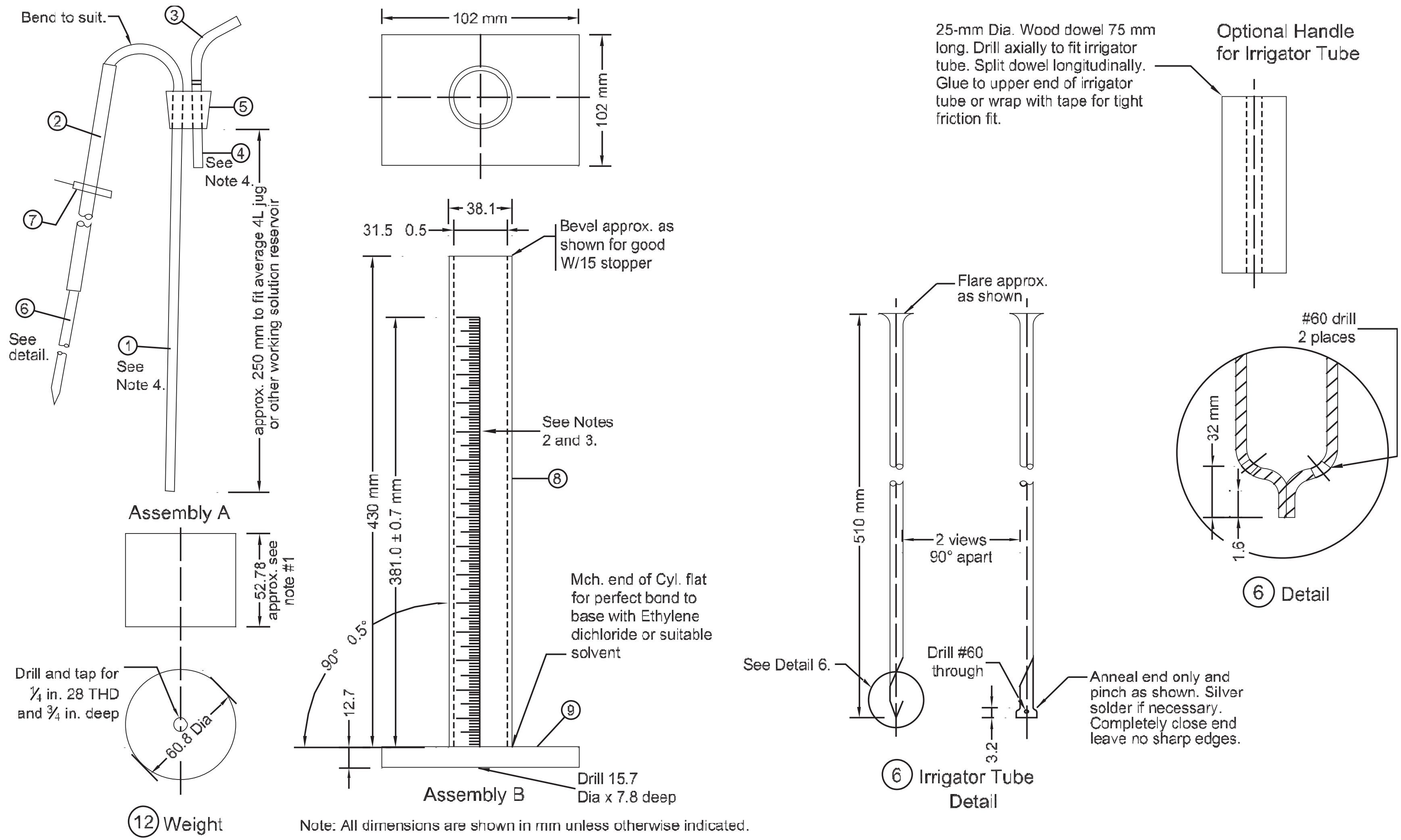
4. APPARATUS

4.1 *Sand Equivalent Apparatus*—A graduated plastic cylinder, rubber stopper, irrigator tube, weighted foot assembly, and siphon assembly, all conforming to their respective specifications and dimensions shown in Figure 1. Fit the siphon assembly to a 4-L (1 gal) bottle of working calcium chloride solution (see Section 2.8) placed on a shelf 915 ± 25 mm (36 ± 1 in.) above the work surface. In lieu of the specified 4-L (1 gal) bottle, a glass or plastic vat having a larger capacity may be used provided the liquid level of the working solution is maintained between 915 and 1170 mm (36 and 46 in.) above the work surface. (See Figure 2.)

Assembly	No. Reg.	Description	Stock Size	Material	Heat Treatment
A		Siphon Assembly			
	1	Siphon Tube	6.4 dia × 400	Copper Tube	
	2	Siphon Hose	4.8 ID × 1220	Rubber Tube	
	3	Blow Hose	4.8 ID × 50.8	Rubber Tube	
	4	Blow Tube	6.4 dia × 50.8	Copper Tube	
	5	Two-Hole Stopper	No. 6	Rubber	
	6	Irrigator Tube	6.4 OD 0.89 Wall × 500 Stainless Tube, Type 316		
	7	Clamp	Pinchcock, Day, BKH No. 21730 or Equiv		
B		Graduate Assembly			
	8	Tube	38.1 OD × 430	Trans Acrylic Plastic	
	9	Base	12.7 × 102 × 102	Trans Acrylic Plastic	
C		Weighted Foot Assembly			
	10	Sand Reading Indicator	6.4 dia × 14.9	Nylon 101 Type 66 Annealed	
	11	Rod	6.4 dia × 438.2	Brass	
	12	Weight	50.8 dia × 52.78	C.R.SH	
	13	Roll Pin	0.16 dia × 12.7	Steel	
	14	Foot	0.16 Hex × 13.7	Brass	
	15	Solid Stopper	No. 7	Rubber	

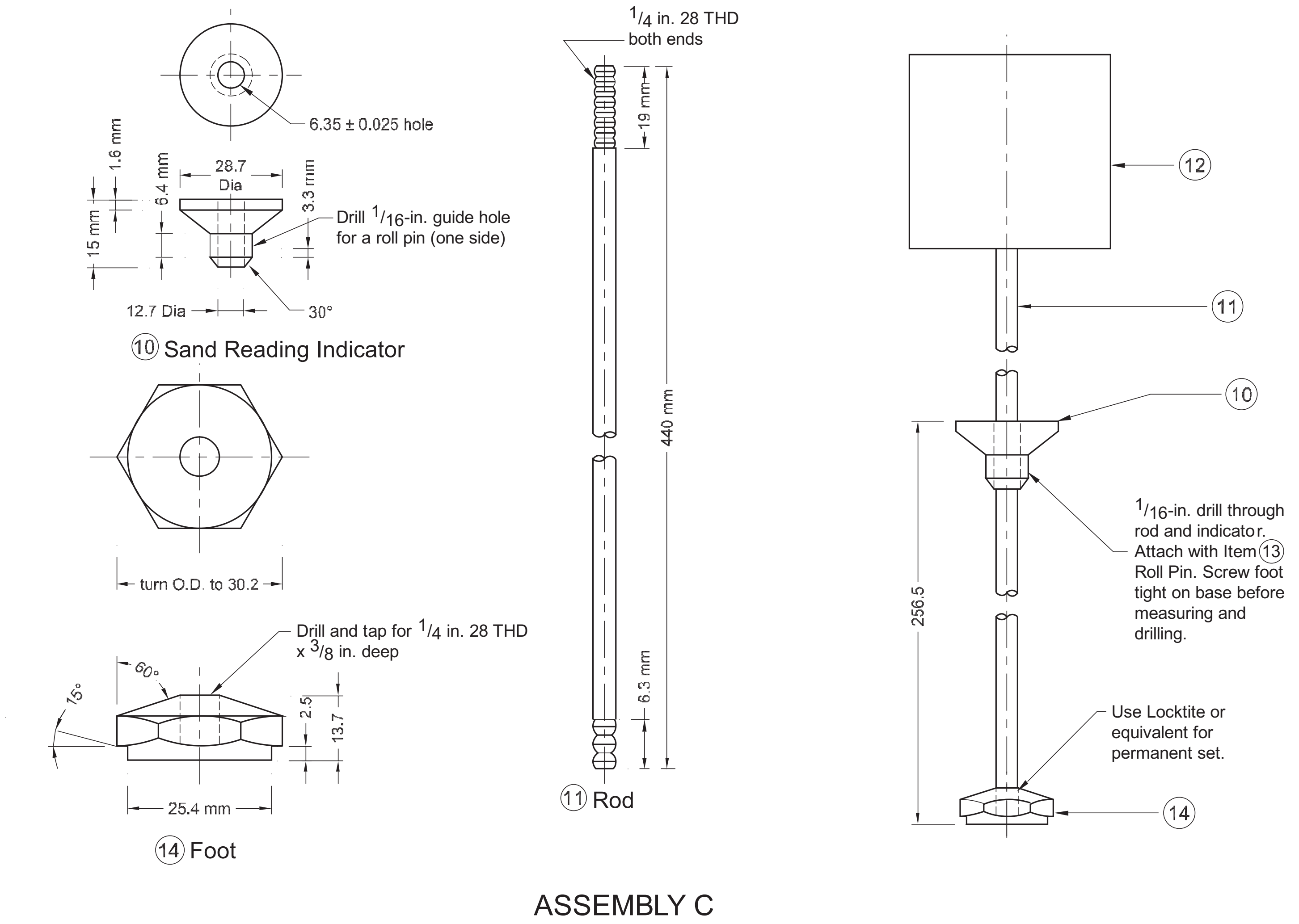
Notes:
1. "C" Weighted Foot Assembly to Weigh 1000 ± 5g.
2. Graduations on graduate to be 2.54 mm apart and every tenth mark to be numerically designated as shown. Every fifth line should be approximately 9.5 mm long. All other lines should be approximately 5.5 mm long. Depth is to be 0.4 mm. Width is to be 0.8 mm across the top.
3. Accuracy of scale to be ±0.25 mm per 2.5 mm. Error at any point on scale to be ±0.75 mm of true distance to zero.
4. Glass or stainless steel may be substituted as a material type for the copper siphon and blow tubing.

Figure 1—Sand Equivalent Apparatus (continued on the following two pages)



Note: All dimensions are shown in mm unless otherwise indicated.

Figure 1—Sand Equivalent Apparatus (*continued*)



Note: All dimensions are shown in mm unless otherwise indicated.

Figure 1—Sand Equivalent Apparatus (*continued*)

Figure 2—Graduated Cylinder, Irrigator Tube, Weighted Foot Assembly, and Siphon

Note 1—An older model of a weighted foot assembly has a guide cap that fits over the upper end of the graduated cylinder and centers the rod in the cylinder; the foot of the assembly has a conical upper surface and three centering screws to center it loosely in the cylinder. The older model does not have the sand reading indicator affixed to the rod (Figure 1), but a slot in the centering screws of the weighted foot is used to indicate the sand reading. Apparatus with the sand reading indicator (Figure 1) is preferred for testing clayey materials.

4.2 *Measure*—A tinned measure, having a capacity of 85 ± 5 mL (3 oz), approximately 57 mm (2.25 in.) in diameter.

4.3 *Balance*—The balance shall have sufficient capacity, be readable to not more than 0.1 percent of the sample mass, and conform to the requirements of M 231.

4.4 *Funnel*—A wide-mouth funnel approximately 100 mm (4 in.) in diameter at the mouth.

4.5 *Timer*—A clock or watch reading in minutes and seconds.

4.6 *Mechanical Shaker*—A mechanical shaker having a throw of 203.2 ± 1.0 mm (8.00 ± 0.04 in.) and operating at 175 ± 2 cycles per minute (2.92 ± 0.03 Hz) (Note 2). Prior to use, fasten the mechanical sand equivalent shaker securely to a firm and level mount.

4.7 *Manual Shaker*—A manually operated shaker, capable of producing an oscillating motion at the rate of 100 complete cycles in 45 ± 5 seconds, with a hand-assisted half stroke length of

127 ± 5 mm (5.0 ± 0.2 in.). The shaker shall be fastened securely to a firm and level mount by bolts or clamps if a large number of determinations are to be made.

Note 2—The mechanical shaker shall be used when performing referee sand equivalent determinations. Either the mechanical or manually operated shaker should be used in lieu of the hand method whenever possible.

4.8 *Stock Solution*—The materials listed in Sections 4.8.1, 4.8.2, or 4.8.3 may be used to prepare the stock solution. A fourth alternative is not to use any biocide, provided the time of storage of stock solution is not sufficient to promote the growth of fungi.

4.8.1 Stock solution with formaldehyde.

4.8.1.1 Anhydrous Calcium Chloride, 454 g (1.0 lb) of technical grade.

4.8.1.2 USP Glycerin, 2050 g (4.515 lb).

4.8.1.3 Formaldehyde, (40 volume percent solution) 47 g (0.10 lb).

4.8.1.4 Dissolve the 454 g (1.0 lb) of calcium chloride in 1.89 L ($^1/_2$ gal) of distilled water. Cool and filter it through ready pleated rapid filtering paper. Add the 2050 g (4.515 lb) of glycerin and the 47 g (0.10 lb) of formaldehyde to the filtered solution, mix well and dilute to 3.78 L (1 gal).

4.8.2 Stock solution with glutaraldehyde.

4.8.2.1 Calcium Chloride Dihydrate, 577 g (1.27 lb) of A.C.S. grade.

Note 3—A.C.S. grade calcium chloride dihydrate is specified for the stock solution prepared with glutaraldehyde because tests indicate that impurities in the technical grade anhydrous calcium chloride may react with the glutaraldehyde resulting in an unknown precipitate.

4.8.2.2 USP Glycerin, 2050 g (4.515 lb).

4.8.2.3 1.5-Pentanedial (Glutaraldehyde), 50 percent solution in water 59 g (0.13 lb).

4.8.2.4 Dissolve the 577 g (1.27 lb) of calcium chloride dihydrate in 1.89 L ($^1/_2$ gal) of distilled water. Cool and add the 2050 g (4.515 lb) of glycerin and the 59 g (0.13 lb) of glutaraldehyde to the solution, mix well, and dilute to 3.78 L (1 gal).

Note 4—1.5 pentanedial, also known as glutaraldehyde, glutaric dialdehyde, and trade name UCARCIDE 250, may be obtained as Glutaraldehyde Solution 50 percent.[1]

4.8.3 Stock solution with Kathon CG/ICP.

4.8.3.1 Calcium Chloride Dihydrate, 577 g (1.27 lb) of A.C.S. Grade.

4.8.3.2 USP Glycerin, 2050 g (4.515 lb).

4.8.3.3 Kathon CG/ICP, 63 g (0.14 lb).

4.8.3.4 Dissolve the 577 g (1.27 lb) of calcium chloride dihydrate in 1.89 L ($^1/_2$ gal) of distilled water. Cool and add the 2050 g (4.515 lb) of glycerin and the 63 g (0.14 lb) of Kathon CG/ICP to the solution, mix well, and dilute to 3.78 L (1 gal).[2]

4.9 *Working Solution*—Working calcium chloride solution: Prepare the working calcium chloride by diluting one measuring tin full (85 ± 5 mL) of the stock calcium chloride solution to 3.8 L (1 gal) with water. Use distilled or demineralized water for the normal preparation of the working solution. However, if it is determined that the local tap water is of such purity that it does not affect the test results, it is permissible to use in lieu of distilled or demineralized water except in the event of dispute. Working solutions more than 30 days old shall be discarded.

4.10 *Straightedge*—A straightedge or spatula, suitable for striking off the excess soil from the tin measure.

4.11 *Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF).

4.12 *Quartering Cloth*—Quartering or splitting cloth, approximately 600 mm (2 ft) square, nonabsorbent material such as plastic or oil cloth.

4.13 *Sieve*—A 4.75-mm (No. 4) sieve conforming to the requirements of M 92.

4.14 *Optional Handle for Irrigation Tube*—A 25-mm diameter wooden dowel to aid in pushing the irrigation tube into firm materials. See Figure 1, Assembly B.

5. TEMPERATURE CONTROL

5.1 The temperature of the working solution should be maintained at 22 ± 3ºC (72 ± 5ºF) during the performance of this test. If field conditions preclude the maintenance of the temperature range, frequent reference samples should be submitted to a laboratory where proper temperature control is possible. It is also possible to establish temperature correction curves for each material being tested where proper temperature control is not possible. However, no general correction curve should be utilized for several materials even within a narrow range of sand equivalent values. Samples that meet the minimums and equivalent requirement at a working solution temperature below the recommended range need not be subject to reference testing.

6. SAMPLING

6.1 Obtain a sample of the material to be tested in accordance with T 2.

6.2 Reduce the sample according to T 248. The sample shall be of sufficient size to yield 1,000 to 1,500 g of material passing the 4.75-mm (No. 4) sieve.

6.3 Sieve the sample over a 4.75-mm (No. 4) sieve. All aggregations of fine-grained soil material shall be pulverized to pass the 4.75-mm (No. 4) sieve, and all fines shall be cleaned from the particles retained on the 4.75-mm (No. 4) sieve and included with the material passing the 4.75-mm (No. 4) sieve.

6.4 Split or quarter the material passing the 4.75-mm (No. 4) sieve to yield 500 to 750 g (1.1 to 1.6 lb) of material. Use extreme care to obtain a truly representative portion of the original sample (Note 5).

Note 5—Experiments show that as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is reduced. It is imperative that the sample be split or quartered carefully. When it appears necessary, dampen the material before splitting or quartering, to avoid segregation or loss of fines.

7. SAMPLE PREPARATION

7.1 Prepare the desired number of test samples by one of the following methods:

7.1.1 *Alternate Method No. 1*—Air Dry.

7.1.1.1 Split or quarter enough material from the portion passing the 4.75-mm (No. 4) sieve to fill the 85-mL (3-oz) tin measure so it is slightly rounded above the brim. While filling the measure, tap the bottom edge of the tin on the work table or other hard surface to cause consolidation of the material and allow the maximum amount to be placed in the tin. Strike off the tin with the spatula or straightedge so the material is level with the top of the measuring tin.

7.1.2 *Alternate Method No. 2*—Pre-Wet.

7.1.2.1 The sample must be in the proper moisture condition to achieve reliable results. This condition is determined by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If the cast that is formed permits careful handling without breaking, the correct moisture range has been obtained. If the material is too dry, the cast will crumble and it will be necessary to add water, remix, and retest until the material forms a cast. If the material shows any free water it is too wet to test and must be drained and air dried, mixing it frequently to insure uniformity. This overly wet material will form a good cast when checked initially, so the drying process should continue until a squeeze check on the drying material gives a cast which is more fragile and delicate to handle than the original. If the moisture content of the original sample prepared in Section 6.2 is within the limits described above, the test sample may be obtained immediately. If the moisture content is altered to meet these limits, the altered sample should be placed in a pan, covered with a lid or with a damp cloth which does not touch the material, and allowed to stand for a minimum of 15 minutes.

7.1.2.2 After the minimum 15-minute tempering period, place the sample on the splitting cloth and mix by alternately lifting each corner of the cloth and pulling it over the sample toward the diagonally opposite corner, causing the material to be rolled. When the material appears homogeneous, finish the mixing with the sample in a pile near the center of the cloth.

7.1.2.3 Fill the 85-mL (3-oz) tin measure by pushing it through the base of the pile while exerting pressure with the hand against the pile on the side opposite the measure. As the tin is moved through the pile, hold enough pressure with the hand to cause the material to fill the tin to overflowing. Press firmly with the palm of the hand, compacting the material and allowing the maximum amount to be placed in the tin. Strike off the tin with the spatula or straightedge so the material is level with the top of the measuring tin.

Note 6—Moist test specimens produce lower sand equivalent values than the corresponding over-dry specimens with almost no exceptions; therefore, if a dual specification encompassing both the wet and dry methods of sample preparation is utilized, it will be necessary to determine the appropriate correction for each material because a standard correction does not appear possible. Either method can be employed with equal confidence, however.

7.1.3 *Reference Method (Mechanical Shaker)*—Obtain the 85-mL (3-oz) tin measure of material by one of the alternate methods, Section 7.1.1 or 7.1.2, above; then dry the test sample to constant mass at 110 ± 5ºC (230 ± 9ºF) and cool to room temperature before testing.

8. PROCEDURE

8.1 Start the siphon by forcing air into the top of the solution bottle through the bent copper, glass, or stainless steel blow tube while the pinch clamp is open. The apparatus is now ready for use.

8.2 Siphon 101.6 ± 2.5 mm (4.0 ± 0.1 in.) of working calcium chloride solution into the plastic cylinder. Pour the prepared test sample from the measuring tin into the plastic cylinder using the funnel to avoid spillage. (See Figure 3.) Tap the bottom of the cylinder sharply on the heel of the hand several times to release air bubbles and to promote thorough wetting of the sample.

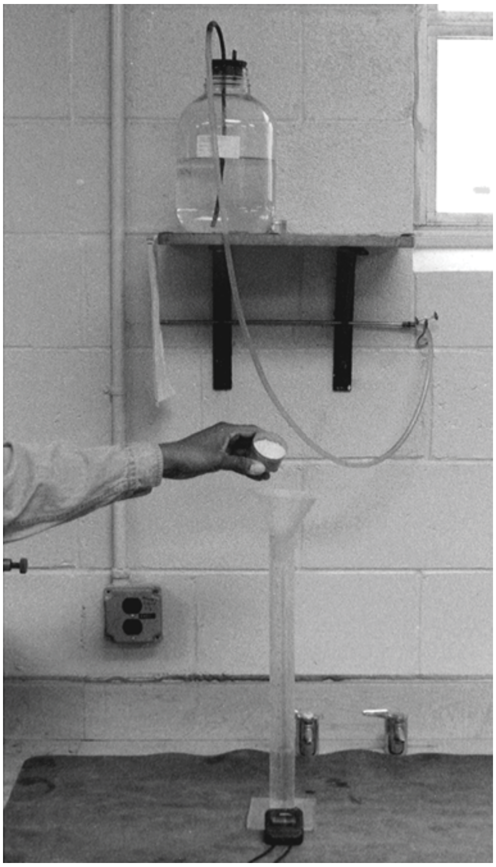


Figure 3—Transfer of Sample from Measuring Tin to Cylinder

8.3 Allow the wetted sample to stand undisturbed for 10 ± 1 minute. At the end of the 10-minute soaking period, stopper the cylinder, then loosen the material from the bottom by partially inverting the cylinder and shaking it simultaneously.

8.4 After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any one of the following methods:

8.4.1 *Mechanical Shaker Method (Reference Method)*—Place the stoppered cylinder in the mechanical sand equivalent shaker, set the timer, and allow the machine to shake the cylinder and contents for 45 ± 1 second.

8.4.2 *Manual Shaker Method*—Secure the stoppered cylinder in the three spring clamps on the carriage of the hand-operated sand equivalent shaker and reset the stroke counter to zero. Stand directly in front of the shaker and force the pointer to the stroke limit marker painted on the backboard by applying an abrupt horizontal thrust to the upper portion of the right-hand spring steel strap. Then remove the hand from the strap and allow the spring action of the straps to move the carriage and cylinder in the opposite direction without assistance or hindrance. Apply enough force to the right-hand spring steel strap during the thrust portion of each stroke to move the pointer to the stroke limit marker by pushing against the strap with the ends of the fingers to maintain a smooth oscillating motion. The center of the stroke limit marker is positioned to provide the proper stroke length and its width provides the maximum allowable limits of variation. The proper shaking action is accomplished only when the tip of the pointer reverses direction within the marker limits. Proper shaking action can best be maintained by using only the forearm and wrist action to propel the shaker. Continue the shaking action for 100 strokes.

8.4.3 *Hand Method*—Hold the cylinder in a horizontal position as illustrated in Figure 4 and shake it vigorously in a horizontal linear motion from end to end. Shake the cylinder 90 cycles in approximately 30 seconds using a throw of 229 ± 25 mm (9 ± 1 in.). A cycle is defined as a complete back and forth motion. To properly shake the cylinder at this speed, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.

Figure 4—Using Hand Method of Shaking

8.5 Following the shaking operation, set the cylinder upright on the work table and remove the stopper.

8.6 *Irrigation Procedure*—Insert the irrigator tube in the cylinder and rinse material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action while the working solution flows from the irrigator tip. This flushes the fine material into suspension above the coarser sand particles. Continue to apply the stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 381-mm (15-in.) mark. Then raise the irrigator slowly without shutting off the flow so the liquid level is maintained at about 381 mm (15 in.) while the irrigator is being withdrawn. Regulate the flow just before the irrigator is entirely withdrawn and adjust the final level to 381 mm (15 in.). The final level of the liquid shall be between the top two graduations on the tube but shall not be above the 381-mm (15-in.) mark when the liquid is read at the bottom of the meniscus.

Note 7—For certain soils, particularly on crushed materials, the stabbing action may not be possible. For these materials, the irrigation technique is as follows: Continue to apply a twisting action as the irrigation tube is slowly withdrawn. As the tube is withdrawn, it is essential that as many fines be flushed upward until the cylinder is filled to the 381-mm mark.

8.7 Allow the cylinder and contents to stand undisturbed for 20 minutes ± 15 seconds. Start the timing immediately after withdrawing the irrigator tube.

8.8 At the end of the 20-minute sedimentation period, read and record the level of the top of the clay suspension. This is referred to as the "clay reading." If no clear line of demarcation has formed at the end of the specified 20-minute sedimentation period, allow the sample to stand undisturbed until a clay reading can be obtained, then immediately read and record the level of the top of the clay suspension and the total sedimentation time. If the total sedimentation time exceeds 30 minutes, rerun the test using three individual samples of the same material. Read and record the clay column height of that sample requiring the shortest sedimentation period only.

8.9 After the clay reading has been taken, the "sand reading" shall be obtained by one of the following methods:

8.9.1 When using the weighted foot assembly having the sand indicator on the rod of the assembly, place the assembly over the cylinder and gently lower the assembly toward the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered. As the weighted foot comes to rest on the sand, tip the assembly toward the graduations on the cylinder until the indicator touches the inside of the cylinder. Subtract 254 mm (10 in.) from the level indicated by the extreme top edge of the indicator and record this value as the "sand reading." (See Figure 5.)

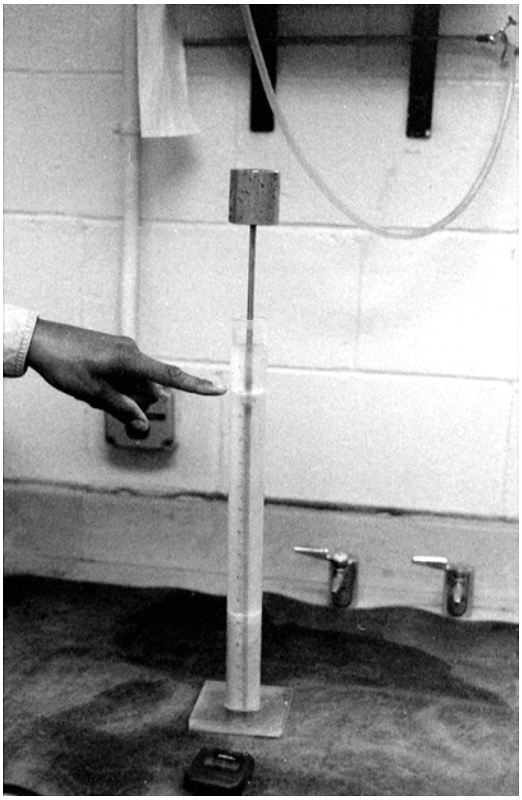


Figure 5—Sand Reading

8.9.2 If an older model weighted foot assembly having centering screws is used, keep one of the centering screws in contact with the cylinder wall near the graduations so it can be seen at all times while the assembly is being lowered. When the weighted foot has come to rest on the sand, read the level of the centering screw and record this value as the "sand reading."

8.10 If clay or sand readings fall between 2.5-mm (0.1-in.) graduations, record the level of the higher graduation as the reading. For example, a clay reading of 7.95 would be recorded as 8.0, and a sand reading of 3.22 would be recorded as 3.3.

Note 8—Samples obtained from aggregate proposed for use in hot-asphalt paving mixtures shall be prepared by oven-drying if acceptance of the material is based on tests on material that has passed through a hot-plant drier.

9. CALCULATIONS

9.1 Calculate the sand equivalent (SE) to the nearest 0.1 using the following formula:

$$SE = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100 \qquad (1)$$

9.2 If the calculated sand equivalent is not a whole number, report it as the next higher whole number, as in the following example:

$$SE = \frac{3.3}{8} \times 100 = 41.25, \qquad (2)$$

which is reported as 42.

9.3 If it is desired to average a series of sand equivalent values, average the whole number values determined as described above. If the average of these values is not a whole number, raise it to the next higher whole number, as in the following example:
Calculated SE values: 41.2, 43.8, 40.9.

After raising each to the next higher whole number, they become: 42, 44, and 41.

The average of these values is then determined:

$$\frac{42 + 44 + 41}{3} = 42.3 \qquad (3)$$

9.3.1 Since the average value is not a whole number, it is raised to the next higher whole number and the reported averages and equivalent value is reported as 43.

10. PRECAUTIONS

10.1 Perform the test in a location free of vibrations; vibrations may cause the suspended material to settle at a rate greater than normal.

10.2 Do not expose the plastic cylinders to direct sunlight any more than is necessary.

10.3 *Removal of Organic Growth*—Occasionally it may be necessary to remove an organic growth from the working calcium chloride solution container and from the inside of the flexible tubing and irrigator tube. This organic material can easily be seen as a slimy substance in the solution. To remove this growth, prepare a cleaning solvent by diluting sodium hypochlorite[3] with an equal quantity of water. Fill the solution container with the prepared cleaning solvent, allow about a liter of the cleaning solvent to flow through the siphon assembly and irrigator tube, then place the pinch clamp on the end of the tubing to cut off the flow of solvent and to hold the solvent in the tube. Refill the container and allow to stand overnight. After soaking, allow the cleaning solvent to flow out through the siphon assembly and irrigator tube. Remove the siphon assembly from the solution container and rinse both with clear water. The irrigator tube and siphon assembly can be rinsed easily by attaching a hose between the tip of the irrigator tube and water faucet and backwashing fresh water through the tube.

10.4 Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out, using extreme care not to enlarge the size of the opening.

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[1] Available from Aldrich Chemical Company, P.O. Box 2060, Milwaukee, WI 53201 or Fisher Scientific, 711 Forbes Ave., Pittsburgh, PA 15219.

[2] Kathon CG/ICP may be obtained from Rohm and Hass Chemical Company, Independence Mall West, Philadelphia, PA 19105. Kathon CG/ICP contains the following components: 5-chloro-2-methyl-4-isothiazolin-3-one; 2-methyl-4 isothiazolin-3-one; magnesium chloride; and magnesium nitrate.

[3] Clorox® or its equivalent has been found satisfactory for this purpose.

Standard Method of Test for

Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop

AASHTO Designation: T 180-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

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1. SCOPE

1.1. This method of test is intended for determining the relationship between the moisture content and density of soils when compacted in a given mold of a given size with a 4.54-kg (10-lb) rammer dropped from a height of 457 mm (18 in.). Four alternate procedures are provided as follows:

- *Method A*—A 101.60-mm (4-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 4 and 5.
- *Method B*—A 152.40-mm (6-in.) mold: Soil material passing a 4.75-mm (No. 4) sieve Sections 6 and 7.
- *Method C*—A 101.60-mm (4-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections 8 and 9.
- *Method D*—A 152.40-mm (6-in.) mold: Soil material passing a 19.0-mm ($^3/_4$-in.) sieve Sections 10 and 11.

1.2. The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Method A shall govern.

1.3. This test method applies to soil mixtures that have 40 percent or less retained on the 4.75-mm (No. 4) sieve, when Method A or B is used and 30 percent or less retained on the 19.0-mm ($^3/_4$-in.) sieve, when Method C or D is used. The material retained on these sieves shall be defined as oversize particles (coarse particles).

1.4. If the test specimen contains oversize particles and the test specimen used for field density compaction control, corrections must be made according to T 224 to compare the total field density with the compacted specimen. The person or agency specifying this method shall specify a minimum percentage of oversize particles below which correction for oversize need not be applied. If no minimum percentage is specified, correction shall be applied to samples with more than 5 percent by mass of oversize particles.

1.5. If the specified oversized maximum tolerances are exceeded, other methods of compaction control must be used.

Note 1—One method for the design and control of the compaction of such soils is to use a test fill to determine the required degree of compaction and a method to obtain that compaction. Then use a method specification to control the compaction by specifying the type and size of compaction equipment, the lift thickness, and the number of passes.

1.6. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off “to the nearest unit’’ in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.7. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 224, Correction for Coarse Particles in the Soil Compaction Test
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- D 2168, Standard Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

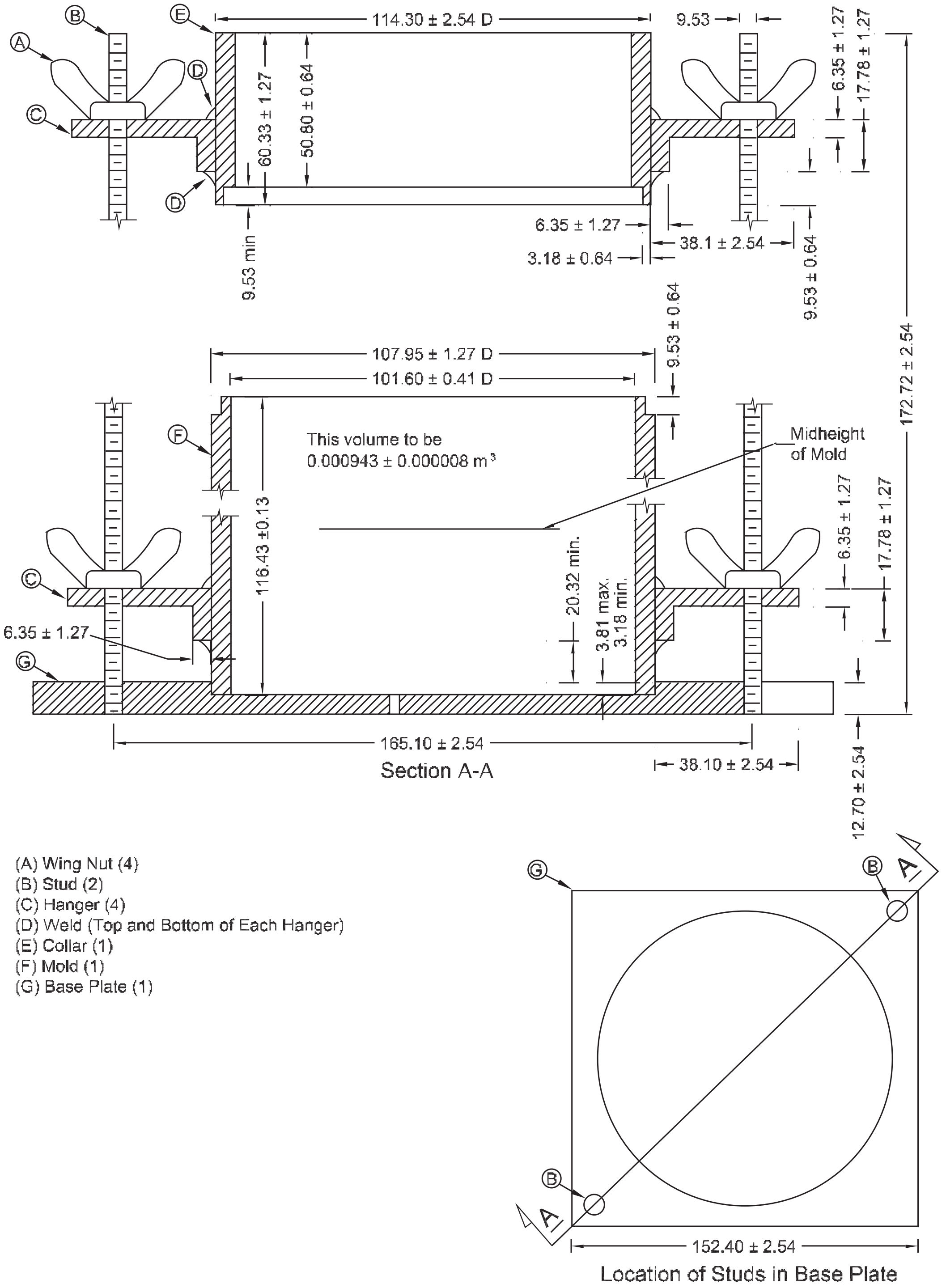
3.1. *Molds*—The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in Sections 3.1.1, 3.1.2, and Figures 1 and 2 below. They shall have a detachable collar assembly approximately 60 mm ($2^{3}/_{8}$ in.) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired height and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material (Note 2). The base plate shall be plane to 0.13 mm (0.005 in.) as shown in Figures 1 and 2.

Note 2—Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection when alternate types of molds are used.

3.1.1. A 101.6-mm (4-in.) mold having a capacity of 0.000943 ± 0.000008 m^3 ($^{1}/_{30}$ (0.0333) ± 0.0003 ft^3) with an internal diameter of 101.60 ± 0.41 mm (4.000 ± 0.016 in.) and a height of 116.43 ± 0.13 mm (4.584 ± 0.005 in.) (Figure 1).

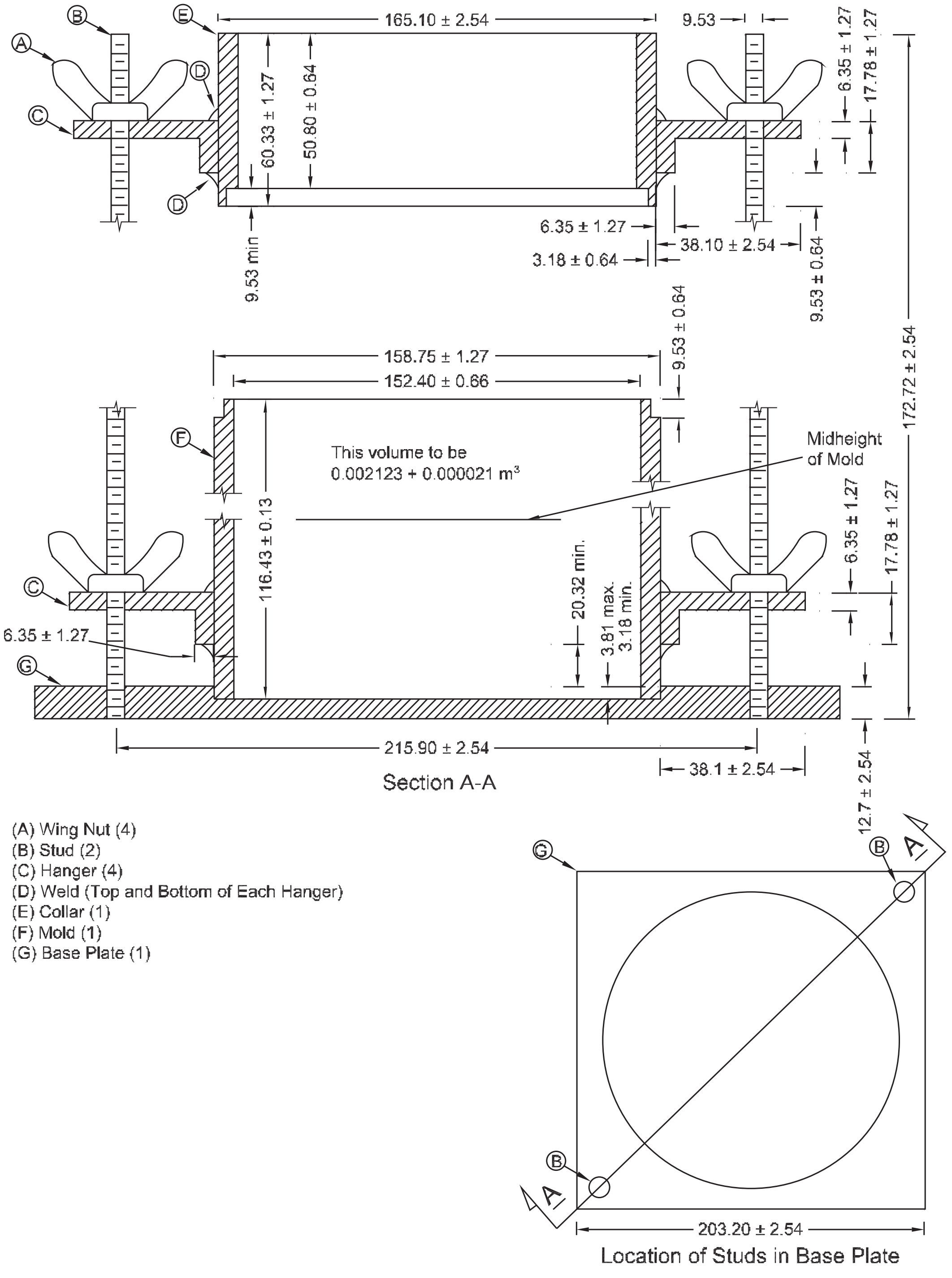
3.1.2. A 152.4-mm (6-in.) mold having a capacity of 0.002124 ± 0.000021 m^3 ($^{1}/_{13.33}$ (0.07500) ± 0.00075 ft^3) with an internal diameter of 152.40 ± 0.66 mm (6.000 ± 0.026 in.) and a height of 116.43 ± 0.13 mm (4.584 ± 0.005 in.) (Figure 2).

3.1.3. *Molds Out of Tolerance Due to Use*—A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with T 19M/T 19, is used in the calculations.



Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Hanger on the mold portion only cannot extend above the midheight line.
3. Figure 1 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).
4. Not to scale.

Figure 1—Cylindrical Mold and Base Plate (101.60-mm Mold)



(A) Wing Nut (4)
(B) Stud (2)
(C) Hanger (4)
(D) Weld (Top and Bottom of Each Hanger)
(E) Collar (1)
(F) Mold (1)
(G) Base Plate (1)

Notes:
1. All dimensions shown in millimeters unless otherwise noted.
2. Hanger on the mold portion only cannot extend above the midheight line.
3. Figure 2 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).
4. Not to scale.

Figure 2—Cylindrical Mold and Base Plate (152.40-mm Mold)

Table 1—Dimensional Equivalents for Figure 1

mm	in.	mm	in.	mm	in.
3.18 ± 0.64	0.125 ± 0.025	17.78 ± 1.27	0.700 ± 0.050	107.95 ± 1.27	4.250 ± 0.050
3.81	0.150	20.32	0.800	114.30 ± 2.54	4.500 ± 0.100
6.35 ±1.27	0.250 ± 0.050	38.10 ± 2.54	1.500 ± 0.100	116.43 ± 0.13	4.584 ± 0.005
7.62	0.300	50.80 ± 0.64	2.000 ± 0.025	152.40 ± 2.54	6.000 ± 0.100
9.53 ± 0.64	0.375 ± 0.025	60.33 ± 1.27	2.375 ± 0.050	165.10 ± 2.54	6.500 ± 0.100
12.70 ± 2.54	0.500 ± 0.100	101.60 ± 0.41	4.000 ± 0.016	172.72 ± 2.54	6.800 ± 0.100
0.000943 ± 0.000008 m^3	1/30 ± 0.0003 ft^3				

Table 2—Dimensional Equivalents for Figure 2

mm	in.	mm	in.	mm	in.
3.18 ± 0.64	0.125 ± 0.025	17.78 ± 1.27	0.700 ± 0.050	152.40 ± 0.66	6.000 ± 0.026
3.81	0.150	20.32	0.800	158.75 ± 1.27	6.250 ± 0.050
6.35 ±1.27	0.250 ± 0.050	38.10 ± 2.54	1.500 ± 0.100	165.10 ± 2.54	6.500 ± 0.100
7.62	0.300	50.80 ± 0.64	2.000 ± 0.025	172.72 ± 2.54	6.800 ± 0.100
9.53 ± 0.64	0.375 ± 0.025	60.33 ± 1.27	2.375 ± 0.050	203.23 ± 2.54	8.000 ± 0.100
12.70 ± 2.54	0.500 ± 0.100	116.43 ± 0.13	4.584 ± 0.005	215.90 ± 2.54	8.500 ± 0.100
0.002124 ± 0.000021 m^3	1/13.33 ± 0.00075 ft^3				

3.2. *Rammer*:

3.2.1. *Manually Operated*—Metal rammer with a mass of 4.536 ± 0.009 kg (10.00 ± 0.02 lb) (Note 3), and having a flat circular face of 50.80 mm (2.000 in.) diameter with a manufacturing tolerance of ±0.25 mm (±0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The rammer shall be equipped with a suitable guide sleeve to control the height of drop to a free fall 457 ± 2 mm (18.00 ± 0.06 in.) above the elevation of the soil. The guide sleeve shall have at least four vent holes, no smaller than 9.5-mm ($^3/_8$-in.) diameter, spaced approximately 90 degrees (1.57 rad) apart and approximately 19 mm ($^3/_4$ in.) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2. *Mechanically Operated*—A metal rammer that is equipped with a device to control the height of drop to a free fall of 457 ± 2 mm (18.00 ± 0.06 in.) above the elevation of the soil, and uniformly distributes such drops to the soil surface (Note 3). The rammer shall have a mass of 4.536 ± 0.009 kg (10.00 ± 0.02 lb) (Note 2), and have a flat circular face of 50.80 mm (2.000 in.) diameter with a manufacturing tolerance of ±0.25 mm (±0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The mechanical rammer shall be calibrated by ASTM D 2168 to give the same moisture-density results as with a manually operated rammer.

Note 3—The mechanical rammer apparatus shall be calibrated with several soil types and the mass of the rammer adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer.

It may be impractical to adjust the mechanical apparatus so the free fall is 457-mm (18 in.) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 457-mm (18-in.) drop is determined; subsequent blows on the layer of soil being compacted may all be applied by dropping the rammer from a height of 457 mm (18 in.) above the initial-setting elevation, or when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have a rammer free fall of 457 mm (18 in.) measured from the elevation of the soil as compacted by the previous blow. A more detailed calibration procedure for laboratory mechanical rammer soil compactors can be found in ASTM D 2168.

3.2.3. *Rammer Face*—The circular face rammer shall be used but a sector face rammer may be used as an alternative provided the report shall indicate type of face used other than the 50.8-mm (2-in.) circular face and it shall have an area equal to that of the circular face rammer.

3.3. *Sample Extruder (for Solid-Walled Molds Only)*—A jack, lever, frame, or other device adapted for the purpose of extruding compacted specimen from the mold.

3.4. *Balances and Scales*—A balance or scale conforming to the requirements of M 231, Class G 20. Also, a balance conforming to the requirements of M 231, Class G 2.

Note 4—The capacity of the metric balance or scale should be approximately 11.5 kg when used to determine the mass of the 152-mm (6-in.) mold and compacted, moist soil; however, when the 102-mm (4-in.) mold is used, a balance or scale of lesser capacity than 11.5 kg may be used, if the sensitivity and readability is 5 g.

3.5. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF) for drying moisture samples.

3.6. *Straightedge*—A hardened steel straightedge at least 250 mm (10 in.) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.1 percent of the length within the portion used for trimming the soil (Note 5).

Note 5—The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.25 mm per 250 mm (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil surface with the cutting edge will cause a concave soil surface.

3.7. *Sieves*—50-mm (2-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves conforming to the requirements of M 92.

3.8. *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

3.9. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

METHOD A

4. SAMPLE

4.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF). Then thoroughly break up the aggregation in such a manner as to avoid reducing the natural size of individual particles.

4.2. Sieve an adequate quantity of the representative pulverized soil over the 4.75-mm (No. 4) sieve. Discard the coarse material, if any, retained on the 4.75-mm (No. 4) sieve.

4.3. Select a representative sample, with a mass of approximately 3 kg (7 lb) or more, of the soil prepared as described in Sections 4.1 and 4.2.

Note 6—When developing a compaction curve for free draining soils, such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content sample from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

5. PROCEDURE

5.1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

5.2. Form a specimen by compacting the prepared soil in the 101.60-mm (4-in.) mold (with collar attached) in five approximately equal layers to give a total compacted depth of about 125 mm (5 in.). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or similar device having a face diameter of approximately 50 mm (2 in.). Following compaction of each of the first four layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed using a knife or other suitable device, and be evenly distributed on top of the layer. Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 457 mm (18 in.) above the elevation of the soil when a sleeve-type rammer is used, or from 457 mm (18 in.) above the approximate elevation of the soil as compacted by the previous blow when a stationary mounted type of rammer is used (Note 7).

Note 7—Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: a block of concrete, with a mass of not less than 90 kg (200 lb), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges, and pavements.

5.2.1. Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and determine the mass of the mold and moist soil in kilograms to the nearest 5 grams, or determine the mass in pounds to the nearest 0.01 pounds. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process (Note 7). Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

5.3. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces (Figure 3), and weigh immediately. Determine the moisture content in accordance with T 265, and record the results.

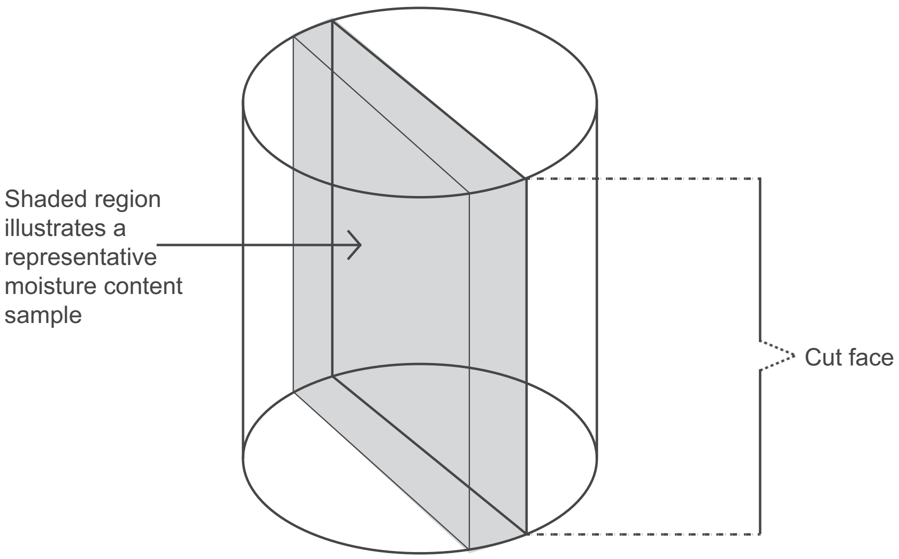


Figure 3—Representative Moisture Content Sample Selection

5.4. Thoroughly break up the remaining portion of the molded specimen until it will pass a 4.75-mm (No. 4) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil by approximately one to two percentage points (water content increments should not exceed 2.5 percent, except when heavy clay soils or organic soils exhibiting flat elongated curves are encountered, the water content increments may be increased to a maximum of four percent), and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass per cubic meter (cubic foot) of the compacted soil (Note 8).

Note 8—In instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, and in cases where the soil is heavy-textured, clayey material into which it is difficult to incorporate water, a separate and new sample shall be used in each compaction test. In these cases, separate samples shall be thoroughly mixed with amounts of water sufficient to cause the moisture contents of the samples to vary by approximately two percentage points. The moisture contents selected shall bracket the optimum moisture content, thus providing samples which, when compacted, will increase in mass to the maximum density and then decrease in mass. The samples of soil-water mixtures shall be placed in covered containers and allowed to stand for not less than 12 hours before making the moisture-density test.

5.4.1. In instances where the soil material is fragile in character and will be reduced significantly in grain size by repeated compaction, a separate and new sample shall be used in each compaction test.

METHOD B

6. SAMPLE

6.1. Select the representative sample in accordance with Section 4.3 except that it shall have a mass of approximately 7 kg (16 lb).

7. PROCEDURE

7.1. Follow the same procedure as described for Method A in Section 5, except for the following: Form a specimen by compacting the prepared soil in the 152.40-mm (6-in.) mold (with collar attached) in five approximately equal layers to give a total compacted depth of about 125 mm (5 in.), each layer being compacted by 56 uniformly distributed blows from the rammer. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

METHOD C

8. SAMPLE

8.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60ºC (140ºF). Then, thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

8.2. Sieve an adequate quantity of the representative pulverized soil over the 19.0-mm ($^3/_4$-in.) sieve. Discard the coarse material, if any, retained on the 19.0-mm ($^3/_4$-in.) sieve.

8.3. Select a representative sample, with a mass of approximately 5 kg (12 lb) or more, of the soil prepared as described in Sections 8.1 and 8.2.

9. PROCEDURE

9.1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately four percentage points below optimum moisture content.

9.2. Form a specimen by compacting the prepared soil in the 101.60-mm (4-in.) mold (with collar attached) in five approximately equal layers to give a total compacted depth of about 125 mm (5 in.). Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a loose or fluffy state, using either the manual compaction rammer or similar device having a face diameter of approximately 50 mm (2 in.). Following compaction of each of the first four layers, any soil adjacent to the mold walls that has not been compacted or extends above the compacted surface shall be trimmed using a knife or other suitable device, and be evenly distributed on top of the layer. Compact each layer by 25 uniformly distributed blows from a rammer dropping free from a height of 457 mm (18 in.) above the elevation of the soil when a sleeve-type rammer is used, or from 457 mm (18 in.) above the approximate elevation of each finely compacted layer when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process (Note 7).

9.2.1. Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and determine the mass of the mold and moist soil in kilograms to the nearest 5 grams, or determine the mass in pounds to the nearest 0.01 pounds. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

9.3. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces and weigh immediately. Determine the moisture content in accordance with T 265 and record the results.

9.4. Thoroughly break up the remainder of the material until it will pass a 19.0-mm ($^3/_4$-in.) sieve and 90 percent of the soil aggregations will pass a 4.75-mm (No. 4) sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass, W_1, per cubic meter (cubic foot) of the compacted soil (Note 8).

METHOD D

10. SAMPLE

10.1. Select the representative sample in accordance with Section 8.3, except that it shall have a mass of approximately 11 kg (25 lb).

11. PROCEDURE

11.1. Follow the same procedure as described for Method C in Section 9, except for the following: Form a specimen by compacting the prepared soil in the 152.40-mm (6-in.) mold (with collar attached) in five approximately equal layers to give a total compacted depth of about 127 mm (5 in.), each layer being compacted by 56 uniformly distributed blows from the rammer. Calculate the wet density, W_1, as described in Section 12.2 or 12.3.

CALCULATIONS AND REPORT

12. CALCULATIONS

12.1. The mold factor can be related to the volume of the mold as follows:

$$F = 1/V$$

where:

F = mold factor; and

V = volume of mold.

12.2. The wet density can be determined using the mold factor. For masses recorded in kilograms, the unit of wet density is kilograms per cubic meter of compacted soil. For masses recorded in pounds, the unit of wet density is pounds per cubic foot of compacted soil.

$$W_1 = (A - B) \times F$$

where:

W_1 = wet density,

A = mass of compacted specimen and mold,

B = mass of mold, and

F = mold factor as given in Table 3.

Table 3—Mold Factors for Molds in Compliance with Sections 3.1.1 or 3.1.2

Method	Mold Factor	
	For masses recorded in kilograms	For masses recorded in pounds
A	1060	30
B	471	13.3
C	1060	30
D	471	13.3

Note: For used molds in compliance with Section 3.1.3, determine the mold factor in accordance with Section 3.1.3 and Equation 1.

12.3. Alternatively, the wet density can be determined using the mold volume. For masses recorded in kilograms, the unit of wet density is kilograms per cubic meter of compacted soil. For masses recorded in pounds, the unit of wet density is pounds per cubic foot of compacted soil.

$$W_1 = (A - B)/V$$

where:

V = mold volume as given in Section 3.1.1 for Methods A and C, or Section 3.1.2 for Methods B and D. For used molds in compliance with Section 3.1.3, determine the mold volume in accordance with Section 3.1.3.

12.4. The dry density is related to the wet density as follows:

$$W = \frac{W_1}{w + 100} \times 100$$

where:

W = dry density, in kilograms per cubic meter of compacted soil, or pounds per cubic foot of compacted soil; and

w = moisture content (percent) of the specimen, as determined by T 265.

13. MOISTURE–DENSITY RELATIONSHIP

13.1. The calculations in Section 12 shall be made to determine wet density (unit mass) and oven-dry density (unit mass) in kilograms per cubic meter or pounds per cubic foot for each of the compacted samples. The oven-dry densities of the soil shall be plotted as ordinates and corresponding moisture contents as abscissae.

13.2. *Optimum Moisture Content*—When the densities and corresponding moisture contents for the soil have been determined and plotted as indicated in Section 13.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "optimum moisture content" of the soil under the above compaction.

13.3. *Maximum Density*—The oven-dry density in kilograms per cubic meter or pounds per cubic foot of the soil at optimum moisture content shall be termed "maximum density" under the above compaction.

14. REPORT

14.1. The report shall include the following:

14.1.1. The method used (Method A, B, C, or D);

14.1.2. The optimum moisture content, as a percentage, to the nearest whole number;

14.1.3. The maximum density in kilograms per cubic meter to the nearest 10 kg/m^3 or in pounds per cubic foot, to the nearest whole number; and

14.1.4. Type of face if other than 50.8-mm (2-in.) circular.

Standard Method of Test for

Resistance R-Value and Expansion Pressure of Compacted Soils

AASHTO Designation: T 190-09
ASTM Designation: D 2844-07

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Resistance R-Value and Expansion Pressure of Compacted Soils

AASHTO Designation: T 190-09
ASTM Designation: D 2844-07

1. SCOPE

1.1. This method covers the procedure for testing both treated and untreated laboratory compacted soils or aggregates with the stabilometer and expansion pressure devices to obtain results indicative of performance when placed in the base, subbase, or subgrade of a road subjected to traffic.

1.2. The values stated in SI units are to be regarded as the standard.

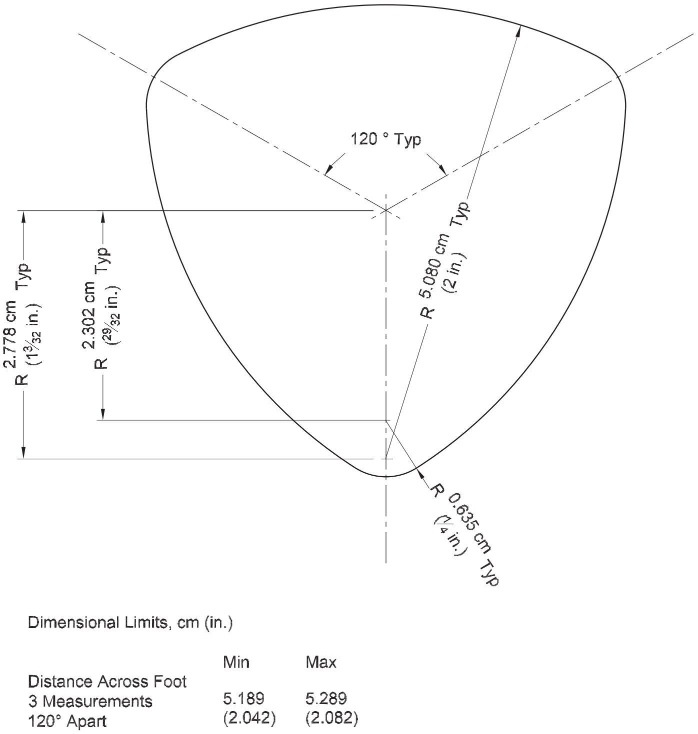
2. APPARATUS

2.1. Kneading Compactor capable of applying an average contact pressure of 2413 ± 110 kPa (350 ± 16 psi) to the tamper foot shown in Figure 1 and with provisions for maintaining this pressure during changes in sample height. The load-time trace shall be free of "chatter" or evidence of impact-associated changes in slope. The rise time for application of foot pressure, in the range from 241 to 2068 kPa (35 to 300 psi), shall not be less than 0.07 nor more than 0.20 seconds. The dwell time, measured at 2068 kPa (300 psi) foot pressure, shall not be less than 0.15 nor more than 0.45 seconds. The pressure-release or removal time shall not be greater than 0.60 seconds.

2.1.1. The compactor shall include a counter or timer for measuring the number of tamps applied to a specimen and a mold holder, for use in compacting specimens, that rotates equally between tamps to give five to seven tamps per revolution of the mold. The holder shall firmly restrain the mold during compaction. The base of the mold holder shall have a metal plate 100.8 mm ($33^1/_{32}$ in.) in diameter and 12.7 mm (1/2 in.) high to which is cemented a rubber disk having a diameter of 100.0 mm ($31^5/_{16}$ in.) and a height of 3.2 mm ($^1/_8$ in.). The plate shall be an integral part of the base of the mold holder. The compactor shall also include a trough for feeding the sample into the mold in 20 increments (Figure 2). Troughs with a semicircular cross section of 3871 mm^2 (6 in.^2) in area and 508 mm (20 in.) long have proven satisfactory.

2.2. Compression Testing Machine, with a minimum capacity of 45 kN (10000 lbf) and satisfying the requirements of ASTM E 4.

2.3. Mold, 101.6 ± 0.05 mm (4 ± 0.002 in.) inside diameter by 127.00 ± 0.20 mm (5 ± 0.008 in.) high. (See Figure 3 for surface roughness.)



mm	in.
50.80 ± 0.05	2.00 ± 0.002
6.35 ± 0.51	$^1/_4$ ± 0.020
6.35	$^1/_4$
50.80	2
22.22	$^7/_8$

Figure 1—Tamper Foot for Kneading Compactor

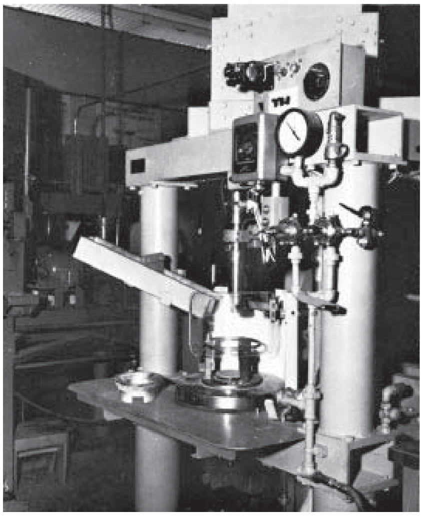
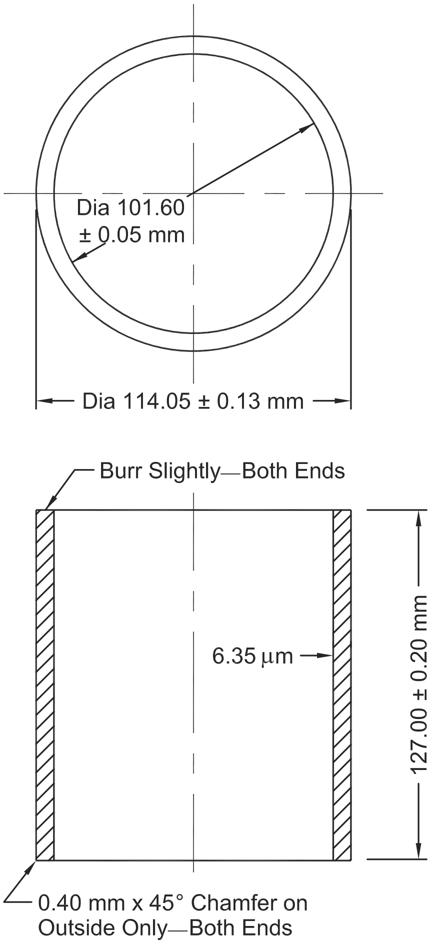


Figure 2—Compactor with Sample Feed Trough



Note: Inside roughness is obtained by smooth machining inside to required diameter of 101.60 ± 0.05 mm (4.000 ± 0.002 in.) diameter followed on final operation with a boring tool ground to a 90-degree point with sharp point ground flat measuring 0.02 to 0.08 mm (0.001 to 0.003 in.) across. Depth of cut is 0.05 mm (0.002 in.) with 0.25 mm (0.010 in.) feed using sulfur-based oil coolant.

Figure 3—Mold

2.4. Rubber Disks, 100 mm ($31^{5}/_{16}$ in.) in diameter by 3.2 mm ($^{1}/_{8}$ in.) thick and having a durometer hardness of 60 ± 15.

2.5. Metal Follower, solid-walled, metal specimen follower 100.33 ± 0.13 mm (3.95 ± 0.005 in.) in outside diameter by 127 mm (5 in.) long.

2.6. Exudation-Indicator Device, as shown in Figures 4 and 5.

2.7. Phosphor Bronze Disk, as shown in Figure 6.

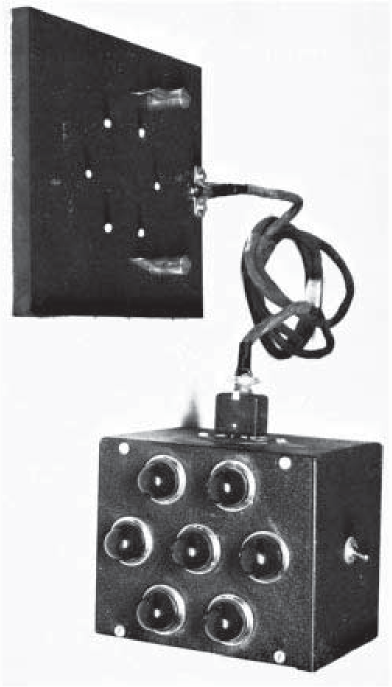


Figure 4—Exudation-Indicator Device

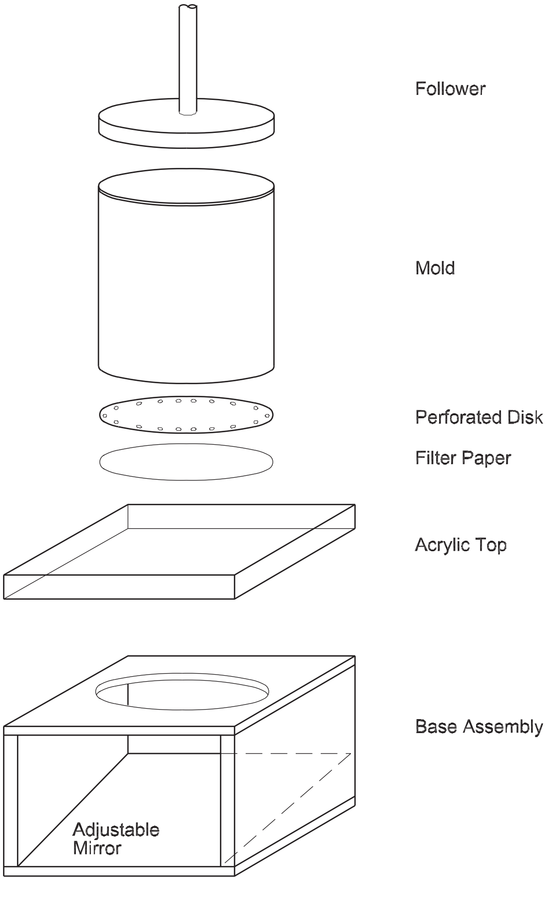


Figure 5—Exudation-Indicator Device (Alternate Method)

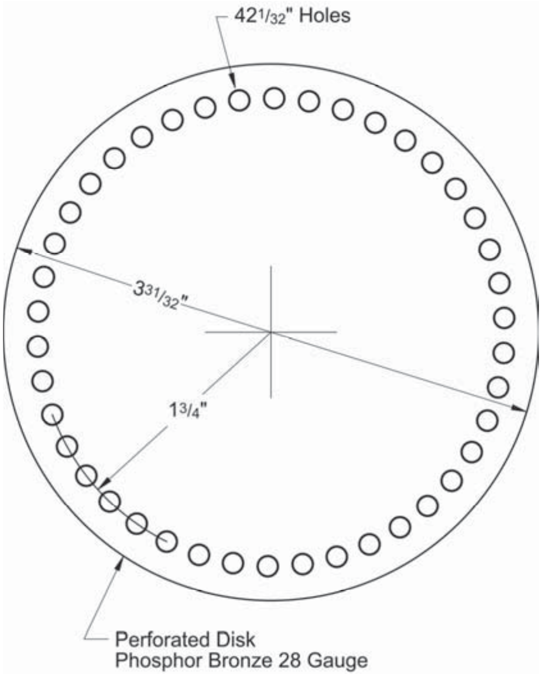


Figure 6—Phosphor-Bronze Disk

2.8. Filter Paper, 100 mm in diameter and 0.15 mm (0.006 in.) thick, smooth surface, medium filtering speed, medium retention.

2.9. Filter Paper, 110 mm in diameter and 0.15 mm (0.006 in.) thick, creped surface, medium-fast filtering speed, medium retention.

2.10. Expansion-Pressure Device, with accessories as shown in Figure 7. There should be at least three of these devices for each sample to be tested within a day's time.

2.11. Deflection Gauge, with divisions of 0.002 mm (0.0001 in.) and an Allen wrench as shown in Figure 7.

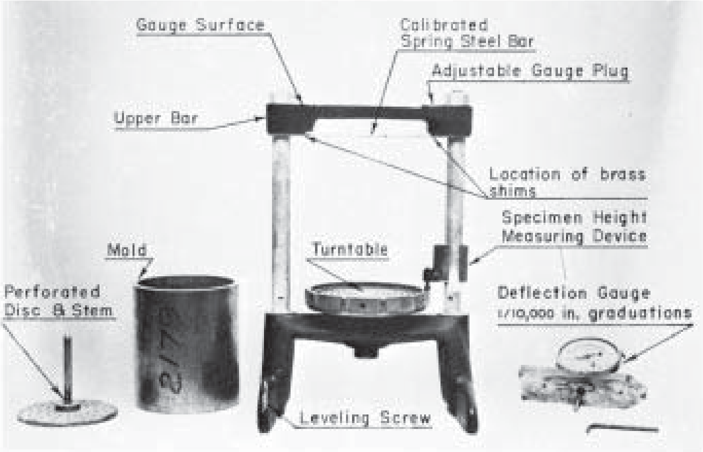


Figure 7—Expansion-Pressure Device and Accessories

2.12. Stabilometer, with accessories, as shown in Figures 8 and 9.

2.13. Standard Metal Specimen, 101.60 mm (4 in.) in outside diameter by 152.4 mm (6 in.) high as shown in Figure 9.

2.14. Balance, of sufficient capacity, conforming to the requirements of M 231, Class G 5.

2.15. Sieves, 25.0-mm (1-in.), 19.0-mm ($^3/_4$-in.) and 4.75-mm (No. 4) conforming to the requirements of M 92 for Wire-Cloth Sieves for Testing Purposes.

2.16. Miscellaneous equipment, including mixing pans, spoons, spatulas, and gallon cans with close-fitting lids.

2.17. Tamping Rod, a metal rod, 38 to 51 mm (1.5 in. to 2.0 in.) in diameter.

2.18. Expansion pressure calibration equipment, a suitable hanger and weights, and a calibrated proving ring.

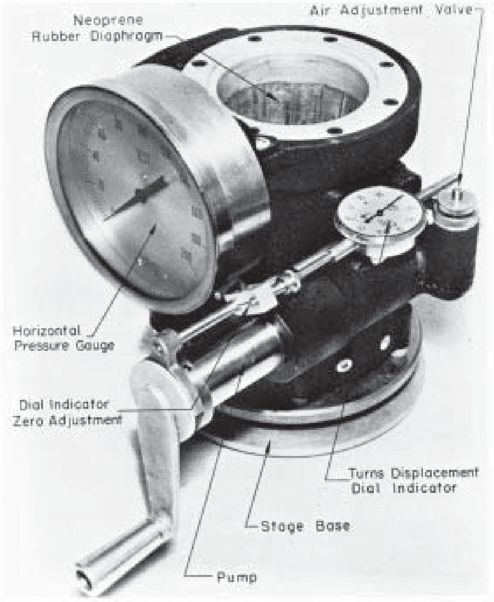


Figure 8—Hveem Stabilometer

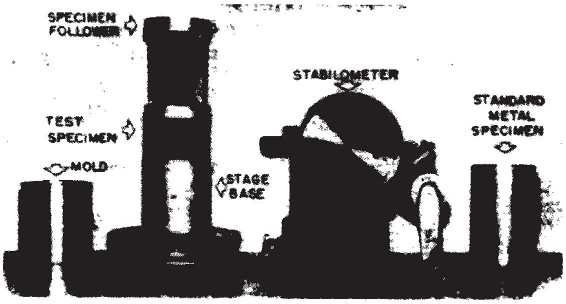


Figure 9—Stabilometer and Accessories

3. SOIL PREPARATION

3.1. Remove any coatings from coarse aggregate and break clay lumps to pass the 4.75-mm (No. 4) sieve.

3.2. Adjust the soil graduation when some of the material is retained on the 19.0-mm ($^{3}/_{4}$-in.) sieve. When 75 percent or more passes the 19.0-mm sieve, use that part of the sample passing the 19.0-mm sieve. If less than 75 percent of the sample passes the 19.0-mm sieve, use that part of the sample passing the 25.0-mm (1-in.) sieve.

4. PREPARATION OF SOIL SPECIMENS

4.1. Thoroughly mix four 1200-g samples of soil with the amount of water estimated to equal one-half to two-thirds of the water required to produce saturation as defined in Sections 4.3 and 4.4. Place the samples in covered containers and allow them to stand overnight. Just prior to compaction, mix the samples with the final amount of water required to produce saturation. The first sample is used as a pilot specimen to assist in determining the final amount of water required.

4.2. Weigh out enough material to fabricate a compacted sample 101.6 mm (4 in.) in diameter by 63.5 mm (2.5 in.) high. Compacted specimens having heights from 58.4 to 68.6 mm (2.3 to 2.7 in.) are acceptable. Compact the soil into the mold by means of the kneading compactor as follows: Place the mold in the mold holder that has a rubber disk, 100 mm ($31^{5}/_{16}$ in.) in diameter and 3 mm ($^{1}/_{8}$ in.) thick cemented to the plate. Adjust the mold for approximately 3-mm ($^{1}/_{8}$-in.) clearance between the lower edge of the mold and base of the mold holder by placing a shim under the edge of the mold or by tightening the set screw (if available) on the mold holder. With the compactor foot pressure set at 1724 ± 172 kPa (250 ± 25 psi), feed 76.2 mm (3 in.) of the soil in the trough into the mold. Feed the balance of the soil into the mold in 20 equal increments with one application of the ram after each increment. Allow 10 additional tamps to level the soil, then place a rubber disk on top of the specimen, loosen the set screw (if available), and remove the shim from under the mold. Apply 100 additional tamps with a foot pressure of 2413 kPa (350 psi). Stop compacting the soil at any time before 100 tamps if water appears around the bottom of the mold.

Note 1—Use lower compaction pressures when necessary to limit penetration of the ram into the soil to not greater than 6.35 mm ($^{1}/_{4}$ in.).

4.3. Remove the mold containing the compacted specimen from the compactor. Level the surface by hand tamping with the tamping rod. Place a phosphor-bronze disk on the tamped surface of the soil and place a filter paper on top of the bronze disk. Invert the mold and place it on the exudation-indicator device so the filter paper is on the bottom. Using the compression testing machine, apply a uniformly increasing pressure to the soil at the rate of 8896 N/minute (2000 lbf/minute). Water should be exuded from the soil at 2068 kPa (300 psi) as evidence that enough moisture is present to produce saturation. Stop the loading and record the exudation pressure when either five of the six outer lights on the exudation pressure device are lighted or three outer lights are lighted and free water is visible around the bottom of the mold. Do not exceed a loading of 5516 kPa (800 psi).

4.4. Mold at least two more specimens with different amounts of moisture so that a range of exudation pressures from 689 to 5516 kPa (100 to 800 psi) (Note 2) is obtained that brackets the 2068 kPa (300 psi) value. For some high volume-change soils, additional specimens having exudation pressures lower than 689 kPa (100 psi) may be necessary to obtain expansion pressures that are low enough to provide a suitable range of data for a complete expansion pressure analysis of the soil.

Note 2—Occasionally, material from very plastic, clay-test specimens will extrude from under the mold and around the follower ram during the loading operation. If this occurs when the 5516-kPa (800-psi) point is reached and fewer than five lights are lighted, or, for the alternate method, $^5/_6$ of the circumference of the filter paper is wet, the soil should be reported as less than five R-value. Coarse granular materials and clean sands may require the use of paper baskets to permit testing.

5. CALIBRATION OF EXPANSION-PRESSURE APPARATUS

5.1. Calibrate the spring steel bar of the expansion-pressure device (Figure 7) by applying upward measured loads at the center of the bar and measuring the respective deflections of the bar with the deflection gauge.

5.2. The spring steel bar is considered in calibration when the deflections are within the following tolerances:

Applied Load, N (lbf)	Dial Reading	
	(mm)	(in.)
36 (8)	0.053 ± 0.005	(0.0021 ± 0.0002)
71 (16)	0.107 ± 0.005	(0.0042 ± 0.0002)
107 (24)	0.160 ± 0.005	(0.0063 ± 0.0002)
142 (32)	0.213 ± 0.005	(0.0084 ± 0.0002)

5.3. If the deflection gauge does not check the above readings, loosen the top frame bar and adjust the position of the shims, between the frame and the spring steel bar, until the required readings are obtained.

Note 3—Some models of the expansion-pressure apparatus have set screw adjustments in lieu of shims.

6. EXPANSION-PRESSURE TESTING

6.1. Allow the test specimen to rebound in a covered mold for at least 30 minutes after determination of the exudation pressure and the compacted specimen height to the nearest 2.5 mm (0.1 in.).

6.2. Place the deflection gauge in position on the expansion-pressure device with the single-bearing end of the gauge base resting on the adjustment ring.

6.3. Using an Allen wrench, raise or lower the adjustment plug until the deflection gauge is on 0.025 mm (1.0010 in.). The deflection gauge will read 0.229 mm (0.0090 in.).

6.4. Place the perforated disk with stem firmly on the face of the compacted specimen in the mold and place the mold in the expansion-pressure device after placing creped surface filter paper on the turntable.

6.5. Seat the perforated disk firmly on the specimen with pressure applied by the fingers. Raise the turntable on the expansion device until the deflection gauge reads zero. If the device was properly adjusted, according to Section 6.3, this will apply the preset surcharge deflection of 0.025 mm (0.0010 in.).

6.6. Put approximately 200 mL of water into the mold and allow pressure from expansion of the specimen to develop for 16 to 24 hours.

Note 4—Do not leave a test specimen unconfined by the expansion-pressure device while there is free water on top of the specimen in the mold.

6.7. Read the deflection of the calibrated spring steel bar to 0.002 mm (0.0001 in.). When the deflection is greater than 0.254 mm (0.0100 in.), the expansion-pressure device should be recalibrated before using again.

6.8. Determine the expansion pressure, P, as follows:

$$P = kd \tag{1}$$

where:

k = spring constant of steel bar calculated from calibration of the expansion-pressure apparatus and expressed in kPa/0.025 mm (psi/0.0010 in.), and,

d = deflection shown by deflection gauge, mm (in.).

7. ADJUSTMENT OF STABILOMETER

7.1. Adjust the bronze nut on the stabilometer stage base so that the top of the stage is 89 mm ($3^1/_2$ in.) below the bottom of the upper tapered ring of the stabilometer. Perform all tests at this setting.

7.2. Adjust the amount of air in the stabilometer cell so that 2 ± 0.05 turns of the pump handle increase the liquid pressure from 34.4 to 689 kPa (5 to 100 psi) with the standard metal specimen in the stabilometer chamber.

8. RESISTANCE-VALUE TESTING OF SPECIMENS

8.1. After testing for expansion pressure, pour water off the top of the specimen (Note 5) and place the mold with the specimen on top of the stabilometer. Place the follower on top of the specimen and force the specimen from the mold into the stabilometer. Lower the testing machine head until it just engages the follower.

Note 5—If all the water has drained through the specimen, add water to the top and allow to stand for 15 minutes. Pour off any excess water and continue to test.

8.2. Apply a horizontal pressure of 34.5 kPa (5 psi) to the specimen by means of the displacement pump, then apply a vertical load using a uniform rate of movement of 1.3 mm/minute (0.05 in./minute).

8.3. Record the horizontal pressure when the vertical load is 8896 N (2000 lbf) and stop loading. Reduce the vertical load to 4448 N (1000 lbf). With the displacement pump, adjust the horizontal pressure to 34.5 kPa (5 psi).

Note 6—This will result in a further reduction in the applied load and should be ignored.

8.4. Turn the stabilometer pump handle at approximately two turns per second and measure the number of turns of the pump handle (using the turns-displacement dial indicator on the stabilometer) to raise the horizontal pressure from 34.5 to 689 kPa (5 to 100 psi). This is the turns displacement, *D*, of the specimen.

8.5. Determine the resistance, *R*, as follows:

$$R = 100 - \left[\frac{100}{\frac{2.5}{D}\left(\frac{1100}{P_h} - 1\right) + 1} \right] \quad \text{for SI units} \qquad (2)$$

$$R = 100 - \left[\frac{100}{\frac{2.5}{D}\left(\frac{160}{P_h} - 1\right) + 1} \right] \quad \text{for U.S. Customary units} \qquad (3)$$

where:

P_h = horizontal pressure, kPa (psi), and

D = turns displacement reading.

8.6. This is the R-value for specimens with compacted heights from 62 to 65 mm (2.45 to 2.55 in.). If the height of the specimen is between 58 and 62 mm or 65 and 68 mm (2.3 and 2.45 in. or 2.55 and 2.7 in., respectively) use the chart (Figure 10) for correcting R-values to a specimen height of 63 mm (2.5 in.).

Note 7—If the R-value is desired at a specific exudation pressure, for example, 2068 kPa (300 psi), within the range of pressures measured in tests of three specimens, it is convenient to construct a graph of R-value versus exudation pressure and interpolate.

Chart for correcting "R" values to
specimen height of 63 mm

Height correction should be
made using the chart below.

Note: No correction for specimen
heights between 62 and 65 mm.
Interpret R-value corrections
for other heights.

Example: Overall height of 67 mm
R-value (uncorrected) = 50
R-value (corrected) = 54

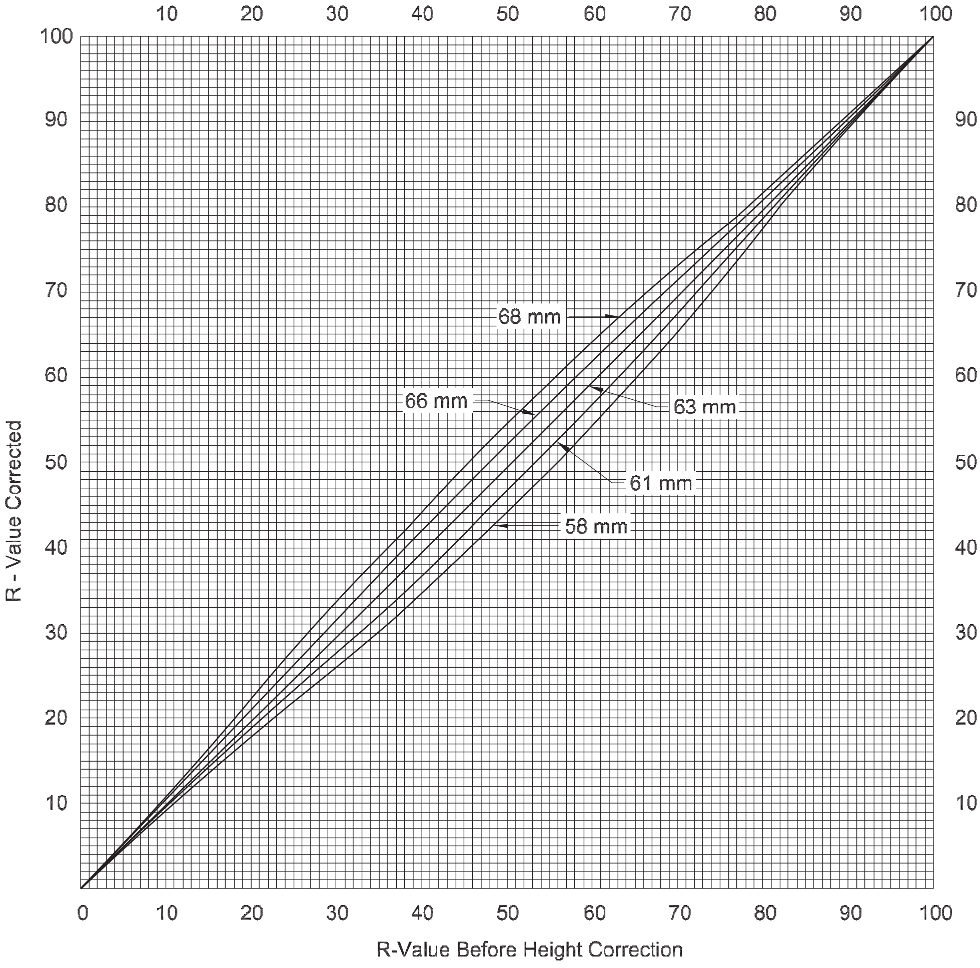


Figure 10—Height-Correction Chart

APPENDIX

(Nonmandatory Information)

X1. RESISTANCE R-VALUE SAMPLE DATA SHEET

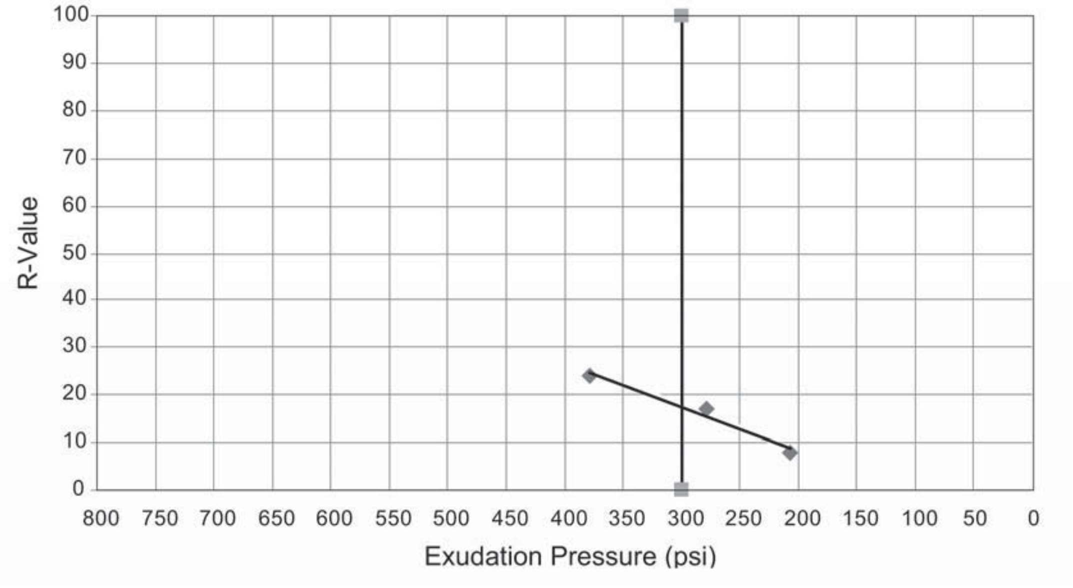
Project Number:
Location:

Report Date:
Lab #:
Sampled by:
Date Sampled:
Color and Type of Material:
Sample Location:

SOILS/AGGREGATES

Resistance R-Value and Expansion Pressure of Compacted Soils (AASHTO T 190)

Specimen ID:	A	B	C
Moisture (%):	16.7	14.6	13.8
Compactor Pressure (psi):	50	100	150
Specimen Height (in.):	2.5	2.65	2.49
Dry Density (pcf):	113.3	117.6	115.2
Horizontal Pressure @ 1000 lb (psi):	57	51	40
Horizontal Pressure @ 2000 lb (psi):	144	128	115
Displacement:	3.42	3.57	3.02
Expansion Pressure (psi)	–0.003	0.066	0.018
Exudation Pressure (psi)	207	278	378
R-Value	8	17	24



R-Value at 300 psi: 17

Standard Method of Test for

Density of Soil In-Place by the Sand-Cone Method

AASHTO Designation: T 191-02 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density of Soil In-Place by the Sand-Cone Method

AASHTO Designation: T 191-02 (2006)

1. SCOPE

1.1. This method is intended for determining the in-place density of soils. The apparatus described herein is restricted to tests in soils containing particles not larger than 50 mm (2 in.) in diameter.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value shall be rounded off to "the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with the rounding-off method of ASTM E 29.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

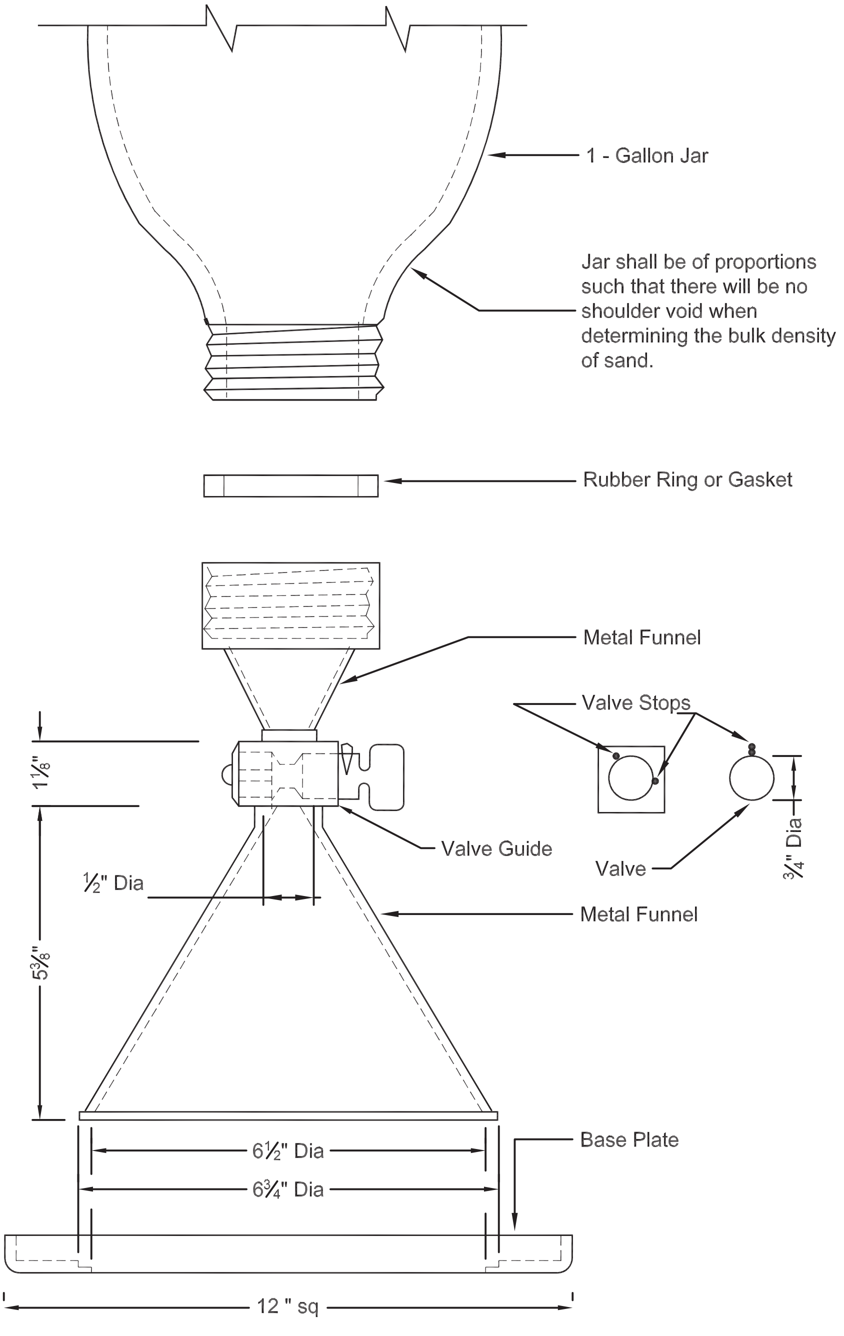
- M 231, Weighing Devices Used in the Testing of Materials
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 217, Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- D 4959, Standard Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating
- D 4643, Standard Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *Density Apparatus with Base Plate*—The density apparatus shall consist of a 4 L (1 gal) jar and a detachable appliance consisting of a cylindrical valve with an orifice 12.7 mm ($^1/_2$ in.) in diameter and having a small funnel continuing to a standard G mason jar top on one end and a large funnel on the other end. The valve shall have stops to prevent rotating the valve past the completely open or completely closed positions. The apparatus shall conform to the requirements shown in Figure 1. The apparatus described here represents a design that has proven satisfactory. Other apparatus of similar proportions will perform equally well so long as the basic principles of the sand-volume determination are observed. The base plate is required for calibrations and testing.



Metric Equivalents

in.	mm	in.	mm
$^{1}/_{2}$	12.7	$6^{1}/_{2}$	165.1
$^{3}/_{4}$	19.1	$6^{3}/_{4}$	171.5
$1^{1}/_{8}$	28.6	12	304.8
$5^{3}/_{8}$	136.5		

Figure 1—Density Apparatus

3.2. *Calibration Container*—A sturdy cylindrical container of known volume (V_c). The container shall be dimensionally approximate to the largest test hole that will be dug. The container shall be calibrated according to T 19M/T 19.

Note 1—The internal diameter of the container shall be equal to or slightly less than the diameter of the opening of the base plate used with the sand-cone.

3.3. *Sand*—Any clean, dry, free-flowing, uncemented sand having few, if any, particles passing the 0.075-mm or retained on the 2.00-mm sieves. In selecting a sand for use, several bulk density determinations should be made using the same representative sample for each determination. To be acceptable the sand shall not have a variation in bulk density greater than 1 percent.

3.4. *Balances*—A balance conforming to the requirements of M 231, Class G 20. Also, a balance conforming to the requirements of M 231, Class G 2.

3.5. *Drying Equipment*—Stove or oven or other suitable equipment for drying moisture content samples.

3.6. *Miscellaneous Equipment*—Small pick, chisels, or spoons for digging test hole; 254 mm (10 in.) frying pan or any suitable container for drying moisture samples; buckets with lids, canvas sacks, or other suitable containers for retaining the density sample, moisture sample, or density sand, respectively; small paintbrush, slide rule, and notebook.

4. CONE CORRECTION AND BULK DENSITY FACTORS

4.1. *Filling the apparatus*:

4.1.1. Place the empty apparatus upright on a firm, level surface, close the valve, and fill the funnel with sand.

4.1.2. Open the valve and keep the funnel at least half full with sand during filling. When the sand stops flowing into the apparatus, close the valve sharply and empty the excess sand (Note 2).

Note 2—Vibration of the sand during any mass-volume determination may increase the bulk density of the sand and decrease the accuracy of the determination. Appreciable time intervals between the bulk density determination of the sand and its use in the field may result in change in the bulk density caused by a change in the moisture content or effective gradation.

4.1.3. Determine and record the mass of the apparatus filled with sand (m_1).

4.2. Determine the mass of sand required to fill the funnel and base plate (cone correction).

4.2.1. Place the base plate on a clean, level, plane surface. Invert the sand-cone filled with sand and seat the funnel in the recess of the base plate.

4.2.2. Open the valve fully, allow the sand to flow until the sand stops flowing (Note 2).

4.2.3. Close the valve sharply, remove the apparatus, and determine the mass of the apparatus and the remaining sand (m_2).

4.2.4. The mass of sand required to fill the cone and base plate is calculated by the difference between the initial mass (Step 4.1.3) and final mass (Step 4.2.3). Record this mass as the cone correction ($C_c = m_1 - m_2$) (Note 3).

Note 3—For each container/bag of sand there will be a unique cone correction and sand calibration factor. Each sand-cone and matched base plate will also have a set of unique cone corrections and bulk sand densities. If more than one sand-cone apparatus is available, the sand-cone and base plate should be marked and the associated correction/density factors recorded.

4.3. Determine the bulk density of sand (D_B) to be used in the field test.

4.3.1. Replace the sand removed in the funnel determination according to Section 4.1, close the valve, and determine the mass of the apparatus and sand (m_3).

4.3.2. Position the calibration container on a clean, level, plane surface. Place the base plate on the calibration container (Note 1). Invert the apparatus and seat the funnel in the recess of the base plate.

4.3.3. Open the valve fully and keep open until the sand stops flowing (Note 2).

4.3.4. Close the valve sharply, remove the apparatus, and determine the remaining mass of the apparatus and sand (m_4).

4.3.5. Calculate the mass of the sand needed to fill the container, funnel, and base plate. Subtract the final mass (Step 4.3.4) from the initial mass (Step 4.3.1).

4.3.6. The mass of the sand needed to fill the container only is determined by subtracting the mass of the cone correction (Step 4.2.4) from the total mass required to fill the container with the funnel and base plate (Step 4.3.5).

4.3.7. Determine the bulk density of the calibration sand (sand calibration factor). Divide the mass of the sand needed to fill the container (Step 4.3.6) by the volume of the calibration container as determined according to T 19M/T 19.

$$D_B = (m_3 - m_4 - C_c)/V_c$$

4.3.8. Record this factor for future reference (Note 3).

5. PROCEDURE

5.1. Determine the density of the soil in place as follows:

5.1.1. Fill the apparatus with sand according to Section 4.1. Record the total mass (m_5).

5.1.2. Prepare the surface of the location to be tested so that it is a level plane.

5.1.3. Seat the base plate on the prepared surface. Dig the test hole inside the opening of the base plate, being very careful to avoid disturbing the soil that will bound the hole. Soils that are essentially granular require extreme care. Place all loosened soil in a container, being careful to avoid losing any material. Care must be taken to avoid moisture loss during excavation.

5.1.4. Place the apparatus on the base plate, open the valve. After the sand has stopped flowing, close the valve (Note 2).

5.1.5. Weigh the apparatus with the remaining sand (m_6) and record.

5.1.6. Weigh the moist material that was removed from the test hole.

5.1.7. Mix the material thoroughly and secure and weigh a representative sample for moisture determination.

5.1.8. Dry and weigh the soil sample for moisture content determination in accordance with T 265 or in accordance with rapid methods such as T 217, ASTM D 4959, or ASTM D 4643. The results obtained using these or other rapid test methods must be corrected to the values obtained in accordance with T 265. Calculate the moisture content to the nearest 0.1 percent.

5.1.9. The minimum test hole volumes suggested in determining the in-place density of soil mixtures are given in Table 1. This table shows the suggested minimum mass of the moisture content sample in relation to the maximum particle size in soil mixtures.

Table 1—Minimum Test Hole Volumes and Minimum Moisture Content Samples Based on Maximum Size of Particle

Maximum Particle Size		Minimum Test Hole, Volume		Minimum Moisture Content Sample, g
mm	Alternate	cm^3	ft^3	
4.75	No. 4 Sieve	710	0.025	100
12.5	$^1/_2$ in.	1415	0.050	250
25.0	1 in.	2125	0.075	500
50.0	2 in.	2830	0.100	1000

6. CALCULATIONS

6.1. Calculate the volume of the test hole (V_H):

$$V_H = (m_5 - m_6 - C_c)/D_B \qquad (1)$$

where:

V_H = volume of the test hole,
m_5 = initial mass of the apparatus and sand,
m_6 = final mass of the apparatus and sand,
C_c = cone correction, and
D_B = bulk density of the sand.

6.1.1. Calculate the volume of the test hole to the nearest 1 cm^3 (0.0001 ft^3).

6.2. Calculate the dry mass of the material removed from the test hole as follows:

$$M_{DS} = (M_{WS} / (1 + (w/100)) \qquad (2)$$

where:

M_{DS} = dry mass of the material removed from the test hole,

M_{WS} = moist mass of the material removed from the test hole, and

w = percentage of moisture, in material removed from the test hole.

6.2.1. Calculate the dry mass of the material to the nearest 1 g (0.01 lb).

6.3. Calculate the dry in-place dry density of the material removed from the test hole as follows:

$$D_D = M_{DS}/V_H \tag{3}$$

where:

D_D = in-place dry density of the material removed from the test hole,

M_{DS} = dry mass of the material removed from the test hole (Section 5.2), and

V_H = volume of the test hole (Section 5.1).

6.3.1. Calculate the in-place dry density to the nearest 1 kg/m^3 (0.1 lb/ft^3).

Note 4—0.001 g/cm^3 = 1 kg/m^3

Note 5—It may be desired to express the in-place density as a percentage of some other density, for example, the laboratory maximum density determined in accordance with T 99. This relationship can be determined by dividing the in-place density by the maximum density and multiplying by 100.

Standard Method of Test for

The California Bearing Ratio

AASHTO Designation: T 193-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

The California Bearing Ratio

AASHTO Designation: T 193-10

1. SCOPE

1.1 This test method covers the determination of the California Bearing Ratio (CBR) of pavement subgrade, subbase, and base/course materials from laboratory compacted specimens. The test method is primarily intended for, but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than 19 mm ($^3/_4$ in.).

1.2 When materials having maximum particle sizes greater than 19 mm ($^3/_4$ in.) are to be tested, this test method provides for modifying the gradation of the material so that the material used for tests all passes the 19.0-mm ($^3/_4$-in.) sieve while the total gravel 4.75-mm (No. 4) to 75-mm (3-in.) fraction remains the same. While traditionally this method of specimen preparation has been used to avoid the error inherent in testing materials containing large particles in the CBR test apparatus, the modified material may have significantly different strength properties than the original material. However, a large experience base has developed using this test method for materials for which the gradation has been modified and satisfactory design methods are in use based on the results of tests using this procedure.

1.3 Past practice has shown that CBR results for those materials having substantial percentages of particles retained on the 4.75-mm (No. 4) sieve are more variable than for finer materials. Consequently, more trials may be required for these materials to establish a reliable CBR.

1.4 This test method provides for the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit mass. The dry unit mass is usually given as a percentage of maximum dry unit mass from the compaction tests of T 99 or T 180.

1.5 The agency requesting the test shall specify the water content or range of water content and the dry unit mass for which the CBR is desired.

1.6 Unless specified otherwise by the requesting agency, or unless it has been shown to have no effect on test results for the material being tested, all specimens shall be soaked prior to penetration.

1.7 The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- T 2, Sampling of Aggregates
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test

- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 265, Laboratory Determination of Moisture Content of Soils

3. SIGNIFICANCE AND USE

3.1 This test method is used to evaluate the potential strength of subgrade, subbase, and base course material, including recycled materials, for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

3.2 For applications where the effect of compaction water content on CBR is small, such as cohesionless, coarse-grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort. The dry unit mass specified is normally the minimum percent compaction allowed by using the agency's field compaction specification.

3.3 For applications where the effect of compaction water content on CBR is unknown or where it is desired to account for its effect, the CBR is determined for a range of water content, usually the range of water content permitted for field compaction by using the agency's field compaction specification.

3.4 The criteria for test specimen preparation of self-cementing (and other) materials that gain strength with time must be based on a geotechnical engineering evaluation. As directed by the engineer, self-cementing materials shall be properly cured until bearing ratios representing long-term service conditions can be measured.

4. APPARATUS

4.1 *Molds*—The molds shall be cylindrical in shape, made of metal, with an internal diameter of 152.40 ± 0.66 mm (6.0 ± 0.026 in.) and a height of 177.80 ± 0.46 mm (7.0 ± 0.018 in.), and provided with an extension collar approximately 50 mm (2.0 in.) in height and a perforated base plate that can be fitted to either end of the mold. (See Figure 1.) It is desirable to have at least three molds for each soil to be tested.

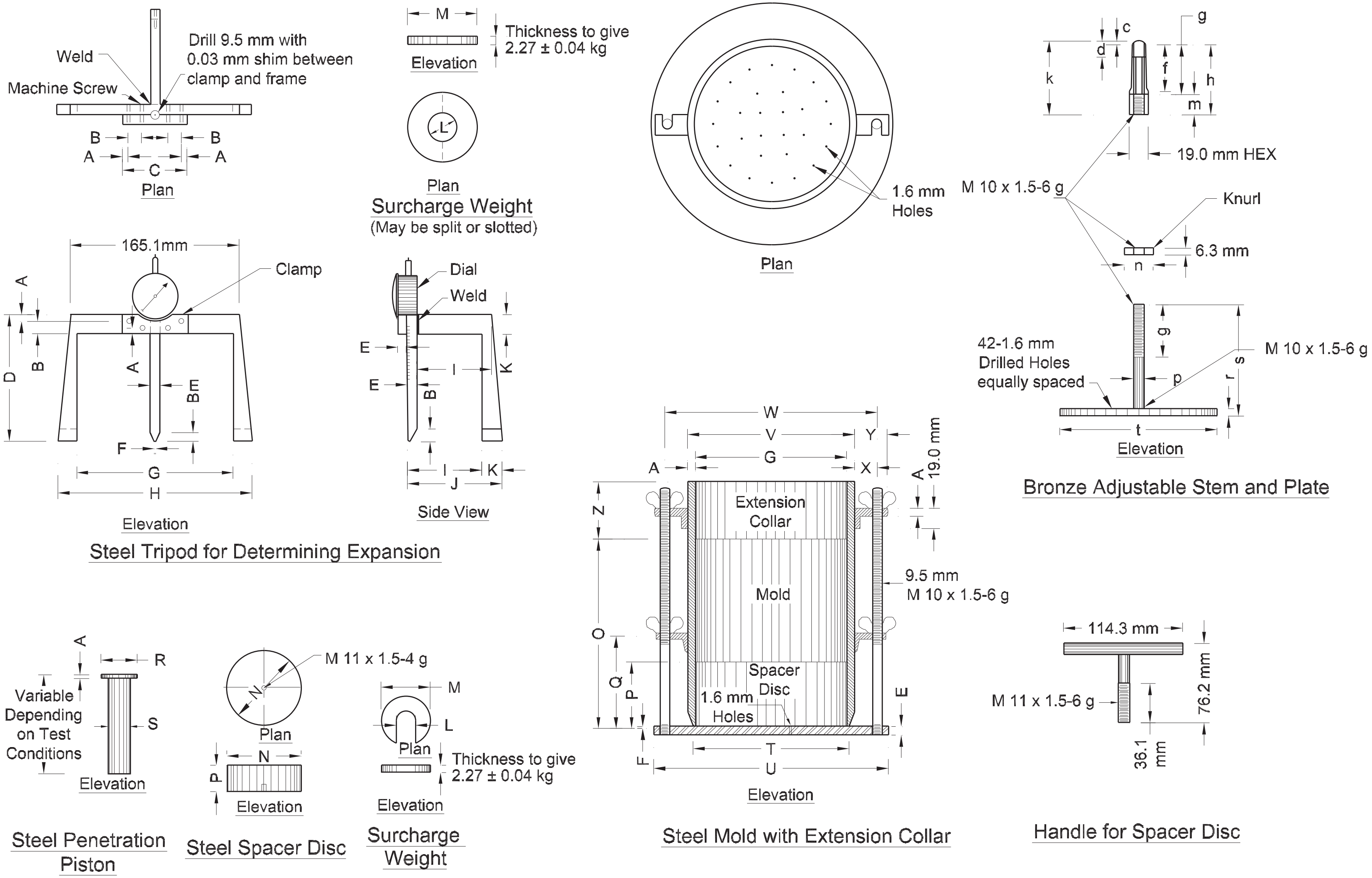


Figure 1—California Bearing Ratio Apparatus

Table of Measurements

	TRIPOD FOR DETERMINING EXPANSION											SURCHARGE		SPACER DISC	
MATERIAL	STEEL **													STEEL **	
DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L*	M*	N*	P
METRIC, mm	6.3	12.7	63.5	120.6	9.5	1.6	152.4	190.5	76.2	95.2	19.0	54.0	149.2	150.8	61.37
TOLERANCE, mm													1.6	0.8	0.25
ENGLISH, in.	1/4	1/2	2 1/2	4 3/4	3/8	1/16	6	7 1/2	3	3 3/4	3/4	2 1/8	5 7/8	5 15/16	2.416
TOLERANCE, in.													1/16	1/32	0.01

	MOLD WITH EXTENSION COLLAR														PISTON		
MATERIAL	STEEL**														STEEL**		
DIMENSION	A	E	F	G*	O	P	Q	T*	U***	V*	W	X	Y	Z	A	R	S*
METRIC, mm	6.3	9.5	1.6	152.40	177.80	61.37	88.9	158.0	238.1	165.1	212.7	23.8	33.3	50.8	6.3	69.8	49.63
TOLERANCE, mm				0.66	0.46	0.25											0.13
ENGLISH, in.	1/4	3/8	1/16	6	7	2.416	3 1/2	6 7/32	9 3/8	6 1/2	8 3/8	15/16	1 5/16	2	1/4	2 3/4	1.954
TOLERANCE, in.				0.026	0.018	0.01											0.005

	ADJUSTABLE STEM AND PLATE													
MATERIAL	BRONZE													
DIMENSION			c	d	e*	f	g	h	k	m	n*	p*	r	s	t
METRIC, mm			5.6	11.9	3.2	46.04	50.8	69.8	75.4	19.0	28.6	9.5	6.3	107.9	149.2
TOLERANCE, mm															1.6
ENGLISH, in.			7/32	15/32	1/8	1 13/16	2	2 3/4	2 31/32	3/4	1 1/8	3/8	1/4	4 1/4	5 7/8
TOLERANCE, in.															1/16

Figure 1—*Continued*

4.2 *Spacer Disk*—A circular spacer disk made of metal 150.8 ± 0.8 mm ($5^{15}/_{16} \pm {}^{1}/_{32}$ in.) in diameter and 61.37 ± 0.25 mm (2.416 ± 0.01 in.) in height. (See Figure 1.)

Note 1—When using molds having a height of 177.80 mm (7.0 in.) (Figure 1), a spacer disk height of 61.37 mm (2.416 in.) is needed to obtain a thickness of compacted specimen that conforms to the thickness: 116.43 mm (4.584 in.) of specimens in T 99 and T 180.

4.3 *Rammer*—A rammer as specified in either T 99 or T 180.

4.4 *Apparatus for Measuring Expansion*—This consists of a swell plate with adjustable stem (Figure 1) and a tripod support for a dial indicator (Figure 1). The swell plate is made of metal, 149.2 ± 1.6 mm ($5^{7}/_{8} \pm {}^{1}/_{16}$ in.) in diameter and is perforated with 1.6-mm (${}^{1}/_{16}$-in.) diameter holes. The tripod used to support the dial indicator is arranged to fit the mold extension collar.

4.5 *Indicators*—Two dial indicators: each indicator shall have a 25-mm (1-in.) throw and read to 0.02 mm (0.001 in.).

4.6 *Surcharge Weights*—One annular metal weight with a center hole approximately 54.0 mm ($2^{1}/_{8}$ in.) in diameter and several slotted or split metal weights, all 149.2 ± 1.6 mm ($5^{7}/_{8} \pm {}^{1}/_{16}$ in.) in diameter and each having a mass of 2.27 ± 0.04 kg (5 ± 0.10 lb) (Figure 1) (Note 2).

Note 2—When using split weights, the mass of the pair shall be 2.27 ± 0.04 kg (5 ± 0.10 lb).

4.7 *Penetration Piston*—A metal piston of circular cross-section having a diameter of 49.63 ± 0.13 mm (1.954 ± 0.005 in.) area = 1935 mm^2 (3 in.^2) and not less than 102 mm (4 in.) long. (See Figure 1.)

4.8 *Loading Device*—A compression-type apparatus capable of applying a uniformly increasing load up to a capacity sufficient for the material being tested at a rate of 1.3 mm/min. (0.05 in./min.), used to force the penetration piston into the specimen.

4.9 *Soaking Tank*—A soaking tank suitable for maintaining the water level 25 mm (1 in.) above the top of the specimens.

4.10 *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5ºC (230 ± 9ºF) for drying moisture samples.

4.11 *Moisture Content Containers*—As specified in T 265.

4.12 *Miscellaneous*—Miscellaneous tools such as mixing pans, spoons, straightedge, filter paper, balances, etc.

5. SAMPLE

5.1 The sample shall be handled and specimen(s) for compaction shall be prepared in accordance with the procedures given in T 99 or T 180 for compaction in a 152.4-mm (6-in.) mold except as follows:

5.1.1 If all material passes a 19.0-mm (${}^{3}/_{4}$-in.) sieve, the entire gradation shall be used for preparing specimens for compaction without modification. If there is material retained on the 19.0-mm sieve, the material retained on the 19.0-mm sieve shall be removed and replaced by an equal amount of material passing the 19.0-mm sieve and retained on the 4.75-mm (No. 4) sieve obtained by separation from portions of the sample not otherwise used for testing.

5.1.2 *Bearing Ratio at Optimum Water Content*—From a sample having a mass of 35 kg (75 lb) or more, select a representative portion having a mass of approximately 11 kg (25 lb) for a moisture-density test and divide the remainder of the sample to obtain three representative portions having a mass of approximately 6.8 kg (15 lb) each.

5.1.3 *Bearing Ratio for a Range of Water Content*—From a sample having a mass of 113 kg (250 lb) or more, select at least five representative portions having a mass of approximately 6.8 kg (15 lb) each for use in developing each compaction curve.

6. MOISTURE-DENSITY RELATION

6.1 *Bearing Ratio at Optimum Water Content*—Using the 11-kg (25-lb) portion prepared as described in Section 5.1, determine the optimum moisture content and maximum dry density in accordance with the compaction method specified, either T 99 or T 180. A previously performed compaction test on the same material may be substituted for the compaction test just described, provided that if the sample contains material retained on the 19.0-mm ($^3/_4$-in.) sieve, soil prepared as described in Section 5.1 is used (Note 3).

Note 3—Maximum dry unit mass obtained from a compaction test performed in a 101.6-mm (4-in.) diameter mold may be slightly greater than the maximum dry unit weight obtained from compaction in the 152.4-mm (6-in.) compaction mold or CBR mold.

6.2 *Bearing Ratio for a Range of Water Content*—Using the 6.8-kg (15-lb) specimens prepared as described in Section 5.1, determine the optimum moisture content and maximum dry density in accordance with the compaction method specified, either T 99 (Method D) or T 180 (Method D), except that the CBR molds shall be used and each specimen shall be penetrated for CBR determination. In addition, the complete moisture-density relationship for 25-blow and 10-blow per layer compactions shall be developed and each test specimen compacted shall be penetrated. Perform all compaction in CBR molds. In cases where the specified unit mass is at or near 100-percent maximum dry unit mass, it will be necessary to include a compactive effort greater than 56 blows per layer (Note 4).

Note 4—A semilog plot of dry unit mass versus compactive effort usually gives a straight-line relation when compactive effort in J/m^3 (ft-lb/ft^3) is plotted on the log scale. This type of plot is useful in establishing the compactive effort and number of blows per layer needed to bracket the specified dry unit mass and water content range.

6.2.1 If the soaked CBR is to be determined, take a representative sample of the material, for the determination of moisture, at the beginning of compaction of each specimen and another sample of the remaining material after compaction of each specimen. Use T 265 to determine the moisture content. If the unsoaked CBR is to be determined, take a moisture content sample in accordance with T 99 or T 180 if the average moisture content is desired.

7. PROCEDURE

7.1 *Bearing Ratio at Optimum Water Content*:

7.1.1 Normally, three specimens must be compacted so that their compacted densities range from 95 percent (or lower) to 100 percent (or higher) of the maximum dry density determined in Section 6.1

Note 5—Generally about 10, 30, and 65 blows per layer are suitable for compacting specimens 1, 2, and 3, respectively. More than 56 blows per layer are generally required to mold a CBR specimen to 100 percent of the maximum dry density determined by T 99 (Method D); this is due to the sample for the moisture-density test being reused, while the sample for the CBR specimen is mixed and compacted only once.

Note 6—Some laboratories may prefer to test only one specimen that would be compacted to maximum dry density at optimum moisture content as determined by either T 99 or T 180.

7.1.2 Clamp the mold to the base plate, attach the extension collar and weigh to the nearest 5 g (0.01 lb). Insert the spacer disk into the mold and place a coarse filter paper on top of the disk.

7.1.3 Mix each of the three 6.8-kg (15-lb) portions prepared in Section 5.1.2 with sufficient water to obtain the optimum moisture content determined in Section 6.1.

7.1.4 Compact the first of the three portions of soil-water mixture into the mold, using three equal layers and appropriate rammer, if maximum density was determined by T 99, or five equal layers if maximum density was determined by T 180, to give a total compacted depth of about 125 mm, compacting each layer with the lowest selected number of blows in order to give a compacted density of 95 percent or less of the maximum density.

7.1.5 Determine the moisture content of the material being compacted at the beginning and end of the compaction procedure (two samples). Each moisture sample shall have a mass of at least 100 g for fine-grained soils and 500 g for coarse-grained soils. Determination of moisture content shall be done in accordance with T 265, Laboratory Determination of Moisture Content of Soils.

7.1.6 Remove the extension collar, and using a straightedge, trim the compacted soil even with the top of the mold. Surface irregularities should be patched with small-sized material. Remove the spacer disk, place a coarse filter paper on the perforated base plate, invert the mold and compacted soil, and place on the filter paper so the compacted soil is in contact with the filter paper. Clamp the perforated base plate to the mold and attach the collar. Determine the mass of the mold and specimen to the nearest 5 g (0.01 lb).

7.1.7 Compact the other two 6.8-kg (15-lb) portions in accordance with the procedure in Sections 7.1.4 through 7.1.6, except that an intermediate number of blows per layer should be used to compact the second specimen and the highest number of blows per layer shall be used to compact the third specimen.

7.2 *Bearing Ratio for a Range of Water Content*:

7.2.1 Prepare specimens in accordance with Section 6.2. Perform all compaction in the CBR molds. Each specimen used to develop the compaction curves for the 10-blow, 25-blow, and 56-blow per layer compactive efforts shall be penetrated. In cases where the specified unit mass is at or near 100 percent maximum dry unit mass, it will be necessary to include a compactive effort greater than 56 blows per layer.

8. SOAKING

8.1 Place the swell plate with adjustable stem on the soil sample in the mold and apply sufficient annular weights to produce an intensity of loading equal to the mass of the subbase and base courses and surfacing above the tested material. The total mass shall be a minimum of 4.54 kg. Additional mass shall be added in increments of 2.26 kg.

8.2 Place the tripod with dial indicator on top of the mold and make an initial dial reading.

8.3 Immerse the mold in water to allow free access of water to top and bottom of the specimen. During soaking, maintain the water level in the mold and the soaking tank approximately 25 mm (1 in.) above the top of the specimen. Soak the specimen 96 hours (4 days).

Note 7—A shorter immersion period (not less than 24 hours) may be used for soil-aggregate materials that drain readily if tests show that the shorter period does not affect the test results. For some clay soils, a soaking period greater than 4 days may be required.

8.4 At the end of 96 hours, make a final dial reading on the soaked specimens and calculate the swell as a percentage of the initial sample length:

$$\text{Percent swell} = \frac{\text{Change in length in mm during soaking}}{116.43 \text{ mm}} \times 100 \qquad (1)$$

8.5 Remove the specimens from the soaking tank, pour the water off the top and allow to drain downward for 15 minutes. Care shall be taken not to disturb the surface of the specimens during removal of the water. After draining, remove the surcharge weights, perforated plates, and top filter paper.

Note 8—The mass of the specimens may be determined after draining when it is desired to determine the average wet density of the soaked and drained material.

9. PENETRATION TEST

9.1 *Application of Surcharge*—Place a surcharge of annular and slotted weights on the specimens equal to that used during soaking. To prevent displacement of soft materials into the hole of the surcharge weights, seat the penetration piston with a 44 N (10-lb) load after one surcharge weight has been placed on the specimen. After seating the penetration piston the remainder of the surcharge weights shall then be placed around the piston.

9.2 *Seating Piston*—Seat the penetration piston with a 44 N (10-lb) load, then set both the penetration dial indicator and the load indicator to zero.

9.3 *Application of Load*—Apply the loads to the penetration piston so the rate of penetration is uniform at 1.3 mm (0.05 in.)/min. Record the load when the penetration is 0.64, 1.27, 1.91, 2.54, 3.81, 5.08, and 7.62 mm (0.025, 0.050, 0.075, 0.100, 0.150, 0.200, and 0.300 in.). Load readings at penetrations of 10.16 and 12.70 mm (0.400 and 0.500 in.) may be obtained if desired.

Note 9—The moisture content of the upper 25 mm (1 in.) may be determined after testing if desired. Moisture samples shall weigh at least 100 g for fine-grained soils and 500 g for granular soils.

10. CALCULATIONS

10.1 *Stress-Strain Curve*—Plot the stress-strain (resistance to penetration-depth of penetration) curve for each specimen as shown in Figure 2. In some instances, the initial penetration takes place without a proportional increase in the resistance to penetration and the curve may be concave upward. To obtain the true stress-strain relationships, correct the curve having concave upward shape near the origin by adjusting the location of the origin by extending the straight line portion of the stress-strain curve downward until it intersects the abscissa. (See dashed lines.)

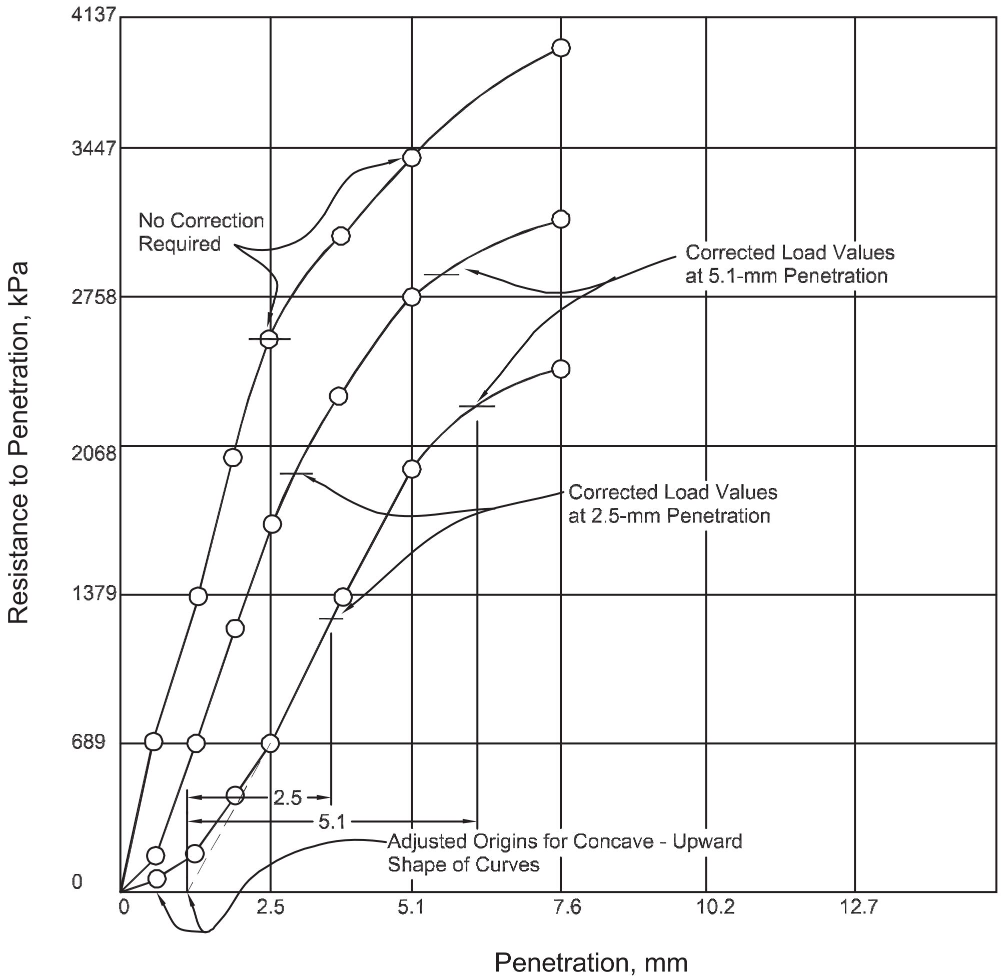


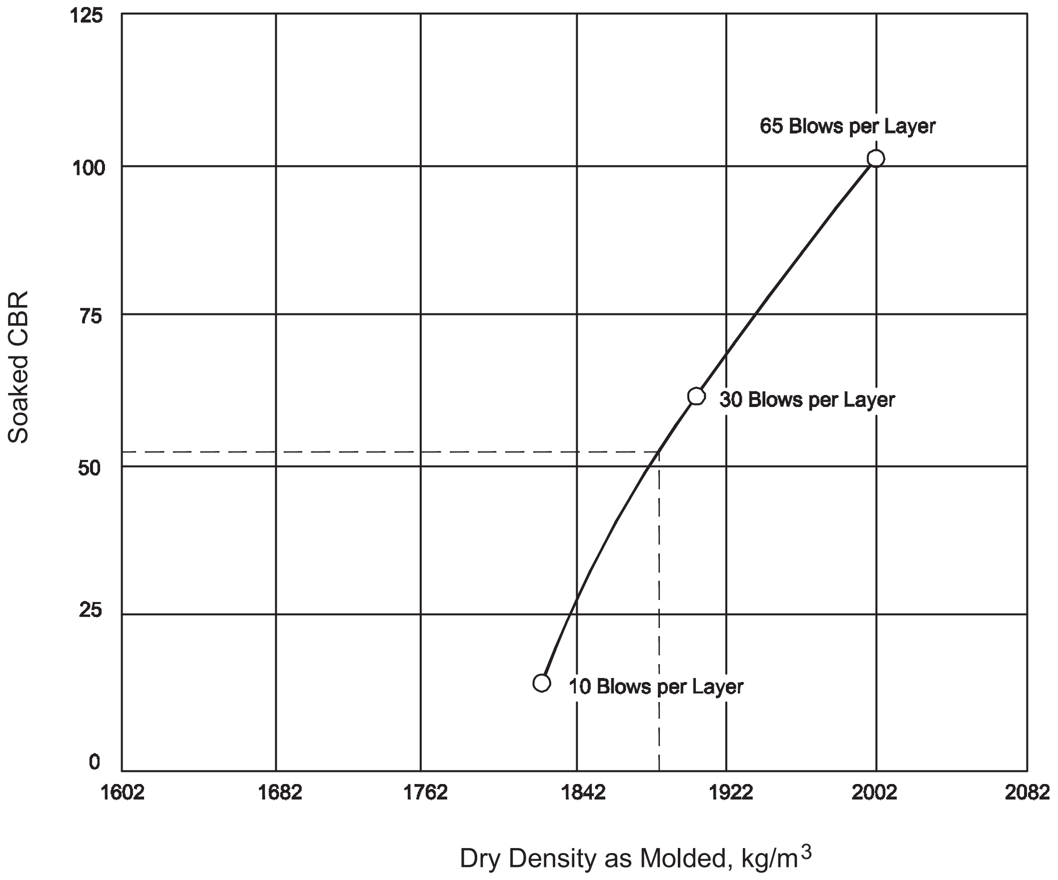
Figure 2—Correction of Stress-Strain Curves

10.2 *California Bearing Ratio*—The corrected load values shall be determined for each specimen at 2.54 and 5.08 mm (0.10 and 0.20 in.) penetration. California Bearing Ratio values are obtained in percent by dividing the corrected load values at 2.54 and 5.08 mm (0.10 and 0.20 in.) by the standard loads of 6.9 and 10.3 MPa (1000 and 1500 psi), respectively, and multiplying these ratios by 100.

$$\text{CBR} = \frac{\text{Corrected load value}}{\text{Standard load}} \times 100 \qquad (2)$$

10.2.1 The CBR is generally selected at 2.54 mm (0.10 in.) penetration. If the ratio at 5.08 mm (0.20 in.) penetration is greater, the test shall be rerun. If the check test gives a similar result, the ratio at 5.08 mm (0.20 in.) penetration shall be used.

10.3 *Design CBR for One Water Content Only*—Using the data obtained from the three specimens, plot the CBR-Dry Density as Molded relation as shown in Figure 3. The design CBR may then be determined at the desired percentage of the maximum dry density, normally the minimum percentage compaction permitted by the agency's compaction specifications.



Example:

Given: Maximum dry density by T 99 = 1986 kg/m^3

Find: The CBR at 95 percent of the above maximum dry density.

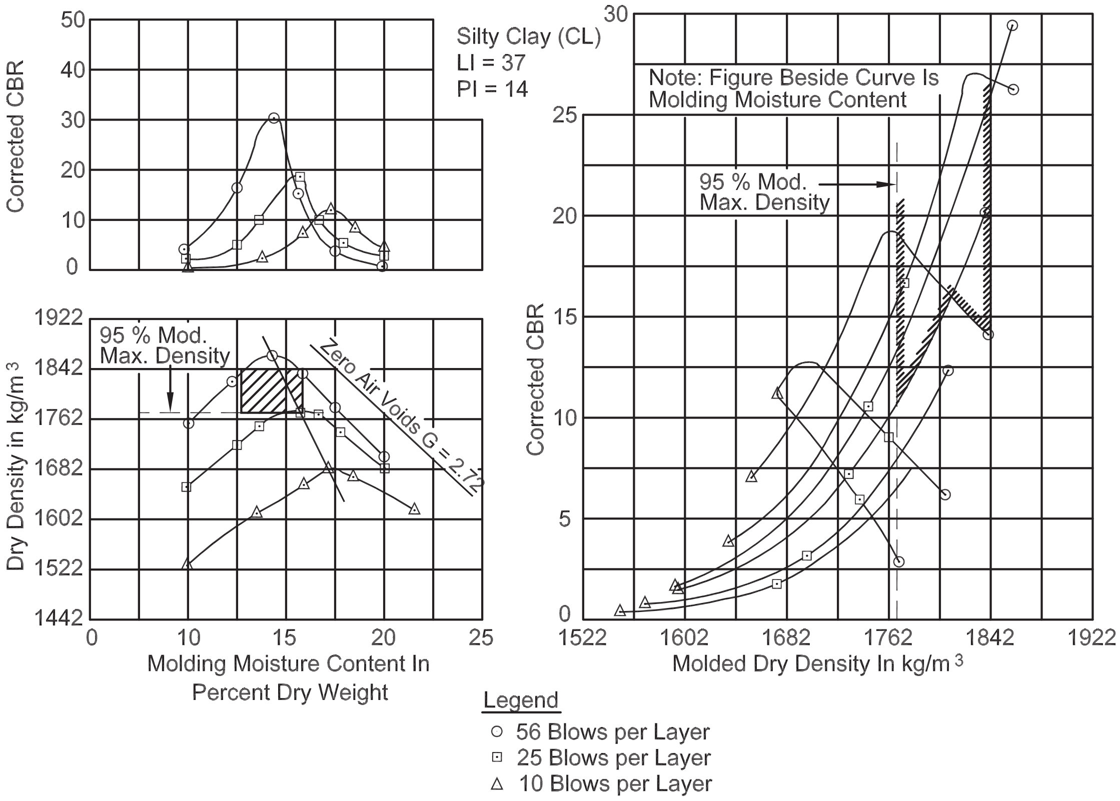
Solution: 95 percent of 1986 kg/m^3 = 1887 kg/m^3

At 1887 kg/m^3 > the CBR is 52.

Note: 1 pcf = 16.02 kg/m^3.

Figure 3—Dry Density Versus CBR

10.4 *Design CBR for Water Content Range*—Plot the data from the tests at the three compactive efforts as shown in Figure 4. The data plotted as shown represent the response of the soil over the range of water content specified. Select the CBR for reporting as the lowest CBR within the specified water content range having a dry unit mass between the specified minimum and the dry unit mass produced by compaction within the water content range.



Note: Surcharge = 50-lb soaking and penetration. All samples soaked top and bottom four days. All samples compacted in five layers, 10-lb rammer, 18-in. drop in CBR mold.

Figure 4—Determining CBR for Water Content Range and Minimum Dry Unit Weight

11. REPORT

11.1 The report shall include the following information for each specimen:

11.1.1 Compaction effort (number of blows per layer).

11.1.2 Dry density as molded, percent.

11.1.3 Moisture content as molded, percent.

11.1.4 Swell (percent of original length), percent.

11.1.5 California Bearing Ratio, percent.

Standard Method of Test for

Determination of Organic Matter in Soils by Wet Combustion

AASHTO Designation: T 194-97 (2008)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Determination of Organic Matter in Soils by Wet Combustion

AASHTO Designation: T 194-97 (2008)

1. SCOPE

1.1. The "Wet Combustion" method for the determination of soil organic matter is most applicable when it is desired to determine the humus-like, easily-oxidized organic material to provide information relating to the suitability of the soil for plant growth. The method provides a good estimate of this type of organic matter, and, when the soil contains only this type, it can also provide a good estimate of the total organic content. However, the reagents used react only very slightly with fresh plant materials such as wood, roots, grass, and weed tops, etc., or with hydrocarbons, charcoal, lignite, coal, and the organic remains in ancient sediments. If such materials are present and the total organic matter is to be determined, the Loss on Ignition method found in T 267 must be used.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. REAGENTS

2.1. *1 Normal Potassium Dichromate*—Dissolve 49.04 g of dry reagent $K_2Cr_2O_7$ in distilled or deionized water and dilute to 1 L.

2.2. *0.5 Normal Ferrous Sulfate*—Dissolve 140 g of reagent grade $FeSO_4 \cdot 7H_2O$ in distilled water, add 40 mL of concentrated sulfuric acid, cool, and dilute to 1 L. Standardize this reagent each day by a "blank" titration against exactly 10.5 mL of 1 Normal potassium dichromate, as described in the method given below, but without a soil sample.

2.3. *Barium Diphenylamine-Sulfonate*—Dissolve 0.16 g of reagent grade barium diphenylamine-sulfonate in 100 mL of distilled water.

2.4. *Sulfuric Acid*—Concentrated (not less than 96 percent), reagent grade.

2.5. *Phosphoric Acid*—85 percent, reagent grade.

3. APPARATUS

3.1. *Balance*—The balance shall conform to AASHTO M 231, Class B.

3.2. *Erlenmeyer flasks*, 400 mL.

3.3. *Volumetric flasks*, 1000 mL.

3.4. *Transfer pipettes*, 10 mL and 20 mL (or burettes).

3.5. *Heat resistant pad.*

3.6. *Graduated cylinders*, 250 mL and 25 mL.

3.7. *Dropping bottles for indicator solutions*. For barium diphenylamine-sulfonate solution, add 0.80 mL, which equals 15 drops from a dropping bottle.

3.8. *Burettes*, 50 mL (two required).

3.9. *Burette holder and laboratory stand.*

3.10. *Washing bottle*, for distilled water.

3.11. *Glass or polyethylene bottle*, minimum capacity, 1 L, for storage of potassium dichromate and ferrous sulfate solutions (two required).

3.12. *Oven*, capable of maintaining 110º ± 5ºC (230º ± 9ºF).

4. PROCEDURE

4.1. Weigh 0.750 to 1.0 g (Note 1) of oven-dried soil passing the 0.425-mm sieve (No. 40), to the nearest 0.001 g, transfer quantitatively to a 400-mL Erlenmeyer flask, and add from a burette or pipette exactly 10 mL of the potassium dichromate solution. Immediately add from a graduate cylinder or a pipette 20 mL of concentrated sulfuric acid, directing the stream into the solution. Immediately swirl the flask vigorously to mix thoroughly and then allow it to stand on a sheet of asbestos for about 30 minutes. (See Note 2.) Add 200 mL of distilled or deionized water from a graduated cylinder, 10 mL of phosphoric acid from a graduated cylinder (Note 3), and 0.80 mL (15 drops) of barium diphenylamine-sulfonate indicator and swirl the flask to ensure thorough mixing. While still swirling the flask, add ferrous sulfate solution quantitatively from a burette. The solution will first turn purple, then from dark blue to light blue, after which the ferrous sulfate should be added slowly until the color changes—with little warning—to brilliant green. Add 0.5 mL (10 drops) more of the dichromate solution to restore an excess of dichromate, wash down the inside walls of the flask with a few mL of water from a wash bottle, and complete the titration to a one-drop, light green end-point by adding the ferrous sulfate drop by drop to the swirling flask. If less than 5 mL of the ferrous sulfate solution has been used in the titration, repeat the determination with less soil. Make a standardizing "blank" run without a soil sample, but using exactly 10.5 mL of dichromate and otherwise following the procedure given above.

Note 1—For peat, use the Loss on Ignition method (T 267). It may be necessary to decrease the amount of soil below the minimum specified under Section 4.1 for soils greater than approximately 10-percent organic. The Loss on Ignition method (T 267) must be used if the soil sample is less than 0.200 g.

Note 2—Because the action of chromic acid on organic matter is considerably affected by temperature, the flask should be kept in a relatively draft-free place at room temperature, 20º to 30ºC (68º to 86ºF) for the 30-minute period.

5. CALCULATIONS

5.1. Determine the amount of dichromate solution that was reduced by the soil organic matter. This requires (1) standardization of the ferrous sulfate solution so the amount of dichromate equivalent to the ferrous sulfate actually used in the test may be determined and subtracted from the total dichromate used in the test; and (2) correction for the small amount of dichromate reduced by impurities in the reagents used. Both of these requirements are satisfied by the "blank" determination described in the procedure. For example, in a blank determination, 10.50 mL of the dichromate solution might require 20.75 mL of ferrous sulfate. In the test procedure for a hypothetical 1.000 g soil sample, 10.50 mL of dichromate would have been used; and the subsequent titration might require 6.80 mL of ferrous sulfate. The amount of dichromate actually reduced by the organic matter of this soil sample would therefore be 10.50 $(1 - {}^{6.80}/_{20.75})$, or 7.06 mL; and since the dichromate is a 1 Normal solution, this corresponds to 7.06 milliequivalents of dichromate reduced.

5.2. A milliequivalent of carbon in the oxidation reaction involved in this test method is 0.003 g. The amount of carbon occurring in easily oxidized carbon would therefore be 7.06 × 0.003, or 0.021 g, and the percentage of easily oxidized carbon would be $0.021 \times {}^{100}/_{1.000} = 2.1$ percent.

5.3. It is widely accepted that humus-like soil organic matter contains about 58 percent carbon. Therefore, to convert the percentage of easily oxidized carbon to the percentage of easily oxidized organic matter, multiply by ${}^{100}/_{58}$ or 1.72. The percentage of easily oxidized organic matter in the example soil would accordingly be 2.1 × 1.72, or 3.6 percent.

5.4. It has been found for many agricultural soils that the amount of organic carbon indicated by the Wet Combustion method is about 77 percent of the total organic content, as determined by the Loss on Ignition method (T 267). Therefore, to approximate the total carbon or total organic matter percentage, the percentage of easily oxidized carbon or organic matter is multiplied by ${}^{100}/_{77}$ or 1.3. In the example soil, the percentage of total carbon would be 2.1 × 1.3, or 2.7 percent, and the percentage of total organic matter would be 3.6 × 1.3, or 4.7 percent.

5.5. The information given above in this section may be summarized in the following equations:

$$\text{Easily oxidized carbon, percent} = 10.5 \times \left(1 - \frac{\text{sample titre, mL}}{\text{blank titre, mL}}\right) \times 0.3 \div \text{mass of soil} \qquad (1)$$

Total carbon, percent = Equation (1) × 1.3. *(2)*

Easily oxidized matter, percent = Equation (1) × 1.72. *(3)*

Total organic matter, percent = Equation (1) × 1.3 × 1.72,
or Equation (1) × 2.236 *(4)*

Note 3—It is possible that a color change during titration with ferrous sulfate solution may be impossible to observe with certain types and/or colors of soil. If this occurs, filter the sample through No. 54 filter paper prior to the addition of the barium diphenylamine-sulfonate and then continue with the standard method.

Standard Method of Test for

Penetration Test and Split-Barrel Sampling of Soils

AASHTO Designation: T 206-09[1]
ASTM Designation: D 1586-99

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Penetration Test and Split-Barrel Sampling of Soils

AASHTO Designation: T 206-09[1]
ASTM Designation: D 1586-99

1. SCOPE

1.1. This test method describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler to obtain a representative soil sample and a measure of the resistance of the soil to penetration of the sampler.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For a specific precautionary statement, see Section 5.4.1.

1.3. The values stated in SI units are to be regarded as the standard.

Note 1—ASTM D 4633 can be used for measuring the energy that enters the drill rod string during testing due to the hammer impact.

Note 2—ASTM D 6066 can be used when testing loose sands below the water table for liquefaction studies or when a higher level of care is required when drilling these soils. This practice provides information on drilling methods, equipment variables, energy corrections, and blow-count normalization.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- R 13, Conducting Geotechnical Subsurface Investigations

2.2. *ASTM Standards*:

- D 4633, Standard Test Method for Energy Measurement for Dynamic Penetrometers
- D 6066, Standard Practice for Determining the Normalized Penetration Resistance of Sands for Evaluation of Liquefaction Potential

3. DESCRIPTIONS OF TERMS SPECIFIC TO THIS STANDARD

3.1. *anvil*—that portion of the drive-weight assembly that the hammer strikes and through which the hammer energy passes into the drill rods.

3.2. *cathead*—the rotating drum or windlass in the rope-cathead lift system around which the operator wraps a rope to lift and drop the hammer by successively tightening and loosening the rope turns around the drum.

3.3. *drill rods*—rods used to transmit downward force and torque to the drill bit while drilling a borehole.

3.4. *drive-weight assembly*—a device consisting of the hammer, hammer fall guide, the anvil, and any hammer drop system.

3.5. *hammer*—that portion of the drive-weight assembly consisting of the 63.5 ± 1 kg (140 ± 2 lb) impact weight that is successfully lifted and dropped to provide the energy that accomplishes the sampling and penetration.

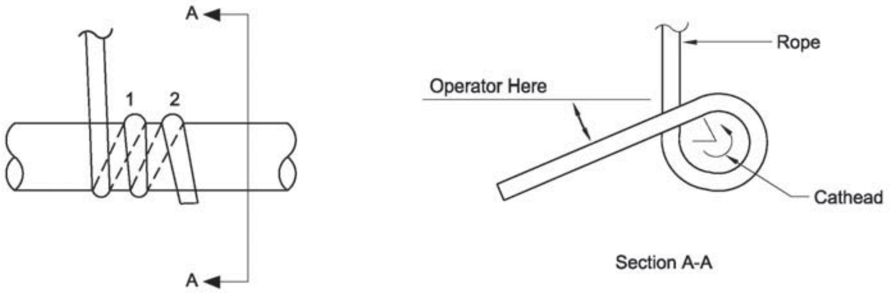
3.6. *hammer drop system*—that portion of the drive-weight assembly by which the operator accomplishes the lifting and dropping of the hammer to produce the blow.

3.7. *hammer fall guide*—that part of the drive-weight assembly used to guide the fall of the hammer.

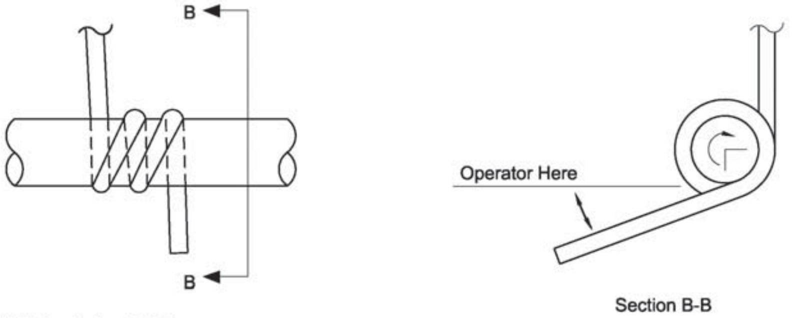
3.8. *N-value*—the blowcount representation of the penetration resistance of the soil. The *N*-value, reported in blows per foot, equals the sum of the number of blows required to drive the sampler over the depth interval of 150 to 450 mm (6 to 18 in.). (See Section 7.3.)

3.9. *ΔN*—the number of blows obtained from each of the 150-mm (6-in.) intervals of sampler penetration. (See Section 7.3.)

3.10. *number of rope turns*—the total contact angle between the rope and the cathead at the beginning of the operator's rope slackening to drop the hammer, divided by 360º. (See Figure 1.)



(a) Counterclockwise Rotation
Approximately 1¾ Turns



(b) Clockwise Rotation
Approximately 2¼ Turns

Figure 1—Definitions of the Number of Rope Turns and the Angle for *(a)* Counterclockwise Rotation and *(b)* Clockwise Rotation of the Cathead

3.11. *sampling rods*—rods that connect the drive-weight assembly to the sampler. Drill rods are often used for this purpose.

3.12. *SPT*—abbreviation for Standard Penetration Test, a term by which engineers commonly refer to this method.

4. SIGNIFICANCE AND USE

4.1. This test method provides a soil sample for identification purposes and for laboratory tests appropriate for soil obtained from a sampler that may produce large shear strain disturbance in the sample.

4.2. This test method is used extensively in a great variety of geotechnical exploration projects. Many local correlations and widely published correlations, which relate SPT blowcount, or *N*-value, and the engineering behavior of earthworks and foundations, are available.

5. APPARATUS

5.1. *Drilling Equipment*—Any drilling equipment that provides at the time of sampling a suitably clean open hole before insertion of the sampler and ensures that the penetration test is performed on undisturbed soil shall be acceptable. The following pieces of equipment have proven to be suitable for advancing a borehole in some subsurface conditions:

5.1.1. *Drag, Chopping, and Fishtail Bits*, less than 162 mm (6.5 in.) and greater than 56 mm (2.2 in.) in diameter may be used in conjunction with open-hole rotary drilling or casing-advancement drilling methods. To avoid disturbing the underlying soil, bottom discharge bits are not permitted; only side discharge bits are permitted.

5.1.2. *Roller-Cone Bits*, less than 162 mm (6.5 in.) and greater than 56 mm (2.2 in.) in diameter may be used in conjunction with open-hole rotary drilling or casing-advancement drilling methods if the drilling fluid discharge is deflected.

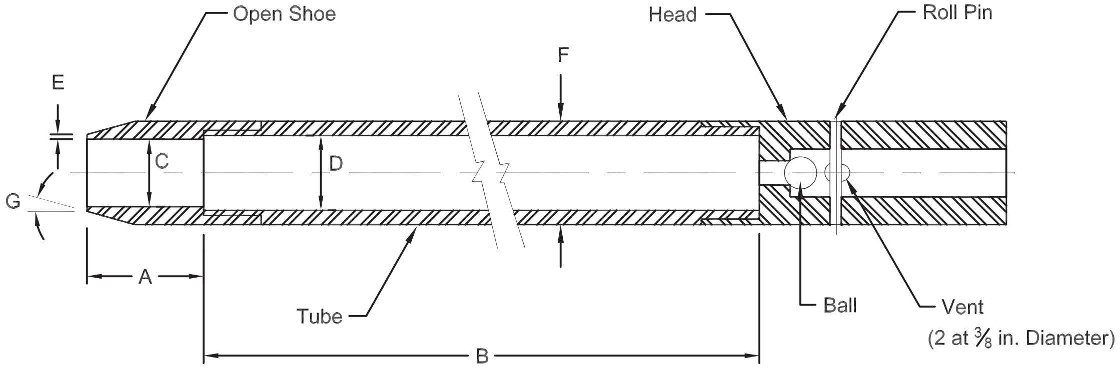
5.1.3. *Hollow-Stem Continuous Flight Augers*, with or without a center bit assembly, may be used to drill the boring. The inside diameter of the hollow-stem augers shall be less than 162 mm (6.5 in.) and greater than 56 mm (2.2 in.).

5.1.4. *Solid, Continuous Flight, Bucket, and Hand Augers*, less than 162 mm (6.5 in.) and greater than 56 mm (2.2 in.) in diameter may be used if the soil on the side of the boring does not cave onto the sampler or sampling rods during sampling.

5.2. *Sampling Rods*—Flush-joint steel drill rods shall be used to connect the split-barrel sampler to the drive-weight assembly. The sampling rod shall have a stiffness (moment of inertia) equal to or greater than that of parallel wall "A" rod (a steel rod that has an outside diameter of 41.2 mm ($1^5/_8$ in.) and an inside diameter of 28.5 mm ($1^1/_8$ in.).

Note 3—Recent research and comparative testing indicates the type of rod used, with stiffness ranging from "A" size rod to "N" size rod, will usually have a negligible effect on the *N*-values to depths of at least 30 m (100 ft).

5.3. *Split-Barrel Sampler*—The sampler shall consist of a heat-treated, case-hardened, steel head, split spoon and shoe assembly, constructed to the dimensions indicated in Figure 2. The driving shoe shall be of hardened steel and shall be replaced or repaired when it becomes dented or distorted. The use of liners to produce a constant inside diameter of 35 mm ($1^3/_8$ in.) is permitted, but shall be noted on the penetration record if used. The use of a sample retainer basket is permitted, and should also be noted on the penetration record if used.



A = 25 to 50 mm (1.0 to 2.0 in.)
B = 0.457 to 0.762 m (18.0 to 30.0 in.)
C = 34.93 ± 0.13 mm (1.375 ± 0.005 in.)
D = 38.1 ± 1.3-0.0 mm (1.50 ± 0.05-0.00 in.)
E = 2.54 ± 0.25 mm (0.10 ± 0.02 in.)
F = 50.8 ± 1.3-0.0 mm (2.00 ± 0.05-0.00 in.)
G = 16.0° to 23.0°

Note: The $1^{1}/_{2}$-in. (38-mm) inside diameter split barrel may be used with a 16-gauge wall thickness split liner. The penetrating end of the drive shoe may be slightly rounded. Metal or plastic retainers may be used to retain soil samples.

Figure 2—Split-Barrel Sampler

Note 4—Both theory and available test data suggest that *N*-values may increase between 10 to 30 percent when liners are used.

5.4. *Drive-Weight Assembly*:

5.4.1. *Hammer and Anvil*—The hammer shall weigh 63.5 ± 1 kg (140 ± 2 lb) and shall be a solid rigid metallic mass. The hammer shall strike the anvil and make steel on steel contact when it is dropped. A hammer fall guide permitting a free fall shall be used. Hammers used with the cathead and rope method shall have an unimpeded overlift capacity of at least 100 mm (4 in.). For safety reasons, the use of a hammer assembly with an internal anvil is encouraged.

Note 5—It is suggested that the hammer fall guide be permanently marked to enable the operator or inspector to judge the hammer drop height.

5.4.2. *Hammer Drop System*—Rope-cathead, trip, semiautomatic, or automatic hammer drop systems may be used, providing the lifting apparatus will not cause penetration of the sampler while re-engaging and lifting the hammer.

5.5. *Accessory Equipment*—Accessories such as labels, sample containers, data sheets, and groundwater level measuring devices shall be provided in accordance with the requirements of the project and other ASTM standards.

6. DRILLING PROCEDURE

6.1. The boring shall be advanced incrementally, using methods outlined in AASHTO R 13, to permit intermittent or continuous sampling. Test intervals and locations are normally stipulated by the project engineer or geologist. Typically, the intervals selected are 1.5 m (5 ft) or less in homogeneous strata with test and sampling locations at every change of strata.

6.2. Any drilling procedure that provides a suitably clean and stable hole before insertion of the sampler and assures that the penetration test is performed on essentially undisturbed soil shall be acceptable. Each of the following procedures has proven to be acceptable for some subsurface conditions. The subsurface conditions anticipated should be considered when selecting the drilling method to be used.

6.2.1. Open-hole rotary drilling method.

6.2.2. Continuous flight hollow-stem auger method.

6.2.3. Wash boring method.

6.2.4. Continuous flight solid auger method.

6.3. Several drilling methods produce unacceptable borings. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. The continuous flight solid auger method shall not be used for advancing the boring below a water table or below the upper confining bed of a confined noncohesive stratum that is under artesian pressure. Casing may not be advanced below the sampling elevation prior to sampling. Advancing a boring with bottom discharge bits is not permissible. It is not permissible to advance the boring for subsequent insertion of the sampler solely by means of previous sampling with the SPT sampler.

6.3.1. The sampler head is vented to prevent pressure buildup during sampling, and must be kept clean. A steel ball water check is located in the head to prevent downward water pressure from acting on the sample. Clogging of the air vents or removal of the water check frequently causes sample loss.

6.4. The drilling fluid level within the boring or hollow-stem augers shall be maintained at or above the *in situ* groundwater level at all times during drilling, removal of drill rods, and sampling.

7. SAMPLING AND TESTING PROCEDURE

7.1. After the boring has been advanced to the desired sampling elevation and excessive cuttings have been removed, prepare for the test with the following sequence of operations:

7.1.1. Attach the split-barrel sampler to the sampling rods and lower into the borehole. Do not allow the sampler to drop onto the soil to be sampled.

7.1.2. Position the hammer above and attach the anvil to the top of the sampling rods. This may be done before the sampling rods and sampler are lowered into the borehole.

7.1.3. Rest the dead weight of the sampler, rods, anvil, and drive weight on the bottom of the boring and apply a seating blow. If excessive cuttings are encountered at the bottom of the boring, remove the sampler and sampling rods from the boring and remove the cuttings.

7.1.4. Mark the drill rods in three successive 0.15-m (6-in.) increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 0.15-m (6-in.) increment.

7.2. Drive the sampler with blows from the 63.5-kg (140-lb) hammer and count the number of blows applied in each 0.15-m (6-in.) increment until one of the following occurs:

7.2.1. A total of 50 blows have been applied during any one of the three 0.15-m (6-in.) increments described in Section 7.1.4.

7.2.2. A total of 100 blows have been applied.

7.2.3. There is no observed advance of the sampler during the application of 10 successive blows of the hammer.

7.2.4. The sampler is advanced the complete 0.45 m (18 in.) without the limiting blow counts occurring as described in Sections 7.2.1, 7.2.2, or 7.2.3.

7.3. Record the number of blows required to affect each 0.15 m (6 in.) of penetration or fraction thereof. The first 6 in. is considered to be a seating drive. The sum of the number of blows required for the second and third 6 in. of penetration is termed the “standard penetration resistance,” or the “*N*-value.” If the sampler is driven less than 0.45 m (18 in.), as permitted in Sections 7.2.1, 7.2.2, or 7.2.3, the number of blows per each complete 0.15-m (6-in.) increment and per each partial increment shall be recorded on the boring log. For partial increments, the depth of penetration shall be reported to the nearest 25 mm (1 in.), in addition to the number of blows. If the sampler advances below the bottom of the boring under the static weight of the drill rods or the weight of the drill rods plus the static weight of the hammer, this information should be noted on the boring log.

7.4. The raising and dropping of the 63.5-kg (140-lb) hammer shall be accomplished using either of the following two methods:

7.4.1. By using a trip, automatic, or semiautomatic hammer drop system that lifts the 63.5-kg (140-lb) hammer and allows it to drop 0.76 m ± 25 mm (30 ± 1.0 in.) unimpeded.

7.4.2. By using a cathead to pull a rope attached to the hammer. When the cathead and rope method is used, the system and operation shall conform to the following:

7.4.2.1. The cathead shall be essentially free of rust, oil, or grease and have a diameter in the range of 150 to 250 mm (6 to 10 in.).

7.4.2.2. The cathead should be operated at a minimum speed of rotation of 100 RPM, or the approximate speed of rotation shall be reported on the boring log.

7.4.2.3. No more than $2^1/_4$ rope turns on the cathead may be used during the performance of the penetration test, as shown in Figure 1.

Note 6—The operator should generally use either $1^3/_4$ or $2^1/_4$ rope turns, depending upon whether or not the rope comes off the top ($1^3/_4$ turns) or the bottom ($2^1/_4$ turns) of the cathead. It is generally known and accepted that $2^3/_4$ or more rope turns considerably impedes the fall of the hammer and should not be used to perform the test. The cathead rope should be maintained in a relatively dry, clean, and unfrayed condition.

7.4.2.4. For each hammer blow, a 0.76-m (30-in.) lift and drop shall be employed by the operator. The operation of pulling and throwing the rope shall be performed rhythmically without holding the rope at the top of the stroke.

7.5. Bring the sampler to the surface and open. Record the percent recovery or the length of sample recovered. Describe the soil samples recovered as to composition, color, stratification, and condition, then place one or more representative portions of the sample into sealable moisture-proof containers (jars) without ramming or distorting any apparent stratification. Seal each container to prevent evaporation of soil moisture. Affix labels to the containers bearing job designation, boring number, sample depth, and the blow count per 0.15-m (6-in.) increment. Protect the samples against extreme temperature changes. If there is a soil change within the sampler, make a jar for each stratum and note its location in the sampler barrel.

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8. REPORT

8.1. Drilling information shall be recorded in the field and shall include the following:

8.1.1. Name and location of job;

8.1.2. Names of crew;

8.1.3. Type and make of drilling machine;

8.1.4. Weather conditions;

8.1.5. Date and time of start and finish of boring;

8.1.6. Boring number and location (station and coordinates, if available and applicable);

8.1.7. Surface elevation, if available;

8.1.8. Method of advancing and cleaning the boring;

8.1.9. Method of keeping boring open;

8.1.10. Depth of water surface and drilling depth at the time of a noted loss of drilling fluid, and time and date when reading or notation was made;

8.1.11. Location of strata changes;

8.1.12. Size of casing, depth of cased portion of boring;

8.1.13. Equipment and method of driving sampler;

8.1.14. Type of sampler and length and inside diameter of barrel (note use of liners);

8.1.15. Size, type, and section length of the sampling rods; and

8.1.16. Remarks.

8.2. Data obtained for each sample shall be recorded in the field and shall include the following:

8.2.1. Sample depth and, if utilized, the sample number, 8.2.2. Description of soil,

8.2.3. Strata changes within sample,

8.2.4. Sampler penetration and recovery lengths, and

8.2.5. Number of blows per 0.15-m (6-in.) or partial increment.

9. PRECISION AND BIAS

9.1. *Precision*—A valid estimate of test procedures has not been determined.

9.2. *Bias*—Because there is no reference material for this test method, there can be no bias statement.

9.3. Variations in *N*-values of 100 percent or more have been observed when using different standard penetration test apparatus and drillers for adjacent borings in the same soil formation. Current opinion, based on field experience, indicates that when using the same apparatus and driller, *N*-values in the same soil can be reproduced with a coefficient of variation of about 10 percent.

9.4. The use of faulty equipment, such as an extremely massive or damaged anvil, a rusty cathead, a low-speed cathead, an old oily rope, or massive or poorly lubricated rope sheaves can significantly contribute to differences in *N*-values obtained between operator-drill rig systems.

9.5. The variability in *N*-values produced by different drill rigs and operators may be reduced by measuring that part of the hammer energy delivered into the drill rods from the sampler and adjusting *N* on the basis of comparative energies. A method for energy measurement and *N*-value adjustment is currently under development.

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[1] Except for the use of SI units, this method is technically equivalent to ASTM D 1586-99.

Standard Method of Test for

Thin-Walled Tube Sampling of Soils

AASHTO Designation: T 207-03 (2007)[1]
ASTM Designation: D 1587-00

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Thin-Walled Tube Sampling of Soils

AASHTO Designation: T 207-03 (2007)[1]
ASTM Designation: D 1587-00

1. SCOPE

1.1. This method covers a procedure for using a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests of engineering properties, such as strength, compressibility, permeability, and density. Thin-walled tubes used in piston, plug, or rotary-type samplers, such as the Denison or Pitcher, must comply with the portions of this practice, which describe the thin-walled tubes (Section 5.3).

Note 1—This method does not apply to liners used within the above samplers.

1.2. Not all tubes specified in this method may be of sufficient diameter to perform all strength or consolidation testing. Refer to the appropriate test method for the minimum sample size to determine if the tube will be appropriate for that test.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 13, Conducting Geotechnical Subsurface Investigations

3. SUMMARY OF METHOD

3.1. A relatively undisturbed sample is obtained by pressing a thin-walled metal tube into the *in situ* soil at the bottom of a boring, removing the soil-filled tube, and sealing the ends to prevent the soil from being disturbed or losing moisture.

4. SIGNIFICANCE AND USE

4.1. This method is used when it is necessary to obtain a relatively undisturbed specimen suitable for laboratory tests of engineering properties or other tests that might be influenced by soil disturbance.

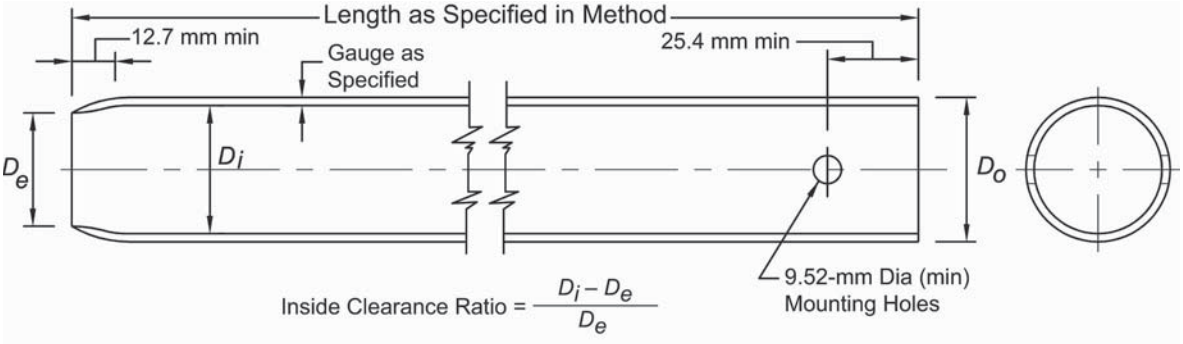
5. APPARATUS

5.1. *Drilling Equipment*—Any drilling equipment may be used that provides a reasonably clean hole; that minimizes disturbance of the soil to be sampled; and that does not hinder the penetration of the thin-walled sampler. Open borehole diameter and the inside diameter of driven casing or hollow stem auger shall not exceed 3.5 times the outside diameter of the thin-walled tube.

5.2. *Sampler Insertion Equipment*, shall be adequate to provide a relatively rapid continuous penetration force. For hard formations it may be necessary, although not recommended, to drive the thin-walled tube sampler.

5.3. *Sampler Head*, serves to couple the thin-walled tube to the insertion equipment and, together with the thin-walled tube, comprises the thin-walled tube sampler. The sampler head shall contain a suitable check valve and a venting area to the outside equal to or greater than the area through the check valve. In some special cases, a check valve may not be required, but venting is required to avoid sample compression. Attachment of the head to the tube shall be concentric and coaxial to assure uniform application of force to the tube by the sampler insertion equipment.

5.4. *Thin-Walled Tubes*, should be manufactured as shown in Figure 1. They should have an outside diameter of 50.8 to 127.0 mm (2 to 5 in.) and be made of metal having adequate strength for use in the soil and formation intended. Tubes shall be clean and free of all surface irregularities including projecting weld seams. Other diameters may be used, but the tube dimensions should be proportional to the tube designs presented here.



Notes:
1. Minimum of two mounting holes on opposite sides for 50.8- to 88.9-mm sampler.
2. Minimum of four mounting holes spaced at 90° for samplers 101.6 mm and larger.
3. Tube held with hardened screws.
4. Tubes with outside diameters of 50.8 mm are specified with an 18-gauge wall thickness to comply with area ratio criteria accepted for "undisturbed samples." Users are advised that such tubing is difficult to locate and can be extremely expensive in small quantities. Sixteen-gauge tubes are generally readily available.

English Equivalents

mm	in.
9.52	$^3/_8$
12.7	$^1/_2$
25.4	1
50.8	2
88.9	$3^1/_2$
101.6	4

Figure 1—Thin-Walled Tube for Sampling

5.4.1. *Length of Tubes*—See Table 1 and Section 6.4.

5.4.2. *Tolerances*, shall be within the limits shown in Table 2.

5.4.3. *Inside Clearance Ratio*, should not be greater than 1 percent or as specified by the engineer or geologist for the soil and formation to be sampled. Generally, the inside clearance ratio used should increase with the increase in plasticity of the soil being sampled, except for sensitive soils or where local experience indicates otherwise. See Figure 1 for definition of inside clearance ratio.

Table 1—Suitable Thin-Walled Steel Sample Tubes[a]

Outside diameter:			
mm	50.8	76.2	127.0
in.	2	3	5
Wall thickness:			
BWG	18	16	11
mm	1.24	1.65	3.05
in.	0.049	0.065	0.120
Tube length:			
m	0.91	0.91	1.37
in.	36	36	54
Clearance:			
ratio, percent	1	1	1

[a] The three diameters recommended in Table 1 are indicated for purposes of standardization, and are not intended to indicate that sampling tubes of intermediate or larger diameters are not acceptable. Lengths of tubes shown are illustrative. Proper lengths to be determined as suited to field conditions.

Table 2—Dimensional Tolerances for Thin-Walled Tubes

	Nominal Tube Diameters from Table 1[a] Tolerances		
Size Outside Diameter, mm in.	50.8 (2)	76.2 (3)	127 (5)
Outside diameter			
mm	+ 0.18	+ 0.25	+ 0.38
in.	(+ 0.007)	(+ 0.010)	(+ 0.015)
mm	– 0.00	– 0.00	– 0.00
in.	(– 0.000)	(– 0.000)	(– 0.000)
Inside diameter			
mm	+ 0.00	+ 0.00	+ 0.00
in.	(+ 0.000)	(+ 0.000)	(+ 0.000)
mm	– 0.18	– 0.25	– 0.38
in.	(– 0.007)	(– 0.010)	(– 0.015)
Wall thickness			
mm	± 0.18	± 0.25	± 0.38
in.	(± 0.007)	(± 0.010)	(± 0.015)
Ovality[b]			
mm	0.38	0.51	0.76
in.	(0.015)	(0.020)	(0.030)
Straightness			
mm/m	2.5	2.5	2.5
in./ft	(0.030)	(0.030)	(0.030)

[a] Intermediate or larger diameters should be proportional. Tolerances shown are essentially standard commercial manufacturing tolerances for seamless steel mechanical tubing. Specific only two of the first three tolerances: that is, OD and ID, or OD and Wall, or ID and Wall.

[b] *Ovality*—the cross-section of the tube that deviates from a perfect circle.

5.4.4. *Corrosion Protection*—Corrosion, whether from galvanic or chemical reaction, can damage or destroy both the thin-walled tube and the sample. Severity of damage is a function of time as well as interaction between the sample and the tube. Thin-walled tubes should have some form of protective coating. Tubes that will contain samples for more than 72 hours shall be coated. The type of coating to be used may vary depending upon the material to be sampled. Coatings may include a light coat of lubricating oil, lacquer, epoxy, Teflon, and others. Type of coating must be specified by the engineer or geologist if storage will exceed 72 hours. Plating of the tubes or alternate base metals may be specified by the engineer or geologist.

6. PROCEDURE

6.1. Advance the borehole using methods outlined in AASHTO R 13. Clean out the borehole to sampling elevation using whatever method is preferred that will ensure the material to be sampled is not disturbed. If groundwater is encountered, maintain the liquid level in the borehole at or above groundwater level during the sampling operation.

6.2. Bottom discharge bits are not permitted. Side discharge bits may be used, with caution. Jetting through an open-tube sampler to clean out the borehole to sampling elevation is not permitted. Remove loose material from the center of a casing or hollow stem auger as carefully as possible to avoid disturbance of the material to be sampled.

Note 2—Roller bits are available in downward-jetting and diffused-jet configurations. Downward-jetting configuration rock bits are not acceptable. Diffuse-jet configurations are generally acceptable.

6.3. Place the sample tube so that its bottom rests on the bottom of the hole. Record the depth to the bottom of the sample tube to the nearest 0.3 m (0.1 ft). Advance the sampler without rotation by a continuous relatively rapid motion.

6.4. Determine the length of advance by the resistance and condition of the formation, but the length shall never exceed 5 to 10 diameters of the tube in sands and 10 to 15 diameters of the tube in clays.

Note 3—The mass of the sample, laboratory-handling capabilities, transportation problems, and commercial availability of tubes will generally limit maximum practical lengths to those shown in Table 1.

6.5. When the formation is too hard for push-type insertion, the tube may be driven. Other methods, as directed by the engineer or geologist, may be used. If driving methods are used, the data regarding mass and fall of the hammer and penetration achieved must be shown in the report. Additionally, that tube must be prominently labeled a “driven sample.”

6.6. In no case shall a length of advance be greater than the sample-tube length minus an allowance for the sampler head and a minimum of 76.2 mm (3 in.) for sludge-end cuttings.

Note 4—The tube may be rotated to shear bottom of the sample after pressing is complete.

6.7. Withdraw the sampler from the formation as carefully as possible in order to minimize disturbance of the sample. Where the soil formation is soft, a delay before withdraw of the sampler (typically 5 to 30 minutes) may improve sample recovery.

7. PREPARATION FOR SHIPMENT

7.1. Upon removal of the tube, measure the length of sample in the tube. Remove the drill cuttings in the upper end of the tube and measure the length again. Seal the upper end of the tube. Remove at least 25 mm (1 in.) of material from the lower end of the tube. Use this material for soil description. Measure the overall sample length. Seal the lower end of the tube. Alternatively, after measurement, the tube may be sealed without removal of soil from the ends of the tube if so directed by the engineer or geologist.

Note 5—Field extrusion and packaging of extruded samples under the specific direction of a geotechnical engineer or geologist is permitted. Samples are extruded in special hydraulic jacks equipped with properly sized platens to extrude the core in a continuous smooth speed. Bent or damaged tubes should be cut off before extruding.

Note 6—Tubes sealed over the ends as opposed to those sealed with expanding packers should contain end padding in end voids in order to prevent drainage or movement of the sample within the tube.

7.2. Prepare and immediately affix labels or apply markings as necessary to identify the sample. Assure that the markings or labels are adequate to survive transportation and storage.

Note 7—Top end of tube should be labeled “TOP.”

8. REPORT

8.1. The appropriate information on the field log is required as follows:

8.1.1. Name and location of the project;

8.1.2. Boring number and precise location on project;

8.1.3. Surface elevation or reference to a datum;

8.1.4. Date and time of boring—start and finish;

8.1.5. Depth to top of sample and number of sample;

8.1.6. Description of sampler: size, type of metal, type of coating;

8.1.7. Method of sampler insertion—push or drive;

8.1.8. Method of drilling, size of hole, casing, and drilling fluid used;

8.1.9. Depth to groundwater level—date and time measured;

8.1.10. Any possible current or tidal effect on water level;

8.1.11. Soil description;

8.1.12. Length of sampler advance; and

8.1.13. Recovery: length of sample obtained.

9. PRECISION AND BIAS

9.1. This method does not produce numerical data; therefore, a precision and bias statement is not applicable.

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[1] Except for the use of SI units, this method is technically equivalent to ASTM D 1587-00.

Standard Method of Test for

Unconfined Compressive Strength of Cohesive Soil

AASHTO Designation: T 208-10
ASTM Designation: D 2166-00

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Unconfined Compressive Strength of Cohesive Soil

AASHTO Designation: T 208-10
ASTM Designation: D 2166-00

1. SCOPE

1.1. This test method covers the determination of the unconfined compressive strength of cohesive soil in the undisturbed, remolded, or compacted condition, using strain-controlled application of the axial load.

1.2. This test method provides an approximate value of the strength of cohesive soils in terms of total stresses.

1.3. This test method is applicable only to cohesive materials that will not expel bleed water (water expelled from the soil due to deformation or compaction) during the loading portion of the test and that will retain intrinsic strength after removal of confining pressures, such as clays or cemented soils. Dry and crumbly soils, fissured or varved materials, silts, peats, and sands cannot be tested with this method to obtain valid unconfined compressive strength values.

Note 1—The determination of the unconsolidated, undrained strength of cohesive soils with lateral confinement is covered by T 296.

1.4. This test method is not a substitute for T 296.

1.5. The values stated in SI units are to be regarded as the standard.

1.6. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 145, Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 100, Specific Gravity of Soils
- T 207, Thin-Walled Tube Sampling of Soils
- T 223, Field Vane Shear Test in Cohesive Soil

- T 265, Laboratory Determination of Moisture Content of Soils
- T 296, Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression

2.2. *ASTM Standards*:

- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids
- D 4220, Standard Practices for Preserving and Transporting Soil Samples

3. TERMINOLOGY

3.1. Refer to ASTM D 653 for standard definitions of terms.

3.2. *Description of Terms Specific to This Standard*:

3.2.1. *Unconfined Compressive Strength (q_u)*—The compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In this test method, unconfined compressive strength is taken as the maximum load attained per unit area or the load per unit area at 15 percent axial strain, whichever is secured first during the performance of a test.

3.2.2. *Shear Strength (s_u)*—For unconfined compressive strength test specimens, the shear strength is calculated to be one-half of the compressive stress at failure, as defined in Section 3.2.1.

4. SIGNIFICANCE AND USE

4.1. The primary purpose of the unconfined compression test is to quickly obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state.

4.2. Samples of soils having slickensided or fissured structure, samples of some type of loess, very soft clays, dry and crumbly soils and varved materials, or samples containing significant portions of silt or sand, or both (all of which usually exhibit cohesive properties), frequently display higher shear strengths when tested in accordance with T 296. Also, unsaturated soils will usually exhibit different shear strengths when tested in accordance with T 296.

4.3. If both an undisturbed and a remolded test are performed on the same sample, the sensitivity of the material can be determined. This method of determining sensitivity is suitable only for soils that can retain a stable specimen shape in the remolded state.

Note 2—For soils that will not retain a stable shape, a vane shear test or T 223 can be used to determine sensitivity.

5. APPARATUS

5.1. *Compression Device*—The compression device may be a platform weighing scale equipped with a screw-jack-activated load yoke, a hydraulic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading prescribed in Section 7.1. For soil with an unconfined compressive strength of less than 100 kPa (1.0 ton/ft^2), the compression device shall be capable of measuring the compressive stress to within 1 kPa (0.01 ton/ft^2). For soil with an unconfined compressive strength of 100 kPa (1.0 ton/ft^2) or greater, the compression device shall be capable of measuring the compressive stress to the nearest 5 kPa (0.05 ton/ft^2).

5.2. *Sample Extruder*—Hand-operated, mechanical, and hydraulic extruders are acceptable provided the device (1) is capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube, (2) has a length of travel at least equal to the required untrimmed test length of the sample and permits the extrusion to occur in one operation without resetting the piston or extrusion mechanism, (3) can be operated at a relatively uniform rate, and (4) causes negligible disturbance of the sample.

5.3. *Deformation Indicator*—The deformation indicator shall be a dial indicator graduated to 0.02 mm (0.001 in.) or better and having a travel range of at least 20 percent of the length of the test specimen, or some other measuring device, such as an electronic deformation measuring device, meeting these requirements.

5.4. *Dial Comparator*, or other suitable device, for measuring the physical dimensions of the specimen to within 0.1 percent of the measured dimension.

Note 3—Vernier calipers are not recommended for soft specimens, which will deform as the calipers are set on the specimen.

5.5. *Timer*—A timing device indicating the elapsed testing time to the nearest second shall be used for establishing the rate of strain application prescribed in Section 7.1.

5.6. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.7. *Equipment*, as specified in T 265, for drying moisture content samples.

5.8. *Miscellaneous Apparatus*, including specimen trimming and carving tools, remolding apparatus, data sheets, and water content cans, as required.

6. PREPARATION OF TEST SPECIMENS

6.1. *Specimen Size*—Specimens shall have a minimum diameter of 30 mm (1.3 in.) and the largest particle contained within the test specimen shall be smaller than one-tenth of the specimen diameter. For specimens having a diameter of 72 mm (2.8 in.) or larger, the largest particle size shall be smaller than one-sixth of the specimen diameter. If, after completion of a test on an undisturbed specimen, it is found, based on visual observation, that larger particles than permitted are present, indicate this information in the remarks section of the report of test data (Note 4). The height-to-diameter ratio shall be between 2 and 2.5. Determine the average height and diameter of the test specimen using the apparatus specified in Section 5.4. Take a minimum of three height measurements (120 degrees apart) and at least three diameter measurements at the quarter points of the height.

Note 4—If large soil particles are found in the sample after testing, a particle-sized analysis performed in accordance with T 88 may be performed to confirm the visual observation and the results provided with the test report.

6.2. *Undisturbed Specimens*—Prepare undisturbed specimens from large undisturbed samples or from samples secured in accordance with T 207 and preserved and transported in accordance with the practices for Group C samples in ASTM D 4220. Tube specimens may be tested without trimming except for the squaring of ends, if conditions of the sample justify this procedure. Handle specimens carefully to prevent disturbance, changes in cross section, or loss of water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut it off in small sections to facilitate removal of the specimen without disturbance. Prepare carved specimens without disturbance, and whenever possible, in a humidity-controlled room. Make every effort to prevent any change in water content of the soil. Specimens shall be of uniform circular cross section with ends perpendicular to the longitudinal axis of the specimen. When carving or trimming, remove any small pebbles or shells encountered. Carefully fill voids on the surface of the specimen with remolded soil obtained from the trimmings. When pebbles or crumbling result in excessive irregularity at the ends, cap the specimen with a minimum thickness of plaster of paris, hydrostone, or similar material. When sample condition permits, a vertical lathe that will accommodate the total sample may be used as an aid in carving the specimen to the required diameter. Where prevention of the development of appreciable capillary forces is deemed important, seal the specimen with a rubber membrane, thin plastic coatings, or with a coating of grease or sprayed plastic immediately after preparation and during the entire testing cycle. Determine the mass and dimensions of the test specimen. If the specimen is to be capped, its mass and dimensions should be determined before capping. If the entire test specimen is not to be used for determination of water content, secure a representative sample of cuttings for this purpose, placing them immediately in a covered container. The water content determination shall be performed in accordance with T 265.

6.3. *Remolded Specimens*—Specimens may be prepared either from a failed undisturbed specimen or from a disturbed sample, providing it is representative of the failed undisturbed specimen. In the case of failed undisturbed specimens, wrap the material in a thin rubber membrane and work the material thoroughly with the fingers to assure complete remolding. Avoid entrapping air in the specimen. Exercise care to obtain a uniform density, to remold to the same void ratio as the undisturbed specimen, and to preserve the natural water content of the soil. Form the disturbed material into a mold of circular cross section having dimensions meeting the requirements of Section 6.1. After removal from the mold, determine the mass and dimensions of the test specimens.

6.4. *Compacted Specimens*—Specimens shall be prepared to the predetermined water content and density prescribed by the individual assigning the test (Note 5). After a specimen is formed, trim the ends perpendicular to the longitudinal axis, remove from the mold, and determine the mass and dimensions of the test specimen.

Note 5—Experience indicates that it is difficult to compact, handle, and obtain valid results with specimens that have a degree of saturation that is greater than 90 percent.

7. PROCEDURE

7.1. Place the specimen in the loading device so it is centered on the bottom platen. Adjust the loading device carefully so the upper platen just makes contact with the specimen. Zero the deformation indicator. Apply the load so as to produce an axial strain at a rate of 0.5 to 2 percent per minute. Record load, deformation, and time values at sufficient intervals to define the shape of the stress-strain curve (usually 10 to 15 points are sufficient). The rate of strain should be chosen so the time to failure does not exceed about 15 minutes (Note 6). Continue loading until the load values decrease with increasing strain, or until 15 percent strain is reached. The rate of strain used for testing sealed specimens may be decreased if deemed desirable for better test results. Indicate the rate of strain in the report of the test data, as required in Section 9.1.7. Determine the moisture content of the test specimen in accordance with T 265, Laboratory Determination of Moisture Content of Soils, using the entire specimen unless representative cuttings are obtained for this purpose as in the case of undisturbed specimens. Indicate on the test report whether the water content sample was obtained before or after the shear test, as required in Section 9.1.2.

Note 6—Softer materials that will exhibit larger deformation at failure should be tested at a higher rate of strain. Conversely, stiff or brittle materials that will exhibit small deformations at failure should be tested at a lower rate of strain.

7.2. Make a sketch, or take a photo, of the test specimen at failure showing the slope angle of the failure surface if the angle is measurable.

7.3. A copy of a sample data sheet is included in the Appendix. Any data sheet can be used, provided the form contains all the required data.

8. CALCULATIONS

8.1. Calculate the axial strain, $\in_1$, to the nearest 0.1 percent, for a given applied load, as follows:

$$\in_1 = \Delta L / L_o \qquad (1)$$

where:

ΔL = length change of specimen as read from deformation indicator, mm (in.); and

L_o = initial length of test specimen, mm (in.).

8.2. Calculate the average cross-sectional area, A, for a given applied load, as follows:

$$A = A_o/(1 - \in_1) \qquad (2)$$

where:

A_o = initial average cross-sectional area of the specimen, mm^2 (in.^{2}); and

$\in_1$ = axial strain for the given load, percent.

8.3. Calculate the compressive stress, σ_c, to three significant figures, or nearest 1 kPa (0.01 ton/ft^2), for a given applied load, as follows:

$$\sigma_c = \frac{1000P}{A} \qquad (3)$$

where:

P = given applied load, N; and

A = corresponding average cross-sectional area m^2 (ft^2).

8.4. *Graph*—If desired, a graph showing the relationship between compressive stress (ordinate) and axial strain (abscissa) may be plotted. Select the maximum value of compressive stress, or the compressive stress at 15 percent axial strain, whichever is secured first, and report as the unconfined compressive strength, q_u. Whenever it is considered necessary for proper interpretation, include the graph of the stress-strain data as part of the data reported.

8.5. If the unconfined compressive strength is determined, the sensitivity, S_T, is calculated as follows:

$$S_T = \frac{q_u(\text{undisturbed specimen})}{q_u(\text{remolded specimen})} \qquad (4)$$

9. REPORT

9.1. The report should include the following:

9.1.1. Identification and visual description of the specimen, including soil classification, symbol, and whether the specimen is undisturbed, remolded, compacted, etc. Also include specimen identifying information, such as project, location, boring number, sample number, depth, etc.;

9.1.2. Initial dry density and water content (specify if the water content specimen was obtained before or after shear, and whether from cuttings or the entire specimen);

9.1.3. Degree of saturation (Note 7), if computed;

Note 7—The specific gravity determined in accordance with T 100 is required for calculation of the degree of saturation.

9.1.4. Unconfined compressive strength and shear strength;

9.1.5. Average height and diameter of specimen;

9.1.6. Height-to-diameter ratio;

9.1.7. Average rate of strain to failure, percent;

9.1.8. Strain at failure, percent;

9.1.9. Liquid and plastic limits, if determined, in accordance with T 88 and T 90;

9.1.10. Failure sketch or photo;

9.1.11. Stress-strain graph, if prepared;

9.1.12. Sensitivity, if determined;

9.1.13. Particle-size analysis, if determined, in accordance with T 88; and

9.1.14. *Remarks*—Note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained; for example, slickensides, stratification, shells, pebbles, roots, or brittleness, the type of failure (that is, bulge, diagonal shear, etc.).

10. PRECISION AND BIAS

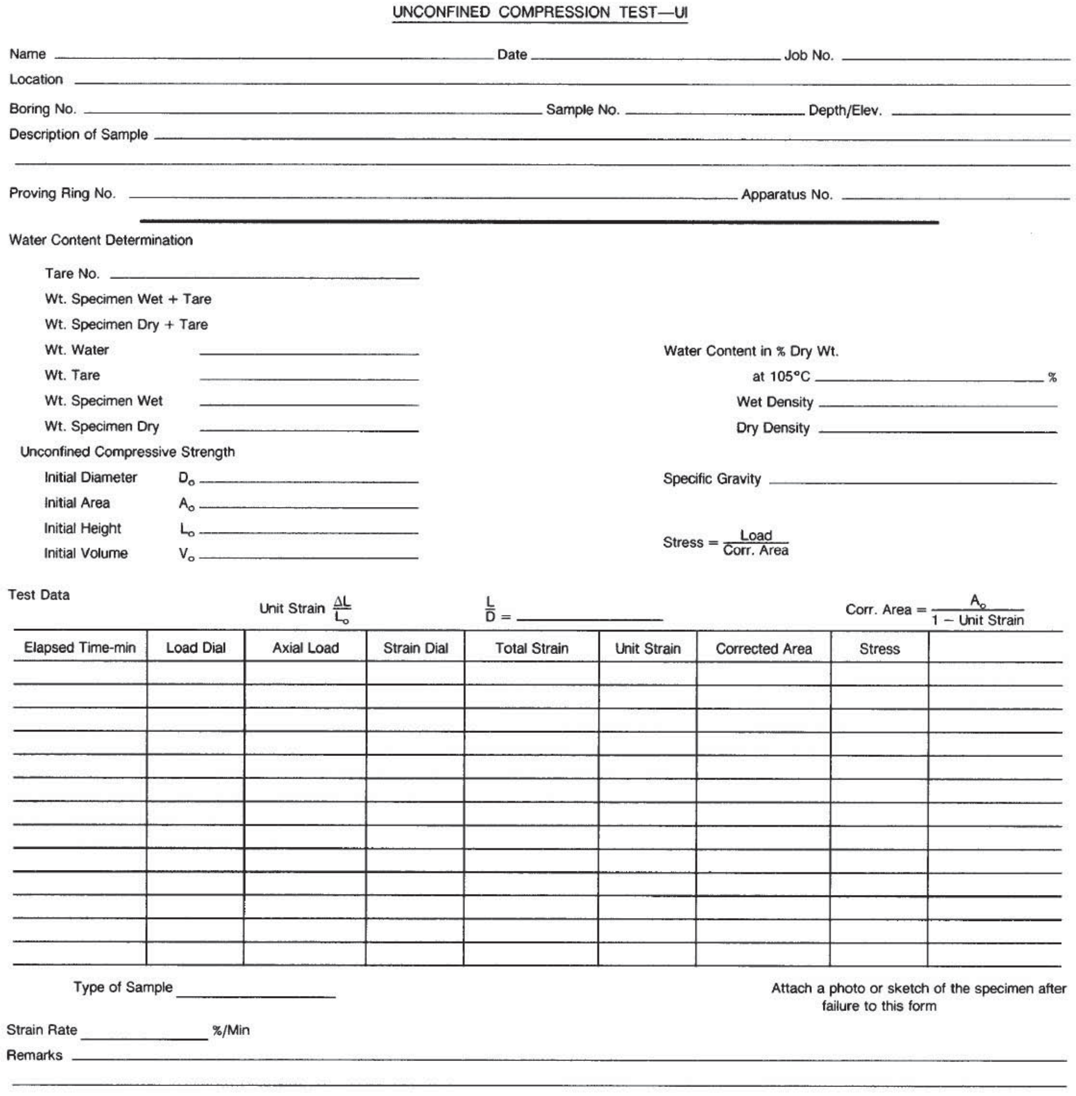
10.1. No method presently exists to evaluate the precision of a group of unconfined compression tests on undisturbed specimens due to specimen variability. Undisturbed soil specimens from apparently homogeneous soil deposits at the same location often exhibit significantly different strength and stress-strain properties.

10.2. A suitable test material and method of specimen preparation have not been developed for the determination of laboratory variances due to the difficulty in producing identical cohesive soil specimens. No estimates of precision for this test method are available.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE OF A VERIFICATION OF CALIBRATION PROGRAM FOR LABORATORIES



UNCONFINED COMPRESSION TEST—UI

Name Date Job No.
Location
Boring No. Sample No. Depth/Elev.
Description of Sample

Proving Ring No. Apparatus No.

Water Content Determination

Tare No.
Wt. Specimen Wet + Tare
Wt. Specimen Dry + Tare
Wt. Water
Wt. Tare
Wt. Specimen Wet
Wt. Specimen Dry

Water Content in % Dry Wt.
at 105°C %
Wet Density
Dry Density

Unconfined Compressive Strength

Initial Diameter D_o
Initial Area A_o
Initial Height L_o
Initial Volume V_o

Specific Gravity

Stress = $\frac{\text{Load}}{\text{Corr. Area}}$

Test Data

Unit Strain $\frac{\Delta L}{L_o}$

$\frac{L}{D}$ =

Corr. Area = $\frac{A_o}{1 - \text{Unit Strain}}$

Elapsed Time-min	Load Dial	Axial Load	Strain Dial	Total Strain	Unit Strain	Corrected Area	Stress	

Type of Sample

Attach a photo or sketch of the specimen after failure to this form

Strain Rate %/Min
Remarks

Figure X1.1—Example Data Sheet

Standard Method of Test for

Determination of Cement Content in Cement-Treated Aggregate by the Method of Titration

AASHTO Designation: T 211-90 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determination of Cement Content in Cement-Treated Aggregate by the Method of Titration

AASHTO Designation: T 211-90 (2008)

1. SCOPE

1.1. This method of test covers a procedure for determining cement content based upon the continuous neutralization of an aqueous solution from the cement-treated aggregate specimen for a specified time period. This is accomplished by adding sufficient acid to just neutralize the OH^- ion that is continuously being liberated during the hydration of the cement. The amount of acid used is directly proportional to the cement content of the treated base sample.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures, used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. APPARATUS

2.1. A 100-mL titrating burette or other device permitting slow, easily controlled addition of acid.

2.2. A burette stand and burette clamp.

2.3. Four 1.9-L (2-qt) wide-mouth polyethylene containers (white).

2.4. Two 18.9-L (5-gal) plastic carboys equipped with siphons, neoprene or tygon tubing hose clamps, etc., for containing acid working solution and water (do not substitute glass containers for the plastic carboys).

2.5. Glass dropping bottle.

2.6. Four stainless steel stirring rods.

2.7. 9.5-mm sieve, 305-mm (12-in.) diameter.

2.8. 37.5-mm sieve, 305-mm (12-in.) diameter.

2.9. A balance or scale conforming to the requirements of M 231, Class G 2, and Class G 5.

3. REAGENTS

3.1. *Hydrochloric Acid (HCl) (Approximately 3 Normal)*—Pour approximately 11.4 L (3 gal) of water into an 18.9-L (5-gal) plastic carboy. Pour the contents of two full standard 2.7-kg (6-lb) bottles of concentrated reagent-grade HCl in the carboy. Stir or mix the solution vigorously for about 1 minute. Add tap water as necessary to bring the total volume of water and acid to 18.9 L (5 gal): then stir or mix the solution vigorously for another minute. Allow the acid solution to stand overnight; then remix it once again prior to using. Remix the acid solution once a week during use and also before using if the acid solution has been in storage for more than one week.

Note 1—The operator mixing the acid solution is required, for safety, to wear protective gloves, goggles, and aprons.

3.2. *Phenolphthalein Indicator Solution (1-Percent Solution)*—Dissolve 5 g of phenolphthalein powder U.S.P. in 250 mL of ethanol. Dilute with 250 mL of distilled water.

4. DETERMINATION OF A STANDARD CURVE

4.1. Use the particular aggregate, cement, and water from the project. Normally only one point is needed to establish the standard curve and this point is determined from duplicate tests on specimens containing 5 percent cement. However, if a small sample of untreated aggregate in water shows a red color on adding a few drops of phenolphthalein solution, indicating the presence of water soluble alkalis, then duplicate aggregate blank specimens should also be tested.

4.2. Determine a representative field moisture in percent for the cement-treated material from road moisture samples obtained after mixing.

4.3. Refer to Table 1 and select the mass of aggregate corresponding to the appropriate moisture content and 5 percent cement. This figure is the dry mass of untreated aggregate required to make a 5 percent calibration test specimen of 300 g. If the samples of untreated aggregate initially contain moisture, then adjust the mass of aggregate plus water to conform to the tabular values.

Table 1—Quantities of Materials for Calibration Specimens Containing 5-Percent Cement

Percent Moisture	Dry Mass of Aggregate, g	Volume of Water, mL	Mass of Cement, g
5	271	15	13.6
6	270	17	13.5
7	267	20	13.3
8	265	22	13.2
9	263	24	13.1
10	260	27	13.0
11	257	30	12.9
12	255	32	12.8
13	252	35	12.6
14	250	37	12.5
15	249	39	12.4
16	247	41	12.3
17	244	44	12.2
18	242	46	12.1
19	240	48	12.0
20	238	50	11.9

4.4. From the project records determine the average percentage of untreated aggregate passing the 9.5-mm sieve. This percentage passing the 9.5-mm sieve along with the portion retained on the 9.5-mm sieve will be the proportion used for the calibration specimens.

4.5. Remove and waste any aggregate in the sample of untreated material retained on the 37.5-mm sieve and then separate the sample on the 9.5-mm sieve. Recombine for duplicate calibration test specimens with the aggregate mass found in Section 4.3, and with the 9.5-mm sieve proportions found in Section 4.4.

4.6. Pour the weighed aggregate and cement (cement weighed to 0.1 g) into the 1.9-L (2-qt) plastic container and dry mix together thoroughly with a stainless steel stirring rod.

4.7. Add the amount of water specified in Table 1 and again mix thoroughly.

4.8. In order to correlate with the field testing operations, allow the mixture to stand in the covered plastic container for a period of time that corresponds to the time required to obtain a field treated sample, transport it to the testing location and prepare the 300 g test specimens.

4.9. Add 250 mL of tap water to each specimen and start timer.

4.10. Add two droppers full (approximately 40 drops) of phenolphthalein solution to each container. The water solution will normally turn red due to the presence of cement.

4.11. Determine the mass of each plastic container, including its contents, to the nearest 0.5 g.

4.12. Ten minutes after the addition of water, start adding the 3 Normal hydrochloric acid with a titrating burette while stirring continuously.

4.12.1. The initial amount of acid to be added is based upon the planned cement content of the mix and is determined from Figure 1.

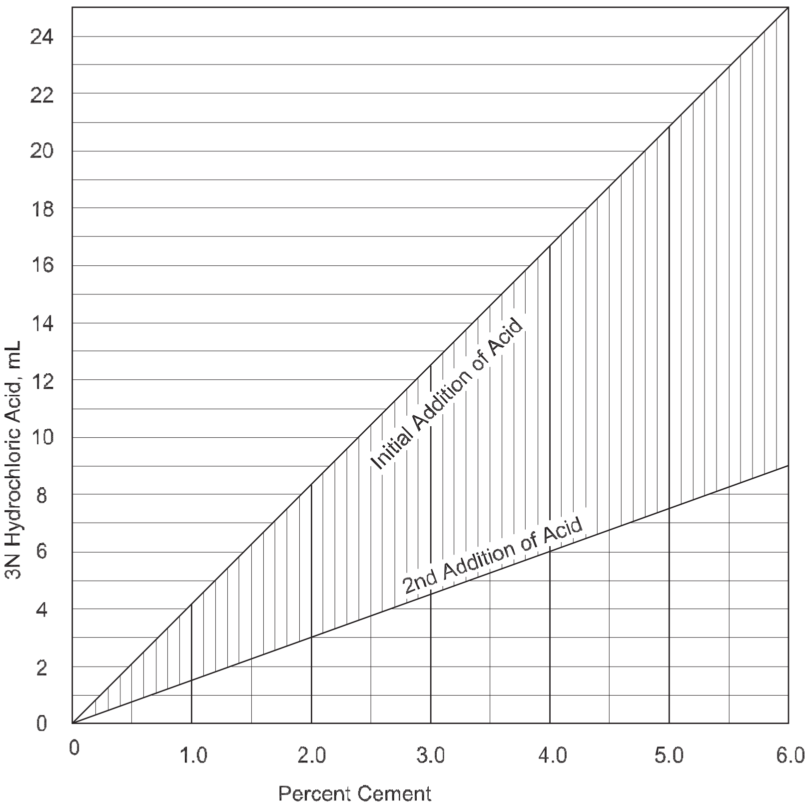


Figure 1—Constant Neutralization Procedure—Hydrochloric Acid Starting Quantities

4.12.1.1. *Example*: Suppose the planned cement content for a given project is 3.5 percent. Enter the abscissa of the chart in Figure 1 at 3.5 percent and find the intersection with the upper diagonal line. Reading from the ordinate to the nearest milliliter, it is noted that 15 mL of HCl is required. Use the titrating burette to measure and add the 15 mL of acid to the specimen in the plastic container. When the proper amount of acid is used, the red color in the solution will disappear.

4.12.2. When the red color starts to reappear, after the initial introduction of acid, use the burette to make a second addition of acid in the amount (mL) indicated by the lower diagonal line (at the planned cement content) of the chart in Figure 1.

4.13. After the first two additions of acid, make subsequent additions at random as soon as the red color reappears using only the minimum amounts necessary to cause the color to just disappear and maintain a neutral solution. This requires constant attention by the operator.

4.14. Besides the stirring accomplished during each introduction of acid, additional light stirring (for about three seconds) should be performed every minute with every fifth minute being devoted to deep stirring (for about six seconds), whether or not color is present.

4.15. Continue this procedure of adding acid and stirring until 1 hour after the initial addition of water to the specimen. Then reweigh the plastic container and contents to the nearest 0.5 g.

4.16. From the difference between the initial and final gross test specimen masses, calculate and record the total mass of hydrochloric acid used to neutralize the solution.

4.17. Plot the grams of acid used against percent cement for both duplicate 5 percent cement specimens (also aggregate blank specimens if tested). Draw a straight line from the origin of the chart (or the average of the duplicate blanks) to the average of the tests on the 5 percent specimens. This is the standard curve for determining the cement content of field mixed cement-treated specimens.

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5. TEST PROCEDURE FOR FIELD SAMPLES

5.1. Secure one to four 3-kg field samples of the cement-treated aggregate. Remove and waste any aggregate retained on the 37.5-mm sieve. Separate sample on the 9.5-mm sieve and determine the proportion passing the 9.5-mm sieve on the basis of total sample mass including retained 37.5-mm material.

5.2. Recombine the retained and passing 9.5-mm portions for the 300-g test specimens in their "As received" proportions, place each specimen in a separate 1.9-L (2-qt) plastic container, and line the containers up along the front of the work bench. Follow steps in Sections 4.9 through 4.16.

5.3. Using the resulting mass of hydrochloric acid, determine the percentage of cement in the specimens from the standard curve established in Section 4.17.

5.4. Report cement content to the nearest 0.1 percent.

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6. PRECAUTIONS

6.1. This test should not be performed by persons subject to "color blindness."

6.2. It is very important that the operator vigilantly maintain a neutral solution by repeatedly adding acid as soon as the pink color reappears.

6.3. After the first two additions of acid, use only the amount necessary to just eliminate the red color. Excess acid may attack the aggregates, particularly in the later phases when the amount of hydration products from the cement remaining in the mixture may be low.

Standard Method of Test for

Permeability of Granular Soils (Constant Head)

AASHTO Designation: T 215-70 (2007)
ASTM Designation: D 2434-68 (1994)$^{\epsilon 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Permeability of Granular Soils (Constant Head)

AASHTO Designation: T 215-70 (2007)
ASTM Designation: D 2434-68 (1994)$^{\in 1}$

AASHTO T 215-70 (2007) is identical to ASTM D 2434-68 (1994)$^{\in 1}$ except that all references to ASTM Standard D 422 contained in ASTM D 2434-68 (1994)$^{\in 1}$ shall be replaced with AASHTO Standard T 88.

Standard Method of Test for

One-Dimensional Consolidation Properties of Soils

AASHTO Designation: T 216-07
ASTM Designation: D 2435-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

One-Dimensional Consolidation Properties of Soils

AASHTO Designation: T 216-07
ASTM Designation: D 2435-04

1. SCOPE

1.1. This test method covers procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. Two alternative procedures are provided as follows:

1.1.1. *Test Method A*—This test method is performed with constant load increment duration of 24 hours, or multiples thereof. Time-deformation readings are required on a minimum of two-load increments.

1.1.2. *Test Method B*—Time-deformation readings are required on all load increments. Successive load increments are applied after 100 percent primary consolidation is reached, or at constant time increments as described in Test Method A.

Note 1—The determination of the rate and magnitude of consolidation of soil when it is subjected to controlled-strain loading is covered by ASTM D 4186.

1.2. This test method is most commonly performed on undisturbed samples of fine grained soils naturally sedimented in water; however, the basic test procedure is applicable as well to specimens of compacted soils and undisturbed samples of soils formed by other processes such as weathering or chemical alteration. Evaluation techniques specified in this test method are generally applicable to soils naturally sedimented in water. Tests performed on other soils, such as compacted and residual (weathered or chemically altered) soils, may require special evaluation techniques.

1.3. It shall be the responsibility of the agency requesting this test to specify the magnitude and sequence of each load increment, including the location of a rebound cycle, if required, and, for Test Method A, the load increments for which time-deformation readings are desired.

Note 2—Time-deformation readings are required to determine the time for completion of primary consolidation and for evaluating the coefficient of consolidation, c_v. Since c_v varies with stress level and load increment (loading or unloading), the load increments with timed readings must be selected with specific reference to the individual project. Alternatively, the requesting agency may specify Test Method B wherein the time-deformation readings are taken on all load increments.

1.4. The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate and given for guidance only. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

1.4.1. In the engineering profession, it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ($F = Ma$) are involved. This implicitly combines two separate systems of units; that is, the absolute system and the gravimetric system. It is scientifically undesirable to combine two separate systems within a single standard. This test method has been written using SI units; however, inch-pound conversions are given in the gravimetric system, where the pound (lbf) represents a unit of force (weight). The use of balances or scales recording pounds of mass (lbm), or the recording of density in lb/ft^3, should not be regarded as nonconformance with this test method.

1.5. *This standard does not purport to address the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 100, Specific Gravity of Soils
- T 207, Thin-Walled Tube Sampling of Soils
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids
- D 2435, Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 3550, Standard Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
- D 4186, Standard Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading
- D 4220, Standard Practices for Preserving and Transporting Soil Samples
- D 4452, Standard Practice for X-Ray Radiography of Soil Samples
- D 4546, Standard Test Methods for One-Dimensional Swell or Collapse of Cohesive Soils
- D 6026, Standard Practice for Using Significant Digits in Geotechnical Data

3. TERMINOLOGY

3.1. *Definitions*—The definitions of terms used in this test method shall be in accordance with ASTM D 653.

4. SUMMARY OF TEST METHOD

4.1. In this test method, a soil specimen is restrained laterally and loaded axially with total stress increments. Each stress increment is maintained until excess pore water pressures are completely dissipated. During the consolidation process, measurements are made of change in the specimen height and these data are used to determine the relationship between the effective stress and void ratio or strain, and the rate at which consolidation can occur by evaluating the coefficient of consolidation.

5. SIGNIFICANCE AND USE

5.1. The data from the consolidation test are used to estimate the magnitude and rate of both differential and total settlement of a structure or earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

5.2. The test results can be greatly affected by sample disturbance. Careful selection and preparation of test specimens is required to minimize disturbance.

5.3. Consolidation test results are dependent upon the magnitude of the load increments. Traditionally, the load is doubled for each increment resulting in a load-increment ratio of one. For undisturbed samples, this load procedure has provided data from which estimates of the preconsolidation pressure also referred to as the maximum past pressure, using established evaluation techniques, compare directly with field measurement. Other load schedules may be used to model particular field conditions or meet special requirements. For example, it may be desirable to inundate and load the specimen in accordance with the wetting or loading pattern expected in the field in order to best simulate the response. Smaller than standard load increment ratios may be desirable for soils that are highly sensitive or whose response is highly dependent on strain rate. The test method specified to estimate the preconsolidation pressure provides a simple technique to verify that one set of time readings are taken after the preconsolidation pressure. Several other evaluation techniques exist and may yield different estimates of the preconsolidation pressure. Therefore, the requesting agency may specify an alternate technique to estimate the preconsolidation pressure.

5.4. Consolidation test results are dependent upon the duration of each load increment. Traditionally, the load duration is the same for each increment and equal to 24 hours. For some soils, the rate of consolidation is such that complete consolidation (dissipation of excess pore pressure) will require more than 24 hours. The apparatus in general use does not have provisions for formal verification of pore pressure dissipation. It is necessary to use an interpretation technique that indirectly determines that consolidation is complete. This test method specifies two techniques; however, the requesting agency may specify an alternative technique and still be in conformance with this test method.

5.5. The apparatus in general use for this test method does not have provisions for verification of saturation. Most undisturbed samples taken from below the water table will be saturated. However, the time rate of deformation is very sensitive to degree of saturation and caution must be exercised regarding estimates for duration of settlements when partially saturated conditions prevail. The extent to which partial saturation influences the test results may be a part of the test evaluation and may include application of theoretical models other than conventional consolidation theory. Alternatively, the test may be performed using an apparatus equipped to saturate the specimen.

5.6. This test method uses conventional consolidation theory based on Terzaghi's consolidation equation to compute the coefficient of consolidation, c_v. The analysis is based upon the following assumptions:

5.6.1. The soil is saturated and has homogeneous properties;

5.6.2. The flow of pore water is in the vertical direction;

5.6.3. The compressibility of soil particles and pore water is negligible compared to the compressibility of the soil skeleton;

5.6.4. The stress-strain relationship is linear over the load increment;

5.6.5. The ratio of soil permeability to soil compressibility is constant over the load increment; and

5.6.6. Darcy's law for flow through porous media applies.

6. APPARATUS

6.1. *Load Device*—A suitable device for applying vertical loads or total stresses to the specimen. The device should be capable of maintaining specified loads for long periods of time with an accuracy of ±0.5 percent of the applied load and should permit quick application of a given load increment without significant impact.

Note 3—Load application generally should be completed in a time corresponding to 0.01 t_{100} or less. For soils where primary consolidation is completed in 3 minutes load application should be less than 2 seconds.

6.2. *Consolidometer*—A device to hold the specimen in a ring that is either fixed to the base or floating (supported by friction on periphery of specimen) with porous disks on each face of the specimen. The inside diameter of the ring shall be determined to a tolerance of 0.075 mm (0.003 in.). The consolidometer shall also provide a means of submerging the specimen, for transmitting the concentric vertical load to the porous disks, and for measuring the change in height of specimen.

6.2.1. *Minimum Specimen Diameter*—The minimum specimen diameter shall be 50 mm (2.00 in.). The diameter of the sample in the tube shall be greater than the diameter of the consolidation test ring. The diameter of the sample must be greater than the test ring to reduce sampling disturbance and prevent lateral displacement.

6.2.2. *Minimum Specimen Height*—The minimum initial specimen height shall be 12 mm (0.5 in.), but shall not be less than 10 times the maximum particle diameter.

Note 4—If large particles are found in the specimen after testing, include in the report this visual observation or the results of a particle-sized analysis in accordance with T 88 (except the minimum sample-sized requirement shall be waived).

6.2.3. *Minimum Specimen Diameter-to-Height Ratio*—The minimum specimen diameter-to-height ratio shall be 2.5.

Note 5—The use of greater diameter-to-height ratios is recommended. To minimize the effects of friction between the sides of the specimen and ring, a diameter-to-height ratio greater than four is preferable.

6.2.4. *Specimen Ring Rigidity*—The rigidity of the ring shall be such that, under hydrostatic stress conditions in the specimen, the change in diameter of the ring will not exceed 0.03 percent of the diameter under the greatest load applied.

6.2.5. *Specimen Ring Material*—The ring shall be made of a material that is noncorrosive in relation to the soil tested. The inner surface shall be highly polished or shall be coated with a low-friction material. Silicone grease or molybdenum disulfide is recommended; polytetrafluoroethylene is recommended for non-sandy soils.

6.3. *Porous Disks*—The porous disks shall be of silicon carbide, aluminum oxide, or similar noncorrosive material. The grade of the disks shall be fine enough to prevent intrusion of soil into the pores. If necessary, a filter paper (Note 6) may be used to prevent intrusion of the soil into the disks; however, the permeability of the disks, and filter paper, if used, must be at least one order of magnitude higher than that of the specimen.

Note 6—Whatman No. 54 filter paper has been found to meet requirements for permeability and durability.

6.3.1. *Diameter*—The diameter of the top disk shall be 0.2 to 0.5 mm (0.01 to 0.02 in.) less than the inside diameter of the ring. If a floating ring is used, the bottom disk shall have the same diameter as the top disk.

Note 7—The use of tapered disks is recommended, with the larger diameter in contact with the soil.

6.3.2. *Thickness*—Thickness of the disks shall be sufficient to prevent breaking. The top disk shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the disk.

6.3.3. *Maintenance*—The disks shall be clean and free from cracks, chips, and nonuniformities. New porous disks should be boiled for at least 10 minutes and left in the water to cool to ambient temperature before use. Immediately after each use, clean the porous disks with a nonabrasive brush and boil to remove clay particles that may reduce their permeability. It is recommended that porous disks be stored in a jar with de-aired water between tests.

6.4. *Specimen Trimming Device*—A trimming turntable or a cylindrical cutting ring may be used for trimming the sample down to the inside diameter of the consolidometer ring with a minimum of disturbance. A cutter having the same inside diameter as the specimen ring shall attach to or be integral with the specimen ring. The cutter shall have a sharp edge, a highly polished surface, and be coated with a low-friction material. Alternatively, a turntable or trimming lathe may be used. The cutting tool must be properly aligned to form a specimen of the same diameter as that of the ring.

6.5. *Deformation Indicator*—To measure change in specimen height, with a readability of 0.0025 mm (0.0001 in.).

6.6. *Miscellaneous Equipment*—Including timing device with 1-second readability, distilled or demineralized water, spatulas, knives, and wire saws, used in preparing the specimen.

6.7. *Balances*, in accordance with T 265.

6.8. *Drying Oven*, in accordance with T 265.

6.9. *Water Content Containers*, in accordance with T 265.

6.10. *Environment*—Tests shall be performed in an environment where temperature fluctuations are less than ±4ºC (±7ºF) and there is no direct exposure to sunlight.

7. STANDARDIZATION

7.1. The measured vertical deformations must be corrected for apparatus flexibility whenever the calibration correction determined in Section 7.4 exceeds 5 percent of the measured deformation and in all tests where filter paper disks are used.

7.2. Assemble the consolidometer with a copper or hard steel disk of approximately the same height as the test specimen and at least 1 mm (0.04 in.) smaller in diameter than the ring, but no more than 5 mm smaller in diameter than the ring, in place of the sample. Moisten the porous disks. If filter papers are to be used (Section 6.3), they should be moistened and sufficient time (a minimum of 2 minutes) allowed for the moisture to be squeezed from them during each increment of the calibration process.

7.3. Load and unload the consolidometer as in the test and measure the deformation for each load applied. When filter papers are used, it is imperative that calibration be performed following the exact loading and unloading schedule to be used. This is due to the inelastic deformation characteristics of filter paper. Recalibration for tests without filter paper need be done only on an annual basis, or after replacement and reassembly of apparatus components.

7.4. At each load applied, plot or tabulate the corrections to be applied to the measured deformation of the test specimen. Note that the metal disk will deform also; however, the correction due to this deformation will be negligible for all but extremely stiff soils. If necessary, the compression of the metal disk can be computed and applied to the corrections.

8. SAMPLING

8.1. AASHTO T 207 and ASTM D 3550 cover procedures and apparatus that may be used to obtain undisturbed samples generally satisfactory for testing (Note 8). Specimens may also be trimmed from large undisturbed block samples fabricated and sealed in the field. Finally, remolded specimens may be prepared from bulk samples to density and moisture conditions stipulated by the agency requesting the test.

Note 8—Not all tube diameters specified may be of sufficient size for testing.

8.2. Undisturbed samples destined for testing in accordance with this test method shall be preserved, handled, and transported in accordance with the practices for Group C and D samples in ASTM D 4220. Bulk samples for remolded specimens should be handled and transported in accordance with the practice for Group B samples.

8.3. *Storage*—Storage of sealed samples should be such that no moisture is lost during storage; that is, no evidence of partial drying of the ends of the samples or shrinkage. Time of storage should be minimized, particularly when the soil or soil moisture is expected to react with the sample tubes.

8.4. The quality of consolidation test results diminishes greatly with sample disturbance. It should be recognized that no sampling procedure can ensure completely undisturbed samples. Therefore, careful examination of the sample is essential in selection of specimens for testing.

Note 9—Examination for sample disturbance, stones, or other inclusions, and selection of specimen location is greatly facilitated by x-ray radiography of the samples. (See ASTM D 4452.)

9. SPECIMEN PREPARATION

9.1. All possible precautions should be taken to minimize disturbance of the soil or changes in moisture and density during specimen preparation. Avoid vibration, distortion, and compression.

9.2. Prepare test specimens in an environment where soil moisture change during preparation is minimized.

Note 10—A high-humidity environment is usually used for this purpose.

9.3. Trim the specimen and insert it into the consolidation ring. When specimens come from undisturbed soil collected using sample tubes, the inside diameter of the tube shall be at least 5 mm (0.25 in.) greater than the inside diameter of the consolidation ring, except as noted in Sections 9.4 and 9.5. It is recommended that either a trimming turntable or cylindrical cutting ring be used to cut the soil to the proper diameter. When using a trimming turntable, make a complete perimeter cut, reducing the specimen diameter to the inside diameter of the consolidation ring. Carefully insert the specimen into the consolidation ring, by the width of the cut, with a minimum of force. Repeat until the specimen protrudes from the bottom of the ring. When using a cylindrical cutting ring, trim the soil to a gentle taper in front of the cutting edge. After the taper is formed, advance the cutter a small distance to form the final diameter. Repeat the process until the specimen protrudes from the ring.

9.4. Fibrous soils, such as peat, and those soils that are easily damaged by trimming, may be transferred directly from the sampling tube to the ring, provided that the ring has the same diameter as the sample tube.

9.5. Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of ASTM D 3550 and this test method.

9.6. Trim the specimen flush with the plane ends of the ring. The specimen may be recessed slightly below the top of the ring, to facilitate centering of the top stone, by partial extrusion and trimming of the bottom surface. For soft to medium soils, a wire saw should be used for trimming the top and bottom of the specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soils, a sharpened straightedge alone may be used for trimming the top and bottom. If a small particle is encountered in any surface being trimmed, it should be removed and the resulting void filled with soil from the trimmings.

Note 11—If, at any stage of the test, the specimen swells beyond its initial height, the requirement of lateral restraint of the soil dictates the use of a recessed specimen or the use of a specimen ring equipped with an extension collar of the same inner diameter as the specimen ring. At no time should the specimen extend beyond the specimen ring or extension collar.

9.7. Determine the initial wet mass of the specimen, M_{T_o}, in the consolidation ring by measuring the mass of the ring with the specimen and subtracting the tare mass of the ring.

9.8. Determine the initial height, H_o, of the specimen to the nearest 0.025 mm (0.001 in.) by taking the average of at least four evenly spaced measurements over the top and bottom surfaces of the specimen using a dial comparator or other suitable measuring device.

9.9. Compute the initial volume, V_o, of the specimen to the nearest 0.25 cm^3 (0.015 in.^3) from the diameter of the ring and the initial specimen height.

9.10. Obtain two or three natural water content determinations of the soil in accordance with T 265 from material trimmed adjacent to the test specimen, if sufficient material is available.

9.11. When index properties are specified by the requesting agency, store the remaining trimmings taken from around the specimen and determined to be similar material in a sealed container for determination as described in Section 10.

10. SOIL INDEX PROPERTY DETERMINATIONS

10.1. The determination of index properties is an important adjunct to but not a requirement of the consolidation test. These determinations when specified by the requesting agency should be made on the most representative material possible. When testing uniform materials, all index tests may be performed on adjacent trimmings collected in Section 9.11. When samples are heterogeneous or trimmings are in short supply, index tests should be performed on material from the test specimen as obtained in Section 11.6, plus representative trimmings collected in Section 9.11.

10.2. *Specific Gravity*—The specific gravity shall be determined in accordance with T 100 on material from the sample as specified in Section 10.1. The specific gravity from another sample judged to be similar to that of the test specimen may be used for calculation in Section 12.2.5 whenever an accurate void ratio is not needed.

10.3. *Atterberg Limits*—The liquid limit shall be determined in accordance with T 89. The plastic limit and plasticity index shall be determined in accordance with T 90 using material from the sample as specified in Section 10.1. Determination of the Atterberg limits is necessary for proper material classification but is not a requirement of this test method.

10.4. *Particle-Sized Distribution*—The particle-sized distribution shall be determined in accordance with T 88 (except the minimum sample-sized requirement shall be waived) on a portion of the test specimen as obtained in Section 11.6. A particle-sized analysis may be helpful when visual inspection indicates that the specimen contains a substantial fraction of coarse-grained material, but is not a requirement of this test method.

11. PROCEDURE

11.1. Preparation of the porous disks and other apparatus will depend on the specimen being tested. The consolidometer must be assembled in such a manner as to prevent a change in water content of the specimen. Dry porous disks and filters must be used with dry, highly expansive soils and may be used for all other soils. Damp disks may be used for partially saturated soils. Saturated disks may be used when the specimen is saturated and known to have a low affinity for water. Assemble the ring with specimen, porous disks, filter disks (when needed), and consolidometer. If the specimen will not be inundated shortly after application of the seating load (Section 11.2), enclose the consolidometer in a loose-fitting plastic or rubber membrane to prevent change in specimen volume due to evaporation.

Note 12—In order to meet the stated objectives of this test method, the specimen must not be allowed to swell in excess of its initial height prior to being loaded beyond its preconsolidation pressure. Detailed procedures for the determination of one-dimensional swell or settlement potential of cohesive soils is covered by ASTM D 4546.

11.2. Place the consolidometer in the loading device and apply a seating pressure of 5 kPa (100 lbf/ft^2). Immediately after application of the seating load, adjust the deformation indicator and record the initial zero reading, d_o. If necessary, add additional load to keep the specimen from swelling. Conversely, if it is anticipated that a load of 5 kPa (100 lbf/ft^2) will cause significant consolidation of the specimen, reduce the seating pressure to 2 or 3 kPa (about 50 lbf/ft^2) or less.

11.3. If the test is performed on an intact specimen that was either saturated under field conditions or obtained below the water table, inundate shortly after application of the seating load. As inundation and specimen wetting occur, increase the load as required to prevent swelling. Record the load required to prevent swelling and the resulting deformation reading. If specimen inundation is to be delayed to simulate specific conditions, then inundation must occur at a pressure that is sufficiently large to prevent swell. In such cases, apply the required load and inundate the specimen. Take time deformation readings during the inundation period as specified in Section 11.5. In such cases, note in the test report the pressure at inundation and the resulting changes in height.

11.4. The specimen is to be subjected to increments of constant total stress. The duration of each increment shall conform to guidelines specified in Section 11.5. The specific loading schedule will depend on the purpose of the test, but should conform to the following guidelines. If the slope and shape of a virgin compression curve or determination of the preconsolidation pressure is required, the final pressure shall be equal to or greater than four times the preconsolidation pressure. In the case of overconsolidated clays, a better evaluation of recompression parameters may be obtained by imposing an unload-reload cycle after the preconsolidation pressure has been defined. Details regarding location and extent of an unload-reload cycle is the option of the agency requesting the test (Section 1.3), however, unloading shall always span at least two decrements of pressure.

11.4.1. The standard loading schedule shall consist of a load increment ratio (LIR) of one which is obtained by doubling the pressure on the soil to obtain values of approximately 12, 25, 50, 100, 200, etc. kPa (250, 500, 1000, 2000, 4000, etc. lbf/ft^2).

11.4.2. The standard rebound or unloading schedule should be selected by halving the pressure on the soil (that is, use the same increments of Section 11.4.1, but in reverse order). However, if desired, each successive load can be only one-fourth as large as the preceding load; that is, skip a decrement.

11.4.3. An alternative loading, unloading, or reloading schedule may be employed that reproduces the construction stress changes or obtains better definition of some part of the stress deformation (compression) curve, or aids in interpreting the field behavior of the soil.

Note 13—Small increments may be desirable on highly compressible specimens or when it is desirable to determine the preconsolidation pressure with more precision. It should be cautioned, however, that load increment ratios less than 0.7 and load increments very close to the preconsolidation pressure may preclude evaluation for the coefficient of consolidation, c_v, and the end-of-primary consolidation as discussed in Section 12.

11.5. Before each pressure increment is applied, record the height or change in height, d_f, of the specimen. Two alternative procedures are available that specify the time sequence of readings and the required minimum load duration. Longer durations are often required during specific load increments to define the slope of the characteristic straight-line secondary compression portion of the deformation versus log of time graph. For such increments, sufficient readings should be taken near the end of the pressure increment to define this straight-line portion. It is not necessary to increase the duration of other pressure increments during the test.

11.5.1. *Test Method A*—The standard load increment duration shall be 24 hours. For at least two load increments, including at least one load increment after the preconsolidation pressure has been exceeded, record the height or change in height, d, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, and 30 minutes, and 1, 2, 4, 8, and 24 hours (or 0.09, 0.25, 0.49, 1, 4, 9 minutes, etc., if using Section 12.3.2 to present time-deformation data), measured from the time of each incremental pressure application. Take sufficient readings near the end of the pressure increment period to verify that primary consolidation is completed. For some soils, a period of more than 24 hours may be required to reach the end-of-primary consolidation (as determined in Section 12.3.1.1 or 12.3.2.3). In such cases, load increment durations greater than 24 hours are required. The load increment duration for these tests is usually taken at some multiple of 24 hours and should be the standard duration for all load increments of the test. The decision to use a time interval greater than 24 hours is usually based on experience with particular types of soils. If, however, there is a question as to whether a 24-hour period is adequate, a record of height or change in height with time should be made for the initial load increments in order to verify the adequacy of a 24-hour period. Load increment durations other than 24 hours shall be noted in the report. For pressure increments where time versus deformation data are not required, leave the load on the specimen for the same length of time as when time versus deformation readings are taken.

11.5.2. *Test Method B*—For each increment, record the height or change in height, d, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 minutes, and 1, 2, 4, 8, and 24 hours (or 0.09, 0.25, 0.49, 1, 4, 9 minutes, etc., if using Section 12.3.2 to present time deformation data), measured from the time of each incremental pressure application. The standard load increment duration shall exceed the time required for completion of primary consolidation as determined by Sections 12.3.1.1, 12.3.2.3 or a criterion set by the requesting agency. For each increment where it is impossible to verify the end of primary consolidation (for example, low LIR or rapid consolidation), the load increment duration shall be constant and exceed the time required for primary consolidation of an increment applied after the preconsolidation pressure and along the virgin compression curve. Where secondary compression must be evaluated, apply pressures for longer periods. The report shall contain the load increment duration for each increment.

Note 14—The suggested time intervals for recording height or change in height are for typical soils and load increments. It is often desirable to change the reading frequency to improve interpretation of the data. More rapid consolidation will require more frequent readings. For most soils, primary consolidation during the first load decrements will be complete in less time (typically one-tenth) than would be required for a load increment along the virgin compression curve; however, at very low stresses the rebound time can be longer.

11.6. To minimize swell during disassembly, rebound the specimen back to the seating load (5 kPa). Once height changes have ceased (usually overnight), dismantle quickly after releasing the final small load on the specimen. Remove the specimen and the ring from the consolidometer and wipe any free water from the ring and specimen. Determine the mass of the specimen in the ring and subtract the tare mass of the ring to obtain the final wet specimen mass, M_{T_f}. The most accurate determination of the specimen dry mass and water content is found by drying the entire specimen at the end of the test. If the soil sample is homogeneous and sufficient trimmings are available for the specified index testing (Section 9.11), then determine the final water content w_f, in accordance with T 265 and dry mass of solids, M_d, using the entire specimen. If the soil is heterogeneous or more material is required for the specified index testing, then determine the final water content, w_{f_p}, in accordance with T 265 using a small wedge shaped section of the specimen. The remaining undried material should be used for the specified index testing.

12. CALCULATION

12.1. Calculations as shown are based on the use of SI units. Other units are permissible, provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations. See Section 1.4.1 for additional comments on the use of inch-pound units.

12.2. *Specimen Properties*:

12.2.1. Obtain the dry mass of the total specimen, K_d, by direct measurement or for the case where part of the specimen is used for index testing, calculate the dry mass as follows:

$$M_d = \frac{M_{T_f}}{1 + w_{f_p}} \qquad (1)$$

where:

M_{T_f} = moist mass of total specimen after test, g or kg; and

w_{f_p} = water content (decimal form) wedge of specimen taken after test.

12.2.2. Calculate the initial and final water content, in percent, as follows:

initial water content:

$$w_o = \frac{M_{T_o} - M_d}{M_d} \times 100 \qquad (2)$$

final water content:

$$w_f = \frac{M_{T_f} - M_d}{M_d} \times 100 \qquad (3)$$

where:

M_d = dry mass of specimen, g or kg; and

M_{T_o} = moist mass of specimen before test, g or kg.

12.2.3. Calculate the initial dry density of the specimen as follows:

$$\rho_d = \frac{M_d}{V_o} \qquad (4)$$

where:

ρ_d = dry density of specimen, g/cm^3 or kg/m^3; and

V_o = initial volume of specimen, cm^3 or m^3.

12.2.4. Calculate the dry unit weight of the specimen as follows:

$$\gamma_d = 9.81 \times \rho_d / 1000 \qquad (5)$$

where:

γ_d = dry unit weight, kN/m^3

ρ_d = dry density, kg/m^3

12.2.5. Compute the volume of solids as follows:

$$V_s = \frac{M_d}{G\rho_w} \qquad (6)$$

where:

G = specific gravity of the solids, and

ρ_w = density of water, 1.0 g/cm^3 or Mg/m^3.

12.2.6. Since the cross-sectional area of the specimen is constant throughout the test, it is convenient for subsequent calculations to introduce the term “equivalent height of solids,” defined as follows:

$$H_s = \frac{V_s}{A} \qquad (7)$$

where:

A = specimen area, cm^2 or mm^2.

12.2.7. Calculate void ratio before and after test as follows:

void ratio before test:

$$e_o = \frac{H_o - H_s}{H_s} \tag{8}$$

void ratio after test:

$$e_f = \frac{H_f - H_s}{H_s} \tag{9}$$

where:

H_o = initial specimen height, cm or mm; and

H_f = final specimen height, cm or mm.

12.2.8. Calculate the degree of saturation, in percent, before and after test as follows:

$$\text{initial degree of saturation: } S_o = \frac{M_{T_o} - M_d}{A\rho_w\left(H_o - H_s\right)} \times 100 \tag{10}$$

$$\text{initial degree of saturation: } S_f = \frac{M_{T_f} - M_d}{A\rho_w\left(H_f - H_s\right)} \times 100 \tag{11}$$

where:

M_{T_o}, M_{T_f}, and M_d = gram

A = cm^2

ρ_w = 1 g/cm^3

H_f and H_s = cm

12.3. *Time-Deformation Properties*—From those increments of load where time-deformation readings are obtained, two alternative procedures (Section 12.3.1 or 12.3.2) are provided to present the data, determine the end-of-primary consolidation, and compute the rate of consolidation. Alternatively, the requesting agency may specify a method of its choice and still be in conformance with this test method. The deformation readings may be presented as measured deformation, deformation corrected for apparatus compressibility, or converted to strain (Section 12.4).

12.3.1. Referring to Tables 1 and 2 (Figure 1), plot the deformation readings, *d*, versus the log of time (normally in minutes) for each increment of load.

12.3.1.1. First draw a straight line through the points representing the final readings that exhibit a straight-line trend and constant slope (C). Draw a second straight-line tangent to the steepest part of the deformation-log time curve (D). The intersection represents the deformation, d_{100}, and time, t_{100}, corresponding to 100 percent primary consolidation (E). Compression in excess of the above estimated 100 percent primary consolidation is defined as secondary compression.

12.3.1.2. Find the deformation representing 0 percent primary consolidation by selecting any two points that have a time ratio of 1 to 4. The deformation at the larger of the two times should be greater than one-fourth, but less than one-half of the total deformation for the load increment. The deformation corresponding to 0 percent primary consolidation is equal to the deformation at the smaller time, less the difference in deformation for the two selected times.

Load Increment (kPa)	d_f Corrected (mm)	$\Sigma\Delta H$ (mm)	Σ $\Sigma\Delta H/H_o$ (%)	H $(H_o - \Delta H)$ (mm)	e $(H - H_s)/H_s$
initial	5.3300	0	0	19.0500	1.231
5	5.3012	0.0288	0.15	19.0212	1.228
10	5.2743	0.0557	0.29	18.0943	1.225
20	5.2167	0.1133	0.59	18.9367	1.218
40	5.1161	0.2139	1.12	18.8361	1.206
80	4.9433	0.3867	2.03	18.6633	1.186
160	4.4740	0.8560	4.49	18.1940	1.131
320	2.9804	2.3496	12.33	16.7004	0.956
640	1.8908	3.4392	18.05	15.6108	0.828
1280	0.9860	4.3440	22.80	14.7060	0.722
320	1.0747	4.2553	22.34	14.7947	0.733
80	1.4000	3.9300	20.63	15.1200	0.771
20	1.8169	3.5131	18.44	15.5369	0.820
5	2.2319	3.0981	16.26	15.9519	0.868

H_o = 19.050 mm

H_s = 8.538 mm

d_{50} Corrected (mm)	$\Sigma\Delta H$ (mm)	Σ_{50} (%)	H_{50} (mm)	e_{50}	t_{50} (sec)	c_v (mm^2/sec)
5.0604	0.2696	1.42	18.780	1.200	52	3.34 × 10-1
4.7945	0.5355	2.81	18.515	1.169	144	1.17 × 10-1
3.7861	1.5439	8.10	17.506	1.050	516	2.93 × 10-1
2.4983	2.8317	14.86	16.218	0.900	282	4.59 × 10-1
1.5077	3.8223	20.06	15.228	0.784	156	7.32 × 10-1

Figure 1—Void Ratio and Strain Information

12.3.1.3. The deformation, d_{50}, corresponding to 50 percent primary consolidation is equal to the average of the deformations corresponding to the 0 and 100 percent deformations. The time, t_{50}, required for 50 percent consolidation may be found graphically from the deformation-log time curve by observing the time that corresponds to 50 percent of the primary consolidation on the curve.

12.3.2. Referring to Figure 1, plot the deformation readings, d, versus the square root of time (normally in minutes) for each increment of load.

12.3.2.1. First draw a straight line through the points representing the initial readings that exhibit a straight-line trend. Extrapolate the line back to $t = 0$ and obtain the deformation ordinate representing 0 percent primary consolidation.

12.3.2.2. Draw a second straight line through the 0 percent ordinate so the abscissa of this line is 1.15 times the abscissa of the first straight line through the data. The intersection of this second line with the deformation-square root of time, curve is the deformation, d_{90}, and time t_{90}, corresponding to 90 percent primary consolidation.

12.3.2.3. The deformation at 100 percent consolidation is one-ninth more than the difference in deformation between 0 and 90 percent consolidation. The time of primary consolidation, t_{100}, may be taken at the intersection of the deformation-square root of time curve and this deformation ordinate. The deformation, d_{50}, corresponding to 50 percent consolidation is equal to the deformation at five-ninths of the difference between 0 and 90 percent consolidation.

12.3.3. Compute the coefficient of consolidation for each increment of load using the following equation and values appropriate to the chosen method of interpretation:

$$c_v = \frac{TH_{D50}^2}{t} \qquad (12)$$

where:

T = a dimensionless time factor: for method in Section 12.3.1, use 50 percent consolidation with $T = T_{50} = 0.197$; for method in Section 12.3.2, use 90 percent consolidation with $T = T_{90} = 0.848$,

t = time corresponding to the particular degree of consolidation, second or minute: for method in Section 12.3.1, use $t = t_{50}$; for method in Section 12.3.2, use $t = t_{90}$; and

$H_{D_{50}}$ = Length of the drainage path at 50 percent consolidation cm or m: for double-sided drainage, $H_{D_{50}}$ is half the specimen height at the appropriate increment; and for one-sided drainage, $H_{D_{50}}$ is the full-specimen height.

12.4. *Load-Deformation Properties*:

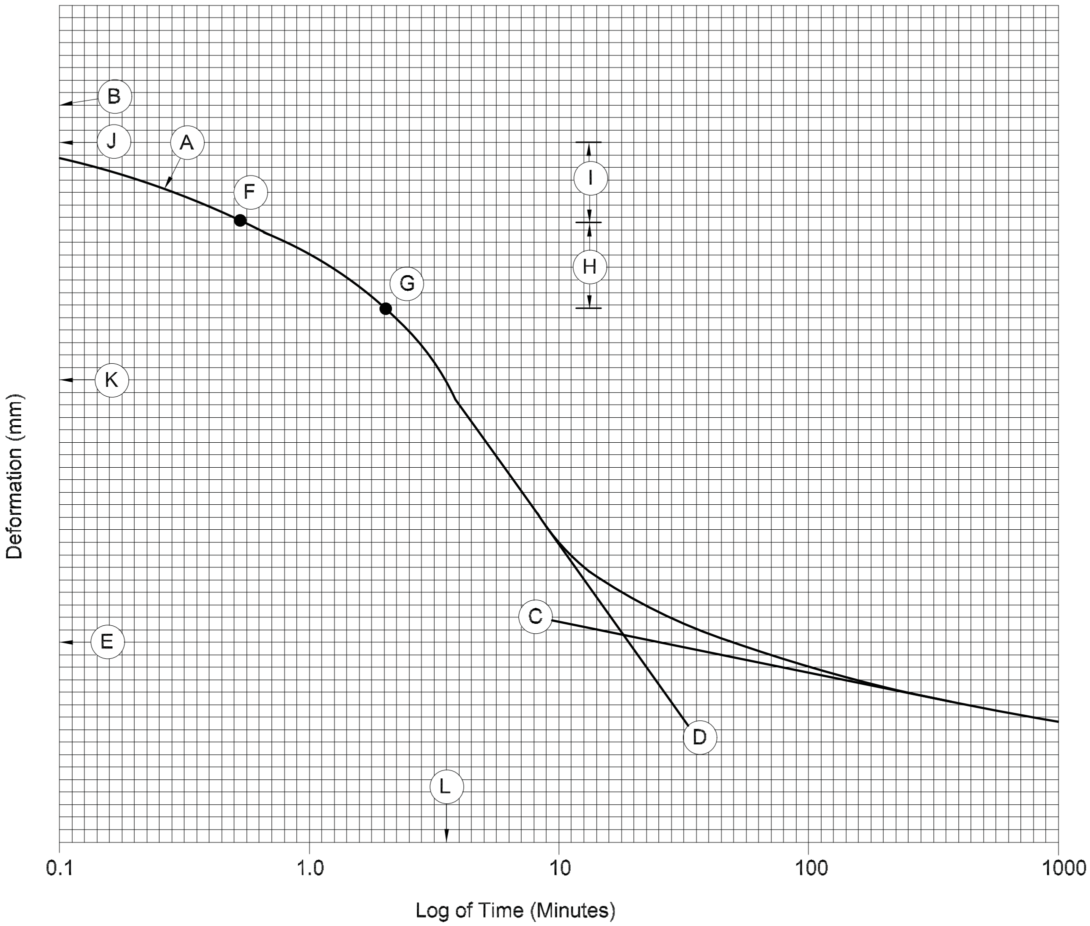
12.4.1. Tabulate the deformation or change in deformation, d_f, readings corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation, d_{100}.

12.4.2. Calculate the change in height, $\Delta H = d - d_0$, relative to the initial specimen height for each reading. If necessary, correct the deformation for the apparatus flexibility by subtracting the calibration value obtained in Section 9 from each reading.

12.4.3. Represent the deformation results in one of the following formats:

12.4.3.1. Calculate the void ratio as follows:

$$e = e_o - \frac{\Delta H}{H_s} \tag{13}$$



A	Time-deformation curve from data points
B	Deformation at time - 0 minutes
C	Extension of final linear portion of curve
D	Extension of steepest linear portion of curve
E	d_{100} Deformation at intersection of lines C and D
F	t_1 Selected point in time
G	t_2 time at four times t_1 (deformation at time t_2 should be less than 50% and larger than 25% of the total deformation for load increment)
H	Increment of deformation between times t_1 and t_2
I	Increment of deformation equal to F
J	d_0 Calculated initial deformation
K	d_{50} mean of d_0 and d_{100}
L	t_{50} time at d_{50}

Figure 2—Time Deformation Curve from Log-of-Time Method

12.4.3.2. Alternatively, calculate the vertical strain, in percent, as follows:

$$\in = \frac{\Delta H}{H_0} \times 100 \qquad (14)$$

12.4.4. Calculate the vertical stress as follows:

$$\sigma_v = \frac{P}{A} \times 10000 \qquad (15)$$

where:

σ_v = vertical stress, kPa;

P = applied load, kN; and

A = specimen area, cm^2.

12.4.5. Referring to Figure 2, plot the deformation results (void ratio or strain) corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation versus the logarithm of the pressure.

Note 15—In some cases, it may be preferable to present the load-deformation curve in arithmetic scale.

12.4.6. Referring to Figure 3, determine the value of the preconsolidation pressure using the following procedure:

Note 16—Any other recognized method of estimating preconsolidation pressure may also be used, provided the method is identified in the report. (See references.)

12.4.6.1. Estimate the point of maximum curvature on the consolidation curve (B).

12.4.6.2. Draw the tangent to the consolidation curve at this point (C), and a horizontal line through the point (D), both extended towards increasing values on the abscissa.

12.4.6.3. Draw the line bisecting the angle between these lines (E).

12.4.6.4. Extend the tangent to the steep, linear portion of the consolidation curve (virgin compression branch) (F) upwards to intersection with the bisector line (E). The pressure (G) (abscissa) corresponding to this point of intersection is the estimated preconsolidation pressure.

12.4.7. Complete evaluation often includes consideration of information not generally available to the laboratory performing the test. For this reason further evaluation of the test is not mandatory. Many recognized methods of evaluation are described in the literature. Some of these are discussed in the documents listed under References in Section 16.

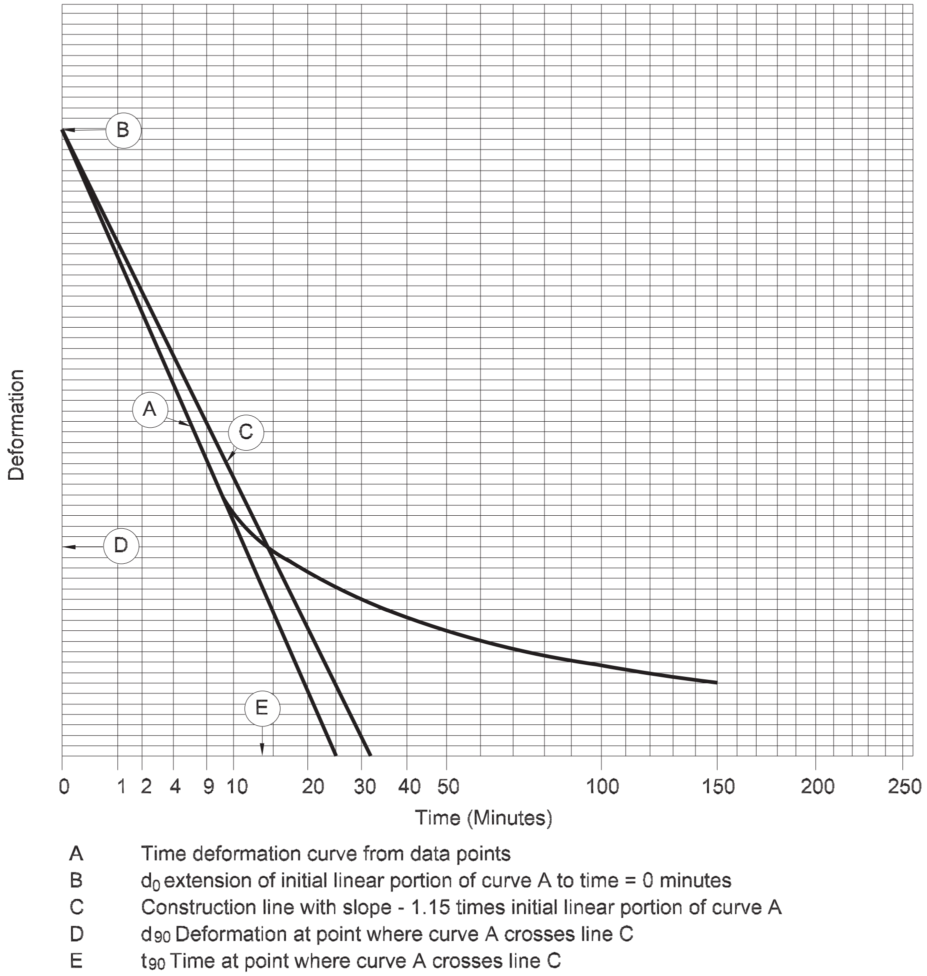


Figure 3—Time-Deformation Curve from Square Root of Time Method

13. REPORT

13.1. In addition to project name and location, boring number, sample number, and depth, report the following information:

13.1.1. Description and classification of the soil in accordance with ASTM D 2488 or ASTM D 2487 when Atterberg limit data are available. Specific gravity of solids, Atterberg limits, and the grain-sized distribution shall also be reported when available, plus the source of such information if other than measurements obtained on the test specimen. Also note occurrence and approximate size of isolated large particles.

13.1.2. *Soil Condition*:

13.1.2.1. Average water content of trimmings,

13.1.2.2. Initial and final water content of specimen,

13.1.2.3. Initial and final dry unit weight of specimen, 13.1.2.4. Initial and final void ratio of specimen,

13.1.2.5. Initial and final degree of saturation of specimen, and

13.1.2.6. Preconsolidation pressure.

13.1.3. *Test Procedure*:

13.1.3.1. Preparation procedure used relative to trimming; state whether the specimen was trimmed using a trimming turntable, trimmed using a cutting shoe, or tested directly in a ring from a ring lined sampler.

13.1.3.2. Condition of test (natural moisture or inundated, pressure at inundation).

13.1.3.3. Method of testing (A or B).

13.1.3.4. Test method used to compute coefficient of consolidation.

13.1.3.5. Listing of loading increments and decrements, and load increment duration, if differing from 24 hours; end of increment deformation results and, for Test Method B, end-of-primary deformation results and coefficient of consolidation. (See Tables 1 and 2.) All departures from the procedure outlined, including special loading sequences.

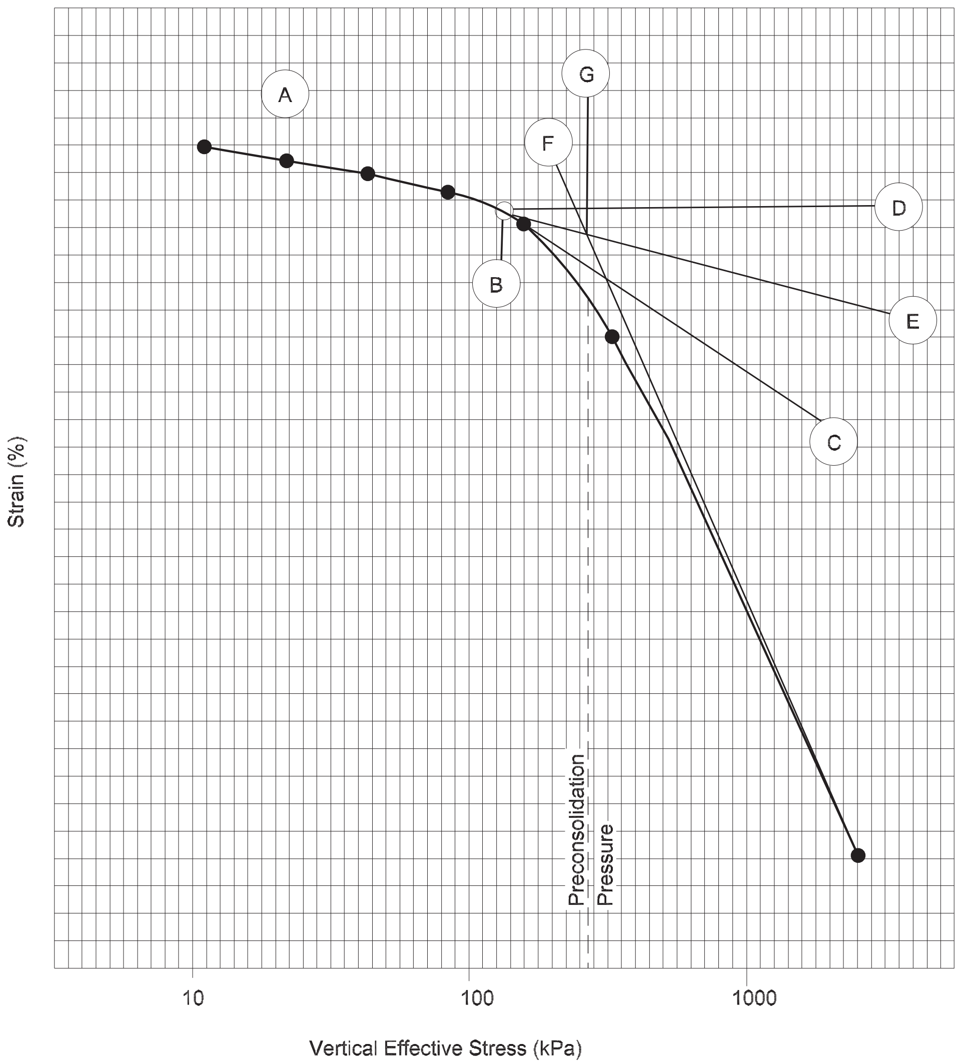
13.1.4. *Graphical Presentations*:

13.1.4.1. Graph of deformation versus log time (Figure 1) or square root of time (Figure 2) for those load increments where time rate readings were taken.

13.1.4.2. Graph of void ratio versus log of pressure curve or percent compression versus log of pressure curve. (See Figure 3.)

13.1.4.3. In cases where time rate of deformation readings have been taken for several load increments, prepare a graph of the log of coefficient of consolidation versus average void ratio or average percent compression for the respective load increments. (See Figure 4.) Alternatively, a graph of coefficient of consolidation or log of coefficient of consolidation versus log of average pressure may be used. If time rate readings were obtained for only two-load increments, simply tabulate the values of cv versus the average pressure for the increment.

Note 17—The average pressure between two-load increments is chosen because it is a convenient coordinate for plotting the result. Unless the rate of pore pressure dissipation is measured, it is not possible to determine the actual effective pressure at the time of 50 percent consolidation. Furthermore, some ambiguity may arise in cases where the test has been carried through one or more intermediate load-rebound cycles.



A Stress-strain curve from data points
B Point of maximum curvature
C Tangent line to curve at point B
D Horizontal line through point B
E Line bisecting angle between lines C and D
F Tangent to linear portion of curve in virgin compression range
G Intersection of lines E and F (vertical effective stress at point G equals the preconsolidation pressure)

Figure 4—Evaluation for Preconsolidation Pressure from Casagrande Method

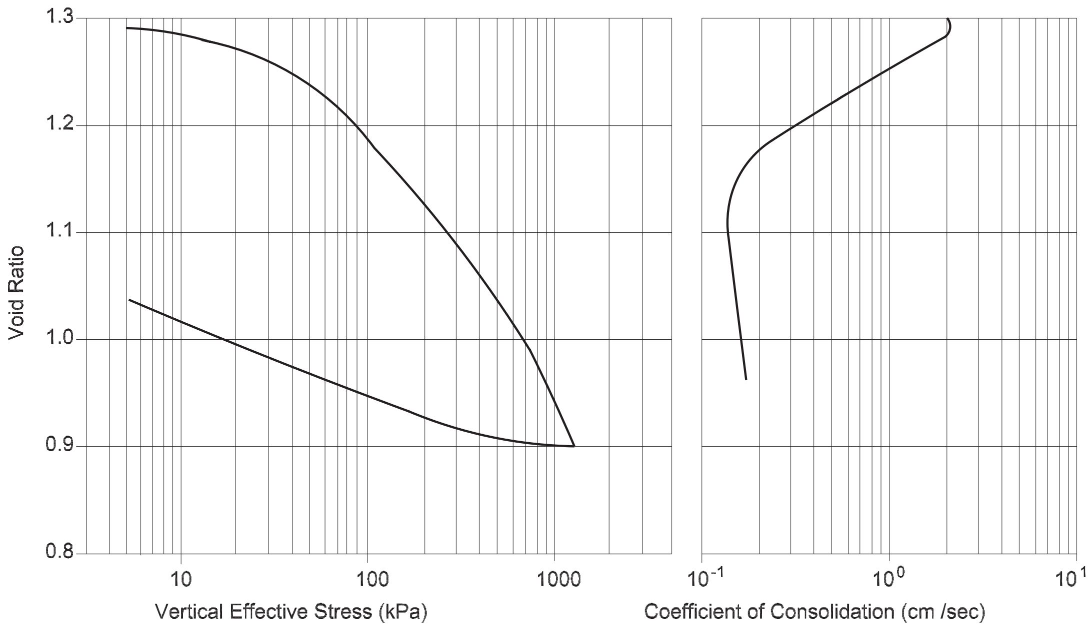


Figure 5—Example of Consolidation Test Summary Plots

14. PRECISION AND BIAS

14.1. *Statement of Precision*—Due to the nature of the soil materials tested by this test method, it is either not feasible or too costly at this time to produce multiple specimens that have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

14.2. *Statement of Bias*—There is no acceptable reference value for this test method; therefore, bias cannot be determined.

15. KEYWORDS

15.1. Compressibility; compression curves; consolidation; consolidation coefficient; consolidation test; consolidometer; preconsolidation pressure; primary consolidation; rebound; secondary compression; settlement; swelling.

16. REFERENCES

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Standard Method of Test for

Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester

AASHTO Designation: T 217-02 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester

AASHTO Designation: T 217-02 (2006)

1. SCOPE

1.1. This test method is intended to determine the moisture content of soils by means of a calcium carbide gas pressure moisture tester. The manufacturer's instructions shall be followed for the proper use of the equipment.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

Note 1—This method shall not be used on granular materials having particles large enough to affect the accuracy of the test—in general any appreciable amount retained on a 4.75-mm sieve. The super 200 D tester is intended to be used to test aggregate.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *Calcium Carbide Pressure Moisture Tester*—A chamber with attached pressure gauge for the water content of specimens having a mass of at least 20 g (Figure 1).

3.2. *Balance*—Shall conform to M 231, Class G 2.

3.3. Two 31.75-mm (1.25-in.) steel balls.

3.4. Cleaning brush and cloth.

3.5. Scoop for measuring calcium carbide reagent.

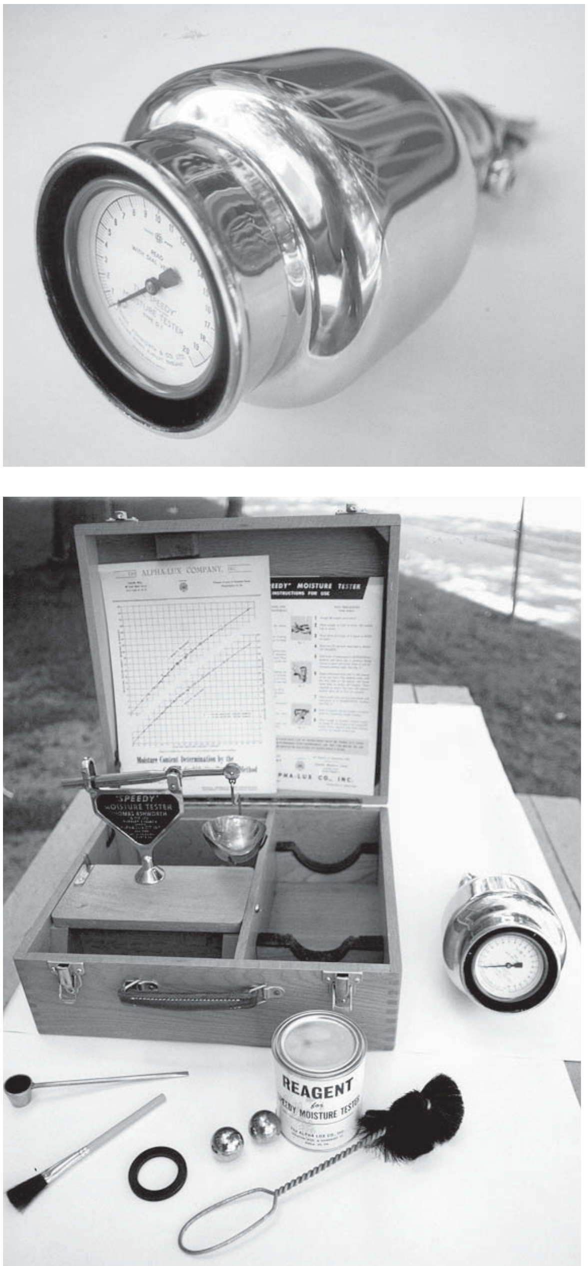

Figure 1—Calcium Carbide Gas Pressure Moisture Meter

4. MATERIAL

4.1. *Calcium carbide reagent.*

Note 2—The calcium carbide must be finely pulverized and should be of a grade capable of producing acetylene gas in the amount of at least 0.14 m^3/kg (2.25 ft^3/lb) of carbide.

Note 3—The “shelf life” of the calcium carbide reagent is limited, so it should be used according to the manufacturer’s recommendations.

5. PROCEDURE

5.1. When using the 20-g or 26-g tester, place three scoops (approximately 24 g) of calcium carbide in the body of the moisture tester. When using the super 200 D tester to test aggregate, place six scoops (approximately 48 g) of calcium carbide in the body of the moisture tester.

Note 4—Care must be exercised to prevent the calcium carbide from coming into direct contact with water.

5.2. Weigh a sample of the exact mass specified by the manufacturer of the instrument in the balance provided, and place the sample in the cap of the tester. When using the 20-g or 26-g sized tester, place two 31.75-mm (1.25-in.) steel balls in the body of the tester with the calcium carbide.

Note 5—Manufacturer’s instructions shall be followed for the use of steel balls, particularly when testing sand.

Note 6—If the moisture content of the sample exceeds the limit of the pressure gauge (12 percent moisture for aggregate tester or 20 percent moisture for soil tester), a one-half size sample must be used and the dial reading must be multiplied by 2. This proportional method is not directly applicable to the dry mass percent scale on the super 200 D tester.

5.3. With the pressure vessel in an approximately horizontal position, insert the cap in the pressure vessel and seal the unit by tightening the clamp, taking care that no carbide comes in contact with the soil until a complete seal is achieved.

5.4. Raise the moisture tester to a vertical position so the soil in the cap will fall into the pressure vessel.

5.5. Shake the instrument vigorously so all lumps will be broken up to permit the calcium carbide to react with all available free moisture. When steel balls are being used in the tester and when using the large tester to test aggregate, the instrument should be shaken with a rotating motion so the steel balls or aggregate will not damage the instrument or cause soil particles to become embedded in the orifice leading to the pressure diaphragm.

Note 7—Shaking should continue for at least 60 seconds with granular soils and for up to 180 seconds for other soils so as to permit complete reaction between the calcium carbide and the free moisture. Time should be permitted to allow dissipation of the heat generated by the chemical reaction.

5.6. When the needle stops moving, read the dial while holding the instrument in a horizontal position at eye level.

5.7. Record the sample mass and the dial reading.

5.8. With the cap of the instrument pointed away from the operator, slowly release the gas pressure. Empty the pressure vessel and examine the material for lumps. If the sample is not completely pulverized, the test should be repeated using a new sample. Clean the cap thoroughly of all carbide and soil before running another test.

Note 8—When removing the cap, care should be taken to point the instrument away from the operator to avoid breathing the fumes, and away from any potential source of ignition for the acetylene gas.

5.9. The dial reading is the percent of moisture by wet mass and must be converted to dry mass. With the super 200 D tester, the dial reading is the percent of moisture by dry mass and no further calculation is required.

6. CALCULATION

6.1. The percentage of moisture by dry mass of the soil may be determined from the correction curve (Figure 2).

6.2. A correction curve similar to Figure 2 is normally supplied with each moisture tester. Each moisture tester, however, should be checked for the accuracy of its gauge, and for the accuracy of its correction curve.

6.2.1. The accuracy of the moisture tester gauge should be checked by using a calibration kit (available from the manufacturer), equipped with a standard gauge. In case of discrepancy, the gauge on the tester should be adjusted to conform with the standard gauge.

6.2.2. The accuracy of the correction curve should be checked by comparing curve-corrected moisture contents to moisture contents of locally prepared soils determined using T 265. In case of discrepancy, develop a new correction curve based on moisture contents determined from T 265.

6.2.3. The range of the factory-supplied or laboratory-determined curves may be extended by additional testing.

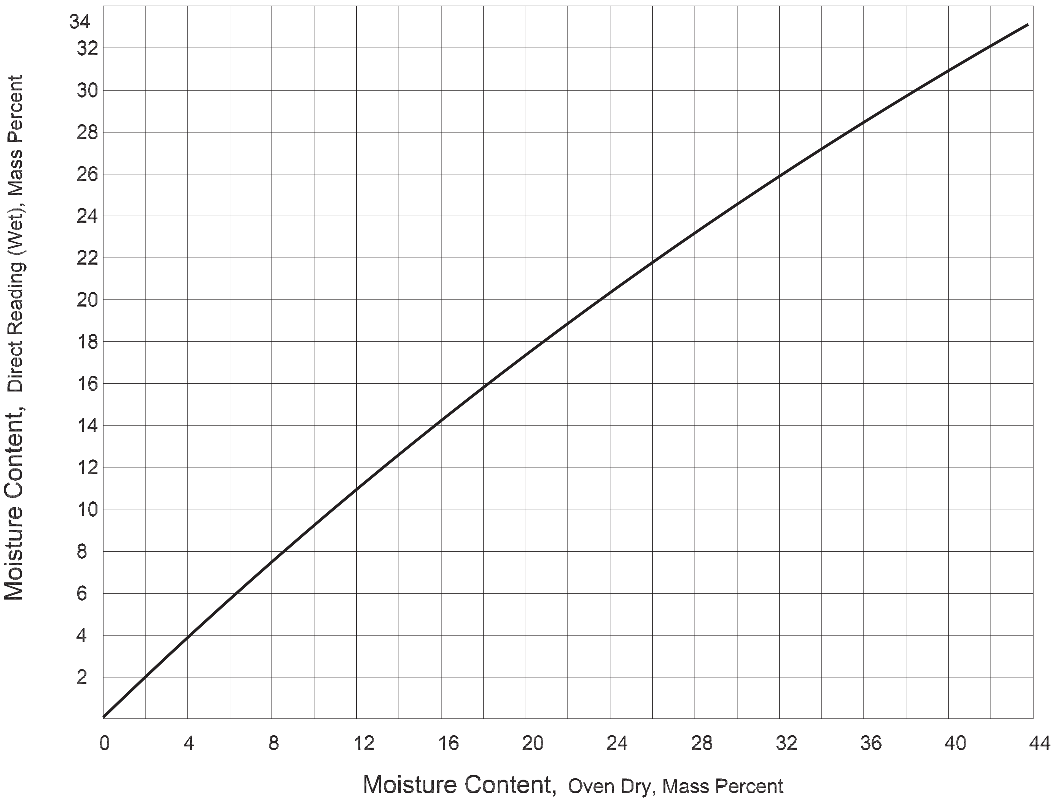

Figure 2—Correction Curve for Moisture Tester Reading (Example Only—Use the curve provided by the manufacturer with the specific apparatus, or a correction curve calibrated or extended for local soils at known moisture contents determined in accordance with Section 6.2.)

Note 9—It may be more convenient for field use of the apparatus to prepare a table of moisture tester readings versus oven-dry moisture content for the moisture tester.

6.3. Determine the percentage of moisture to the nearest whole percent.

Standard Method of Test for

Sampling Hydrated Lime

AASHTO Designation: T 218-86 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling Hydrated Lime

AASHTO Designation: T 218-86 (2008)

1. SCOPE

1.1. This method covers the procedure for sampling hydrated lime from various conveyors, points of shipment, and while in various states of storage.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. Refer to R 16 for regulatory information for chemicals.

2. APPARATUS

2.1. Apparatus shall consist of a 50-mm (2-in.) wide paint brush, 4 L (1 gal) buckets (or other container of approximately that capacity) with double seal friction lids (or other sealing method) and suitable lengths of sampling tubes such as 25-mm (1-in.) diameter and 2.5 m (8 ft) in length, and 19 mm ($^3/_4$ in.) in diameter and 1 m (3 ft) in length, with suitable diagonal cut on one end.

3. SAMPLING PROCEDURE FOR POWDERED LIME IN BULK

3.1. Being loaded or recently loaded into tank trucks, railway hopper cars, or box cars, take a representative 2-L (half-gal) portion of the powdered lime to be analyzed and place it in a 4-L (1-gal) bucket. Fit the bucket with a tight-fitting lid. Clean the lime from the groove before placing the lid; brushing with a 50-mm (2-in.) paint brush has been found to be satisfactory for this purpose.

Note 1—These sample buckets shall be only half filled with sample material so that subsequent mixing may take place within the bucket itself. Half filling the container will allow sufficient space to permit proper agitation during subsequent mixing operations. The sample bucket shall be dry and clean so as to prevent sample contamination.

3.1.1. Tank trucks or railroad cars being loaded with material shall be sampled during the loading operation by inserting the bucket into the flowing stream of material if conditions permit. The sampler should exercise due discretion in taking samples during the loading operation so that the total sample obtained is representative of the material. If material is being loaded from one or more bins or silos or from silo and plant production or various combinations, the composite sample contained in the bucket shall be representative of the composite material. Insofar as the possibility of poor mixing may exist, the sampler may at his or her discretion take separate samples of individual portions of material being loaded. This is particularly advisable where, in order to effect a complete load, material is being loaded from more than one plant source.

Note 2—If conveyors are being loaded in the rain, make every effort to ensure that the material contained in the sample bucket is typical of the material being shipped. In cases of suspected moisture difficulty, it is always advisable to rod the load with the long sampling tubes.

3.1.2. Trucks shall be rodded in three separate places from the top through the openings provided. Rod the center of the load and the two ends, rodding the material vertically or diagonally so as to obtain a composite 2-L (half-gal) portion of material that will be representative insofar as possible of the material.

3.1.3. If loading has been completed rather recently and weather conditions permit, "scoop" samples may be taken from the top of the loaded material and, depending upon the plant source of the material, the sampler may consider this sample to be representative. If the load is composed of one or more portions from more than one plant source, a "scoop" sample may be taken from the top of each portion during the loading operation and these samples may either be combined or submitted separately for analysis.

3.1.4. Added precautions are necessary in sampling railway hopper cars. The sampler should request assistance from plant personnel in attempting to sample material in hopper cars. From the standpoint of safety it is advisable that two people lift the heavy steel doors on as many openings as the sample requires be opened to allow for proper sampling. Should the level of material in the hopper car be too low to obtain a "scoop" sample with a minimum of hazard, then the material should be rodded in as many places as the sampler feels necessary, or the option of sampling from the loading spout with the assistance of plant personnel may be employed. Rodding the entire load in the prescribed fashion is the preferred method to be employed, but the sampler shall have the option of using any of the other methods described for such conditions should he/she feel the situation warrants employing such optional sampling procedures. With the exceptions noted the details and principles suggested for the sampling of tank trucks while being loaded, or recently loaded, also apply in the case of railway hopper cars under like conditions.

3.2. *In Storage Awaiting Shipment*—This procedure applies to material loaded and left standing awaiting shipment in what might be considered a modification of bin storage. These loads in so-called "truck-storage" should be sampled by rodding the material with the long 2.5-m (8-ft) sampling tube. The sampler shall decide if the trucks have been loaded recently enough to permit "scoop" sampling or if sufficient time has elapsed since loading to make it advisable to rod the material so as to obtain a representative "through" sample of the material. The sampler shall base all decisions concerning the optional forms of sampling on what he or she considers will yield a representative sample of the material being shipped within the practicalities of the situation at hand.

3.3. *At Job Site*—A representative 2-L (half-gal) portion of material should be taken by rodding the material in the rail car or tank truck (before unloading) in at least three positions, the center and on both ends. Use the long 2.5-m (8-ft) sampling tube.

Note 3—The material in rail cars should be sampled by rodding the material before unloading, thus preventing the possibility of material contamination after unloading and possibility of obtaining an otherwise unrepresentative composite sample. Due to varying conditions of storage, and the possibility of sample contamination due to moisture, exposure to air, etc., scoop samples are not recommended.

3.4. *At Loading Spouts Feeding from Plant Production, from Bin Storage or at Bagger Outlet Spouts Being Supplied by Either Plant Production or Bin Storage*—Make sure that a reasonable quantity of material has moved through the feed system so the possibility of contamination by material of long standing will be minimized. The 2-L (half-gal) sample should be taken from loaded bags rather than from the bagger outlet spout because sampling from the latter often tends to be nonrepresentative due to the presence of non-fresh or contaminated material in the outlet itself and the usual spillage that occurs in attempting to sample at the bagger outlet spout does not add to overall plant cleanliness.

Note 4—Samplers shall keep in mind that no plant equipment shall be operated by sampling personnel. In general, it should be the responsibility of the plant personnel to operate all equipment and to make the sample available in the sampler. Reasonable and safe sampling facilities shall be arranged for by the producer and provided wherever possible, provided such arrangements meet with the principles involved in obtaining a truly representative sample of the material shipped.

3.5. *From Loaded Silos or Storage Bins*—There is usually a considerable lack of mixing in the material contained in bulk hydrate storage bins. Stratification and flow patterns tend to occur and experience in attempting to correlate silo samples with samples obtained from rodded trucks loaded from such silos indicates poor correlation. Wherever possible, avoid taking silo or bin storage samples and concentrate the sampling on individual loads or shipments rather than taking composite samples of larger reservoirs which due to poor mixing or other conditions prevalent may contain portions of potentially unsatisfactory material which a composite sample might indicate to be satisfactory.

Note 5—Screw conveyors being supplied by either plant production or bin storage are dangerous sources for sampling material, and no attempt should be made to obtain material at such locations.

Note 6—Cumulative samples obtained by rodding should be thoroughly blended, after the container is tightly sealed, by repeatedly inverting and agitating the container.

4. SAMPLING PROCEDURE FOR BAGGED HYDRATED LIME

4.1. *From Warehouse Stock Consigned for Shipment*—If necessary, request that plant personnel make the material available to the sampler. Take care not to sample amongst bagged material that is stacked dangerously high. If necessary, the sampler should ask plant personnel to make available the sacks that he or she desires to sample. Choice of sacks should be made on the basis of obtaining a representative sample of the lot being shipped. If the entire lot consigned for an individual truck or group of trucks is from several different warehouse lots, the sampler may at his or her discretion take samples from the separate lots that comprise the whole. The sampler should use the short sampling rod and, through the sack loading spout, take sufficient diagonal roddings to insure a representative portion from each sack but not a sufficient quantity to materially reduce the poundage being supplied in any individual sack. For this reason and for the obvious reason of attempting to obtain a representative sample, it is suggested that at least four to six sacks from each lot to be inspected be sampled. These sampled lots may be combined to form one sample representing the individual truck or they may be submitted for analysis separately. Generally speaking at least six sacks should be sampled to represent each truck being shipped from consigned previously produced and stored, warehouse stock, to obtain the 2-L (half-gal) sample.

4.2. *From Bag Loads*—If the truck is partially loaded, the sampler may choose sacks at his or her discretion to effect a representative sample and may also sample floor stock consigned for the partially loaded truck so as to obtain a representative sample. The sampler may combine sampling from a partially loaded truck with material being produced by obtaining a sample at the bagger, but due to the usual spillage and interruption of plant activities, this bagger sampling option is not recommended. Rather than sampling at the bagger, it would be preferable to sample the bags being loaded on the truck or the loaded bags at various stages of the loading operation. This matter of which bags to sample should be at the discretion of the sampler; however, the sacks chosen for sampling should be selected from various points in the load so as to effect a representative sample. In sampling from loaded trucks and rail cars, the short sampling rod should be used to obtain a total of a 2-L (half-gal) sample from at least six sacks of material. Insert the sampling rod through the loading valve and take several through samples diagonally from each sack, taking care not to puncture the bottom or sides of the sack with the sharp sampling tube. (See Note 6.)

5. PRECISION

5.1. Since this method of sampling produces no numerical values, determination of the precision and accuracy is not applicable.

Standard Method of Test for

Testing Lime for Chemical Constituents and Particle Sizes

AASHTO Designation: T 219-87 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Testing Lime for Chemical Constituents and Particle Sizes

AASHTO Designation: T 219-87 (2008)

1. SCOPE

1.1. This test procedure is intended to serve as a reasonably accurate, fairly rapid means of determining the chemical limits of Type I hydrated lime and the particle size requirements of Types I and II hydrated lime on a routine basis.

Note 1—The chemical limits of Type II lime shall be determined in accordance with ASTM C 25.

1.2. The entire procedure, as well as the calculations it involves, is based on certain hypothetical assumptions. Lime products by their very nature contain many ingredients other than those mentioned or considered in the test procedure. For our purposes, only the principal constituents usually present are considered. This aids greatly in the simplification of the test procedure to the obvious loss of some degree of accuracy. All test values to be reported shall be rounded off to the first decimal place. *Example*: percent $Ca(OH)_2$ = 95.5 percent (rather than the 95.53 percent shown on the sample calculation sheets). The inherent accuracy obtainable through the use of this procedure is felt to be adequate for the purpose intended. The limitations of this test procedure, along with the object and intent of this same procedure, should be fully realized so that it may be evaluated as merely one approach to the problem of routine quality control on a quality basis.

1.2.1. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 192, Fineness of Hydraulic Cement by the 45-µm (No. 325) Sieve

2.2. *ASTM Standards*:

- C 25, Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

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3. APPARATUS

3.1. *Electric muffle furnace with temperature controlling device*—capable of sustained operation at a temperature of 1100 ± 11°C (2012 ± 20°F).

3.2. *Platinum crucible*—low-form wide bottom type, with reinforced rim and bottom, 30 mL-capacity.

3.3. *Metallic tongs for muffle furnace*—750 mm in length.

3.4. *Balances*—A general purpose balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231. The analytical balance shall conform to M 231, Class A.

3.5. *Beakers*—400-mL capacity.

3.6. *Buret*—100-mL capacity.

3.7. *Buret*—50-mL capacity of alkali resistant glass and fitted with a Teflon stopcock.

3.8. *Magnetic-type stirrer*—with stirring bars preferably of the Teflon-covered type.

3.9. *Stopwatch*—with 60 seconds long hand to indicate 0.2 seconds. The long hand is to complete one turn of the dial in 60 seconds. The watch should also have a short hand to register up to 30 minutes. Operation should preferably be by successive depressions of the crown to accomplish starting, stopping, and returning to zero.

3.10. *Sieves*—conforming to M 92 as follows: 3.35, 2.00, 0.600, and 0.075 mm.

3.11. *pH meter*—having an accuracy of 0.1 pH.

3.12. *pH meter electrode*—standard combination.

3.13. *Desiccator*.

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4. REAGENTS

4.1. Reagent grade chemicals shall be used in all tests.

4.2. *Acid Potassium Phthalate*—(National Institute of Standards and Technology Standard Sample or equal).

4.3. *Bromphenol Blue*—tetrabromophenol sulfonphthalein.

4.4. *Hydrochloric Acid*.

4.5. *Phenolphthalein powder*.

4.6. *Potassium Biphthalate*—crystal primary standard. This reagent is satisfactory for use as a pH standard used in Section 5.5.

4.7. *Sodium Hydroxide*—50 percent solution.

5. PREPARATION OF SPECIAL SOLUTIONS

5.1. *Standardized Sodium Hydroxide Solution*:

5.1.1. This solution shall have a normality of 1.000 ± 0.015 when the normality of the solution is accurately determined by direct standardization against a National Institute for Standards and Technolgy Acidimetric Standard-Acid Potassium Phthalate. This acidimetric standard shall be used without prior crushing or drying. Once the standard sample bottle has been opened, it should be restoppered, sealed with plastic tape, and stored in a desiccator pending further use. For the purpose of this standardization, 8.1691 g of the prescribed acid potassium phthalate shall be considered as equivalent to 40.00 mL of 1.000 normal sodium hydroxide.

5.1.2. Prepare the desired volume of 1.0 normal sodium hydroxide by measuring out 52.3 mL of the 50 percent NaOH solution and dilute with distilled water to 1 L volume.

5.1.3. Standardize the sodium hydroxide solution by accurately determining the mass, to the nearest 0.1 mg, from 7.5 to 8.5 g of original acid potassium phthalate. Transfer the weighed material to a 400-mL beaker. Add 185 mL of carbon dioxide free distilled water at a temperature of 25 to 28°C (77 to 83°F) and stir the mixture gently until the crystals dissolve. The carbonate-free distilled water can be prepared by boiling 1 L of distilled water and cooling it to room temperature. Add five drops of prepared phenolphthalein indicator and titrate the prepared standard with the sodium hydroxide solution to be standardized. Titrate to a visual end point of light pink, which will persist for at least 60 seconds. Record the number of mL of sodium hydroxide solution required for the titration. Calculate the normality of the sodium hydroxide solution as follows:

$$N\ \text{NaOH} = \frac{\text{Mass of Acid Potassium Phthalate in g}}{\text{mL of NaOH Required} \times 0.204228} \qquad (1)$$

5.2. *Standardized Hydrochloric Acid Solution*—This solution shall have a normality of 1.000 ± 0.015 when the normality is accurately determined by direct comparison with the previously standardized sodium hydroxide. This solution is prepared by adding 86 mL of concentrated HCl to the distilled water such that the final volume is 1 L.

5.2.1. Determine the normality of the acid solution according to the following procedure: Transfer an approximate 40 mL portion of the acid solution to be standardized into a 400-mL beaker. Use a buret to deliver this volume and accurately record the volume delivered. Add 140 mL of distilled water plus five drops of the prepared phenolphthalein indicator to the contents of the beaker and proceed to titrate the contents of the beaker by adding from a buret some of the previously standardized sodium hydroxide. Titrate to a visual end point of light pink, which will persist for at least 60 seconds. Record the number of mL of sodium hydroxide solution required for the titration. Calculate the normality of the hydrochloric acid solution as follows:

$$N\ \text{HCl} = \frac{\text{mL of NaOH Required} \times N \text{ of NaOH Used}}{\text{mL of HCl used}} \qquad (2)$$

5.3. *Phenolphthalein Indicator Solution*—Prepare this solution by dissolving 0.5 g of powdered phenolphthalein, A.C.S. Grade, in 50 mL of absolute ethyl alcohol and add 50 mL of distilled water.

5.4. *Bromphenol Blue Indicator Solution*—Prepare this solution by dissolving 0.1 g of powdered bromphenol blue in 7.5 mL of 0.02 Normal NaOH and dilute the resulting solution to 250 mL.

5.5. *Potassium Hydrogen Phthalate Reference Solution (0.05 Molar)*—Prepare this solution by dissolving 10.21 g of potassium biphthalate crystal primary standard in distilled water and dilute to 1 L. It is necessary to dry the salt before use in preparing this solution.

5.6. *Color Reference Standard for Use with Bromphenol Blue Indicator Solution*—Transfer 2.0 mL of the prepared bromphenol blue indicator solution to a 400 mL tall-form titration beaker. Add 250 mL of the 0.05 Molar potassium hydrogen phthalate reference solution and then add from a 10-mL buret 1.86 mL of the 1.000 Normal NaOH solution. The resulting solution should be blue colored with a slight purple cast. This solution should be tightly stoppered and set aside to act as a visual color reference standard to be used for comparison purposes in the titration to pH 4.4. The end point of this solution when prepared as directed shall have a pH of 4.4 and be of the color described.

6. TEST PROCEDURE

6.1. *Sample Preparation*:

6.1.1. Take a representative 2-L (half-gal) portion of the powdered lime to be analyzed and mix well by thoroughly shaking, inverting, etc., in a 4-L (1 gal) bucket fitted with a double friction-type lid.

6.1.2. The portion of material chosen for actual analysis shall be taken from the well-mixed material contained in the bucket. After each withdrawal, special precaution should be taken to replace the lid on the bucket so as to minimize atmospheric contamination of the material to be analyzed.

6.2. *Titrimetric Analysis of Various Alkaline Components of the Sample*:

6.2.1. *Titration to pH 8.3 with HCl*—Weigh out a 2.9 to 3.1-g portion of the well-mixed material contained in the bucket accurately to the third decimal place on an analytical-type balance. The weighed sample shall then be transferred quantitatively to a 400-mL beaker. Slowly add 150-mL of distilled water to the sample contained in the beaker and titrate immediately with approximately 1.0 normal hydrochloric acid to a prescribed end point of pH 8.3 using the pH meter. Gentle stirring of the mixture to be titrated shall be accomplished through the use of a magnetic-type stirrer. The first 50 mL of titrant may be added rather rapidly after which continued additions of titrant shall be made in "rapid drop-wise" fashion until a pH indication of nine or slightly less is obtained. A suitable rate for this "rapid drop-wise" addition has been found to be approximately 12 mL/min. After attaining a momentary pH indication of nine, or slightly less, proceed with the titration by adding titrant at the rate of approximately 2 mL/min. until the pH is in the vicinity of pH 8.5; then add acid in four-drop increments until the prescribed end point of 8.3 or of slightly less for 60 seconds is reached. The prescribed end point for this portion of the titration shall be taken to that point at which the addition of one two-drop increment of titrant produces a pH meter indication of 8.3 or slightly less than 8.3 when observed exactly 60 seconds after the addition of titrant. The first occurrence of such an end point in the normal course of the titration shall be considered as the end point for this portion of the analysis. The volume of titrant required to reach this end point should be recorded before proceeding with the further addition of HCl. The end point can also be obtained by taking a series of readings of pH vs. mL of HCl added and making a plot; the sharpest slope of the curve gives rise to the end point.

6.2.2. *Titration to "Measured Excess" of HCl*—After the pH 8.3 end point has been reached, continue to add hydrochloric acid titrant to the sample contained in the beaker to a point where a total of approximately 100 mL of titrant has been added to the sample since the beginning of the titration. The sample mixture contained in the titration beaker at this point shall be considered as containing a "measured excess" of hydrochloric acid. Record the total volume of acid added to the sample since the beginning of the titration before proceeding with the back-titration.

6.2.3. *Back-Titration to pH 4.4 with NaOH*—Titrate the sample mixture plus the "measured excess" of hydrochloric acid contained in the beaker with approximately 1.0 normal sodium hydroxide to a pH meter indication of 4.4 or of slightly greater than 4.4 when observed exactly 10 seconds after a one-drop addition of titrant. The first occurrence of such an end point in the normal course of the back-titration shall be taken to be the prescribed end point for this portion of the analysis. For an alternative method of obtaining the end point, see the last sentence in Section 6.2.1.

6.3. *Determination of Percent Loss on Ignition*—Weigh out 2.9 to 3.1 g, accurately to 0.1 mg, of the well-mixed material contained in the bucket. Transfer the material by means of a spatula directly from the bucket to a previously ignited and weighed platinum crucible, after which the crucible and sample portion that it contains shall be placed uncovered in an electric muffle furnace maintained at a temperature of 1100°C (2012°F) where it shall be allowed to remain for a required ignition period of 3 hours. After the sample has been ignited in this fashion, it should be removed from the furnace and placed on a piece of ceramic board for a period of 10 to 30 seconds prior to placing the crucible in a desiccator for further cooling. If several samples are being run simultaneously, it has been found expedient to remove all of the samples from the furnace, place them on the ceramic board and then proceed to place them in the desiccator. After they have been placed in the desiccator, replace the desiccator lid with a small opening. The heated air will expand through the opening for a period of several seconds after which the lid should be closed. The residue for the loss on ignition shall be allowed to cool for 30 minutes prior to the mass determination. The mass determination shall take place promptly after the cooling period so as to avoid possible contamination of the highly reactive quicklime residue. The actual mass determination of this residue shall be accomplished as rapidly as possible so as to prevent hydration of the residue due to exposure to the atmosphere. The mass determination shall be accurate to 0.1 mg.

7. SIEVE ANALYSIS

7.1. Weigh out two samples consisting of approximately 500 and 5 g portions of well-mixed material contained in the bucket.

7.1.1. Determine the mass of the 500 g portion to the nearest 0.1 g and then proceed in attempting to water-wash this material through each of the following sieves in the order listed. First, screen the material on the 3.35-, 2.00-, and 0.600-mm sieves. The wash water to be used for this purpose may be obtained from a piece of plastic tubing attached to a water faucet. The velocity of the wash water may be increased, if necessary, by pinching the tubing somewhat. In no case should the velocity of the stream of water being used to wash the residue be allowed to become sufficiently strong as to cause loss of sample over the sides of the sieve. The washing shall be continued until the water coming through each sieve is clear. If milkiness persists, the washing operation may be continued up to a maximum of 30 minutes. In no case shall the washing operation be continued past the point where the wash water appears clear. When the washing is complete, the residue on each sieve shall then be oven-dried at 100°C (212°F) for a period of 1 hour. After drying, the residue retained on each of the three sieves shall be transferred to separate tared weighing bottles in which the residues shall be cooled for 30 minutes and then the mass shall be determined separately on an analytical balance to the nearest 0.01 g. Use the cumulative masses to calculate the percentage retained on the various sieves on the basis of total dry mass of original sample taken before washing.

7.1.2. Residue on the 0.075-mm (No. 200) sieves shall be determined in accordance with T 192 except that a 5-g sample of lime rather than 1 g of cement shall be used and that a 0.075-mm (No. 200) sieve instead of the 0.045-mm (No. 325) sieve shall be used.

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8. OPTIONAL INDICATOR METHOD FOR THE TITRIMETRIC ANALYSIS OF VARIOUS ALKALINE COMPONENTS OF THE SAMPLE

8.1. This method may be used in lieu of the prescribed pH meter method. However, for all reference tests, or in cases of dispute, the prescribed pH meter method shall be considered the official method to be used. In some cases, impurities such as aluminum compounds will prevent or hinder the appearance of the color change in the back-titration portion of the optional method. If such a difficulty is encountered with a particular sample, use the prescribed pH meter method. The procedure to be followed in employing this optional indicator method shall be exactly as outlined in the pH meter method with the following exceptions:

8.1.1. *Titration to Phenolphthalein End Point with HCl*—At the beginning of the titration to the phenolphthalein end point, add five drops of the prepared phenolphthalein indicator solution to the sample mixture and proceed with the titration by adding 50 mL of titrant rather rapidly, after which continued addition of titrant at the rate of approximately 12 mL/min shall be made in a "rapid dropwise" fashion to the point where the color of the solution changes temporarily from pink to clear. Before adding additional titrant, allow the pink color to return. At the return of the pink color, additional titrant should be added at the rate of approximately 2 mL/min until the color change appears imminent, then add acid in four-drop increments to where the pink coloration disappears for some 35 seconds. Then add two-drop increments until the prescribed end point of "failure to regain pink coloration for 60 seconds" is reached. The prescribed end point for this portion of the titration shall be taken to be that point at which the addition of one two-drop increment of titrant produces a condition in which the mixture in the titration beaker fails to regain its pink coloration when observed exactly 60 seconds after the last addition of titrant. The first occurrence of such an end point in the normal course of the titration shall be considered as the end point for this portion of the analysis. Once the prescribed end point has been reached, the further reappearance of pink color shall be ignored. The phenolphthalein end point shall be considered as being roughly equivalent to the pH 8.3 end point described in the official pH meter method of titration. For purposes of calculation, this phenolphthalein end point shall be considered to be the pH 8.3 end point when using this optional indicator method of titration. The volume of titrant required to reach this end point should be recorded before proceeding with the further addition of HCl.

8.1.2. *Titration to "Measured Excess" of HCl*—Consider the phenolphthalein end point as being the pH 8.3 end point and proceed to add a "measured excess" of hydrochloric acid by adding titrant to the 100-mL point and recording the total volume of acid added to the sample since the beginning of the titration before proceeding with the back-titration.

8.1.3. *Back-Titration to the Bromphenol Blue End Point with NaOH*—Add 2.0 mL of the bromphenol blue indicator to the sample mixture plus "measured excess" of HCl contained in the titration beaker. Proceed to titrate this mixture to the point where the color of the mixture changes from yellow to blue with a slight tinge of purple, and maintains this prescribed color of blue when observed exactly 10 seconds after a one-drop addition of titrant. The particular color of blue, which is prescribed as the end point for this portion of titration, should be visually color matched to the color standard that should be reserved for such comparison purposes. For the preparation of this color standard, refer to Section 5.6. The first occurrence of the prescribed end point in the normal course of the back-titration shall be taken to the bromphenol blue end point. For purposes of calculation, this bromphenol blue end point shall be considered to be the pH 4.4 end point when using this optional indicator method of back-titration.

9. CALCULATIONS

9.1. *Basic Data*:

9.1.1. *Chemical Constituents*:

$$\text{I} = \text{normality of acid used} \times \frac{54.08}{2000} \times 100$$

Note 2—I = factor derived by multiplying the normality of the acid used by the product of the mass weight of calcium oxide divided by 2000 (to convert to milli-equivalents) multiplied by 100 (so as to express the final unit to be calculated in percent). Example: In a case where the normality of the acid being used is 1.012 then the correct value for I = 1.012 × 2.804 = 2.838.

$$\text{II} = \text{normality of base used} \times \frac{56.08}{2000} \times 100$$

III = mL of acid to pH of 8.3,

IV = (I) × (III),

V = total mL of acid used,

Note 3—This volume of acid should approximate 100 mL and represents that volume of acid used in the titration to reach a pH of 8.3 plus that volume of acid added to insure a "measured excess" before proceeding with the prescribed "back-titration."

VI = (I) × (V),

VII = mL of base used in the "back-titration" to proceed from the point of "measured excess" to the prescribed end point of pH of 4.4,

VIII = (II) × (VII),

IX = (VI) – (VIII),

X = titration sample mass expressed in grams,

XI = "Loss on ignition" sample mass expressed in grams,

XII = "Loss on ignition" residual mass expressed in grams.

9.1.2. *Sieve Analysis*:

XIII = mass of the approximate 500-g sample (determined to the nearest 0.2 g) screened on the 3.35-mm sieve,

XIV = mass of the approximate 500-g sample (determined to the nearest 0.2 g) screened on the 2.00-mm sieve,

XV = mass of the approximate 500-g sample (determined to the nearest 0.2 g) screened on the 0.600-mm sieve,

XVI = mass of solids retained on the 3.35-mm sieve,

XVII = mass of solids retained on the 2.00-mm sieve, and

XVIII = mass of solids retained on the 0.600-mm sieve.

9.2. *Basic Calculations and Remarks*:

9.2.1. *Chemical Constituents*:

A = apparent hydrate alkalinity of the sample is indicated by titration and calculated as percent of CaO, Calculations:

$$\text{Percent CaO} = \frac{(IV)}{(X)}$$

B = carbonate alkalinity of the sample derived by titration and calculated as percent CaO,
Calculations:

$$\text{Percent CaO} = C - A$$

B′ = carbonate alkalinity of the sample derived by titration and calculated as percent $CaCO_3$,
Calculations:

$$\text{Percent } CaCO_3 = B \times (1.78479)$$

Note 4—1.78479 is a gravimetric factor used to convert percent CaO to percent $CaCO_3$.

C = total alkalinity of the sample calculated as percent CaO,
Calculations:

$$\text{Percent CaO} = \frac{(IX)}{(X)}$$

D = apparent hydrate alkalinity of the sample indicated by titration and expressed as percent $Ca(OH)_2$,
Calculations:

$$\text{Percent } Ca(OH)_2 = A \times (1.32126)$$

Note 5—1.32126 is a gravimetric factor used to convert percent CaO to percent $CA(OH)_2$.

E = carbonate alkalinity of the sample derived by titration and calculated as percent CO_2,
Calculations:

$$\text{Percent } Ca(OH)_2 = B \times (0.78479)$$

Note 6—0.78479 is a gravimetric factor used to convert percent CaO to percent CO_2.

F = loss on ignition of the sample when heated for 3 hours at 1100 °C (2012°F),
Calculations:

$$\text{Percent loss on ignition} = \frac{(XI - XII)}{(XI)} \times 100$$

Note 7—This equation is derived from the expression:

$$\text{Percent loss on ignition} = \frac{(\text{Sample Mass}) - (\text{Residue Mass})}{(\text{Sample Mass})} \times 100$$

For the purpose of this test procedure, *loss on ignition* shall be taken to be the sum of the losses due to "water of dehydration," "free water," and chemically combined carbon dioxide.

Water of Dehydration—that portion of the loss on ignition due to the loss of water resulting from the forced dehydration or disassociation of calcium hydroxide at elevated temperatures.

Free Water—the portion of the loss on ignition which is not accounted for by the loss due to "water of dehydration" plus the loss due to chemically combined carbon dioxide.

Total Water—that portion of the loss on ignition due to "water of dehydration" plus "free water."

G = "Total water" of the sample expressed as percent H_2O,
Calculations:

$$\text{Percent } H_2O = F - E$$

Note 8—This equation is derived from the assumption that at 1100°C, the principal losses to be encountered will be carbon dioxide and water, and that any gain in mass due to oxidation of other impurities such as sulfides to sulfates will be negligible. The basic assumption is that "total water" expressed as percent H_2O = (loss on ignition) – (carbonate alkalinity of the sample derived by titration expressed as percent CO_2).

H = apparent hydrate alkalinity of the sample indicated by the "total water" portion of the loss on ignition and expressed as percent $Ca(OH)_2$,
Calculations:

$$\text{Percent } Ca(OH)_2 = G \times (4.1128)$$

Note 9—4.1128 is a gravimetric factor used to convert percent H_2O to percent $Ca(OH)_2$.

I = corrected value for the hydrate alkalinity of the sample calculated as percent $Ca(OH)_2$,
Calculations:

$$\text{Percent } Ca(OH)_2 = H \text{ in Case I}$$

where $D > H$, then unhydrated lime is indicated as being present in the sample, = *D* or *H* in Case II

where $D = H$, then neither unhydrated lime nor "free water" is indicated as being present in the sample,= *D* in Case III

where $H > D$, then "free water" is indicated as being present in the sample.

Note 10—In instances in which this revised test procedure is used to arrive at a value for "hydrate alkalinity," mass percent $Ca(OH)_2$, then it is to be understood that it is to be the value "*I*" which shall be reported since this is the correct value for the hydrate alkalinity of the samples.

J = "Free water" of the sample calculated as percent H_2O,
Calculations:

$$\text{Percent } H_2O = \text{zero in Case I}$$

where $D > H$, then unhydrated lime is indicated as being present in the sample,= zero in Case II

where $D = H$, then neither unhydrated lime nor "free water" is indicated as being present in the sample, = $(H – D) \times (0.24314)$ in Case II

where $H > D$, then "free water" is indicated as being present in the sample.

Note 11—0.24314 is a gravimetric factor used to convert $Ca(OH)_2$ equivalents to H_2O equivalents.

K = unhydrated lime content of the sample calculated as percent CaO,
Calculations:

$$\text{Percent CaO} = (D - H) \times (0.75686) \text{ in Case I}$$

where $D > H$, then unhydrated lime is indicated as being present in the sample, = zero in Case II

where $D = H$, then neither unhydrated lime nor "free water" is indicated as being present in the sample, = zero in Case III

where $H > D$, then "free water" is indicated as being present in the sample.

Note 12—0.75686 = the conversion factor to convert $Ca(OH)_2$ equivalents to CaO equivalents.

L = "Inert matter" content of the sample calculated as percent inert matter,
Calculations:

Percent "inert matter" = $100 – (C + F)$.

Note 13—For the purpose of this test procedure, "inert matter" shall be defined as those sample constituents which by their chemical nature do not react under the conditions prescribed in acid titration nor do they volatilize under the conditions prescribed for the loss on ignition determination. It shall be assumed to consist essentially of acid insolubles plus possible metallic oxides.

9.2.2. *Sieve Analysis*—screen analysis on the sample expressed as mass percent of the total solids retained on the various sieves shall be calculated as follows:

$$M \;=\; \text{percent solids retained on the 3.35 – mm sieve} \frac{(\text{XVI})}{(\text{XIII})} \times 100$$

$$N \;=\; \text{percent solids retained on the 2.00 – mm sieve} \;=\; \frac{(\text{XVII})}{(\text{XIV})} \times 100,$$

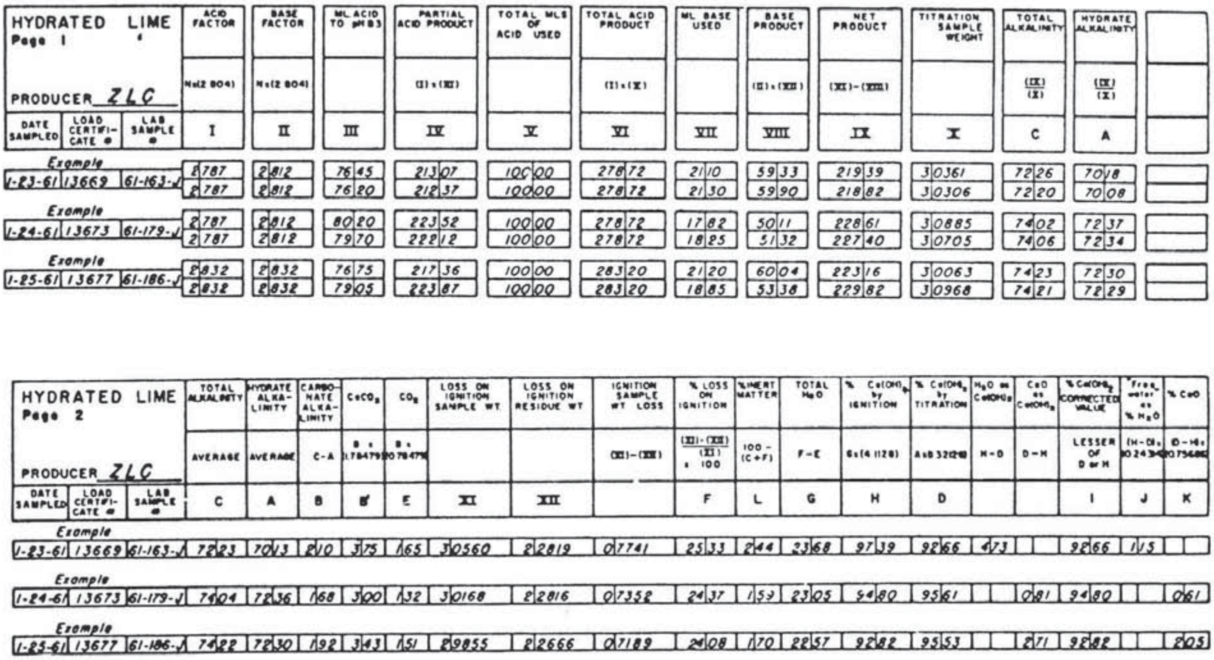
$$O \;=\; \text{percent solids retained on the 0.600 – mm sieve} \;=\; \frac{(\text{XVIII})}{(\text{XV})} \times 100,$$

$$O' \;=\; \text{percent solids retained on the 0.075-mm sieve, and}$$

$$O' \;=\; R_c = [(R_s/5 \times 100 + C] \text{ (Note 14)}$$

Note 14—See T 192 for the definitions of variables R_c, R_s, and C. The value 100 is a constant in T 192 and the value five is used to correct the calculation in T 192 because a five-gram sample is used instead of a 1-gram sample.

Note 15—Sample calculations are given in Figure 1.



HYDRATED LIME
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PRODUCER ZLC

DATE SAMPLED	LOAD CERTIFICATE #	LAB SAMPLE #	ACID FACTOR	BASE FACTOR	ML ACID TO pH 8.3	PARTIAL ACID PRODUCT	TOTAL MLS OF ACID USED	TOTAL ACID PRODUCT	ML BASE USED	BASE PRODUCT	NET PRODUCT	TITRATION SAMPLE WEIGHT	TOTAL ALKALINITY	HYDRATE ALKALINITY	
			N×(2.804)	N×(2.804)		(I)×(III)		(I)×(V)		(II)×(VII)	(VI)−(VIII)		(IX)/(X)	(IX)/(X)	
			I	II	III	IV	V	VI	VII	VIII	IX	X	C	A	
Example 1-23-61	13669	61-163-J	2.787 2.787	2.812 2.812	76.45 76.20	213.07 212.37	100.00 100.00	278.72 278.72	21.10 21.30	59.33 59.90	219.39 218.82	3.0361 3.0306	72.26 72.20	70.18 70.08	
Example 1-24-61	13673	61-179-J	2.787 2.787	2.812 2.812	80.20 79.70	223.52 222.12	100.00 100.00	278.72 278.72	17.82 18.25	50.11 51.32	228.61 227.40	3.0885 3.0705	74.02 74.06	72.37 72.34	
Example 1-25-61	13677	61-186-J	2.832 2.832	2.832 2.832	76.75 79.05	217.36 223.87	100.00 100.00	283.20 283.20	21.20 18.85	60.04 53.38	223.16 229.82	3.0063 3.0968	74.23 74.21	72.30 72.29	

HYDRATED LIME
Page 2
PRODUCER ZLC

DATE SAMPLED	LOAD CERTIFICATE #	LAB SAMPLE #	TOTAL ALKALINITY	HYDRATE ALKALINITY	CARBONATE ALKALINITY	$CaCO_3$	CO_2	LOSS ON IGNITION SAMPLE WT	LOSS ON IGNITION RESIDUE WT	IGNITION SAMPLE WT LOSS	% LOSS ON IGNITION	% INERT MATTER	TOTAL H_2O	% $Ca(OH)_2$ by IGNITION	% $Ca(OH)_2$ by TITRATION	H_2O as $Ca(OH)_2$	CaO as $Ca(OH)_2$	% $Ca(OH)_2$ CORRECTED VALUE	Free water as % H_2O	% CaO
			AVERAGE	AVERAGE	C − A	B × 1.78479	B × 0.78479			(XI)−(XII)	$\frac{(XI)-(XII)}{(XI)} \times 100$	100 − (C + F)	F − E	G × (4.1128)	A × 1.3212	H − D	D − H	LESSER OF D or H	(H − D) × 0.2434	(D − H) × 0.7568
			C	A	B	B′	E	XI	XII		F	L	G	H	D			I	J	K
Example 1-23-61	13669	61-163-J	72.23	70.13	2.10	3.75	1.65	3.0560	2.2819	0.7741	25.33	2.44	23.68	97.39	92.66	4.73		92.66	1.15	
Example 1-24-61	13673	61-179-J	74.04	72.36	1.68	3.00	1.32	3.0168	2.2816	0.7352	24.37	1.59	23.05	94.80	95.61		0.81	94.80		0.61
Example 1-25-61	13677	61-186-J	74.22	72.30	1.92	3.43	1.51	2.9855	2.2666	0.7189	24.08	1.70	22.57	92.82	95.53		2.71	92.82		2.05

Figure 1—Sample Calculations

10. BASIC ASSUMPTIONS CONCERNING THE LOSS ON IGNITION PORTION OF TEST PROCEDURE

10.1. For the purpose of this test procedure, it shall be assumed that the loss in mass of sample during the loss on ignition portion of the test procedure is attributable solely to the volatilization of "free water," "water of dehydration," and of chemically combined carbon dioxide. The residue remaining in the platinum crucible, after the loss on ignition portion of the analysis, is assumed to be unhydrated calcium oxide plus "inert matter" that will not volatilize during the ignition at elevated temperatures nor react chemically during the acid titration of the principal alkaline constituents of the sample. This "inert matter" is usually termed "SiO_2," "acid insolubles," "combined metallic oxides," etc.

11. BASIC ASSUMPTIONS CONCERNING THE TITRATION PORTION OF THE TEST PROCEDURE

11.1. The titration portion of the analysis involved the assumption that the principal acid neutralizable alkaline constituents are calcium hydroxide, calcium oxide, and calcium carbonate. All of these constituents need not be present simultaneously, of course. This test procedure implies that under the conditions set forth for analysis, alkaline carbonates will not enter into the reaction during the first stage of titration (to the end point of 8.3). The "measured excess" of acid plus the back-titration with base is intended to cope with the bulk of the alkaline carbonates present and they are calculated as being present in the usual form of calcium carbonate. If unhydrated oxides are present in the sample, they will usually hydrate and/or react with the acid during the first state of titration (to the end point of 8.3) and will be calculated as calcium hydroxide. If they do not react under the conditions of the test, they will of course be considered as "inert matter" and calculated as such.

12. POSSIBLE PRESENCE OF MAGNESIUM COMPOUNDS

12.1. This entire test procedure is intended to be used in connection with the testing of a high-calcium-type lime hydrate. Magnesium compounds when present are assumed to be present to only a small degree and, as such, are either ignored or else calculated to the basis of calcium compounds. In instances where magnesium compounds are present to a significant degree, such a hydrate will usually encounter difficulty in meeting the requirements of the high-calcium-type lime specifications for which the particular test procedure was designed.

Standard Method of Test for

Determination of the Strength of Soil-Lime Mixtures

AASHTO Designation: T 220-66 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determination of the Strength of Soil-Lime Mixtures

AASHTO Designation: T 220-66 (2008)

1. SCOPE

1.1. This method provides for the determination of the unconfined compressive strength of soil-lime stabilization mixtures.

Note 1—Generally, an unconfined compressive strength of 690 kPa (100 psi) is satisfactory for the final course of base construction, and it is desirable that materials for such courses contain a minimum of 50 percent plus 0.425-mm (No. 40) material before treatment. Various soil materials may be treated for subbase, and, in such cases, the minimum suggested unconfined compressive strength is 345 kPa (50 psi).

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- M 216, Lime for Soil Stabilization

2.2. *ASTM Standard*:

- D 2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

3. APARATUS

3.1. *Automatic Tamper*—A compaction device with base plate to hold 152 mm (6 in.) ID forming molds, equipped with 4.54-kg (10-lb) ram and adjustable height of fall. Ram fall is 457 mm (18 in.). The striking face of the ram is a 40-degree segment of a circle of 76-mm (3-in.) radius. Automatic tamper shall be furnished an extra base plate to hold the forming mold during specimen top finishing.

3.2. *Compaction Mold with Removable Collar*—Mold is 152 mm (6 in.) ID and 215 mm ($8^1/_2$ in.) high.

3.3. *Measuring Device for Specimen Height*—A micrometer dial assembly with a standard set of spacer blocks.

3.4. *Scale*, rated 18.1-kg (40-lb) capacity, sensitive to 0.0005 kg (0.001 lb).

3.5. *Press*, hydraulic, to extrude specimens from mold.

3.6. *Drying Oven*, controlled from 60 ± 5ºC (140 ± 9ºF) to 110 ± 5ºC (230 ± 9ºF).

3.7. *A Supply of Metal Pans*, wide and shallow, for mixing and drying materials, and a supply of rectangular stainless steel pans approximately 230 by 400 by 60 mm (9 by 16 by $2^{1}/_{4}$ in.) deep, equipped with porous spacer plates.

3.8. *Circular Porous Stones* slightly less than 152 mm (6 in.) in diameter and 51 mm (2 in.) high.

3.9. *Axial Cells*, lightweight stainless steel cylinders, 171 mm ($6^{3}/_{4}$ in.) ID and 305 mm (12 in.) high, fitted with standard air valve and straight, tubular rubber membrane 152 mm (6 in.) in diameter.

3.10. *Vacuum Pump*, 20 to 35 liters per minute (0.70 to 1.25 cfm), or aspirator.

3.11. *Air Compressor*, 4.7 to 7.1 L/s (10 to 15 cfm) with 230-L (60-gals) storage tank and controls, pressure regulators, gauges, and valves.

3.12. *Moist Room*, equipped with shelves and a constant pressure supply of air.

3.13. *Micrometer Dial Gauge*, calibrated to 0.02 mm (0.001 in.) with support to measure deflection of specimen.

3.14. *A supply of 2.27 and 4.54-kg (5 and 10-lb) Lead Surcharge Weights*.

3.15. *Calibrated Proving Ring or Other Continuous Force Measuring Device*, according to T 67 Verification of Testing Machines, except that an error of plus or minus 2 percent is allowed.

3.16. *Circumference Measuring Device*—A specially made metal tape measure.

3.17. *Screw Jack Press and Assembly* or other suitable testing press, with dial housing and two loading blocks.

3.18. *Sieves* with square openings of the following sizes conforming to the Standard Specification for Sieves for Testing Purposes (M 92) 75, 53, 50, 45, 31.5, 22.4, 16.0, 12.5, 9.5, 4.75, 2.00, 0.850, and 0.425-mm (3.0, 2.12, 2.00, 1.75, 1.25, $^{7}/_{8}$, $^{5}/_{8}$, $^{1}/_{2}$, $^{3}/_{8}$ in., No. 4, No. 10, No. 20, and No. 40) sieves.

3.19. *Mechanical Pulverizer* adjustable clearance rotating plate.

3.20. *Mechanical Sieve Shaker*—A laboratory size [0.014 m^3 ($^{1}/_{2}$ ft^3)] sieve shaker, convenient but not absolutely necessary, used for separating material for recombining specimens.

3.21. *A Supply of Small Tools and Accessories* such as wedgewood mortar and pestle, rubber covered pestle, rawhide hammer, spatulas, trowels, level, scoops, siphon tubes, sample containers, cardboard cartons, 510 by 510-mm (20 by 20-in.) filter papers, etc.

4. MATERIALS

4.1. A supply of lime, preferably meeting the requirements of M 216 for either Type I or II lime.

4.2. Good quality tap water.

5. SOIL PREPARATION

5.1. Select a 91-kg (200-lb) minimum representative sample for testing.

5.2. Spread the sample on a clean, dry floor to air-dry or use forced drafts of warm air.

5.3. The aggregations or hard lumps of clay in soils containing no appreciable amounts of coarse particles shall be crushed to pass the 2.00-mm (No. 10) sieve without breaking the coarse particles. The sample shall then be screened on the 0.850-mm (No. 20) sieve and the percentages retained and passing the 0.850-mm (No. 20) sieve determined.

5.4. Clays and other soils containing coarse particles shall be broken up to pass the 4.75-mm (No. 4) sieve without breaking the coarse particles. This may be done by means of a plastic mallet, rubber covered tamper, or similar hand tools. The material shall then be separated as follows:

5.4.1. Coarse particle materials (crushed stone, gravel, sand, and caliche) shall be dry-screened over the following suggested sieves: 45, 31.5, 22.4, 16, 9.5, 4.75, and 2.00 mm (1.75, 1.25, $^7/_8$, $^5/_8$, $^3/_8$ in., No. 4 and No. 10) to separate the various sizes of materials. Retain all material passing the 2.00-mm (No. 10) sieve. The material passing the 45-mm sieve (1.75-in.) is used in making specimens. Mix all minus 2.00-mm (No. 10) material on the floor until it is uniformly blended with respect to color, appearance, and moisture content.

5.5. Determine the mass of each size of material and compute the cumulative percentages retained on each sieve and the percent passing the 2.00-mm (No. 10) sieve. These values are not to be used as true sieve analysis, but are used to recombine individual specimens to ensure uniform graduation within each specimen.

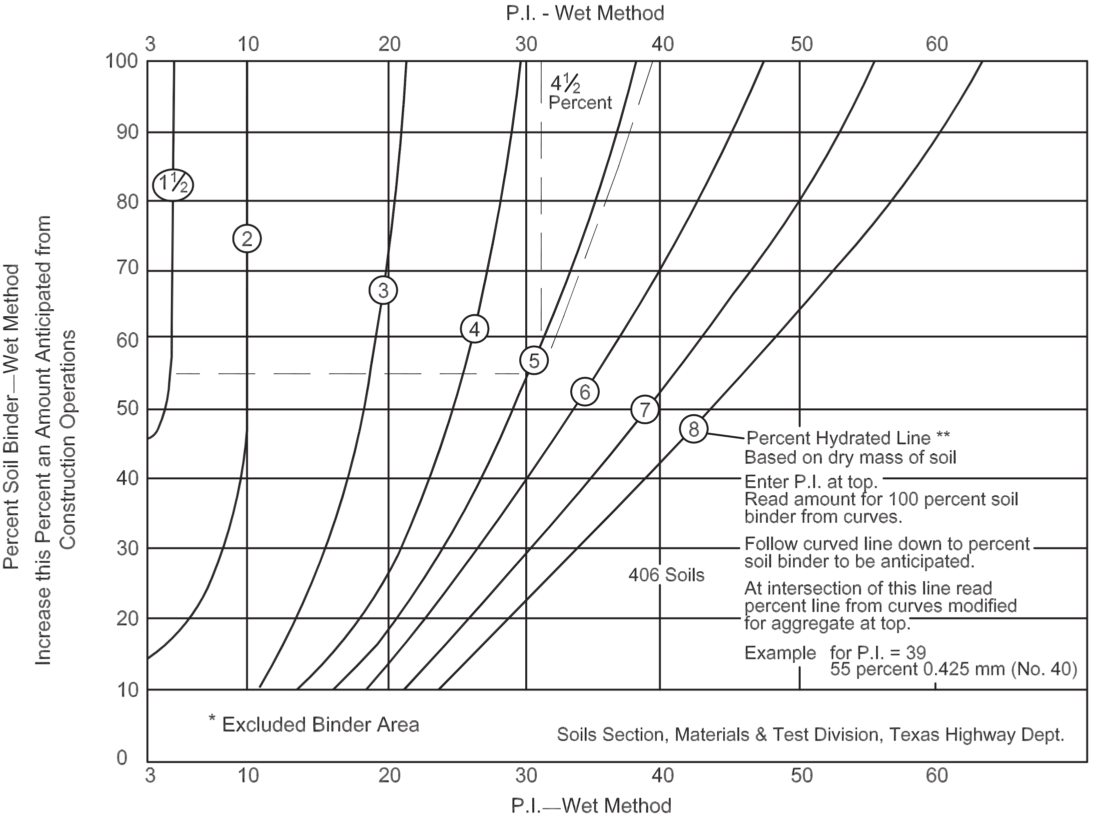
5.6. On the basis of the cumulative sieve size percentages obtained in Section 5.5 above, calculate and weigh out a 4.54-kg (10-lb) representative sample for sieve analysis and soil constants (Atterberg Limits). This 4.54-kg (10-lb) sample is prepared for testing by the wet method, T 146. Rolls, tumblers, or mills that might alter the coarse particles should not be used in this preparation. After preparation of the sample by the wet method, the following tests shall be performed in Table 1:

Table 1—Required Soils Tests

Mechanical Analysis	T 88
Liquid Limit, LL	T 89
Plastic Limit (PL) and Plasticity Index (PI)	T 90

6. SELECTION OF PERCENTAGE OF LIME

6.1. Enter plasticity index and percent minus 0.425 mm (No. 40), determined as in Section 4, of untreated soil on Figure 1, and determine the percentage of lime to add to the soil.



Percent Hydrated Line **
Based on dry mass of soil

Enter P.I. at top.
Read amount for 100 percent soil binder from curves.

Follow curved line down to percent soil binder to be anticipated.

At intersection of this line read percent line from curves modified for aggregate at top.

Example for P.I. = 39
55 percent 0.425 mm (No. 40)

Soils Section, Materials & Test Division, Texas Highway Dept.

* Exclude use of chart for materials with less than 10 %—No. 40 and cohesionless materials (P.I. less than 3).

** Percent of relatively pure lime usually 90% or more of Ce and/or Mg hydroxides and 85% or more of which pass the No. 200 sieve. Percentages shown are for stabilizing subgrades and base courses where lasting effects are desired. Satisfactory temporary results are sometimes obtained by the use of as little as ½ of above percentages. Reference to cementing strength is implied when such terms as "Lasting Effects" and "Temporary Results" are used.

Figure 1—Recommended Amounts of Lime for Stabilization of Subgrades and Bases (These percentages should be substantiated by approved testing methods on any particular soil material.)

7. PROCEDURE FOR DETERMINING OPTIMUM MOISTURE AND DENSITY

7.1. Determine the percent hygroscopic moisture in the soil using a representative sample of the soil according to ASTM Method D 2216. Estimate the mass of air-dry material that will, when wetted and compacted, fill the 152-mm (6-in.) ID mold to a height of 200 mm (8 in.). Using this estimated mass and the air dry screen analysis already obtained in preparing the large sample, compute the cumulative masses of each size to combine to make the 152-mm (6-in.) diameter by 200-mm (8-in.) high specimen. The amount of lime to use is the percentage from Section 5 and is based on the dry density of the soil.

7.2. Weigh up the material as calculated in Section 6.1. Keep the coarse particle fraction separate from (1) the passing 2.00-mm (No. 10) sieve material for flexible base, and (2) the clay lumps and passing 0.850-mm (No. 20) sieve for fine soils.

7.3. Calculate the mass of water to add on the basis of the dry soil and weigh into a tared sprinkling jar.

7.4. In preparing the soil-lime mixture for the moisture-density test, mix the lime with the portion of material passing the 2.00-mm (No. 10) sieve. Wet the plus 2.00-mm (No. 10) portion with some or all of the weighed quantity of water (depending on how little or how much plus 2.00-mm (No. 10) the sample contains) and stir and wet the coarse particles thoroughly. Let set until free water on surface has been absorbed.

Note 2—In clay soils or fine-grained soils, separate the material on the 0.850-mm (No. 20) sieve. Mix approximate proportionate amounts of the lime to be used with both fractions. Sprinkle the mixing water on the +0.850-mm (No. 20) fraction using most or all of the water required. Add in the –0.850-mm (No. 20) fraction and the remainder of water if any. Mix thoroughly and mold as above.

7.5. Pour the fine material passing the 2.00-mm (No. 10) or 0.850-mm (No. 20) sieve over the wet portion of the specimen and spread evenly. Use a trowel to cut grooves in the material allowing dry fines to fall toward the bottom of the pan; then mix until uniform. Take care not to lose any of the material and keep the mixing pan covered, when possible, to prevent loss of water by evaporation. In order to get uniform distribution of moisture in clay soils, pass the material through a 6.3-mm ($^1/_4$-in.) sieve.

7.6. Calculate and weigh out the material for one layer. This should be one-fourth of the mass of the wet mixture. Place this layer in the mold using putty knives, your hand, or convenient tools, keeping close watch in order to avoid segregation of rock sizes or fines. In base coarse materials or other coarse particle-type materials, place some excess fines, usually about 15 mm (0.5 in.) thick, loosely on the bottom flat surface, and then begin with large particles and other sizes, ending up with some fines to ensure a dense layer. Successive layers do not require as much fines as the 15-mm (0.5-in.) loose thickness in the first layer. This procedure ensures a smooth, tight bottom for each layer. Level the layer by hand or spatula, then use the spatula around the insides of the mold, spading the layer to intermix fines and coarse particles for a denser, more uniform layer. Do not tamp the loose material either by hand or any other hand tool, but compact the layer using a compactive effort of 50 accurately adjusted 457-mm (18-in.) drops of the 4.54-kg (10-lb) ram; determine the optimum moisture and maximum density for the soil-lime mixture. Keep the ram face clean of sticky or adhering material. Repeat this until all four layers are compacted.

7.7. After the last layer has been compacted, fasten the mold containing the specimen upon the top of the extra base plate and finish the top by means of various hand tools, such as a putty knife, or a lead, rawhide, or plastic mallet, and a circular steel plate with a smooth surface. Use the small level to check the surface of the specimen so that it will be plane and level with the top of the forming mold. Do not trim the specimen.

7.7.1. After the final layer has been compacted and while the hand finishing of the specimen is being done, the following type of blows (with hand hammers) shall be used after leveling, etc., to complete the hand finishing. (See Table 2.)

Table 2—Type of Blows

No. of 4.54-kg (10-lb), 457-mm (18-in.) Blows per Layer	Type of Hammer	No. of Blows and Description
15 to 20	0.45 to 0.90-kg (1 to 2-lb) hammer	2 to 4 light “pecking” blows
25	0.45 to 0.90-kg (1 to 2-lb) plastic 1.80 to 2.2-kg (4 to 5-lb) rawhide	5 to 10 light and 2 medium firm
50 and above	0.45 to 0.90-kg (1 to 2-lb) plastic 1.80 to 2.2-kg (4 to 5-lb) rawhide	5 to 10 light and 5 firm

7.8. Remove the mold from the base plate, determine the mass of the specimen in the mold to the nearest 0.5 g (0.001 lb), and measure the height, by means of the measuring device, to the nearest 0.02 mm (0.001 in.). Record the data.

7.9. Carefully center the specimen over a porous stone and place in the press to extrude molded specimens. Push the material on the bottom stone upward out of the mold.

7.10. Place the specimen in a large tared pan, break up material by hand or using convenient hand tools, and oven dry to constant mass at 110 ± 5ºC (230 ± 9ºF).

7.11. If necessary, adjust the mass of the material to obtain a 200-mm (8-in.) height of specimen, vary the amount of molding water, and repeat the above operations using individual batches for each specimen to obtain several points for a good moisture-density curve.

8. COMPACTION OF THE TEST SPECIMEN

8.1. Compact three specimens 152 mm (6 in.) in diameter and 200 mm (8 in.) in height at the optimum moisture and density found in Section 6. These lime-treated subgrade soil or flexible base specimens should be compacted as nearly identical as possible. The data for these specimens, as well as those obtained in the following test procedures, should be recorded on the test data sheet (Figure 2).

Sample No.						
Date Molded						
Date Tested						
Percent Lime						
Percent Water Added						
Percent Hygro. Moist						
Total Percent Moist. In Spec.						
Kilograms Soil (Dry)						
Kilograms Lime						
Kilograms Soil (Dry) + Lime						
Kilograms soil + (Hygro. Moist.)						
Kilograms Lime						
Kilograms Soil + Hygro. Moist. + Lime						
Mass Water Added						
Tare Mass Jar						
Mass Water + Jar						
Mass per Layer						
Mold No.						
Wet Mass Spec. + Mold						
Tare Mass Mold						
Wet Mass Specimen						
Dry Mass Specimen						
Height Specimen						
Vol. per Lin. M						
Volume of Spec.						
Dry Density Spec.						
Total Load—Comp.						
Comp. Str. kPa (psi)						
Remarks:						

Figure 2—Compressive Strength Test Worksheet for Soil-Lime Mixes

9. CURING TEST SPECIMENS

9.1. Immediately after extruding the test specimens from the forming mold, with top and bottom porous stones in place, insert the specimens in a triaxial cell. Store the specimens at room temperature for a period of 7 days.

9.2. After moist curing, remove the cells and place the specimens in an air dryer and dry at a temperature not to exceed 60ºC (140ºF) for about 6 hours or until one-third to one-half of the molding moisture has been removed. All lime-treated soils are dried as given above even though a considerable amount of cracking may occur. Allow the specimen to cool for at least 8 hours before continuing the test.

9.3. Determine the mass and measure the specimens and subject them to capillarity for 10 days by the method described in Section 10.

10. SUBJECTING TEST SPECIMENS TO CAPILLARITY

10.1. Specimens are subject to capillarity for 10 days as follows:

10.1.1. Apply a vacuum to the axial cell and remove the cell from the specimen. Do not remove porous stones from specimens until after specimens have been tested. Cut a piece of filter paper, 250 by 510 mm (10 by 20 in.) in size, fold to 125 by 510 mm (5 by 20 in.) and make several cuts with scissors (jack-o'-lantern fashion). These cuts will prevent any restriction by the paper. Wrap the filter paper around the specimen and stones and fasten with a small piece of cellophane tape. Replace the cell.

10.2. Place the specimens into the rectangular pans provided for capillary absorption and adjust the water level on the lower porous stones to a distance of 13 mm (0.5 in.) below the bottom of the specimens.

10.3. Connect each cell to the air manifold and open the valve to apply a constant lateral pressure of 6.9 kPa (1 psi). Maintain this constant pressure throughout the period of absorption.

10.4. Place a suitable vertical surcharge load (which will depend upon the proposed use or location of the material in the roadway) on the top porous stone. For flexible base, use 3.45 kPa (0.5 psi) and for subgrade soils, use 6.90 kPa (1 psi) of the end area of the specimen. Consider the mass of the top porous stone as part of the surcharge mass.

11. PREPARING SPECIMENS FOR TESTING

11.1. Specimens subjected to 10 days of capillarity shall be prepared as follows:

11.1.1. Disconnect the air hose from the cell, remove the surcharge weight, and return the specimens to the laboratory for testing. Use a vacuum and deflate the rubber membrane to aid in removing the cell from the specimens, and discard the filter paper. If any appreciable material clings to the paper, carefully press it back into the available holes along the side of the specimen.

11.1.2. Determine the mass of the specimens and record their total mass after capillary absorption. Note that the wet mass of stones is obtained after the specimens are tested.

11.1.3. Measure the circumference of each specimen by means of the metal measuring tape. Measure the height of the specimen including the stones and enter on the data sheet as height over stones. Record the height of each stone.

11.2. Specimens that set overnight in cells shall be prepared as follows:

11.2.1. Use a vacuum and deflate the rubber membrane to aid in removing the cell from the specimens. Any material clinging to the membrane is pressed back into the available side holes or saved to place with the specimen when it is dried out.

11.2.2. Measure the specimen as in Section 11.1.3 and replace the cell.

12. TESTING SPECIMENS

12.1. In brief, the specimens are tested in compression while being subjected to their assigned constant lateral pressure. The motorized press is geared to travel at a rate of 3.3 to 3.8 mm (0.13 to 0.15 in.) per minute. Simultaneous readings of load and deformation shall be taken at intervals of 0.25-mm (0.01-in.) deformation until the specimen fails.

12.2. Disengage the worm gear drive and crank the press down far enough to have room to place the specimen, metal loading blocks, and the special bell dial housing in the press.

12.3. Center the specimen with the upper and lower metal loading blocks in place in the press. Adjust the deformation gauge in such a manner that it will be down against the center of the top spacer block and also compressed for almost the length of travel of the stem. The gauge must be placed in this position because the specimen moves away from the gauge during the compression. Set the dial of the deformation gauge to read zero.

12.4. Place the bell housing over the deformation gauge and adjust so that it does not touch the gauge or its mountings. At this point it should be noted that the compressive stress will necessarily be applied along a vertical line through the center of the ball that is mounted in the top of the bell housing. Since it is desirable to apply the compressive force along the vertical axis of the test specimen, shift the bell housing laterally to bring the ball directly over the axis of the specimen. Raise the press by means of the motor, then align and seat the ball on the bell housing into the socket in the proving ring. Then apply just enough pressure to obtain a perceptible reading on the proving ring gauge. Read the deformation gauge and record as deformation under dead load.

12.5. Connect the air line to the axial cell and apply lateral pressure to the specimen. The usual lateral pressures used for a series of tests are 0, 21, 34, 69, 103, and 138 kPa (0, 3, 5, 10, 15, and 20 psi). In cases where the load or stress is high (1207 to 1241 kPa (175 to 180 psi)) for the specimen tested at 103 kPa (15 psi) lateral pressure, use 48 kPa (7 psi) instead of 138 kPa (20 psi) for the last specimen. The lateral pressure applied by the air will tend to change the initial reading of the deformation gauge. As the air pressure is adjusted, start the motor momentarily to compress the specimen until the deformation gauge reads the same as recorded in Section 12.4. Read the proving ring gauge and enter in the load column opposite the initial deformation reading.

12.6. Turn on the motor and read the proving ring dial at each 0.25-mm (0.01-in.) deformation of the specimen. Continue reading until 60 readings have been taken, unless failure occurs earlier. Failure is reached when the proving ring dial readings remain constant or decrease with further increments of deformation. In testing specimens with coarse particles, the slipping and shearing of the coarse particles will cause temporary decreases in proving ring readings. The test shall be continued until true failure is reached. After 60 readings the cross-sectional area of the specimen has increased so that the subsequent small increase in load readings is little more than the increase in tension of the membrane acting as lateral pressure.

12.7. All of the above procedure applies to the unconfined specimen except that no air or axial cell is used. For materials that contain a large amount of coarse particles, compact and test two specimens at zero lateral pressure. Use the average of the test results unless large rocks appear to have created point bearings; in this case use the highest value.

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13. CALCULATIONS AND GRAPHS

13.1. *Obtaining Dry Mass of Specimen and Stones*:

13.1.1. The specimen and stones are removed from the cell over a tared flat drying pan. Use a spatula to clean the material from the inside of the cell and the porous stones. Break up the specimen in the drying pan, taking care to lose none of the material, and place an identification tag in the pan.

13.1.2. Dry the material to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF) and determine the dry mass.

13.1.3. On specimens that have been subjected to capillarity overnight, determine the mass of the damp stones, dry at 60ºC (140ºF) to constant mass, and record the mass.

13.2. Calculate the volume in m^3 (ft^3) for 1 mm (1 in.) of height of the mold as follows:

$$V = \frac{\text{area of mold in mm}^2 \times 1\text{ mm}}{10^9} \tag{1}$$

or,

$$V = \frac{\text{area of mold in in.}^2 \times 1\text{ in.}}{1728} \tag{2}$$

13.3. Calculate the volume of the specimens as molded by multiplying the value obtained in Section 12.2 times the height of the specimen in mm (in.).

13.4. Calculate dry density as follows:

$$\text{Dry density} = \frac{\text{dry mass of specimen}}{\text{volume of specimen}} \tag{3}$$

13.5. Calculate compactive effort for a 50-mm (2-in.) layer expressed as J/m^3 (ft·lbf/ft^3):

Compactive effort (J/m^3) =

$$\frac{9.8\text{ m/s}^2}{1000\text{ mm/m}} \times \frac{\text{no. of blows} \times \text{mass of ram (kg)} \times \text{fall of ram (mm)}}{\text{volume of layer (value from Section 13.2} \times \text{layer thickness in mm)}} \tag{4}$$

or,

Compactive effort (ft·lbf/ft^3) =

$$\frac{1}{12\text{ in./ft}} \times \frac{\text{no. of blows} \times \text{mass of ram (lbm)} \times \text{fall of ram (in.)}}{\text{volume of layer (value from Section 13.2} \times \text{layer thickness in in.)}} \tag{5}$$

13.6. Calculate the percent molding moisture as follows:

$$\text{molding moisture, percent} = \frac{\text{mass of wet spec} - \text{mass of dry spec}}{\text{mass of dry spec}} \times 100 \tag{6}$$

13.7. Calculate percent moisture after specimens have been in capillarity, using the formula:

$$M_C = \frac{W_A - W_B - W_D}{W_D} \times 100 \tag{7}$$

where:

W_A = wet mass of specimen and stones after capillarity,

W_B = wet mass of stones, and

W_D = dry mass of specimen.

13.8. Calculate the values of strain and stress for each individual specimen from the following relations:

$$S = \frac{d}{h} \times 100 \tag{8}$$

where:

S = percent strain,

d = total vertical deformation at the given instant, and

h = the height of the specimen measured after specimen is removed from capillarity.

$$p = \frac{P}{A}\left(1 - \frac{S}{100}\right) \tag{9}$$

where:

p = the corrected vertical unit stress. A correction is necessary because the area of the cross section increases as the specimen is reduced in height. The assumption is made that the specimen deforms at constant volume.

P = the total vertical load on the specimen at any given deformation. It is the sum of the applied load measured by the proving ring, plus the dead weight of the upper stone, loading block, and dial housing.

A = the end area of the cylindrical specimen at the beginning of the test.

13.9. Plot a moisture-density curve (Figure 3).

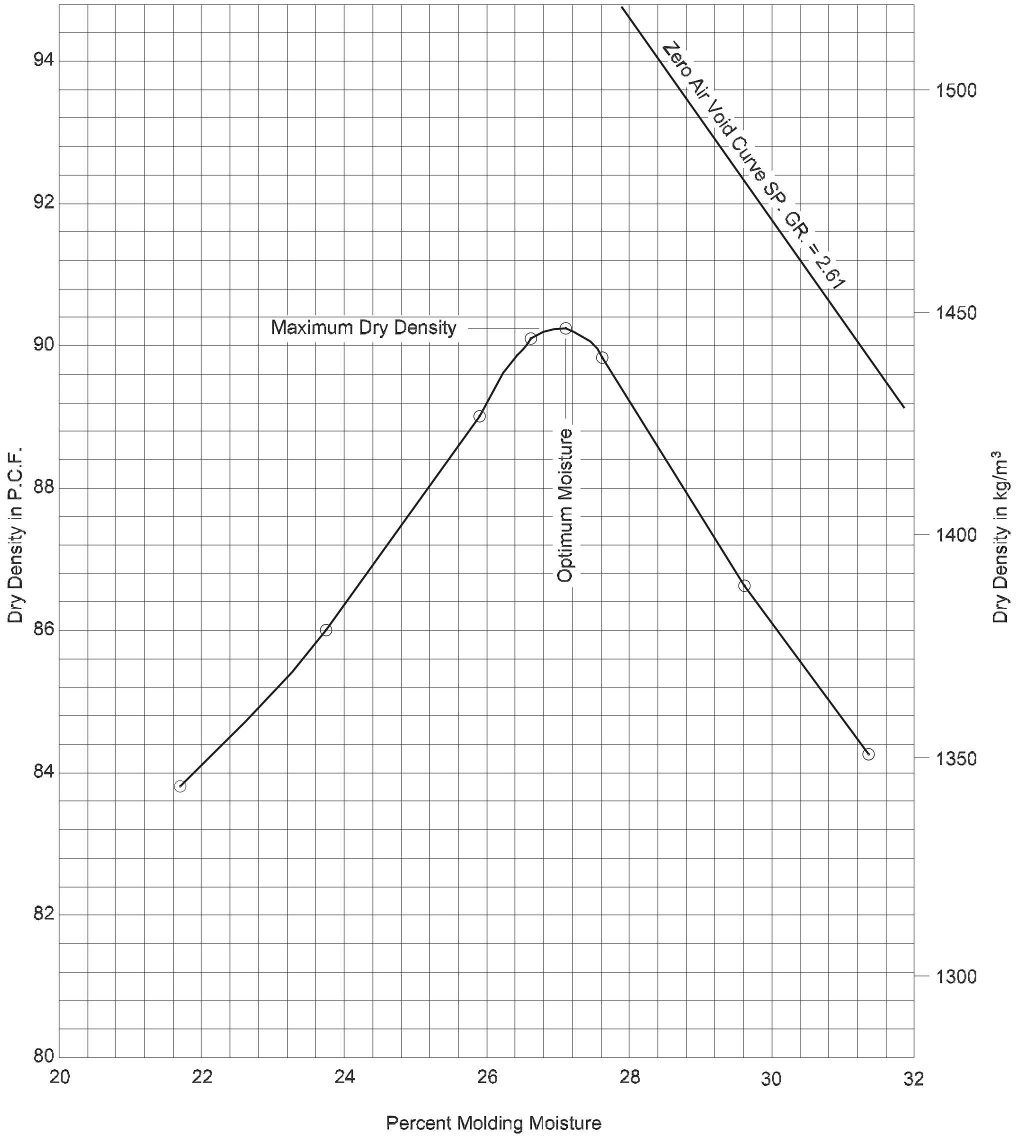

Figure 3—Moisture-Density Curve

14. REPORTING OF TEST RESULTS

14.1. Report the unconfined compressive strength values, density, moisture, and lime content as indicated in Figure 4. Use the average of the three specimen test values when reporting the unconfined compression test results.

Lab No.	Percent Lime Basis Dry Mass Soil	Dry Density kg/m^3 (lb/ft^3) Soil Lime	Compressive Strength kPa (psi)	Percent Moisture Absorbed	Optimum Moisture Soil Plus Lime

Figure 4—Compression Test Results

Standard Method of Test for

Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements

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AASHTO Designation: T 221-90 (2008)[1]
ASTM Designation: D 1195-93 (2004)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements

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1. SCOPE

1.1. This test method covers a procedure for making repetitive static plate load tests on subgrade soils and compacted pavement components, in either the compacted condition or the natural state, and is to provide data for use in the evaluation and design of rigid and flexible-type airport and highway pavements.

1.2. The values stated in inch-pound units are to be regarded as the standard.

2. DEFINITIONS

2.1. *deflection*—the amount of downward vertical movement of a surface due to the application of a load to the surface.

2.2. *rebound deflection*—the amount of vertical rebound of a surface that occurs when a load is removed from the surface.

2.3. *residual deflection*—the difference between original and final elevations of a surface resulting from the application and removal of one or more loads to and from the surface.

3. APPARATUS

3.1. *Loading Device*—A truck or trailer or a combination of both a tractor-trailer, an anchored frame, or other structure loaded with sufficient weight to produce the desired reaction on the surface under test. The supporting points (wheels in the case of a truck or trailer) shall be at least 8 ft (2.44 m) from the circumference of the largest diameter bearing plate being used.

3.2. *Hydraulic Jack Assembly*—with a spherical bearing attachment, capable of applying and releasing the load in increments. The jack shall have sufficient capacity for applying the maximum load required, and shall be equipped with an accurately calibrated gauge that will indicate the magnitude of the applied load.

3.3. *Bearing Plates*—A set of circular steel bearing plates not less than 1 in. (25.4 mm) in thickness, machined so that they can be arranged in pyramid fashion to ensure rigidity, and having diameters ranging from 6 to 30 in. (152 to 762 mm). The diameters of adjacent plates in the pyramid arrangement shall not differ by more than 6 in. (152 mm) (Note 1).

Note 1—A minimum of four different plate sizes is recommended for pavement design or evaluation purposes. For evaluation purposes alone, a single plate may be used, provided that its area is equal to the tire-contact area corresponding to what may be considered as the most critical combination of conditions of wheel load and tire pressure. For the purpose of providing data indicative of bearing index (for example, the determination of relative subgrade support throughout a period of a year), a single plate of any selected size may be used.

3.4. *Dial Gauges*—two or more, graduated in units of 0.001 in. (0.02 mm) and capable of recording a maximum deflection of 1 in. (25 mm) or other equivalent deflection-measuring devices.

3.5. *Beam for Mounting Dial Gauges*—A beam upon which the dial gauges shall be mounted. The beam shall be a $2^1/_2$-in. (63.5-mm) standard black pipe or a 3 by 3 by $^1/_4$ in. (76 by 76 by 6-mm) steel angle, or equivalent. It shall be at least 18 ft (5.5 m) long and shall rest on supports located at least 8 ft (2.44 m) from the circumference of the bearing plate or nearest wheel or supporting leg. The entire deflection measuring system shall be adequately shaded from direct rays of the sun.

3.6. *Miscellaneous Tools*—including a spirit level, for preparation of the surface to be tested and for operation of the equipment.

4. PROCEDURE

4.1. Carefully center a bearing plate, of the selected diameter, under the jack assembly. Set the remaining plates of small diameter concentric with, and on top of, the bearing plate. Set the bearing plate level in a thin bed of a mixture of sand and plaster of paris, or plaster of paris alone, or of fine sand, using the least quantity of materials required for uniform bearing. To prevent loss of moisture from the subgrade during the load test, cover the exposed subgrade to a distance of 6 ft (1.83 m) from the circumference of the bearing plate with a tarpaulin or waterproof paper.

4.2. Where unconfined load tests are to be made at a depth below the surface, remove the surrounding material to provide a clearance equal to $1^1/_2$-plate diameters from the edge of the bearing plate. For confined tests, the diameter of the excavated circular area shall be just sufficient to accommodate the selected bearing plate.

4.3. Use a sufficient number of dial gauges, so located and fixed in position as to indicate the average vertical movement of the bearing plate. When using two dial gauges, they shall be set near each extremity of a diameter of the bearing plate, 1 in. (25.4 mm) from the circumference. When three gauges are employed, they shall be set at an angle of 120 degrees from each other, and equidistant from the circumference of the bearing plate. Each individual set of readings shall be averaged, and this value is recorded as the average settlement reading.

4.4. After the equipment has been properly arranged, and with all of the dead load (jack, plates, etc.) acting, seat the bearing plate and assembly by the quick application and release of a load sufficient to produce a deflection of not less than 0.01 in. (0.25 mm) nor more than 0.02 in. (0.51 mm), as indicated by the dial gauges. When the dial needles come to rest following the release of this load, reseat the plate by applying one-half of the recorded load producing the 0.01- to 0.02-in. (0.25- to 0.51-mm) deflection. When the dial needles have again come to rest, set each dial accurately at its zero mark.

Note 2—The use of additional dial gauges, placed on the surface of the material being tested at one-half, one, one-and-one-half, etc. bearing plate diameters from the edge of the bearing plate, is optional.

4.5. Apply a load giving a deflection of about 0.04 in. (1.02 mm), start a stopwatch, and maintain the same load constantly until the rate of deflection is 0.001 in. (0.03 mm) per minute or less for 3 successive minutes. Then completely release the load, and observe the rebound until the rate of recovery is 0.001 in. (0.03 mm) per minute or less, for 3 successive minutes. Apply and release the same load in this manner six times. Record the reading of the dial gauges resting on the bearing plate at the end of each minute; record the readings of the dial gauges set beyond the perimeter of the bearing plate just before the application, and just before the release of load, for each repetition. To ensure good contact between the gauges and the bearing plate or other surface on which they are resting, briefly buzz an electric bell attached to the deflection beam 10 seconds before the dial gauges are to be read.

4.6. Increase the load to give a deflection of about 0.2 in. (5.08 mm) and proceed as directed in Section 4.5.

4.7. Increase the load to give a deflection of about 0.4 in. (10.2 mm) and proceed as directed in Section 4.5.

4.8. In all cases, the standard end point shall be a rate of 0.001 in. (0.03 mm) per minute or less for 3 successive minutes.

4.9. From a thermometer suspended near the bearing plate, read and record the air temperature at half-hour intervals.

5. RECORD OF TESTS

5.1. In addition to the continuous listing of all load, deflection, and temperature data, as prescribed in Section 3, a record shall also be made of all associated conditions and observations pertaining to the test, including the following:

5.1.1. Date;

5.1.2. Time of beginning and completion of test;

5.1.3. List of personnel;

5.1.4. Weather conditions;

5.1.5. Any irregularity in routine procedure;

5.1.6. Any unusual conditions observed at the test site; and

5.1.7. Any unusual observations made during the test.

6. CALCULATION AND PLOTTING OF LOAD-DEFLECTION RELATIONSHIPS

6.1. For each repetition of each load, determine the deflection at which the rate of deflection is exactly 0.001 in. (0.03 mm) per minute. This is termed end-point deflection and can be determined with sufficient accuracy from visual inspection of the deflection data for each repetition of load recorded.

6.2. Correct the recorded loads, as read from the pressure gauge of each hydraulic jack employed, by means of the calibration curve for each jack and pressure gauge used.

6.3. Determine graphically the zero point corrections for both applied load and deflection. This requires taking into account the weight of the hydraulic jack, that of the pyramid of bearing plates, etc., and that of the corrected jack loads at which the dial gauges were set to zero at the beginning of the test.

6.4. Plot the corrected deflection at which the rate of deflection is exactly 0.001 in. (0.03 mm) per minute versus the number of repetitions of each corrected load. Similar graphs may be prepared in which corrected residual deflection and rebound deflection are plotted versus the number of repetitions of each corrected load.

7. PRECISION AND BIAS

7.1. The precision and bias of this test method for making repetitive static plate load tests on subgrade soils and flexible pavement components has not been determined. Soils and flexible pavement components at the same location may exhibit significantly different load-deflection relationships. No method presently exists to evaluate the precision of a group of repetitive plate load tests on soils and flexible pavement components due to the variability of these materials. The subcommittee is seeking pertinent data from users of this method that may be used to develop meaningful statements of precision and bias.

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[1] This method is technically equivalent to ASTM D 1195-93 (2004).

Standard Method of Test for

Nonrepetitive Static Plate Load Test of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements

AASHTO Designation: T 222-81 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Nonrepetitive Static Plate Load Test of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements

AASHTO Designation: T 222-81 (2008)

1. SCOPE

1.1. This method covers the making of nonrepetitive static plate load test on subgrade soils and flexible pavement components, in either the compacted condition or the natural state, and is intended to provide data for use in the evaluation and design of rigid and flexible-type airport and highway pavements.

1.2. The values stated in SI units are to be regarded as the standard.

2. DEFINITIONS

2.1. *deflection*—the amount of downward vertical movement of a surface due to the application of a load to the surface.

2.2. *residual deflection*—the difference between original and final elevations of a surface resulting from the application and removal of one or more loads to and from the surface.

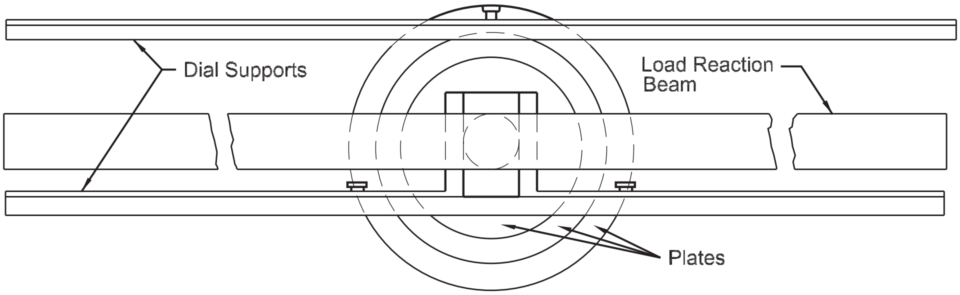
2.3. *rebound deflection*—the amount of vertical rebound of a surface that occurs when a load is removed from the surface.

3. APPARATUS

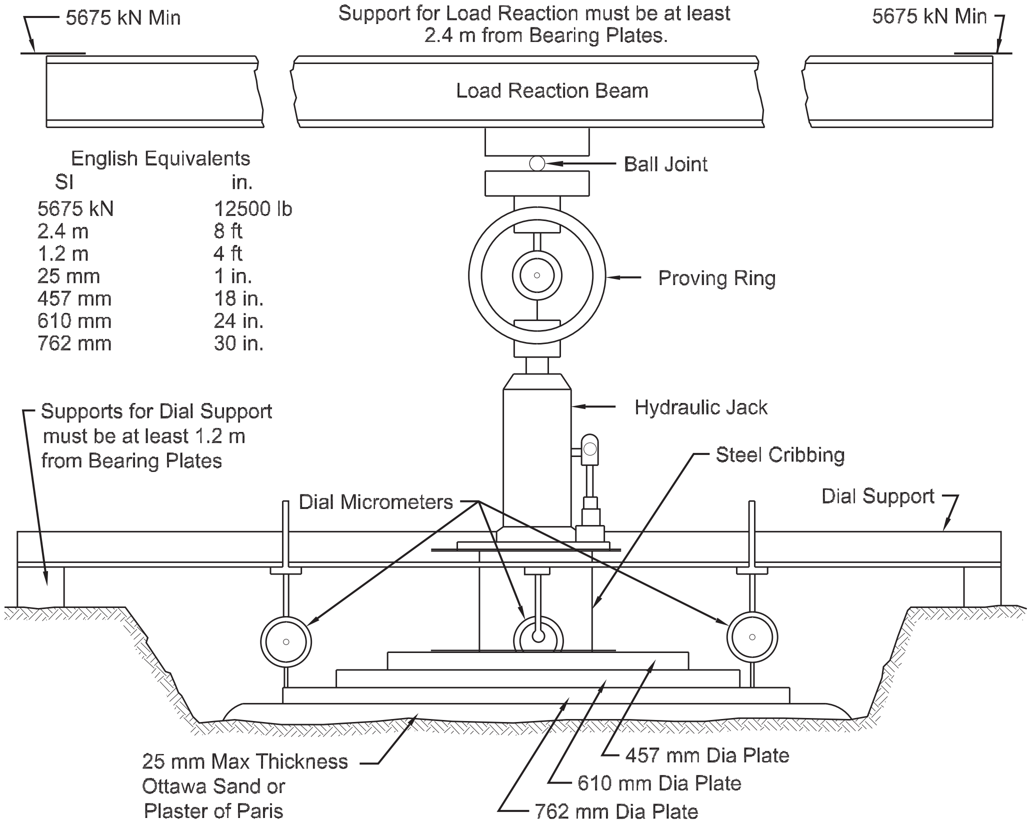
3.1. *Field Test Apparatus*—The required field test apparatus, part of which is shown in Figure 1, is as follows:

3.1.1. *Loading Device*—a truck or trailer, or a combination of both, a tractor trailer, an anchored frame, or other structure loaded with sufficient mass to produce the desired reaction on the surface under test. The supporting points (wheels in the case of a truck or trailer) shall be at least 2.4 m (8 ft) from the circumference of the largest diameter bearing plate being used. The dead load shall be at least 5675 kg (25000 lb).

3.1.2. *Hydraulic Jack Assembly*—with a spherical bearing attachment, capable of applying and releasing the load in increments. The jack shall have sufficient capacity for applying the maximum load required, and shall be equipped with an accurately calibrated gauge, or proving ring, that will indicate the magnitude of the applied load.



Plan



Elevation

Figure 1—Plate Bearing Test Equipment

3.1.3. *Bearing Plate*—A set of circular steel bearing plates not less than 25.4 mm (1 in.) in thickness, machined so that they can be arranged in pyramid fashion to ensure rigidity, and have diameters ranging from 152 to 762 mm (6 to 30 in.). The diameters of adjacent plates in the pyramid arrangement shall not differ by more than 152 mm (6 in.) (Note 1). Aluminum alloy No. 24ST plates 38 mm ($1^1/_2$ in.) thick may be used in lieu of steel plates.

Note 1—A minimum of four different plate sizes is recommended for pavement design or evaluation purposes. For evaluation purposes alone, a single plate may be used, provided that its area is equal to the tire-contact area corresponding to what may be considered as the most critical combination of conditions of wheel load and tire pressure. For the purpose of providing data indicative of bearing index (for example, the determination of relative subgrade support throughout a period of a year), a single plate of any selected size may be used.

3.1.4. *Dial Gauges*—Three or more, graduated in units of 0.02 mm (0.001 in.) and capable of recording an accumulated deflection of at least 25.4 mm (1 in.), or other equivalent deflection measuring devices.

3.1.5. *Deflection Beam*—Upon which the dial gauges shall be mounted. The beam shall be a 63.5 mm ($2^1/_2$ in.) standard black pipe or a 76 by 76 by 6 mm (3 by 3 by $^1/_4$ in.) steel angle, or equivalent. It shall rest on supports located at least 1.2 m (4 ft) from the circumference of the bearing plate or nearest wheel or supporting leg. The entire deflection measuring system shall be adequately shaded from direct rays of the sun and weather protected from rain, etc.

3.1.6. *Miscellaneous Tools*—Including a spirit level, for preparation of the surface to be tested and for operation of the equipment.

3.1.7. *Consolidometer Apparatus*—Necessary equipment for cutting an undisturbed specimen of the soil into a consolidometer test ring. Scales, oven, and miscellaneous tools for making moisture-content determination.

4. PROCEDURE

4.1. Where unconfined load tests are to be made, strip an area of the soil to be tested to the proposed elevation of the subgrade surface. The stripped area should be at least twice the diameter of the plates to eliminate surcharge or confining effects. If the subgrade is to be composed of fill material, construct a test embankment at least 762 mm (30 in.) in height using the proposed fill material compacted to the moisture content and density that will be required during construction. Clear the area to be tested of any loose materials and make it level. Extreme care should be taken not to disturb the soil in the test area, especially in granular material. For confined tests, the diameter of the excavated circular area shall be just sufficient to accommodate the selected bearing plate.

Carefully center a bearing plate of the selected diameter under the jack assembly. Set the remaining plates of smaller diameter concentric with, and on top of, the bearing plates. Set the bearing plate level in a thin bed of a mixture of sand and plaster of paris, of plaster of paris alone, or of fine sand, using the least quantity of materials required for uniform bearing. To prevent loss of moisture from the subgrade during the load test, cover the exposed subgrade to a distance of 2.0 m (6 ft) from the circumference of the bearing plate with a tarpaulin or waterproof paper.

4.2. Seat the 762-mm (30-in.) diameter bearing plate on the Ottawa sand or plaster of paris. Turning or working the plate back and forth will help to provide uniform seating of the plate. Center the 610-mm (24-in.) and 457-mm (18-in.) diameter plates on the 762-mm (30-in.) diameter plate, and center the hydraulic jack on the 457-mm (18-in.) diameter plate.

If cribbing is needed, crib between the top plate and the jack. If a steel proving ring is being used to measure load, it should be placed on top of the jack and the ball joint used between the proving ring and load reaction device. For safety reasons, shims should not be used between the ball joint and the reaction device. The load reaction device must be long enough so that its supports will be at least 2.4 m (8 ft) from the bearing plate. A steel beam between two loaded trucks provides a good load reaction device. Three dial gauges shall be used to measure deformation of the soil under load. Place these gauges so that the dial stems rest on the bottom 762-mm (30-in.) diameter plate not more than 6 mm ($^1/_4$ in.) from the outer edge, spaced 120 degrees apart. Fasten the gauges to a frame whose supports are at least 1.22 m (4 ft) from the edge of the 762-mm (30-in.) diameter plate.

4.3. Use one of the following initial procedures:

4.3.1. *Seating Procedure No. 1*—Seat the loading system and bearing plate by applying a load of 321 kg (707 lb), 6.9 kPa (1 psi) when the design thickness of the pavement will be less than 380 mm (15 in.) or a load of 642 kg (1414 lb), 13.8 kPa (2 psi) when the design thickness of the pavement is 380 mm (15 in.) or more. Allow the seating load to remain in place until practically complete deformation has taken place. Then take a reading on all three dial gauges, which will be used as the "zero" reading. The seating load is also considered to be the "zero" load. Cyclic loading under the seating load may be used to assure good seating of the apparatus and bearing plate.

4.3.2. *Seating Procedure No. 2*—After the equipment has been properly arranged, with all of the dead load (jacks, plates, etc.) acting, seat the bearing plate and assembly by the quick application and release of a load sufficient to produce a deflection of not less than 0.25 mm (0.01 in.) or more than 0.50 mm (0.02 in.) as indicated by the dials. When the dial needles come to rest following release of this load, reseat the plate by applying one half of the recorded load producing the 0.25- to 0.50-mm (0.01- to 0.02-in.) deflection. When the dial needles have then again come to rest, set each dial accurately at its zero mark.

4.4. Without releasing the seating load, Load Application Procedure No. 1 or 2 shall then be followed.

4.4.1. *Load Application Procedure No. 1*—Apply loads at a moderately rapid rate in uniform increments. The magnitude of each load increment shall be small enough to permit the recording of a sufficient number of load-deflection points to produce an accurate load-deflection curve (not less than six). After each increment of load has been applied, allow its action to continue until a rate of deflection of not more than 0.02 mm/min (0.001 in./min) has been maintained for 3 consecutive minutes. Record load and deflection readings for each load increment. Continue this procedure until the selected total deflection has been obtained, or until the load capacity of the apparatus has been reached, whichever occurs first. At this point, maintain the load until an increased deflection of not more than 0.02 mm/min (0.001 in./min) for 3 consecutive minutes occurs. Record the total deflection, after which release the load to that at which the dial gauges were set at zero, and maintain the zero-setting load until the rate of recovery does not exceed 0.02 mm (0.001 in.) for 3 consecutive minutes. Record the deflection at the zero-setting load.

Each individual set of readings shall be averaged, and this value is recorded as the average settlement reading.

4.4.2. Apply two load increments of 1605 kg (3535 lb), 34.5 kPa (5 psi) each with load increment being held until deformation averages less than 0.02 mm/min. (0.001 in./min) for 10 consecutive minutes. Read all three dial gauges at the end of each load increment. Following the completion of the 3210-kg (7070-lb), 69.0-kPa (10-psi) load increment, determine the average deflection by averaging the total movement between the "zero" and 69.0-kPa (10-psi) increment for each dial.

4.5. Compute a value of k'_u (uncorrected modulus of soil reaction) using the following formula:

$$k'_u = \frac{69.0\text{ kPa (10 psi)}}{\text{average deflection}} \qquad (1)$$

If the value of k'_u is less than 54.3 kPa/mm (200 psi/in.), the test is considered complete and the load may be released. Should the value of k'_u be 54.3 kPa/mm (200 psi/in.) or greater, apply load increments of 1605 kg (3535 lb) 34.5 kPa (5 psi) until a total load of 9630 kg (21210 lb) 207 kPa (30 psi) is reached, allowing each load increment to remain until the deformation averages less than 0.02 mm/min (0.001 in./min) for 10 consecutive minutes. Read all three dial gauges at the completion of each load increment.

4.6. Obtain an undisturbed sample of the foundation material for laboratory testing to determine the saturation correction to apply to the field test value. The undisturbed sample must be large enough to obtain two consolidometer specimens side by side (i.e., at the same elevation). Take the sample in a container suitable for sealing to preserve the moisture content until the laboratory correction tests can be performed. When the plate-bearing test is performed directly on cohesive subgrade material, obtain the undisturbed specimen from the foundation at the same elevation at which the test is performed, but alongside rather than under the plates. When the test is performed on a granular base coarse material which is underlaid by a cohesive material, and when the base coarse is less than 1.9 m (75 in.) in thickness, take the undisturbed sample from the cohesive material at the bottom of the base course.

4.7. From a thermometer suspended near the bearing plate, read and record the air temperature at 30-minute intervals.

5. RECORD THE TESTS

5.1. In addition to the continuous listing of all load, deflection, and temperature data, as prescribed in Section 3, a record shall also be made of all associated conditions and observations pertaining to the test, including the following:

5.1.1. Date;

5.1.2. Time of beginning and completion of test;

5.1.3. List of personnel;

5.1.4. Weather conditions;

5.1.5. Any irregularity in routine procedure;

5.1.6. Any unusual conditions observed at the test site; and

5.1.7. Any unusual observations made during the test.

6. CALCULATIONS AND PLOTTING OF LOAD DEFLECTION RELATIONSHIPS

6.1. When the k'_u value, as computed in Section 4.5, is less than 54.3 kPa/mm (200 psi/in.), load-deformation curves need not be prepared. However, when the k'_u value is 54.3 kPa/mm (200 psi/in.) or greater, it is necessary to plot the load-deformation curve and correct the curve for such things as poor seating of the plates, nonlinear load-deformation relations, or shear failure, the unit load (kPa (lb/in.^{2})) on the plate is plotted versus the average deflection for each load increment. The average deflection is the average of the three dial readings between the "zero" and the end of each load increment. When averaging the three dial gauge readings, the data should be carefully examined to ensure that a reasonable average is being computed. If the load-deformation relation does not plot a straight line passing through the origin, the curve is corrected, as shown in Figure 2. Generally, the load-deformation curve will approximate a straight line between the unit loads of 69.0 and 207 kPa (10 and 30 psi). The correction consists of drawing a straight line, parallel to the straight-line portion of the plotted curve, through the origin. When correcting the load-deformation curve, good engineering judgment will be required. If the curve is nonlinear through its length, the straight-line correction will be based on the average slope of the curve through at least three points in the region of the curve having the least curvature.

6.2. An uncorrected modulus of soil reaction k'_u is computed from the field test data using the formula:

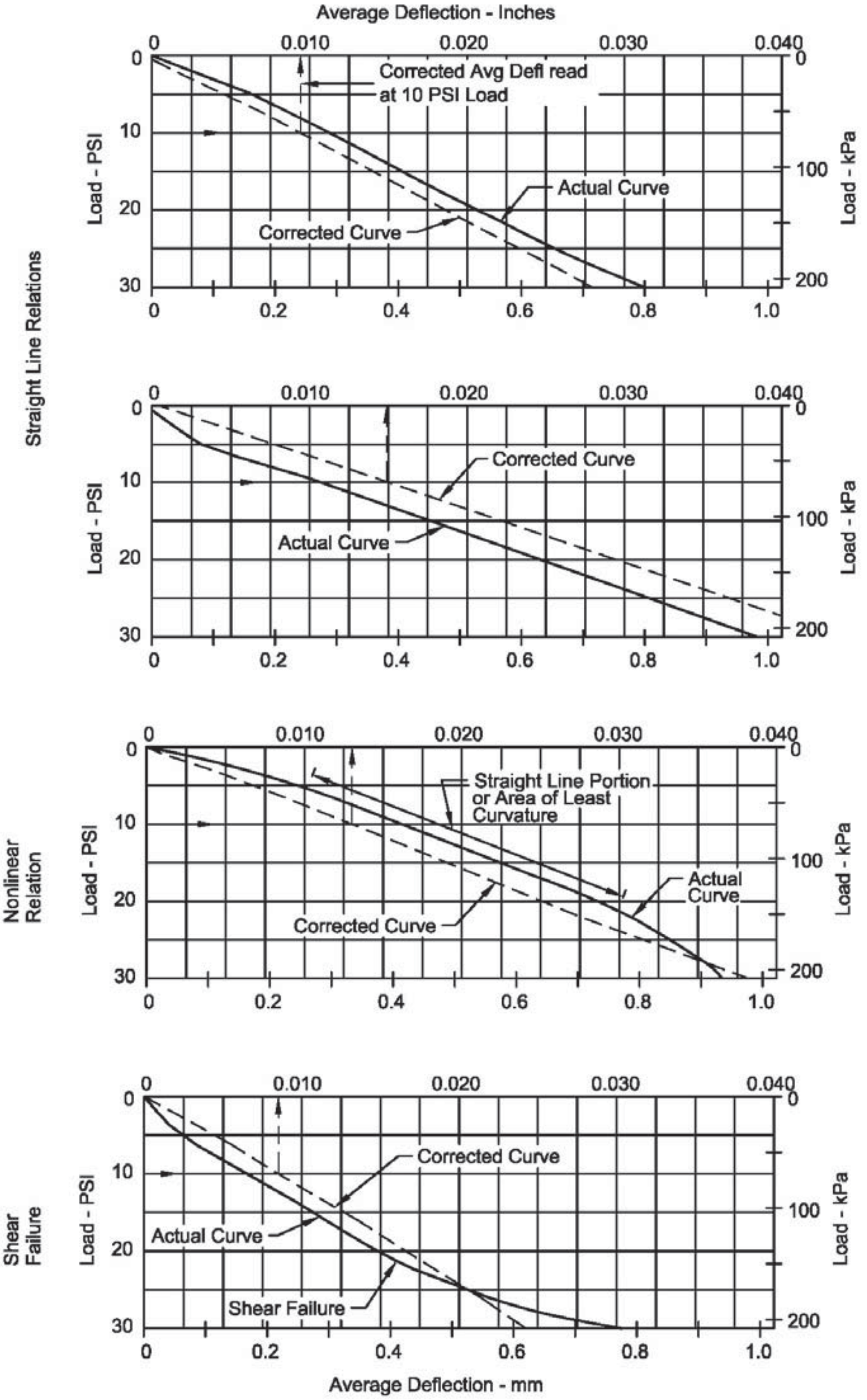
$$k'_u = \frac{69.0 \text{ kPa } (10 \text{ psi})}{\text{average deflection}} \tag{2}$$

When a load-deformation curve is unnecessary, as outlined in Section 6.1, the average deflection is the average of the total deflection recorded on each of the three gauges between the "zero" and the completion of the load increment. If a load deformation curve is required, the average deflection is read from the corrected curve as a load of 69.0 kPa (10 psi). The value of k'_u computed from the above formula must then be corrected for bending of the bearing plates and saturation of the soil as outlined in the following paragraphs:

6.3. There is a certain amount of bending in the bearing plates, even when a nest of plates is used. The bending results in a greater deflection at the center of the plate than at the rim where the deflections are measured. Since the modulus of soil reaction is actually a measurement of volume displacement under load, the lower deflection measured at the rim results in a k'_u value higher than actually exists. The amount of plate bending is related only to the strength of the soil being tested. Hence, for any one k'_u value, the correction to be made is always the same. This correction has been determined by test and is shown by the curve in Figure 3. The correction of k'_u is made by entering the plot in Figure 3 with the computed value of k'_u on the ordinate and projecting horizontally to the intersection of the plotted curve. The corrected value for the modulus of soil reaction (k'_u) is then determined by projecting vertically to the abscissa of the plot and reading the value.

6.4. The design of pavement is generally based upon the modulus of soil reaction when the soil is saturated. It is not feasible to saturate the soil in the field prior to the field test and seldom will the soil be in a saturated condition in its natural state. Therefore, the field test value must be corrected to reflect the value that will be obtained when the soil becomes saturated. Saturation correction is not normally required when evaluating pavements older than 3 years. Cohesionless soils are insensitive to saturation, and when the field test is performed on this type soil, the correction for saturation is not necessary. The most applicable method for correcting for saturation is through an adaption of the consolidation test. The correction test will be made on undisturbed specimens of the soil from the location of the field test. For the case where a field test is performed on the surface of a cohesionless base course material, but which is underlain by a cohesive soil, the saturation correction will be determined by tests on the underlying cohesive material.

The saturation correction factor is the ratio of the deformation of the consolidation specimen at the natural moisture content to the deformation in a saturated specimen under a 69.0-kPa (10-psi) loading. Two specimens of the undisturbed material are placed in a consolidometer. One specimen will be tested at the in situ moisture content, and the other specimen will be saturated after the seating load has been applied. Each specimen is then subjected to the same seating load (6.9 or 13.8 kPa (1 or 2 psi)) that was used for the field test. (See Section 4.3.1 or 4.3.2.) The seating load is allowed to remain on the in situ moisture-content specimen until all deformation occurs, at which time a "zero" reading is taken on the vertical deformation dial. Without releasing the seating load, an additional 69.0-kPa (10-psi) load is applied to the specimen and allowed to remain until all deformation has occurred. A final reading is then taken on the vertical deformation dial.



Note: Corrected Curve may lie above or below actual curve.

Figure 2—Correction of Load-Deformation Curve

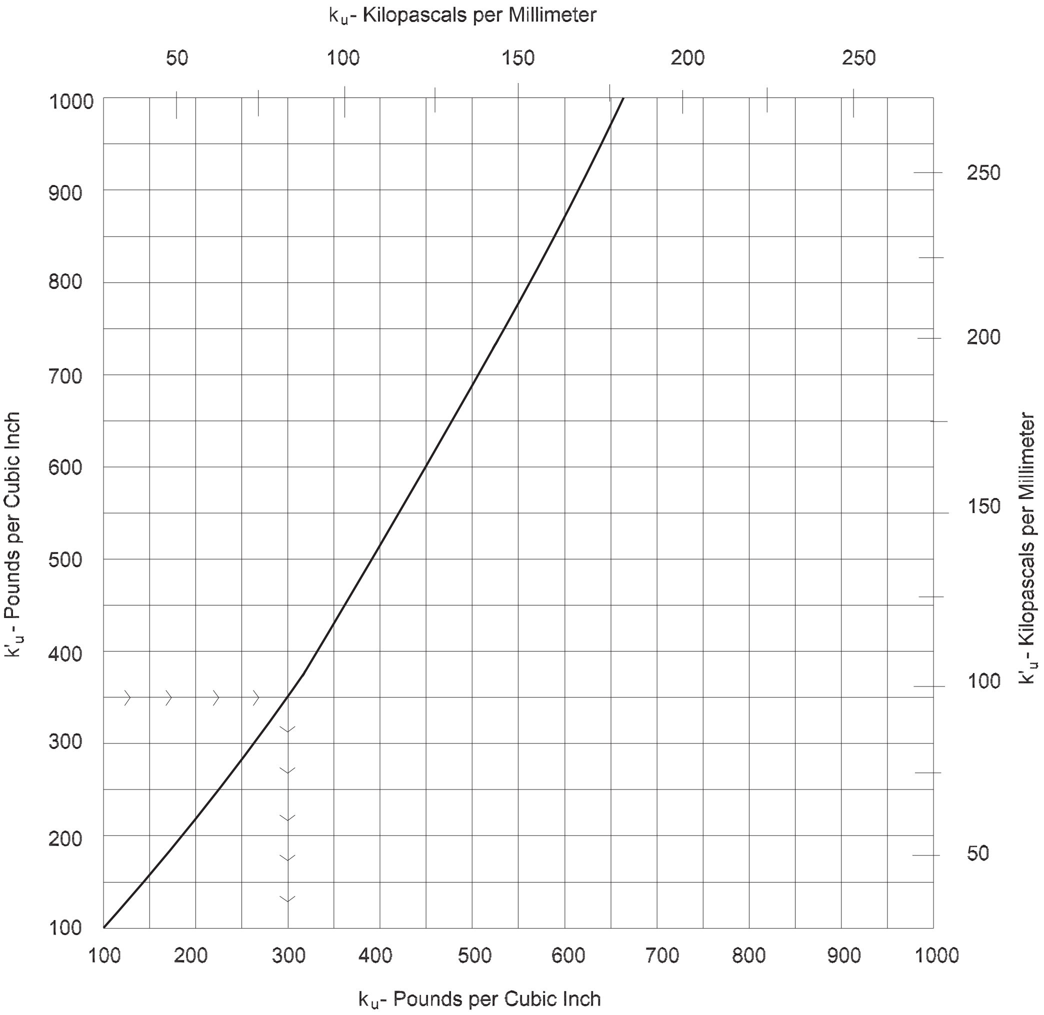


Figure 3—Correction of k'_u for Bending of the Plate

The other specimen is allowed to soak in the consolidometer under the seating load (6.9 or 13.8 kPa (1 or 2 psi)). After the specimen is saturated, a "zero" dial reading is obtained; then, without releasing the seating load, an additional 69.0-kPa (10-psi) load is applied. This load is allowed to remain on the specimen until all vertical deformation has occurred, after which a final reading on the dial is obtained. For soils of certain types, the specimen may swell under the seating load as it becomes saturated. Swelling of the material will result in extrusion of material above the top of the consolidometer ring, so that when the 69.0-kPa (10-psi) load is applied, the material may squeeze out over the ring rather than consolidate, which will lead to erroneous results. To prevent this, when dealing with a swelling-type soil or one that is suspected of being a swelling-type soil, the consolidometer ring will not be completely filled with soil. This can be accomplished by trimming the top of the specimen a sufficient amount, generally 1.6 mm ($^1/_{16}$ in.) to allow for the swelling. When the specimen for saturation is trimmed to allow for swelling, the specimen to be tested at the in situ moisture content will also be trimmed an equal amount so that the heights of the specimens will be equal at the beginning of the test.

The correction for saturation will be applied in proportion to the deformation of the two specimens under a unit load of 69.0 kPa (10 psi) as follows:

SI Units:

$$K = k_u \left[\frac{d}{d_s} + \frac{b}{1905} \left(1 - \frac{d}{d_s} \right) \right] \tag{3}$$

U.S. Customary Units:

$$K = k_u \left[\frac{d}{d_s} + \frac{b}{75} \left(1 - \frac{d}{d_s} \right) \right] \tag{4}$$

where:

K = corrected modulus of soil reaction, kPa (psi);

k_u = modulus of soil reaction uncorrected for saturation, kPa (psi);

d = deformation [mm (in.)] of a consolidometer specimen at in situ moisture content under a unit load of 69.0 kPa (10 psi);

d_s = deformation [mm (in.)] of saturated consolidometer specimen under a unit load of 69.0 kPa (10 psi); and

b = thickness of base course material, [mm (in.)].

Standard Method of Test for

Field Vane Shear Test in Cohesive Soil

AASHTO Designation: T 223-96 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Field Vane Shear Test in Cohesive Soil

AASHTO Designation: T 223-96 (2008)

1. SCOPE

1.1. This method covers the field vane test in soft, saturated, cohesive soils. Knowledge of the nature of the soil in which each vane test is to be made is necessary for assessment of the applicability and interpretation of the test.

1.2. The values stated in SI units are to be regarded as the standard.

2. SUMMARY OF METHOD

2.1. The vane shear test basically consists of placing a four-bladed vane in the undisturbed soil and rotating it from the surface to determine the torsional force required to cause a cylindrical surface to be sheared by the vane; this force is then converted to a unit shearing resistance of the cylindrical surface. It is of basic importance that the friction of the vane rod and instrument be accounted for; otherwise, the friction would be improperly recorded as soil strength. Friction measurements under no-load conditions (such as the use of a blank stem in place of the vanes, or a vane that allows some free rotation of the rod prior to loading) are satisfactory only provided that the torque is applied by a balanced moment that does not result in a side thrust. As torsional forces become greater during a test, a side thrust in the instrument will result in an increase in friction that is not accounted for by initial no-load readings. Instruments involving side thrust are not recommended. The vane rod may be of sufficient rigidity that it does not twist under full-load conditions; otherwise, a correction must be made for plotting torque-rotation curves.

3. APPARATUS

3.1. The vane shall consist of a four-bladed vane, as illustrated in Figure 1. Vane dimensions shall be as specified in Table 1. Sizes other than those specified in Table 1 shall be used only with the permission of the engineer in charge of the boring program. The ends of the vane may be tapered. (See Figure 1.) The penetrating edge of the vane blade shall be sharpened having an included angle of 90 degrees.

3.2. The vane shall be connected to the surface by means of steel torque rods. These rods shall have sufficient diameter such that their elastic limit is not exceeded when the vane is stressed to its capacity (Note 1). They shall be so coupled that the shoulders of the male and female ends shall meet to prevent any possibility of the coupling tightening when the torque is applied during the test. If a vane housing is used, the torque rods shall be equipped with well-lubricated bearings where they pass through the housing. These bearings shall be provided with seals to prevent soil from entering them.

The torque rods shall be guided so as to prevent friction from developing between the torque rods and the walls of casing or boring.

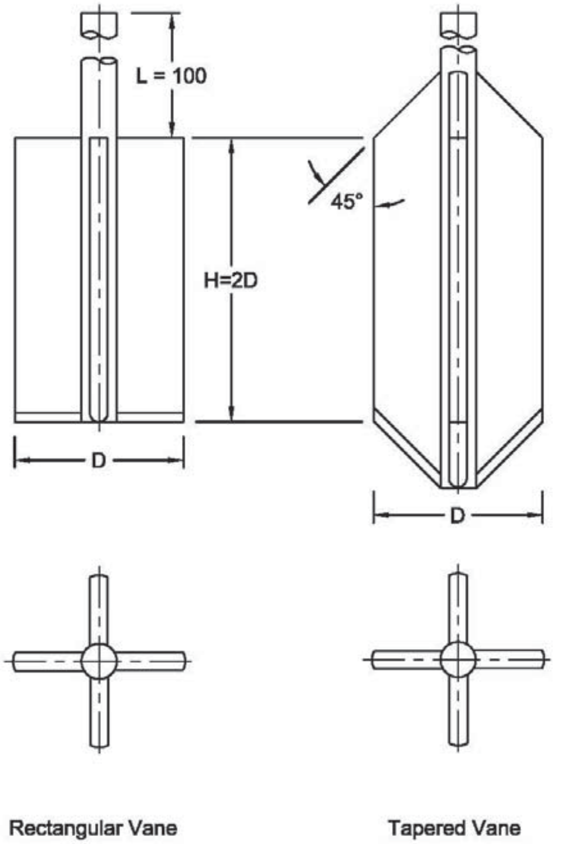


Figure 1—Geometry of Field Vane

Table 1—Recommended Dimensions of Field Vanes[a]

Minimum Casting Requirement		Diameter		Height		Thickness of Blade		Diameter of Vane Rod	
		mm	in.	mm	in.	mm	in.	mm	in.
	A	38.1	1.5	76.2	3	1.59	0.0625	12.7	0.5
Acker	B	50.8	2	102	4	1.59	0.0625	12.7	0.5
Type	N	63.5	2.5	127	5	3.18	0.125	12.7	0.5
	H	92.1	3.625	184	7.25	3.18	0.125	12.7	0.5
SGI[b]	H	55	2.17	110	4.33	2	0.078	11	0.43
Type	H	65	2.56	130	5.12	2	0.078	11	0.43
	B	50	1.97	110	4.33	2[d]	0.078	20	0.79
Nilcon[c]	N	65	2.56	130	5.12	2	0.078	20	0.79
Type	H	80	3.15	172	6.77	2	0.078	20	0.79

[a] Selection of the vane size is directly related to the consistency of the soil being tested; that is, the softer the soil, the larger the vane diameter.

[b] This is a totally self-contained, portable vane shear unit, which is capable of providing its own cased hole. Where overburden is too stiff, casing is required for the 77-OD mm vane housing.

[c] This is a totally self-contained, portable shear unit, which is capable of being pushed directly into the soil. The vane is followed by a slip coupling during penetration, which provides for rod friction calibration before each test. Where overburden is too stiff, casing is required.

[d] This is the average thickness. Vane blades are tapered 2.5 mm (0.098 in.) at the shaft to 1.5 mm (0.059 in.) at the edge.

3.3. Torque shall be applied to the torque rods, thence to the vane. The accuracy of the torque reading should be such that it will produce a variation not to exceed ±1.2 kPa (25 lb/ft^2) shear strength.

3.4. It is preferable to apply torque to the vane with a geared drive. In the absence of a geared drive, it is acceptable to apply the torque directly by hand with a torque wrench or equivalent. The duration of the test should be controlled by the requirements of Section 4.3.

Note 1—If torque versus rotation curves are to be determined, it is essential that the torque rods be calibrated (prior to use in the field). The amount of rod twist (if any) must be established in degrees per meter (foot) per unit torque. This correction becomes progressively more important as the depth of the test increases and the calibration must be made at least to the maximum depth of testing anticipated.

4. PROCEDURE

4.1. In the case where a vane housing is used, advance the housing to a depth that is at least five vane housing diameters less than the desired depth of the vane tip. Where no vane housing is used, stop the hole in which the vane is lowered at a depth such that the vane tip may penetrate undisturbed soil for a depth of at least five times the diameter of the hole.

4.2. Advance the vane from the bottom of the hole or the vane housing in a single thrust to the depth at which the test is to be conducted. Take precautions to make sure no torque is applied to the torque rods during the thrust.

4.3. With the vane in position, apply the torque to the vane at a rate that should not exceed 0.1 degrees per second. This generally requires a time to failure of from 2 to 5 minutes, except in very soft clays where the time to failure may be as much as 10 to 15 minutes. In stiffer materials, which reach failure at small deformations, it may be desirable to reduce the rate of angular displacement so that a reasonable determination of the stress-strain properties can be obtained. During the rotation of the vane, hold it at a fixed elevation. Record the maximum torque. With apparatus with geared drives it is desirable to record intermediate values of torque at intervals of 15 seconds or at lesser frequency if conditions require.

4.4. Following the determination of the maximum torque, rotate the vane rapidly through a minimum of 10 revolutions; the determination of the remolded strength should be started immediately after completion of rapid rotation and in all cases within 60 seconds after the remolding process.

4.5. In the case where soil is in contact with the torque rods, determine the friction between the soil and the rod by means of torque tests conducted on similar rods at similar depths with no vane attached. Conduct the rod friction test at least once on each site; this shall consist of a series of torque tests at varying depths.

4.6. In apparatuses in which the torque rod is completely isolated from the soil, conduct a friction test with a blank rod (Note 2) at least once on each site to determine the magnitude of the friction of the bearings. In a properly functioning vane apparatus, this friction should be negligible.

4.7. Conduct undisturbed and remolded vane tests in cohesive soils only. Do not conduct the vane test in any soil that will permit drainage or dilates during the test period, such as sands or silts or in soils where stones or shells are encountered by the vane in such a manner as to influence the results.

Note 2—In some cases, it is not necessary to remove the vane for the friction test. As long as the vane is not in contact with the soil, that is, where it is retracted into a casing, the friction measurements are not affected.

5. CALCULATION

5.1. Calculate the shear strength of the soil in the following manner:

The turning moment required to shear the soil is as follows:

$$T = s \times K \tag{1}$$

where:

T = torque, kN·m (or lbf·ft);

s = shear strength of the clay kPa (or lbf/ft^2);

K = constant depending on dimensions and shape of the vane, m^3 (or ft^3).

5.2. Assuming the distribution of the shear strength is uniform across the ends of a cylinder and around the perimeter, calculate the value of *K* as follows:

SI Units:

$$K = \frac{\pi}{10^9} \times \frac{D^2 H}{2} \times \left[1 + \frac{D}{3H}\right] \tag{2}$$

U.S. Customary Units:

$$K = \frac{\pi}{1728} \times \frac{D^2 H}{2} \times \left[1 + \frac{D}{3H}\right] \tag{3}$$

where:

D = measured diameter of vane, mm (in.); and

H = measured height of vane, mm (in.).

It is important that these dimensions are checked periodically to ensure the vane is not distorted or worn.

5.3. If the ratio of length to breadth of the vane is 2:1, the value of *K* may be simplified in terms of the diameter so that it becomes the following:

SI Units:

$$K = \frac{3.66}{10^9} \times D^3 \tag{4}$$

U.S. Customary Units:

$$K = \frac{2.12}{10^3} \times D^3 \tag{5}$$

5.4. Since the value of *s* is required, it is more useful to write the equation as follows:

$$s = T \times K \tag{6}$$

where:

T = the torque, is measured so that *s* can be calculated.

5.5. For the tapered vane of Figure 1, the following modified equation may be used for the vane constant:

SI Units:

$$K = \frac{1}{10^9}\left[\pi D^3 + 0.37\left(2D^3 - d^3\right)\right] \tag{7}$$

U.S. Customary Units:

$$K = \frac{1}{1728}\left[\pi D^3 + 0.37\left(2D^3 - d^3\right)\right] \tag{8}$$

where:

d = rod diameter, mm (in.).

6. REPORT

6.1. For each vane test, record the following observations:

6.1.1. Date of test;

6.1.2. Boring number;

6.1.3. Size and shape of the vane (tapered or rectangular);

6.1.4. Depth of the vane tip;

6.1.5. Depth of the vane tip below the housing or bottom of the hole;

6.1.6. Maximum torque reading, and intermediate readings if required for the undisturbed test;

6.1.7. Time to failure of the test;

6.1.8. Rate of remolding;

6.1.9. Maximum torque reading for the remolded test; and

6.1.10. Notes on any deviations from standard test procedure.

6.2. In addition, record the following observations for the boring:

6.2.1. Boring number;

6.2.2. Location;

6.2.3. Location of the soil conditions;

6.2.4. Reference elevation;

6.2.5. Method of making the hole;

6.2.6. Description of the vane, that is, housed or not;

6.2.7. Description of the method of applying and measuring the torque;

6.2.8. Notes on the driving resistance;

6.2.9. Name of the drilling foreman; and

6.2.10. Name of the supervising engineer.

Standard Method of Test for

Correction for Coarse Particles in the Soil Compaction Test

AASHTO Designation: T 224-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Correction for Coarse Particles in the Soil Compaction Test

AASHTO Designation: T 224-10

1. SCOPE

1.1. This method describes a procedure for adjusting the densities of soil and soil aggregate mixtures to compensate for differing percentages of coarse particles retained on either the 4.75-mm (No. 4) or 19.0-mm ($^3/_4$-in.) sieve. This is necessary to adjust either the field wet density to a dry density of the material passing these sieves or the reverse, by adjusting the lab density to the field density when doing compaction control testing. Comparisons are made by comparing the field densities with the maximum dry density as determined by T 99 or T 180.

1.2. Two methods are available for correction: either lab to field or field to lab density. The method specified in Section 4.1 adjusts the compacted lab density to the field density. The method specified in Section 4.2 adjusts the field wet density to dry density of the fine fraction and compares its results with the compacted lab density.

1.3. This test method applies to soil mixtures that have 40 percent or less retained on the 4.75-mm (No. 4) sieve, when Method A or B of T 99 or T 180 is used, or mixtures that have 30 percent or less retained on the 19.0-mm ($^3/_4$-in.) sieve, when Method C or D of T 99 or T 180 is used. The material retained on these sieves shall be defined as oversize particles (coarse particles).

1.4. This method applies to soils with any percentage of oversize particles as specified in Section 1.3. However, the correction may not be of practical significance for soils with only a small percentage of oversize particles. The person or agency specifying this method shall specify a minimum percentage of oversize particles below which the method need not be applied. If a minimum percentage is not specified, this method shall be applied to samples with more than 5 percent by weight of oversize particles.

1.5. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off to the nearest 10 kg/m^3 (1 pcf), according to ASTM E 29.

1.6. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop

- T 217, Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 265, Laboratory Determination of Moisture Content of Soils
- T 272, Family of Curves—One-Point Method

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. OUTLINE OF METHOD

3.1. When Method A or Method B of T 99 or T 180 is employed, the total field wet density is compared with the dry density of the soil particles passing the 4.75-mm (No. 4) sieve.

3.2. When Method C or Method D of T 99 or T 180 is employed, the total field wet density is compared with the dry density of the soil particles passing the 19.0-mm ($^3/_4$-in.) sieve.

3.3. Significant figures are as follows:

3.3.1. Adjusted wet density of the fine material passing the 4.75-mm (No. 4) sieve, Methods A and B; or 19.0-mm ($^3/_4$-in.) sieve, Methods C and D; (D_f) 1 kg/m^3 (0.1 pcf).

3.3.2. Bulk specific gravity of the coarse material retained on the 4.75-mm (No. 4) sieve, Methods A and B; or 19.0-mm ($^3/_4$-in.) sieve, Methods C and D; (G_m) 0.01.

3.3.3. Percent by mass, of coarse and fine particles, of material retained and passing the 4.75-mm (No. 4) sieve, Methods A and B; or 19.0-mm ($^3/_4$-in.) sieve, Methods C and D; (P_c) and (P_f) 0.1 percent.

3.3.4. In-place (field) wet density of the total sample (D) 1 kg/m^3 (0.1 pcf).

4. ADJUSTMENT EQUATION

4.1. *Compacted Laboratory-Dry Density Corrected to Field-Dry Density*

4.1.1. This section corrects the laboratory density obtained by either T 99 or T 180 for the moisture content and density of the material retained on the 4.75-mm (No. 4) sieve, Methods A and B; or the material retained on the 19.0-mm ($^3/_4$-in.) sieve, Methods C and D. The maximum lab-dry density, adjusted for oversized particles and total moisture content, are compared with the field-dry density and field moisture content. This method is limited to field samples containing 40 percent or less for material retained on the 4.75-mm (No. 4) sieve, Methods A and B; or 30 percent or less of material retained on the 19.0-mm ($^3/_4$-in.) sieve, Methods C and D.

4.1.2. Determine the moisture content of the fine particles and oversize particles of the material used during compaction. The moisture contents can be determined by T 265, T 217, or T 255. The moisture content of the oversize material retained on the sieve can be assumed to be 2 percent for most construction applications. If the moisture content of the oversized material is generally known, substitute that moisture content in the calculations. It is recommended that if drying equipment is available, determine the actual moisture contents. Calculate the moisture contents according to the calculations specified in T 265.

4.1.3. Calculate the dry mass of the coarse and fine particles as follows:

$$M_D = M_M/(1+MC) \tag{1}$$

where:

M_D = mass of dry material (fine or oversize particles);

M_M = mass of moist material (fine or oversize particles); and

MC = moisture content of respective fine or oversize particles, expressed as a decimal.

4.1.4. Calculate the percentage of the fine particles and oversized particles by dry weight of the total sample as follows:

$$P_f = 100\ M_{DF}/(M_{DF} + M_{DC}) \tag{2}$$

and

$$P_C = 100\ M_{DC}/(M_{DF} + M_{DC}) \tag{3}$$

where:

P_f = percent of fine particles of sieve used, by weight;

M_{DF} = mass of dry particles;

M_{DC} = mass of oversize particles; and

P_C = percent of oversize particles of sieve used, by weight.

4.1.5. Calculate the corrected moisture content and corrected dry density of the total sample (combined fine and oversized particles) as follows:

$$MC_T = (MC_f P_f + MC_C P_C)/100 \tag{4}$$

where:

MC_T = corrected moisture content of the combined fine and oversize particles, expressed as a decimal;

MC_f = moisture content of the fine particles, expressed as a decimal;

P_f = percent of fine particles of sieve used, by weight;

MC_C = moisture content of the oversize particles, expressed as decimal; and

P_C = percent of oversize particles of sieve used, by weight.

and

$$D_d = 100\ D_f k/(D_f P_C + kP_f) \tag{5}$$

where:

D_d = corrected total dry density (combined fine and oversize particles), kg/m^3 (pcf);

D_f = dry density of the fine particles, kg/m^3 (pcf);

k = 1000 × Bulk Specific Gravity (G_m) (oven-dry basis) of coarse particles, kg/m^3; or 62.4 × Bulk Specific Gravity (G_m) (oven-dry basis) of coarse particles, pcf;

P_C = percent of oversize particles of sieve used by weight; and

P_f = percent of fine particles of sieve used, by weight.

Note 1—If the specific gravity has been determined, this value may be used in the calculations. Determine the Bulk Specific Gravity according to T 85. For most construction activities, the specific gravity can be assumed to be 2.60.

4.2. *Field-Wet Density Corrected to Compacted-Laboratory Density*:

4.2.1. The in-place total (field) wet density is corrected to a dry density of the sample passing the 4.75-mm (No. 4) sieve or the sample passing the 19.0-mm ($^3/_4$-in.) sieve. This adjusted dry density is compared with the maximum dry density obtained by methods T 99 or T 180.

4.2.2. Determine the moisture content of the total sample and for the material retained on the sieve used during compaction. Moisture content can be determined by T 265, T 217, or T 255. If using the nuclear moisture/density gauge, read the moisture content directly from the gauge for the total moisture content. The moisture content of the oversize material retained on the sieve can be assumed to be 2 percent for most construction applications. If the moisture content of the oversize material is generally known, substitute that moisture content in the calculations. It is recommended that if drying equipment is available, determine the actual moisture contents. Calculate the moisture contents according to the calculations specified in T 265.

4.2.3. Calculate the moisture content of the fine particles of the field sample as follows:

$$MC_f = (100\ MC_T - MC_C P_C)/P_f \qquad (6)$$

where:

MC_f = moisture content of the fine particles, expressed as a decimal;
MC_T = moisture content of total field sample, expressed as a decimal;
MC_C = moisture content of the oversize particles, expressed as a decimal;
P_c = percent of oversize particles of sieve used, by weight; and
P_f = percent of fine particles of sieve used, by weight.

4.2.4. Calculate the dry field density of the sample as follows:

$$D_d = D/(1 + MC_T) \qquad (7)$$

where:

D_d = dry field density of total sample, kg/m^3 (pcf);
D = total field wet density, kg/m^3 (pcf); and
MC_T = moisture content of total field sample, expressed as a decimal.

4.2.5. Calculate the dry field density of the fine particles of the field sample as follows:

$$D_f = D_d P_f/(100 - ((D_d P_C)/(k))) \qquad (8)$$

where:

D_f = adjusted dry density of the fine particles, kg/m^3 (pcf);
D_d = total field dry density, kg/m^3 (pcf);
P_f = percent of fine particles of sieve used, by weight;
P_C = percent of oversize particles of sieve used, by weight;
k = 1000 × Bulk Specific Gravity (G_m) (oven-dry basis) of coarse particles, kg/m^3; or 62.4 × Bulk Specific Gravity (G_m) (oven-dry basis) of coarse particles, pcf (Note 1).

5. PRECISION

5.1. Since this correction for coarse particles involves no testing but instead utilizes the results of other tests and mathematically combines the results, determination of the precision and accuracy is not applicable.

APPENDIX

X1. NOTES

X1.1. These methods, described for coarse particle correction, are applicable to one type of soil and soil aggregate material only. If the characteristic of the material changes, then a moisture density relationship (T 99 or T 180) test is performed to determine a new maximum density.

X1.2. T 272 describes the methods for determining different maximum densities of soil and soil-aggregate materials, which reveal certain similarities and trends characteristic of the material type and source.

X1.2.1. *Utilization of a Family of Curves*—When using the One Point Method (T 272), the percentage of oversized particles, when performing the density of soil and soil aggregate in-place, must be determined to adjust the T 99 or T 180 maximum density to compensate for this percentage.

Standard Method of Test for

Diamond Core Drilling for Site Investigation

AASHTO Designation: T 225-06

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Diamond Core Drilling for Site Investigation

AASHTO Designation: T 225-06

1. SCOPE

1.1. This method covers a procedure for diamond core drilling designing for securing intact samples of rock and some soils which are too hard to sample by soil sampling methods. This method is primarily for obtaining data for foundation and slope design and similar civil engineering purposes rather than for mineral development and mining.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 206, Penetration Test and Split-Barrel Sampling of Soils
- T 207, Thin-Walled Tube Sampling of Soils

2.2. *ASTM Standard*:

- D 5079, Standard Practices for Preserving and Transporting Rock Core Samples

3. EQUIPMENT

3.1. *A Rotary Drilling Machine*, capable of providing a rotary motion and hydraulically, or mechanically, actuated feed or thrust.

3.2. *A Water or Drilling Mud Pump*, or air compressor capable of delivering sufficient drilling fluid volume and pressure for the size of the hole to be drilled.

3.3. *Core Barrels* as required.

3.3.1. *A Single Tube* core barrel consists of a hollow tube with a threaded head at the upper end to fit the drill rod. The lower end of the barrel is fitted with a blank or set reaming shell, a core lifter, and a core bit.

3.3.2. *A Double Tube* core barrel (swivel-type) has a swiveling inner barrel that is contained in the core barrel suspended on a bearing hanger. Drilling fluid is routed between the inner and outer barrels. This method improves core recovery. More sophisticated double tubes are available having an inner tube which extends into the core bit, and the core lifter mounted inside the inner tube to protect cores of a soft or friable formation.

3.3.3. *Single Tube Type, WG Design*, consisting of a hollow steel tube, with a head at one end threaded for drill rod, and a threaded connection for a reaming shell and core bit at the other end. A core lifter, or retainer located within the core bit, is normal but may be omitted at the discretion of the geologist or engineer.

3.3.4. *Double Tube, Swivel-Type, WG Design*—An assembly of two concentric steel tubes joined and supported at the upper end by means of a ball or roller-bearing swivel arranged to permit rotation of the outer tube without causing rotation of the inner tube. The upper end of the outer tube, or removable head, is threaded for drill rod. A threaded connection is provided on the lower end of the outer tube for a reaming shell and core bit. A core lifter located within the core bit is normal but may be omitted at the discretion of the geologist or engineer.

3.3.5. *Double-Tube, Swivel-Type, WT Design*—is essentially the same as the double tube, swivel-type, WG design, except that the WT design has thinner tube walls, a reduced annular area between the tubes, and takes a larger core from the same diameter bore hole. The core lifter is located within the core bit.

3.3.6. *Double Tube, Swivel Type, WM Design*—is similar to the double tube, swivel-type, WG design, except that the inner tube is threaded at its lower end to receive a core lifter case that effectively extends the inner tube well into the core bit, thus minimizing exposure of the core to the drilling fluid. A core lifter is contained within the core lifter case on the inner tube.

3.3.7. *Double Tube Swivel-Type, Large-Diameter Design*—is similar to the double tube, swivel-type, WM design, with the addition of a ball valve to control fluid flow in all three available sizes and the addition of a sludge barrel to catch heavy cuttings on the two larger sizes. The large-diameter design double tube, swivel-type, core barrels are available in three-core-per hole sizes as follows: $2^3/_4$ in. (69.85 mm) by $3^7/_8$ in. (98.43 mm), 4 in. (101.6 mm) by $5^1/_2$ in. (139.7 mm), and 6 in. (152.4 mm) by $7^3/_4$ in. (196.85 mm). Their use is generally reserved for very detailed investigative work or where other methods do not yield adequate recovery.

3.3.8. *Double Tube, Swivel-Type, Retrievable Inner-Tube Method*—in which the core-laden inner-tube assembly is retrieved to the surface and an empty inner-tube assembly returned to the face of the borehole through the matching, large-bore drill rods without need for withdrawal and replacement of the drill rods in the borehole. The inner-tube assembly consists of an inner tube with removable core lifter case and core lifter at one end and a removable inner-tube head, swivel bearing, suspension adjustment, and latching device with release mechanism on the opposite end. The inner-tube latching device locks into a complementary recess in the wall of the outer tube such that the outer tube may be rotated without causing rotation of the inner tube and such that the latch may be actuated and the inner-tube assembly transported by appropriate surface control. The outer tube is threaded for the matching, large-bore drill rod and internally configured to receive the inner-tube latching device at one end and threaded for a reaming shell and bit, or bit only, at the other end.

3.3.9. *Longitudinally Split Inner Tubes*—As opposed to conventional cylindrical inner tubes, these allow inspection of, and access to, the core by simply removing one of the two halves. They are not standardized but are available for most core barrels, including many of the retrievable inner-tube types.

3.3.10. The size and design nomenclature shall be in accordance with the standards adopted by the Diamond Core Drill Manufacturers Association.

3.4. *Core Bits*—The core bits shall be set with diamonds, tungsten carbide, or similar hard materials appropriate to the hardness of the materials being drilled and shall be furnished in X- or M-design or equivalent as required. The sizes of the core barrels and bits shall be as given in Table 1.

Table 1—Sizes of Core Barrels[a]

Size	Hole, Diameter in.	Hole, Diameter mm	Core, Diameter in.	Core, Diameter mm
EWX, EWM	1.5	38.1	0.812	20.6
AWX, AWM	1.957	49.2	1.375	30.2
BWX, BWM	2.375	60.3	1.625	41.3
NWX, NWM	3	76.2	2.125	54.0
$2^{3}/_{4}$ by $3^{7}/_{8}$ in. (69.9 by 98.4 mm)	3.875	98.4	2.687	68.3
4 by $5^{1}/_{2}$ in. (102 by 140 mm)	5.5	140	3.937	100
6 by $7^{3}/_{4}$ in. (152 by 197 mm)	7.75	197	5.937	151

[a] As standardized by the Diamond Core Drill Manufacturers Assn., Bulletin No. 2. Other sizes may be specified, but should be so noted.

3.5. *Drive Pipe or Casing*—Standard weight or extra heavy pipe, as required by the nature of overburden or the drilling method, shall be furnished where necessary for driving through soils to bedrock. The casing or pipe shall have an inside diameter of sufficient size to accommodate the largest size core barrel to be employed. The inside of the casing or pipe shall be free of burrs and obstructions.

3.6. *Auxiliary Casing*—When it is necessary to case through formations already penetrated by the drill or when no drive casing has been employed, casing shall be provided with an outside diameter that will fit inside the hole and an inside diameter that will permit the use of the next smaller bit and core barrels. Standard sizes of casing are given in Table 2.

Table 2—Standard Sizes of Casing

Size	Outside Diameter in.	Outside Diameter mm	Inside Diameter in.	Inside Diameter mm	Will Fit Hole Drilled by:
EX	1.8125	46	1.5	38.1	AWX, AWM
AX	2.25	57.2	1.906	48.4	BWX, BWM
BX	2.875	73.0	2.187	60.3	NWX, NWM
NX	3.5	88.9	3.0	76.2	$2^{3}/_{4}$ by $3^{7}/_{8}$ in. (69.9 by 98.4 mm)

3.7. *Drill Rods*—The drill rods shall have an inside diameter that will permit the flow of drilling fluid through the rods in a quantity sufficient to provide an upward velocity of the fluid between the rod and the hole wall that will remove the cuttings effectively.

3.8. *Auxiliary Equipment*—Auxiliary equipment shall be furnished as required by the work including roller bits, fishtail bits, wrenches, equipment for mixing the drilling mud, hand tools, safety equipment, etc.

3.9. *Core Boxes*—Core boxes of wood or other durable material shall be provided for protection, transport, and storage of the cores. The boxes shall be provided with longitudinal spacers that will separate the core into compartments. Small blocks that fit snugly between the spacers shall be provided to secure core in place and/or fill space if the material recovered is insufficient to completely fill the box. The top of the core length, which corresponds to the shallowest depth, should be placed at one corner of the box and the core placed progressing downward in a continuous manner to the deepest depth, through the compartments toward the opposite corner. The top and bottom of the core length and each run shall be clearly indicated on the longitudinal spacers or blocks with waterproof marker. The top and bottom of the core length shall also be clearly indicated on the box cover, at the corresponding corners along with the core depths. Additional guidance regarding labeling and use of core boxes can be found in ASTM D 5079.

4. PROCEDURE

4.1. When formations are encountered that are too hard to be sampled by soil sampling methods, the core drilling procedure shall be used. A penetration of 1 in. (25 mm) or less for 50 blows (Notes 1 and 2) according to T 206 shall be considered as indicating that soil sampling methods are not applicable.

Note 1—When the subsurface investigation requires a sample for testing and identification for material that has a penetration-resistance between $N = 100$ specified in T 206 and 50 blows per inch, coring may be required. Materials such as very stiff clay or weathered shale bedrock can be sampled using core barrels such as the Denison-type Double Tube Core Barrel. The sampling can be enhanced by the use of air for the drilling medium and the use of bits with steel teeth hardfaced.

Note 2—The limit of 50 blows per in. (25.4 mm) may be increased if the core recoveries prove to be small and samples can be secured by the soil sampling method.

4.2. Firmly seat the casing on bedrock or hard material to prevent loose materials from entering the hole and to prevent the loss of drilling fluid. Level the surface of the rock or hard material when necessary by the use of a fishtail or other bits. If an open drill hole can be maintained without casing, the casing may be omitted. Bentonite mud is often effective in maintaining an open hole without the use of casing.

4.3. Begin the core drilling using the NWX or NWM double tube swivel-core barrel. The first core run will usually be 5 ft (1.52 m) because of nonuniform conditions at the soil rock contact (Note 3). The NWM barrel should be inspected prior to lowering into the hole to insure that the swivel is in good working order and rotating freely. The clearance between the inner barrel, when incorporated in the barrel, and the bit should be checked and adjusted if necessary to insure that the space between the bit and the inner barrel is sufficient so as not to restrict the flow of drilling fluid. Either type barrel should be inspected for dents or bends that impair rock recovery. The barrel should also be checked for material left in the barrel from previous drilling to insure the barrel is clean and unobstructed. The core retainer should be inspected, and if worn excessively or damaged, it should be replaced. The choice of bit setting shall be consistent with the type of material to be drilled. (Use extreme caution not to drop foreign material into the hole. Should an object be dropped into the hole and not be recoverable, abandon the hole and start a new one.) Inspect all drill rods to be used for straightness. If any rods display bends when rolled over a flat surface, they should not be used.

Note 3—In soft materials, a larger starting size may be specified; where local experience indicates satisfactory core recovery or where hard, sound materials are anticipated, a smaller size or the single-tube type may be specified in place of the NWX or NWM tube, and longer runs may be drilled.

4.4. Lower the barrel into the hole, using care to set the barrel on the formation to be drilled gently to prevent damage to the bit or buckling of the barrel. Measurement of barrel and rods to be used is essential; measurement shall be to the nearest 0.1 ft (30.5 mm). Log the depth when the barrel makes contact with the bottom of the hole. If the depth is more than 0.1 ft (30.5 mm) less than the depth logged from the previous run, there is probably loose material or core in the hole. Connect the drill chuck to the string of tools and connect the drilling fluid supply line. Prior to rotating, lift the string of tools slightly and start the circulation of the drilling fluid. Allow the fluid to circulate until a full-flow condition is reached. Lower the tools slowly to the bottom and seat the bit by slowly starting the rotation and slowly increasing the vertical pressure, maintaining full flow of the drilling fluid. When the bit is seated, adjust the vertical pressure and the rotation to achieve proper penetration in accordance with the formation being drilled (Note 4). Log the depth where the coring began to the nearest 0.1 ft (30.5 mm). If the flow of the drilling fluid is blocked during drilling, raise the bit slightly to allow the fluid flow to return. If the flow does not return, remove the drilling tools and correct the problem as necessary to maintain adequate flow of the drilling fluid. A judgment may be required when different types of material are encountered in a given run and recovery is less than 100 percent of the actual thickness of a given formation. To aid in making this judgment, the rate of penetration and the drilling fluid color and texture shall be monitored as drilling proceeds. The depths where changes are noted in the penetration rate and/or the color and/or texture of the cuttings in the return fluid are to be recorded for reference when this judgment is required. It may be desirable to retain samples of the cuttings contained in the return fluid at changes of color or texture or onset intervals.

Note 4—The life expectancy of the bit and the rate of penetration are dependent upon proper force on the bit and the peripheral velocity of the bit. The peripheral velocity should be as high as possible without causing undue strain on the drill rig or excessive vibration of the drilling tools. The force on the bit should be adjusted to match the information and the design of the bit. (For a given bit design, a softer formation would require less force than a harder formation.) It may be necessary to anchor the drill rig to obtain sufficient force on the bit.

4.5. After drilling a depth equivalent to the length of the barrel (not to exceed 10 ft (or 3.05 m) and minus any loose material noted during the seating of the barrel), remove the core barrel from the hole, and remove the core from the barrel. Place the core in the core box in such a manner that the top of the rock stratum will be located at one corner of the box as described in Section 3.9. When the run is greater than the length of the first compartment, the next compartment to the right is measured and temporarily marked at a point that will be equivalent to the difference between the length of the compartment and the length of the run measured from upper left to lower left. The first segment of rock removed from the core barrel (bottom of core run) shall be placed in the box so that the bottom of the core is either at the lower left end of the left compartment or at the temporary mark in the next compartment to the right. Each additional piece removed from the barrel shall be placed in the box one after another, orienting each piece of core with the direction of the box so that the upper stratum is to the upper and/or left of the box in respect to lower stratum. Proceed to place the core in the box from the lower end to the upper end as the core is removed from the barrel in such a manner that the top of the stratum falls in the upper left end of the left compartment as described in Section 2.9. When all of the core has apparently been removed from the barrel, check the barrel by inserting a rule into the core barrel and check the length to insure that all of the material has been removed. After all the material has been removed from the barrel, adjust the core in the box so that the pieces are consolidated together to represent as nearly as practical their in situ length, taking care to fit the broken pieces together in such a manner that will not cause a false measure of the recovered core. Measure the recovered core to the nearest 0.1 ft (30.5 mm) and record the recovery. After performing the measurement for core recovery, mark the depths of the top and bottom of the core and each noticeable gap in the formation by a spacer block clearly labeled. Wrap delicate cores or those which change materially upon drying in plastic film or seal in wax or both, when such treatment is considered necessary by the engineer. Subsequent core runs from the same project and hole shall continue this procedure with the top of the next run beginning at the bottom of the last proceeding run. Measure the length of the run from the end of the last run from upper to lower in the compartment, utilizing the next compartment to the right when the compartment will not accommodate the entire run, and mark the bottom of the run with a temporary marker. Place the first segment of rock removed from the core barrel (bottom of core run) at the newly established temporary mark. Place the core in the box as described previously.

4.6. When soft materials are encountered from a core run which produce less than 50 percent recovery changes in the type of barrel, a change to drilling procedure or soil sampling should be considered. If soil samples are desired, secure such samples in accordance with the procedures described in T 206 or T 207. Resume diamond core drilling when refusal materials are again encountered.

4.7. Since rock structure and the occurrence of seams, fissures, cavities, and broken areas are among the most important items to be detected and described, take special care to observe and record these features. If broken rock or cavities prevent the advance of the boring, (1) cement the hole or (2) ream and case, or (3) case and advance with the next smaller-sized core barrel, as the conditions warrant. Follow the same procedure where fissures are encountered which cause the loss of drilling fluid return (Notes 5 and 6).

Note 5—Whenever the drilling water loss indicates conditions of engineering or geologic importance, the procedure for advancing the boring will be as determined by the engineer.

Note 6—Other optional procedures are as follows: (1) In soft, seamy, or otherwise unsound rock, where core recovery may be difficult, the M-design core barrels may be specified; (2) In hard sound rock where a high percentage of core recovery is anticipated, the single tube core barrel may be employed.

5. REPORT

5.1. *The report shall include the following*:

5.1.1. Project identification, boring number, location, and driller;

5.1.2. Elevation of the ground surface;

5.1.3. Elevation of ground water, including dates and times measured;

5.1.4. Elevations (or depths) at which drilling water return was lost;

5.1.5. Size and design of core barrel used. Size and length of all casing and any movements of the casing;

5.1.6. Length of each core run and the length or percentage, or both, of the core recovered;

5.1.7. Description of the rock in each run;

5.1.8. Structure including stratification, angle of dip, cavities, fissures, and any other observations that could give information on these features;

5.1.9. Depth, thickness, and apparent nature of the filling in each cavity or soft seam in the rock;

5.1.10. Depth of sample cuttings retained from the drilling fluid;

5.1.11. Any changes in the character of the drilling fluid; and

5.1.12. Date of beginning and end of boring.

Standard Method of Test for

Triaxial Compressive Strength of Undrained Rock Core Specimens without Pore Pressure Measurements

AASHTO Designation: T 226-90 (2008)
ASTM Designation: D 2664-86

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Triaxial Compressive Strength of Undrained Rock Core Specimens without Pore Pressure Measurements

AASHTO Designation: T 226-90 (2008)
ASTM Designation: D 2664-86

1. SCOPE

1.1. This test method covers the determination of the strength of cylindrical rock specimens in an undrained state under triaxial compression loading. The test provides data useful in determining the strength and elastic properties of rock, namely: shear strengths at various lateral pressures, angle of internal friction (angle of shearing resistance), cohesion intercept, and Young's modulus. It should be observed that this method makes no provision for pore pressure measurements. Thus the strength values determined are in terms of total stress, that is not corrected for pore pressures.

1.2. The values stated in inch-pound units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:[1]

- D 4543, Standard Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances
- E 4, Standard Practices for Force Verification of Testing Machines
- E 122, Standard Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

3. SIGNIFICANCE AND USE

3.1. Rock is known to behave as a function of the confining pressure. The triaxial compression test is commonly used to stimulate the stress conditions under which most underground rock masses exist.

4. APPARATUS

4.1. *Loading Device*—A suitable device for applying axial load to the specimen. It shall be of sufficient capacity to apply load at a rate conforming to the requirements set forth in Section 7.2.

It shall be verified at suitable time intervals in accordance with the procedures given in ASTM E 4, Verification of Testing Machines, and comply with the requirements prescribed therein.

4.2. *Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier,[2] or other system of sufficient capacity to maintain constant the desired lateral pressure, σ_3.

4.3. *Triaxial Compression Chamber*[3]—An apparatus in which the test specimen may be enclosed in an impermeable flexible membrane; placed between two hardened platens, one of which shall be spherically seated; subjected to a constant lateral fluid pressure; and then loaded axially to failure. The platens shall be made of tool steel hardened to a minimum of Rockwell 58 HRC, the bearing faces of which shall not depart from plane surfaces by more than 0.0005 in. (0.013 mm) when the platens are new and which shall be maintained within a permissible variation of 0.001 in. (0.025 mm). In addition to the platens and membrane, the apparatus shall consist of a high-pressure cylinder with overflow valve, a base, suitable entry ports for filling the cylinder with hydraulic fluid and applying the lateral pressure, and hoses, gauges, and valves as needed.

4.4. *Deformation Measuring Device*—High-grade dial micrometers or other measuring devices graduated to read to 0.0001 in. (0.0025 mm); and accurate within 0.0001 in. (0.0025 mm); in any 0.0010 in. (0.025 mm) range, and within 0.0002 (0.005 mm) in any 0.0100 in. (0.25 mm) range shall be provided for measuring axial deformation due to loading. These may consist of micrometer screws, dial micrometers, or linear variable differential transformers securely attached to the high pressure cylinder.

4.4.1. Electrical resistance strain gauges applied directly to the rock specimen in the axial direction may also be used. In addition, the use of circumferentially applied strain gauges will permit the observation of data necessary in the calculation of Poisson's ratio. In this case two axial (vertical) gauges should be mounted on opposite sides of the specimen at mid-height and two circumferential (horizontal) gauges similarly located around the circumference, but in the direction perpendicular to the axial gauges.

4.5. *Flexible Membrane*[4]—A flexible membrane of suitable material to exclude the confining fluid from the specimen, and that shall not significantly extrude into abrupt surface pores. It should be sufficiently long to extend well onto the platens and when slightly stretched be of the same diameter as the rock specimen.

5. SAMPLING

5.1. The specimen shall be selected from the cores to represent a true average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, and partings and defects such as pores and fissures.

6. TEST SPECIMENS

6.1. *Preparation*—The test specimens shall be prepared in accordance with ASTM D 4543.

6.2. Moisture condition of the specimen at time of test can have a significant effect upon the indicated strength of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen should be preserved until time of test. On the other hand, there may be reasons for testing specimens at other moisture contents including zero. In any case, the moisture content of the test specimens should be tailored to the problem at hand and reported in accordance with Section 9.1.6.

7. PROCEDURE

7.1. Place the lower platen on the base. Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and place the test specimen on the lower platen. Place the upper platen on the specimen and align properly. Fit the flexible membrane over the specimen and platens and install rubber or neoprene O-rings to seal the specimen from the confining fluid. Place the cylinder over the specimen, ensuring proper seal with the base, and connect hydraulic pressure lines. Position the deformation measuring device and fill the chamber with hydraulic fluid. Apply a slight axial load, approximately 25 lbf (111 N), to the triaxial compression chamber by means of the loading device in order to properly seat the bearing parts of the apparatus. Take an initial reading on the deformation device. Slowly raise the lateral fluid pressure to the predetermined test level and at the same time apply sufficient axial load to prevent the deformation measuring device from deviating from the initial reading. When the predetermined test level of fluid pressure is reached, note and record the axial load registered by the loading device. Consider this load to be the zero or starting load for the test.

7.2. Apply axial load continuously and without shock until the load becomes constant, or reduces, or a predetermined amount of strain is achieved. Apply the load in such a manner as to produce a strain rate as constant as feasible throughout the test. Do not permit the strain rate at any given time to deviate by more than 10 percent from that selected. The strain rate selected should be that which will produce failure of a similar test specimen in unconfined compression, in a test time of between 2 and 15 minutes. The selected strain rate for a given rock type shall be adhered to for all tests in a given series or investigation (Note 1). Maintain constant the predetermined confining pressure throughout the test and observe and record readings of deformation as required.

Note 1—Results of tests by other investigators have shown that strain rates within this range will provide strength values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances.

Note 2—If the specimen diameter is not the same as the piston diameter through the chamber, a correction must be applied to the measured load to account for differences in area between the specimen and the loading piston where it passes through the seals into the chamber.

7.3. To make sure that no testing fluid has penetrated into the specimen, the specimen membrane shall be carefully checked for fissures or punctures at the completion of each triaxial test. If in question, weigh the specimen before and after the test.

8. CALCULATIONS

8.1. The following calculations and graphical plots shall be made:

8.1.1. A stress difference versus axial strain curve shall be constructed (Note 3). Stress difference is defined as the maximum principal axial stress, σ_1, minus the lateral pressure, σ_3. The value of the lateral pressure, σ_3, shall be indicated on the curve.

Note 3—Because total deformation is recorded during the test, suitable calibration for apparatus deformation must be made. This may be accomplished by inserting into the apparatus a steel cylinder having known elastic properties and observing differences in deformation between the assembly and steel cylinder throughout the loading range. The apparatus deformation is then subtracted from the total deformation at each increment of load in order to arrive at specimen deformation, from which the axial strain of the specimen is computed.

8.1.2. Mohr stress circles shall be constructed on an arithmetic plot with shear stresses as ordinates and normal stresses as abscissas. At least three triaxial compression tests, each at a different confining pressure, shall be made on the same material to define the envelope to the Mohr stress circles.

Note 4—Because of the heterogeneous nature of rock and the scatter in results often encountered, it is considered good practice to make at least three tests of essentially identical specimens at each confining pressure or single tests at nine different confining pressures covering the range investigated. Individual stress circles shall be plotted and considered in drawing the envelope.

8.1.3. A "Best-Fit," smooth curve (the Mohr envelope) shall then be drawn approximately tangent to the Mohr circles as in Figure 1. The figure shall also include a brief note indicating whether a pronounced failure plane was or was not developed during the test and the inclination of this plane with reference to the plane of major principal stress.

Note 5—If the envelope is a straight line, the angle the line makes with the horizontal shall be reported as the angle of interval friction ϕ (or the slope of the line as tan ϕ depending upon preference), and the intercept of this line at the vertical axis reported as the cohesion intercept, *C*. If the envelope is not a straight line, values of ϕ (or tan ϕ) should be determined by constructing a tangent to the Mohr circle for each confining stress at the point of contact with the envelope, and the corresponding cohesion intercept noted.

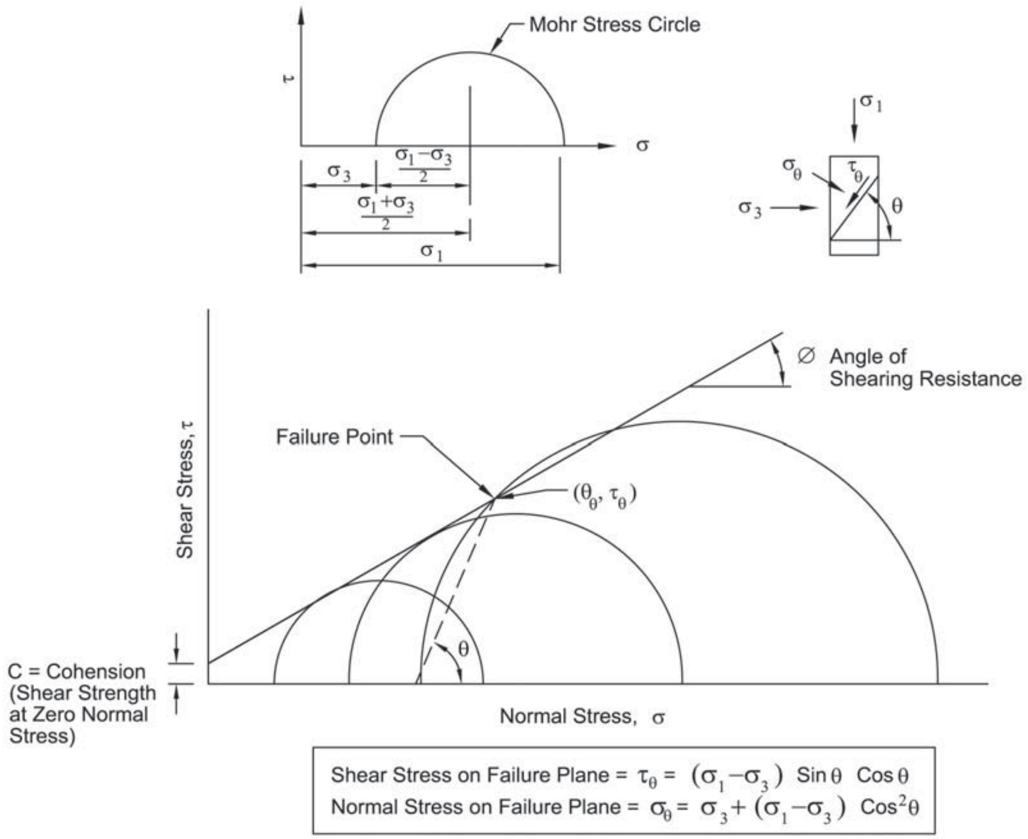


Figure 1—Typical Mohr Stress Circles

9. REPORT

9.1. In addition to the plots discussed in Section 8, Calculations, the report should include the following:

9.1.1. Sources of the specimen including project name and location, and if known, storage environment. The location is frequently specified in terms of the borehole number and depth of specimen from collar of hole.

9.1.2. Physical description of the specimen including rock type; location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions of inhomogeneities, if any.

9.1.3. Dates of sampling and testing.

9.1.4. Specimen diameter and length, conformance with dimensional requirements.

9.1.5. Rate of loading or deformation or strain rate.

9.1.6. General indication of moisture condition of the specimen at time of test such as: as-received, saturated, laboratory air-dry, or oven dry. It is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation.

9.1.7. Type and location of failure. A sketch of the fractured specimen is recommended.

Note 6—If it is a ductile failure and $\sigma_1 - \sigma_3$ is still increasing when the test is terminated, the maximum strain at which $\sigma_1 - \sigma_3$ is obtained shall be clearly stated.

10. PRECISION AND BIAS

10.1. An interlaboratory study was conducted in which six laboratories each tested five specimens of three different rocks, three confining pressure and four replications. The specimens were prepared by a single laboratory from a common set of samples and randomly distributed to the testing laboratories for testing. The study was carried out in accordance with ASTM E 691. Details of the study are given in ISR Research Report "Interlaboratory Testing Program for Rock Properties (ITP/RP) Round Two," 1994. Tables 1 through 3 give the repeatability (within a laboratory) and reproducibility (between laboratories) for the method at confining pressure of 10, 25, and 40 MPa.

10.1.1. The probability is approximately 95 percent that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit. Likewise, the probability is approximately 95 percent that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit.

Table 1—Compressive Strength (MPa) at 10 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	127	173	282
Repeatability	5.29	32.2	13.5
Reproducibility	22.5	38.3	25.7

Table 2—Compressive Strength (MPa) at 25 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	179	206	366
Repeatability	8.69	43.3	22.5
Reproducibility	34.7	51.8	31.0

Table 3—Compressive Strength (MPa) at 40 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	215	237	N/A
Repeatability	7.95	42.4	N/A
Reproducibility	52.0	73.5	N/A

11. KEYWORDS

11.1. Compression strength; compression testing; loading tests; rock; triaxial compression.

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[1] Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

[2] A pressure intensifier as described by Leonard Obert in U.S. Bureau of Mines Report of Investigations No. 6332, "An Inexpensive Triaxial for Testing Mine Rock," has been found to fulfill the above requirements.

[3] Assembly and detail drawings of an apparatus that meets these requirements and that is designed to accommodate $2^1/_8$-in. (54-mm) diameter specimens and operate at a lateral fluid pressure of 10000 psi (69 MPa) are available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. Request Adjunct No. 12-426640-00.

[4] Neoprene rubber tubing of $^1/_{16}$ in. (1.588 mm) wall thickness and of 40 to 60 Durometer hardness, Shore Type A or various sizes of bicycle inner tubing, have been found generally suitable for this purpose.

Standard Method of Test for

Determination of Lime Content in Lime-Treated Soils by Titration

AASHTO Designation: T 232-90 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determination of Lime Content in Lime-Treated Soils by Titration

AASHTO Designation: T 232-90 (2008)

1. SCOPE

1.1. A method of test is described for determining the percentage of lime in soils or aggregates that have been treated with hydrated lime. It is based on the continuous neutralization of an aqueous solution from the lime-treated specimen for a specified time period. This is accomplished by adding sufficient acid to just neutralize the lime which is continuously being dissolved during the test. The amount of acid used is directly proportional to the lime content of the specimen.

1.2. The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications. (This test has a statement pertaining to significant figures.) (No statistical data are available.)

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests

2.2. *ASTM Standard*:
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. A 100-mL titrating buret or other device permitting slow, easily controlled addition of acid, with stand and clamp.

3.2. Ten 1.9-L (2-quart) wide-mouth polyethylene containers (white).

3.3. Two 18.9-L (5-gal) plastic carboys, equipped with siphons, neoprene or tygon tubing, hose clamps, etc., for dispensing acid-working solution and water.

3.4. Glass (or plastic) dropping bottle.

3.5. *Four stirring rods*—of stainless steel or other suitable material.

3.6. *Sieves*—37.5-mm and 9.5-mm sieves conforming to the requirements of the Specification for Wire-Cloth Sieves for Testing Purposes (M 92).

Note 1—Although sieves in 203-mm (8-in.) frames are satisfactory, a 9.5-mm sieve in 305-mm (12-in.) frame may be more suitable for separating the field samples (Sections 5.4 and 8.3).

3.7. *Balances*—The balances shall conform to M 231, Class G 5 and Class G 2.

3.8. *Four plastic beakers*, having a minimum capacity of 500 mL.

3.9. A 200-mL glass beaker.

3.10. Four 50-mL graduates.

3.11. *Fluorescent light*, one 915 mm (36 in.) long, or two 457 mm (18 in.) long.

4. REAGENTS

4.1. *Hydrochloric Acid (HCl) (Approximately 3 Normal)*—Pour approximately 11.4 L (3 gal) of water into an 18.9-L (5-gal) plastic carboy. Pour the contents of two full standard 2.7-kg (6-lb) bottles of concentrated reagent-grade HCl in the carboy. Stir or mix the solution vigorously for about 1 minute. Add tap water as necessary to bring the total volume of water and acid to 18.9 L (5 gal); then stir or mix the solution vigorously for another minute. Allow the acid solution to stand overnight; then remix it once again prior to using. Remix the acid solution once a week during use and also before using if the acid solution has been in storage for more than 1 week.

4.2. *Phenolphthalein Indicator Solution (1 Percent Solution)*—Dissolve 5 g of phenolphthalein (U.S.P.) in 250 mL of 95 percent ethyl alcohol. Dilute with 250 mL of distilled water.

4.3. *Polyacrylamide (Flocculating Agent) Stock Solution*—Mix 0.5 g of polyacrylamide (such as “separan” NP-10 by Dow Chemical Company) with 1000 mL of distilled water in a glass beaker. Stir frequently and allow to stand until no precipitates are visible. Prepare a fresh solution weekly.

5. MATERIALS FOR CALIBRATION TEST SPECIMENS

5.1. Two specimens with 1 percent less than the planned lime content and two specimens with 1 percent more than the planned lime content for the project must be tested and the data used in preparing a lime titration calibration curve. Aggregate, lime, and water to be used in the field project shall be used in preparing the calibration specimens. The moisture content of the specimens should be representative of that to be used for the lime-treated material on the project.

5.2. From Table 1, select the mass of aggregate corresponding to the appropriate lime and moisture content. This is the mass of dry untreated aggregate required to prepare calibration test specimens of 300 g. If the sample of untreated aggregate initially contains moisture, adjust the mass of moist aggregate to yield the correct mass of dry material. A correction is also made in the water measurement in Section 5.6 for the water contained in the moist aggregate.

Table 1—Quantities of Materials for Calibration Specimens Containing Various Percentages of Lime

		1% Lime		2% Lime		3% Lime		4% Lime		5% Lime		6% Lime		7% Lime	
Moisture Content, Percent	Water, mL	Dry Mass Agg., g	Lime, g	Dry Mass Agg., g	Lime, g	Dry Mass Agg., g	Lime, g	Dry Mass Agg., g	Lime, g	Dry Mass Agg., g	Lime, g	Dry Mass Agg., g	Lime, g	Dry Mass Agg., g	Lime, g
5	14	283	2.8	280	5.6	278	8.3	275	11.0	272	13.6	270	16.2	267	18.7
6	17	280	2.8	277	5.5	275	8.2	272	10.9	270	13.5	267	16.0	264	18.5
7	20	277	2.8	275	5.5	272	8.2	269	10.8	267	13.4	264	15.9	262	18.3
8	22	275	2.8	272	5.5	270	8.1	267	10.7	265	13.2	262	15.7	260	18.2
9	25	272	2.7	270	5.4	267	8.0	264	10.6	262	13.1	259	15.6	257	18.0
10	27	270	2.7	268	5.4	265	8.0	262	10.5	260	13.0	258	15.5	255	17.9
11	30	267	2.7	265	5.3	262	7.9	260	10.4	257	12.9	255	15.3	252	17.7
12	32	265	2.7	263	5.3	260	7.8	258	10.3	255	12.8	253	15.2	250	17.5
13	34	262	2.6	260	5.2	257	7.7	255	10.2	252	12.6	250	15.0	248	17.3
14	37	260	2.6	258	5.2	255	7.7	253	10.1	250	12.5	248	14.9	246	17.2
15	39	258	2.6	256	5.1	253	7.6	251	10.0	249	12.4	246	14.8	244	17.1
16	41	256	2.6	254	5.1	251	7.5	249	10.0	247	12.3	244	14.6	242	16.9
17	44	253	2.5	251	5.0	249	7.5	246	9.8	244	12.2	242	14.5	239	16.7
18	46	252	2.5	249	5.0	247	7.4	244	9.8	242	12.1	240	14.4	238	16.6
19	48	250	2.5	247	4.9	245	7.3	242	9.7	240	12.0	238	14.3	236	16.5
20	50	248	2.5	245	4.9	243	7.3	240	9.6	238	11.9	236	14.2	234	16.4
21	52	246	2.5	243	4.9	241	7.2	238	9.5	236	11.8	234	14.0	232	16.2
22	54	244	2.4	241	4.8	239	7.2	236	9.4	234	11.7	232	13.9	230	16.1
23	56	242	2.4	239	4.8	237	7.1	235	9.4	232	11.6	230	13.8	228	16.0
24	58	240	2.4	237	4.7	235	7.1	233	9.3	230	11.5	228	13.7	226	15.8
25	60	238	2.4	235	4.7	234	7.0	231	9.2	229	11.4	226	13.6	224	15.7
26	62	236	2.4	233	4.7	231	6.9	229	9.2	227	11.4	225	13.5	222	15.6
27	64	234	2.3	231	4.6	229	6.9	229	9.1	225	11.3	223	13.4	221	15.5
28	66	232	2.3	229	4.6	227	6.8	225	9.0	223	11.2	221	13.3	219	15.3
29	68	231	2.3	228	4.6	226	6.8	224	9.0	222	11.1	220	13.2	218	15.3
30	69	229	2.3	226	4.5	224	6.7	222	8.9	220	11.0	218	13.1	216	15.1
31	71	227	2.3	225	4.5	222	6.7	220	8.8	218	10.9	216	13.0	214	15.0
32	73	225	2.3	223	4.5	220	6.6	218	8.7	216	10.8	214	12.8	212	14.8
33	75	224	2.2	222	4.4	219	6.6	217	8.7	215	10.8	213	12.8	211	14.8
34	76	222	2.2	220	4.4	217	6.5	215	8.6	213	10.7	211	12.7	209	14.6
35	78	220	2.2	218	4.4	216	6.5	213	8.5	211	10.6	209	12.5	207	14.5

5.3. From the project records, determine the average percentage of untreated aggregate passing the 37.5-mm sieve and retained on the 9.5-mm sieve. These percentages will be used for proportioning the calibration specimens.

5.4. Remove and waste any aggregate in the sample of untreated material retained on the 37.5-mm sieve and separate the sample on the 9.5-mm sieve. Recombine for duplicate calibration test specimens with the aggregate mass found in Section 5.2, and with the 9.5-mm sieve proportions found in Section 5.3.

5.5. Select the required amount of lime from Table 1 and determine the mass to the nearest 0.1 g.

5.6. Measure in a glass graduate, the required amount of water (corrected as in Section 5.2) in mL, given in Table 1.

6. CALIBRATION CURVE

6.1. Each test operator must establish two calibration curves at least once each day; one for a 4 or 5-hour curing time, for use with field samples that are completely mixed and tested during the same day; and one for a 24-hour curing time, for use with field samples that are tested on the next day after mixing. If there is a change in acid, lime, aggregate or water, new curves must be established after the change.

Note 2—Less correction will be needed and the results will be more accurate if similar curing times are used for calibration test and field sample tests.

Note 3—A new calibration curve should be established when a fresh batch of diluted acid solution is prepared and when the source of the aggregate or water is changed. The calibration curve for each curing time should be checked when there is a suspected change in character of aggregate specimen or water from the same source.

6.2. For each specimen, pour the weighed aggregate and lime from Sections 5.4 and 5.5, respectively, into the 1.9-L (2-quart) plastic container and mix thoroughly with stirring rod.

6.3. Add the quantity of water measured in Section 5.6 and mix thoroughly. The time that the water is added is considered the start of the curing period.

6.4. Place the 1.9-L (2-quart) containers in a row on the table that is to be used for the testing, leave the samples uncovered, and allow to cure for the times given in Section 6.1.

6.5. Just prior to expiration of the curing time in Section 6.1, prepare the polyacrylamide solution as follows: behind each testing specimen, place a plastic beaker into which has been measured 200 mL of tap water and 50 mL of the polyacrylamide stock solution (prepared from Section 4.3); also for each test specimen, determine the mass of a glass graduate, add to it 50 mL of the polyacrylamide stock solution and record the net mass to the nearest 0.1 g.

6.6. At the end of the curing period, the constant neutralization test is performed as follows:

6.6.1. Start the timer and add the mixed water and polyacrylamide stock solution to the first specimen. Add the liquid to successive specimens at intervals of 120 seconds.

6.6.2. Add two full droppers (approximately 40 drops) of phenolphthalein solution to each container. The water will normally turn red due to the presence of lime.

6.6.3. Determine the mass of each plastic container including its contents to the nearest 0.1 g.

6.6.4. Place the fluorescent light behind the plastic containers.

6.6.5. At 8 minutes after the addition of the mixed water and polyacrylamide stock solution to the first specimen (Section 6.6.1), start adding 3 Normal HCl to this specimen from a buret while stirring continuously. Only enough acid is added to cause the red color to just disappear. Similarly, add acid to successive specimens at 120-second intervals; that is, at timer readings of 10, 12, and 14 minutes for the second, third, and fourth specimens, respectively, or a series.

6.6.6. When the red color starts to reappear after the initial introduction of acid, use the buret to make a second addition of acid in the amount (mL) necessary to cause the color to just disappear. Subsequent additions of acid are made as necessary to cause the color to just disappear.

Note 4—**Caution**—Stir lightly. Vigorous stirring at this time will cause the flocculated particles to disperse, making it difficult to see the end point.

6.6.7. In addition to the stirring accomplished during each introduction of acid, stir lightly for about 3 seconds of every minute and for about 6 seconds of every fifth minute, whether or not color is present. Perform the stirring in a circular and zigzag pattern across the bottom of the plastic container. Be careful to avoid the possibility of leaving any deposit of unneutralized lime in the center of the container.

6.6.8. At the end of 25 minutes after adding the initial amount of mixed water and polyacrylamide stock solution to the first sample, stir the sample vigorously, add the additional 50 mL of polyacrylamide stock solution (Section 6.5), and continue the test. Repeat this procedure with each of the specimens allowing a 120-second interval between specimens. This will require timer readings of 27, 29, and 31 minutes, respectively, for the second, third, and fourth specimens of a series.

6.6.9. Continue the procedure of adding acid and stirring until 38 minutes have elapsed since the initial addition (Section 6.6.1) of mixed water and polyacrylamide stock solution to the first specimen. Then reweigh the plastic container contents to the nearest 0.1 g. Repeat this procedure with each of the specimens allowing 120-second intervals between specimens. This will require readings of 40, 42, and 44 minutes, respectively, for the second, third, and fourth specimens of a series.

6.6.10. Using the difference between the initial mass (determined in Section 6.6.3) plus the additional mass of polyacrylamide stock solution (determined in Section 6.5) and the final test specimen masses (determined in Section 6.6.9), calculate and record the total mass of hydrochloric acid (HCl) used to neutralize the solution; then determine the average mass of HCl used for each pair of test specimens.

6.7. Plot the average mass of HCl used (Section 6.6.10) against the percent lime used in the paired specimens. Draw a straight line between the two points. This is the calibration curve for determining the lime content of field-mixed lime-treated specimens (Figure 1).

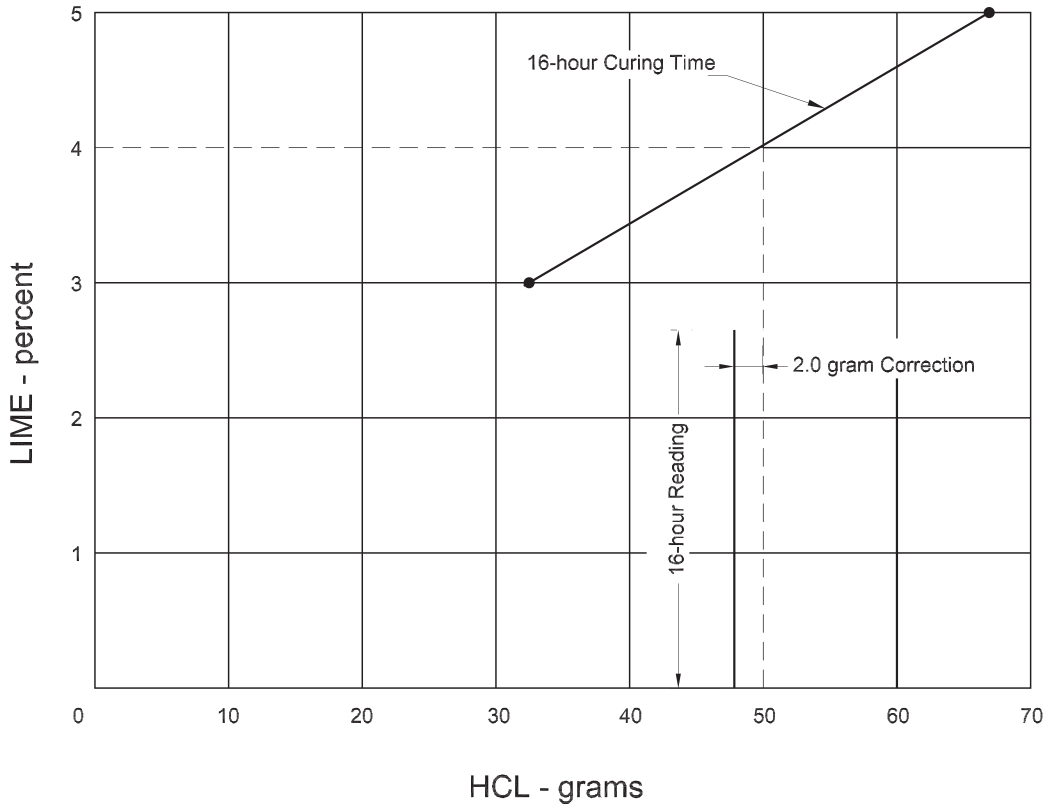


Figure 1—Lime Titration Calibration Curve

7. CURING TIME CORRECTION CURVE

7.1. Since it will normally be impossible to select lime-treated samples from the field project that have been cured for the same time as the specimens used in preparing the calibration curve, preparation of a correction curve is necessary.

7.2. Using the aggregate, lime, and water from the field project, prepare 10 specimens at the planned lime content. Preparation of the required quantities of materials shall be as in Section 5, and mixing shall be as in Sections 6.2 and 6.3.

7.3. Test the specimens in pairs at approximate curing times of 1, 3, 7, 24, and 48 hours to establish a curing time curve as shown in Figure 2. Leave the samples uncovered during the curing period.

Note 5—The test is very sensitive to curing time during the first hour after mixing. Therefore, it is advisable not to perform the first tests until at least 1 hour after mixing.

7.4. At the end of each of the curing times given in Section 7.3, perform the constant neutralization test on two of the specimens, using the procedure described in Section 6.6.

7.5. Plot the grams of HCl used against the curing time to establish the correction curve (Figure 2).

Note 6—The curing time correction needs to be established only once for a project unless there is a change in aggregate or lime source.

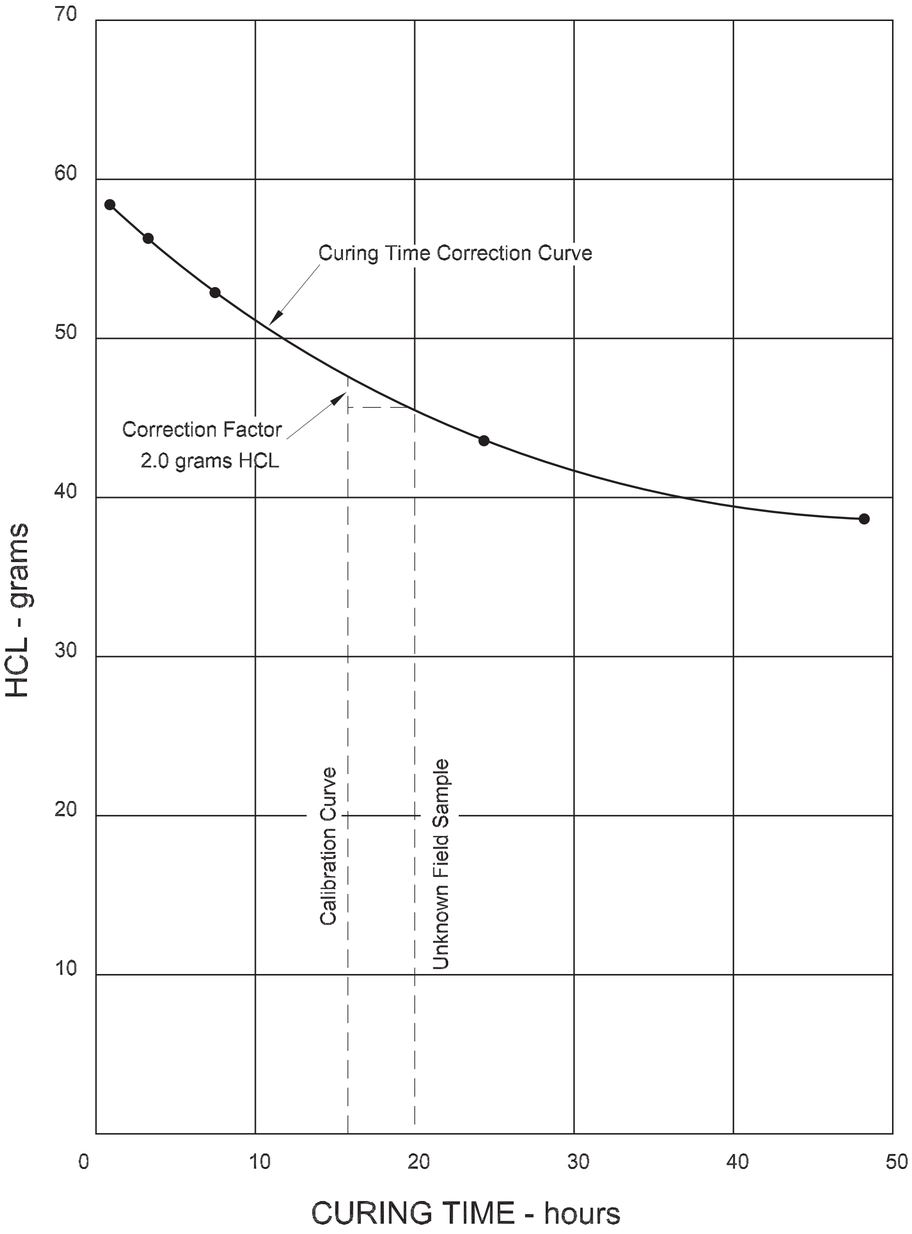


Figure 2—Curing Time Correction Curve

8. TEST PROCEDURE FOR FIELD SAMPLES

8.1. Secure one to four field samples of the lime-treated aggregate, with each sample having a mass of approximately 3000 g. Determine the mass of the sample to the nearest 1.0 g.

8.2. Remove any waste and aggregate retained on the 37.5-mm sieve.

8.3. Separate sample on the 9.5-mm sieve and determine the proportion retained and passing the 9.5-mm sieve on the basis of total sample mass including retained 37.5-mm material.

8.4. Prepare 300-g test specimens in the same proportions of retained and passing 9.5-mm material as contained in the original 3000-g sample. The retained 9.5-mm material is made up of passing 37.5-mm and retained 9.5-mm material to represent all the retained 9.5-mm material including the retained 37.5-mm material.

8.5. Perform the constant neutralization test in accordance with Section 6.6.

8.6. Determine the correction factor in grams of acid between the curing time for the calibration and field samples from the curing time correction curve (Figure 2). Apply a plus correction factor if the curing time of the field sample is greater than the curing time of the calibration samples. Apply a minus correction factor if the curing time of the field sample is less than the curing time of the calibration samples.

Note 7—The curing time for a field sample begins with the time for mixing and includes the time required for sampling the mixture, for transporting the sample to the testing location, and for preparing the 300 g test specimens.

8.7. Apply the correction factor to the grams of HCl required for neutralization. (See Section 6.6.10.)

8.8. From the calibration curve, determine the percent lime (Figure 1).

9. CALCULATIONS

9.1. Assume the following data:

9.1.1. The curing time correction curve was established using the planned lime content (Figure 2).

9.1.2. The calibration curve was established with a 16-hour curing time (Figure 1).

9.1.3. The field sample had a 20-hour curing time.

9.1.4. The titration of the field sample required 48.0 g of acid.

9.2. Plot the curing time for the calibration and field sample against the curing time correction curve, as shown in Figure 2. For this field sample, the correction is +2.0 g. Apply this correction to the grams of acid required to titrate the field sample (48 + 2.0 = 50.0 g of acid). Apply the 50.0 g of acid to the calibration curve (Figure 1). Then, the calculated lime content is 4.0 percent (Figure 1).

10. PRECAUTIONS

10.1. This test should not be performed by persons subject to color blindness.

10.2. It is very important that the operator vigilantly maintain a neutral solution by repeatedly adding acid as soon as the pink color reappears.

10.3. Use only the amount of hydrochloric acid (HCl) necessary to just eliminate the red color. Excess acid may attack the aggregates, particularly in the later phases when the amount of lime remaining in the mixture is low.

10.4. This test should not be performed in direct sunlight or at any location where there is a steady air movement over the containers. The amount of evaporation caused by exposure to air currents or sunlight can affect test data.

10.5. Glass carboys should not be substituted for plastic carboys described in the test apparatus, and all containers having acids or solutions made from them should be clearly labeled.

10.6. Exercise extreme care in handling the concentrated solutions of HCl and also exercise care in the use of the diluted solutions of HCl, as it can be harmful to the eyes, skin, or clothing. If this chemical is splashed in the eyes, on the skin, or on the clothing, flush the affected areas immediately with liberal quantities of water.

10.7. When handling acids, personnel should wear chemical protective gloves, goggles, and aprons.

10.8. Phenolphthalein has been known to cause allergic symptoms in humans and has a powerful laxative effect. It can be toxic. Exposed personnel who are sensitive to it should wear protective clothing, if necessary, to avoid bodily contact. Do not ingest.

Standard Method of Test for

Density of Soil In-Place by Block, Chunk, or Core Sampling

AASHTO Designation: T 233-02 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density of Soil In-Place by Block, Chunk, or Core Sampling

AASHTO Designation: T 233-02 (2006)

1. SCOPE

1.1. This method of test is intended to determine the density of cohesive soil in the natural state, compacted cohesive soil, and stabilized soil by measuring the weight and volume of undisturbed samples.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. Refer to R 16 for regulatory information for chemicals.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 217, Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

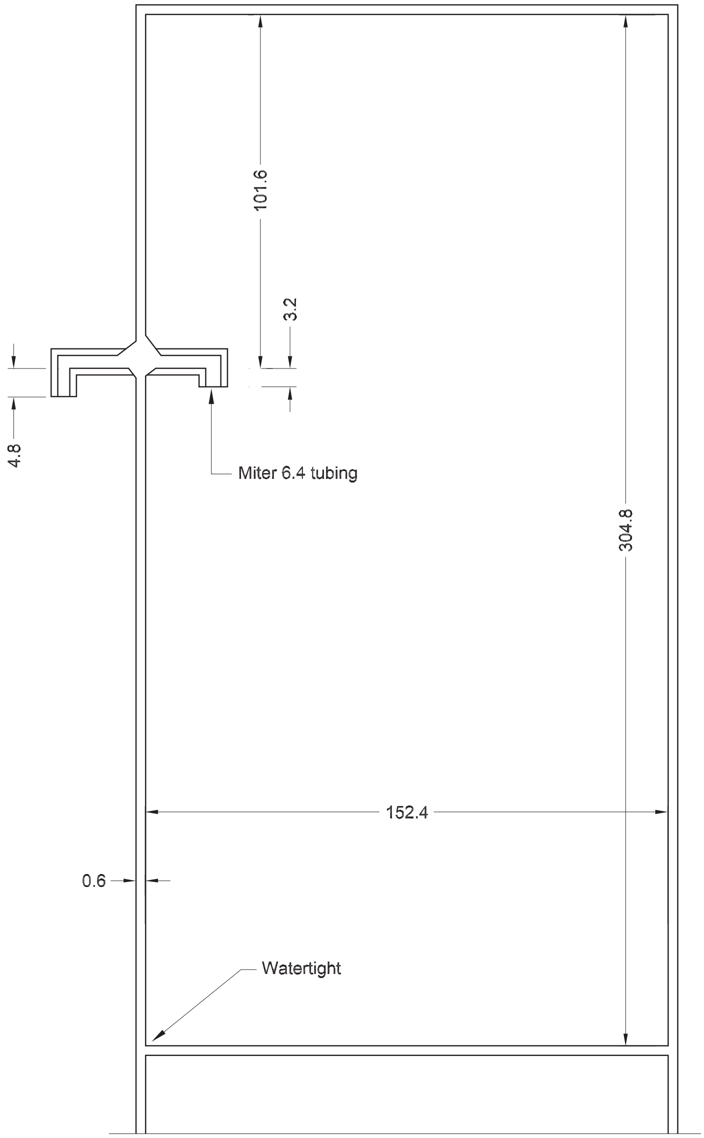
3. APPARATUS AND MATERIALS

3.1. *Sampling Tools*—Trowel, thick-blade spatula, knife, small spade suitable for removing sample, or a coring device suitable for obtaining an undisturbed sample. Diamond and Carborundum saws may be used.

3.2. *Balances and Scales*—A balance or scale conforming to the requirements of M 231, Class G 20. Also, a balance conforming to the requirements of M 231, Class G 2.

3.3. *Water Bath*, for immersing the paraffin-coated sample in water while on the holder under the balance, equipped with an overflow outlet for maintaining a constant water level.

3.4. *Volume Measuring Device*—An overflow, volumetric displacement apparatus as shown in Figure 1, or similar.



Note: All dimensions are shown in millimeters unless otherwise noted. (See Table 1 for dimensional equivalents.)

Figure 1—Volumetric Displacement Apparatus

Table 1—Dimensional Equivalents

mm	in.
304.8	12
152.4	6
101.6	4
6.4	$^1/_4$
4.8	$^3/_{16}$
3.2	$^1/_8$
0.6	26 gauge

Note 1—The volume-measuring device is not needed if the suspension apparatus with holder (Section 3.2) and water bath (Section 3.3) is used.

3.5. *Oven*—An oven, stove, or other suitable equipment for drying soil samples for moisture content determination.

3.6. *Containers*—Containers for moisture content samples, made of metal or other suitable material, and with close-fitting lids to prevent loss of moisture prior to or during mass determinations.

Note 2—The moisture content may also be determined in accordance with T 217.

3.7. *Coating Material*—Paraffin and a kettle or other container suitable for melting paraffin and dipping samples.

4. SAMPLING

4.1. Obtain a sample of the soil or stabilized soil by marking the area from which the desired sample is to be cut and digging the soil or stabilized soil from around it with a sharp tool, such as a trowel, spatula, knife, or small spade. Exercise care in digging around the sample to prevent disturbance of the soil structure. Sample the depth of the layer for which the density is desired. The minimum size of the untrimmed sample should be slightly greater than shown in Table 2, so as to provide for final trimming (Section 5.2).

Table 2—Minimum Density-Sample Volumes and Minimum Moisture Content Samples Based on Maximum Size of Particle

Maximum Particle Size		Minimum Sample Volume		Minimum Moisture Content Sample
mm	Alternate	cm^3	ft^3	g
4.75	No. 4 Sieve	710	0.025	100
12.7	$^1/_2$ in.	1415	0.050	250
25.0	1 in.	2125	0.075	500
50	2 in.	2850	0.100	1000
63	$2^1/_2$ in.	3550	0.125	1500

4.2. Other suitable methods of obtaining the undisturbed sample include drilling with a coring device and cutting with a diamond or Carborundum saw.

5. PROCEDURE

5.1. After removal of the undisturbed sample, take a representative moisture sample from the wall of the hole or from the trimmings obtained in cutting the undisturbed sample, place in a container, determine the mass to the nearest 0.1 g, dry to constant mass, and determine the moisture content. The minimum size of the moisture content sample, based on the maximum particle size, is given in Table 2.

5.2. Trim any loose material from the undisturbed sample and determine the mass of the sample to the nearest 1.0 g. The minimum sample volume, after trimming, is given in Table 2.

5.3. Immerse the undisturbed sample in melted paraffin, being careful that the sample is completely coated. Allow the paraffin coating to cool, and then determine the mass of the coated sample to the nearest 1.0 g. The gain in mass represents the mass of paraffin and the volume of the coating is calculated using the density of paraffin.

5.4. The volume of the paraffin-coated sample in water shall be determined by one of the following methods:

5.4.1. Determine the mass of the paraffin-coated sample submerged in the water bath described in Section 3.3 and record the mass to the nearest 1.0 g. Determine the volume of the sample in accordance with Section 6.2.

5.4.2. Fill the volume measuring device (Figure 1) with water above the overflow. Permit the excess water to drain. Immerse the coated sample and determine the mass of the displaced water to the nearest 1.0 g. Determine the volume of the sample in accordance with Section 6.2.

Note 3—Kerosene or another suitable liquid may be used instead of water in the water bath (Section 3.3) to avoid the necessity for (1) coating the undisturbed sample with paraffin (Section 5.3) prior to immersion (Section 5.4) and (2) making a correction for the volume of the paraffin coating.

6. CALCULATIONS

6.1. Calculate the moisture content as follows:

$$w = \frac{A - B}{B - C} \times 100 \tag{1}$$

where:

w = percentage of moisture in the sample, based on dry mass of soil;

A = mass of container and wet soil;

B = mass of container and dry soil; and

C = mass of container.

6.2. Calculate the in-place density (dry unit mass), D, of the soil, in kg/m^3, as follows:

$$I = \frac{F - E}{D_p} \tag{2}$$

$$J = \frac{F - G}{D_m} = \frac{H}{D_m} \tag{3}$$

$$V = J - I \tag{4}$$

$$D = \frac{(1000)D_w}{1 + \frac{w}{100}} \tag{5}$$

For determining D in lb/ft^3 use:

$$D = \frac{(62.43)\,D_w}{1 + \frac{w}{100}} \qquad (6)$$

where:

E = mass of soil sample in grams;
F = mass of paraffin-coated sample in grams;
G = mass of submerged paraffin-coated sample in grams;
H = mass of displaced water in grams;
I = volume of paraffin in cubic centimeters;
J = volume of paraffin-coated soil sample in cubic centimeters;
V = volume of soil sample in cubic centimeters;
D_p = density of paraffin in grams per cubic centimeter;
D_m = density of water in grams per cubic centimeter;
D_w = wet density of soil in grams per cubic centimeter;
D = in-place density of soil in kg/m^3 (lb/ft^3); and
w = moisture content of soil, in percent.

Standard Method of Test for

Direct Shear Test of Soils under Consolidated Drained Conditions

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AASHTO Designation: T 236-08[1]
ASTM Designation: D 3080-72 (2003)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Direct Shear Test of Soils under Consolidated Drained Conditions

AASHTO Designation: T 236-08[1]
ASTM Designation: D 3080-72 (2003)

1. SCOPE

1.1. This method describes procedures for determining the consolidated drained shear strength of a soil material in direct shear. The test may be conducted in either a single shear or in a double shear, as shown in Figure 1. The direct shear test is well-suited to a consolidated drained test because the drainage paths through the test specimen are short, thereby allowing excess pore pressures to be dissipated fairly rapidly. The test can be made on all soil material,[2] and on undisturbed or remolded samples.

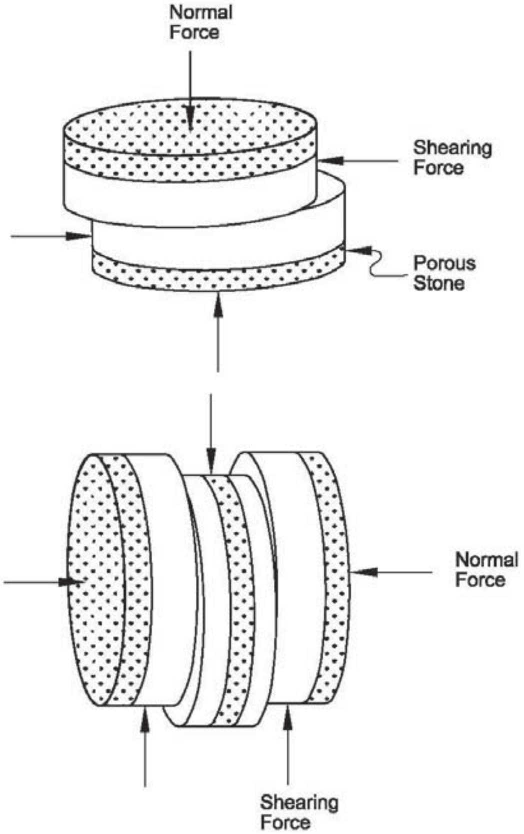

Figure 1—Test Specimens in (a) Single and (b) Double Shear

1.2. The test results are applicable to field situations where complete consolidation has occurred under the existing overburden and failure is reached slowly so that excess pore pressures are dissipated. The test is also useful in determining the shearing resistance along recognizable weak planes within the soil material.

Note 1—If failure is forced to occur on or near a horizontal plane at the middle of the specimen, it may not necessarily occur along the weakest plane, thereby overestimating shear strength parameters. Only when weak plane(s) are recognizable within the soil mass or interfaces between dissimilar materials are being tested, and the plane or interface at question is placed within the limits of the forced failure zone, can the shear resistance along these planes or interfaces be evaluated. The usefulness of direct shear test results was discussed in the Symposium on Direct Shear Testing of Soils; the proceedings appear in ASTM Special Technical Publication 131.

1.3. The test is not suited to the development of exact stress-strain relationships nor for evaluating any other associated quantities such as moduli within the test specimen because of the non-uniform distribution of shearing stresses and displacements. The slow rate of displacement provides for dissipation of excess pore pressures, but it also permits plastic flow of soft cohesive soils. Care should be taken that the testing conditions represent those being investigated.

1.4. The values stated in SI units are to be regarded as the standard.

2. SUMMARY OF METHOD

2.1. The method consists of (a) placing the test specimen in the direct shear device, (b) applying a predetermined normal stress, (c) providing for drainage or wetting of the test specimen, (d) consolidating the specimen under the normal stress, (e) unlocking the frames that hold the test specimen, and (f) applying a shearing force to shear the specimen (Figures 1 and 2). Generally three or more specimens are tested, each under a different normal stress to determine the effects upon shear resistance and displacement. The range in normal stresses should be appropriate for the soil conditions being investigated.

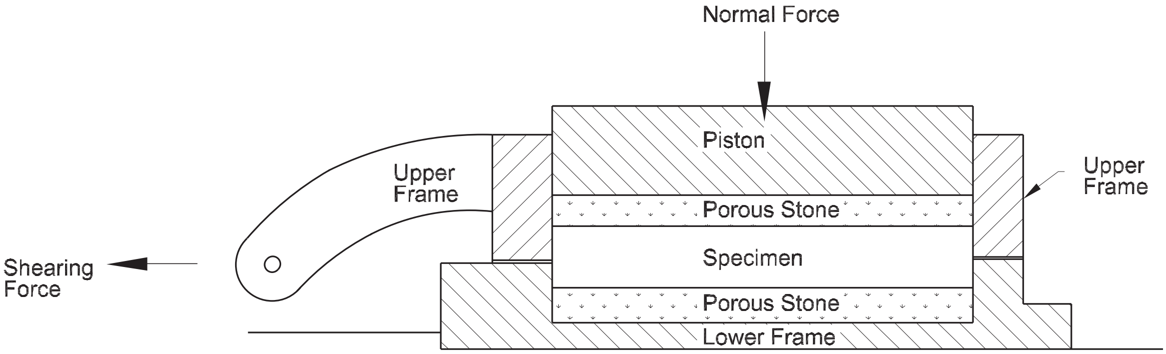

Figure 2—Typical Direct Shear Box for Single Shear

3. APPARATUS

3.1. *Shear Device*—A device (square or circular) to hold the specimen securely between two porous stones in such a way that torque cannot be applied to the specimen. The shear device shall provide means for applying a normal stress to the faces of the specimen, for measuring change in thickness of the specimen, for permitting drainage of water through the porous stones, and for submerging the specimen in water. The device shall be capable of applying a shearing force to shear the specimen along a predetermined shear plane (single shear) or shear planes (double shear) parallel to the faces of the specimen. The frames that hold the specimen shall be sufficiently rigid to prevent their distortion during shearing. The various parts of the shear device shall be made of material not subject to corrosion by substances within the soil or soil moisture.

3.2. *Porous Stones*—The porous stones shall consist of silicon carbide, aluminum oxide, or metal that is not susceptible to corrosion by soil substances or soil moisture. The proper grade of stone depends upon the soil being tested. The stone should be coarse enough to develop adequate interlock with the specimen and fine enough to prevent excessive intrusion of the soil into the pores. Exact criteria for this have not been established. For normal soil testing, medium grade stones with a permeability of about 0.5 to 1 mm/s are appropriate.

3.3. *Loading Devices*:

3.3.1. Device for applying the normal force shall be capable of applying the specified force quickly, without exceeding it, and capable of maintaining it with an accuracy of ±1 percent for the duration of the test.

3.3.2. Device for applying the shear force. The capabilities will depend upon whether a controlled-displacement test or controlled-stress test is used. The former is generally preferred because the ultimate stress as well as the maximum stress can be determined. Controlled displacement equipment shall be capable of shearing the specimen at a uniform rate of displacement, with less than ±5 percent deviation, and should permit adjustment of the rate of displacement over a relatively wide range. The rate depends upon the consolidation characteristics of the soils.[3] The rate is usually maintained with a motor and gear box arrangement and the shear force is determined by a force indicating device such as a proving ring. Controlled-stress equipment, if used, should be capable of applying the shear force in increments to the specimen in the same manner and to the same degree of accuracy as that described under Section 3.3.1.

3.4. *Calibration Disk*—A metal disk having a thickness equal to the desired test specimen and about 5 mm smaller in diameter.

3.5. *Moisture Room* for storing samples as well as for preparing samples where moisture loss during preparation does not exceed 0.5 percent.

3.6. *Trimmer or Cutting Ring* for trimming oversized samples to the inside dimensions of the shear box with a minimum of disturbance. An exterior jig may be needed to maintain the succession of rings—two or three—in axial alignment.

3.7. *Balance* sensitive to 0.1 g or to 0.1 percent of the specimen mass.

3.8. *Displacement Indicators* to measure change in thickness of the test specimen, with a sensitivity to 0.002 mm (0.0001 in.), and to measure horizontal displacement with a sensitivity of 0.02 mm (0.001 in.).

3.9. *Drying Oven* that can be maintained at 110 ± 5ºC (230 ± 9ºF).

3.10. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

3.11. *Equipment for Remolding or Compacting Specimens*.

3.12. *Miscellaneous Equipment*, including a timing device with a second hand, distilled or demineralized water, spatulas, knives, straightedge, wire saws, etc., used in preparing the sample.

4. CALIBRATION

4.1. The calibration step is necessary in order to determine the deformation of the testing device when subjected to consolidation load. For each consolidation step, the corresponding device deformation will be subtracted from the observed deformation so that only deformations due to sample consolidation will be reported at the end of each consolidation step. Calibration of the testing device must be performed when the device is originally placed in service as well as whenever any of its components are changed. An annual calibration, at a minimum, should be performed.

4.2. Assemble the single shear direct shear device with the calibration disk used in place of the test specimen. The calibration disk should be a copper or hard steel disk of approximately the same height as the test specimen and at least 1 mm (0.04 in.) but no more than 5 mm (0.20 in.) smaller in diameter than the ring.

Note 2—The double shear device will require two calibration disks.

4.3. Position and adjust the normal displacement indicator so it can be used to measure either consolidation or swell from the "calibration disk" reading. Record the zero or "no load" reading.

4.4. Apply increments of normal force up to the equipment limitations and record both the applied normal force and the normal displacement indicator reading for future reference in determining the thickness of the test specimen and compression within the test apparatus itself. Remove the applied normal force in reverse sequence of the applied force and again record the normal displacement indicator readings and normal force. Calculate the average of the two recorded deformation values corresponding to each value of applied normal loading sequences (loading and unloading). Plot the average deformation of the device as a function of the applied load. As indicated in Section 4.1, this information will be used in determining the thickness of the test specimen and its compression within the testing device at the end of each consolidation loading step.

4.5. Remove the calibration disk.

Note 3—Other equally accurate methods for calibrating the apparatus are acceptable.

5. SAMPLE PREPARATION

5.1. If an undisturbed sample is used, it should be large enough to provide a minimum of three similar specimens. Prepare the specimens so that moisture loss is negligible. Trim oversized specimens to the inside diameter of the direct shear device and to the length of the trimmer. Extreme care shall be taken in preparing undisturbed specimens of sensitive soils to prevent disturbance of their natural structure. Determine the initial mass of the specimen for subsequent use in determining initial moisture content.

5.2. If specimens of compacted soil are used, they shall be compacted to the moisture content and unit weight as prescribed in the test request. They may be compacted directly in the shear device, in a mold of equal dimensions and extruded into the shear device, or in a larger mold and trimmed as in Section 5.1.

5.3. Minimum specimen diameter for circular specimens, or width of rectangular (square) specimens, shall be approximately 50 mm (2.00 in.). For undisturbed samples, the diameter of the sampling tube shall be greater than the specimen diameter to reduce disturbance in the specimen and prevent lateral displacement (Note 4).

Note 4—The diameter of undisturbed test specimens cut from tube samples should be at least 6 mm (0.25 in.) less than the diameter of the sampling tube to minimize disturbance caused by sampling.

5.4. Minimum specimen thickness shall be approximately 13 mm (0.5 in.), but not less than six times the maximum grain diameter.

5.5. Minimum specimen diameter-to-thickness ratio shall be 2:1. For square or rectangular specimens, the minimum width-to-thickness ratio shall also be 2:1.

6. PROCEDURE

6.1. Assemble the shear box with the frames aligned and locked in position.

A light coating of grease between the frames may be used to ensure watertightness during consolidation and reduce friction during shear.

Teflon® spacers or Teflon®-coated surfaces may also be used to reduce friction during shear. Carefully insert the test specimen. Connect the loading devices. Position and/or activate the displacement indicators for measuring shear deformation and changes in specimen thickness. Determine the initial thickness of the specimen.

Note 5—The decision to dampen the porous stones before insertion of the specimen and before application of the normal force depends upon the problem under study. For undisturbed samples from below the water table, the porous stones are usually dampened. For swelling soils, wetting should probably follow application of the normal force to prevent swell not representative of field conditions.

6.2. Consolidate each test specimen under the appropriate normal force. As soon as possible after applying the initial normal force, fill the water reservoir to a point above the top of the specimen. Maintain this water level during the consolidation and subsequent shear phases so that the specimen is at all times effectively submerged. Allow the specimen to drain and consolidate under the desired normal force or increments thereof prior to shearing. During the consolidation process, record the normal displacement readings before each increment of normal force is applied and at appropriate times.[4] Plot the normal displacement readings against elapsed time. Allow each increment of normal force to remain until primary consolidation is complete. The final increment should equal the previous normal force developed and should produce the specified normal stress.

Note 6—The normal force used for each of the three or more specimens will depend upon the information required. Application of the normal force in one increment may be appropriate for relatively firm soils. For relatively soft soils, however, several increments may be necessary to prevent damage to the specimen. The initial increment will depend upon the strength and sensitivity of the soil. This force should not be so large as to squeeze the soil out of the device.

6.3. *Shear the Specimen*—After consolidation is complete, unlock the frames and separate them slightly (0.64 mm [0.025 in.]) so the specimen can be sheared. Apply the shearing force and shear the specimen slowly to ensure complete dissipation of excess pore pressure. The following guide for total elapsed time to failure (t_f) may be useful in determining rate of loading:

$t_f = 50\ t_{50}$

where:

t_{50} = time required for the specimen to achieve 50 percent consolidation under the normal force.

Note 7—If the normal displacement versus square root of time is used, t_{50} can be calculated from the time to complete 90 percent consolidation using the following expression:

$$t_{50} = \frac{t_{90}}{4.28}$$

where:

t_{90} = time required for the specimen to achieve 90 percent consolidation under the specified normal force.

4.28 = constant, relates displacement and time factors at 50 and 90 percent consolidation.

Note 8—If the material exhibits a tendency to swell, the soil must be saturated with water and must be permitted to achieve equilibrium under an increment of normal stress large enough to counteract the swell tendency before the minimum time to failure can be determined. The time-consolidation curve for subsequent normal stress increments is then valid for use in determining t_f.

Note 9—Some soils, such as dense sands and over-consolidated clays, may not exhibit well defined time-settlement curves. Consequently, the calculation of t_f may produce an inappropriate estimate of the time required to fail the specimen under drained conditions. For over-consolidated clays that are tested under normal stresses less than the soil's pre-consolidation pressure, it is suggested that a time to failure be estimated using a value of t_{50} equivalent to one obtained from normal consolidation time-settlement behavior. For clean, dense sands that drain quickly, a value of 10 minutes may be used for t_f. For dense sands with more than 5 percent fines, a value of 60 minutes may be used for t_f. If an alternative value of t_f is selected, the rationale for the selection shall be explained with the test results.

Note 10—The screws used for separating the frames should be retracted so they are not in contact with the lower frame before the shear force is applied. Also remove the pins or screws used for locking the frames together

Note 11—In a controlled-displacement test, the rate of displacement (d_r mm/min or in./min) may be determined approximately by dividing the estimated shear (lateral) deformation (d_f mm or in.) at maximum shear stress by the computed time to failure (t_f):

$$d_r = \frac{d_f}{t_f}$$

The magnitude of the estimated shear (lateral) displacement at failure is dependent on many factors, among them the type and the stress history of the soil. As a guide, use $d_f = 12$ mm (0.5 in.) if the material is normally or lightly over-consolidated fine-grained soil, otherwise use $d_f = 5$ mm (0.2 in.).

6.3.1. Compute the percent relative shear (lateral) displacement for each shear force reading.

6.3.2. Continue the test until the shear stress becomes essentially constant or until a shear deformation of 10 percent of original diameter has been reached. In a controlled-stress test, begin with shearing force increments equal to about 10 percent of the estimated maximum. Permit at least 95 percent consolidation before applying the next increment. When 50 to 70 percent of the estimated failure force has been applied to the specimen, reduce the increment to one-half the initial size or 5 percent of the estimated maximum shear stress. As failure is approached, use a series of increments equal to one-fourth the initial increment. Record the applied shear force and the shear and normal deformations at convenient intervals. A continuous buildup of shearing force would be preferable.

6.4. At the completion of the test, remove the entire specimen from the shear box, oven-dry it in accordance with T 265, Laboratory Determination of Moisture Content of Soils, and weigh it to determine the mass of solids.

7. CALCULATIONS

7.1. Measure initial moisture content, specific gravity, mass, and volume of the total specimen.

7.2. Based on these measured quantities, compute initial void ratio, wet and dry densities, and initial degree of saturation of the sample.

7.3. Calculate shear stress data (maximum shear stress, normal stress at failure, actual displacement rates, etc.).

7.4. Void ratio after consolidation, as well as after the shear test, is desirable.

7.5. Final degree of saturation.

8. REPORT

8.1. Description of type of shear device used in the test and components serial or lab numbers, if available. List also the PIN (Project Identification Number) and its exact location (county and municipality, route number, and mile marker).

8.2. Identification and description of sample, including tube or jar number, depth of retrieval, whether soil is undisturbed, remolded, compacted, or otherwise prepared, and noting any unusual features such as stratification and soil structure.

8.3. Initial moisture content and degree of saturation,

8.4. Dry mass (mass of solids), initial wet and dry density.

8.5. Initial sample dimensions (thickness, width, length, diameter, etc.).

8.6. All basic test data including normal stress, shear displacements and corresponding shear resistance values, specimen thickness changes, and specimen final dimensions. Include Atterberg limits and grain size data, if available.

8.7. Plot of maximum shear stress versus normal stress. For each test specimen, a plot of shear stress and specimen thickness change versus shear displacement.

8.8. Plot of nominal shear stress versus percent shear (lateral) displacement.

8.9. Plots of log of time or square root of time versus deformation of those load increments where t_{50} was determined in the time to failure calculations.

8.10. Final degree of saturation, final moisture content, final wet density (unit weight), final dry density (unit weight).

8.11. Departure from the procedure outlined, such as special loading sequences or special wetting requirements.

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[1] Similar except for SI units, but not technically identical to ASTM D 3080-72 (2003).

[2] See Section 5.4 for specimen/particle-size relationship.

[3] Section 6.3 includes guides for determining rate.

[4] See AASHTO T 216, One-Dimensional Consolidation Properties of Soils.

Standard Method of Test for

Measurements of Pore Pressures in Soils

AASHTO Designation: T 252-09

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

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INTRODUCTION

The principal reasons for measuring pore pressures in highway construction are:

1. to monitor strength increases during construction;
2. to estimate remaining settlements after construction; and
3. to determine existing pore pressures in landslides.

This method consists of installing the pore water pressure measuring device in a soil layer at a point determined by detailed knowledge of the field conditions and theoretical evaluation of the need required. Pore pressure measurement may be made by determining the total pore pressure at the point or determining the differential pore pressure at that point relative to the surrounding normal groundwater table. The data are usually reduced to “excess” pore pressure, which is the difference between the measured pore pressure and the “normal” pore pressure under the general groundwater table for the area at the time of reading.

Interpretation of pore pressure measurements in the field are complicated by the variability both vertically and horizontally in the soils. Therefore, interpretation of any pore pressure measurement can be misleading if the complete soil profile, loading history, and detailed soil parameters are not adequately known.

1. SCOPE

1.1. This method covers procedures for determining field pore pressure measurements in the natural soils.

1.1.1. This does not include methods of pore pressure measurement in the laboratory or field installations in dams.

1.2. The values stated in SI units are to be regarded as the standard.

2. APPARATUS

2.1. *Open System*—The following equipment may be used to obtain pore pressure in soils of relatively high (Note 1) permeability:

Note 1—This equipment is also satisfactory for low-permeability soils.

2.1.1. A simple open observation well consisting of an open hole supported by plastic or metal casing if necessary.

2.1.2. A standard well point installation which consists of a screened well point on the end of standard pipe. Various screen lengths and openings are available for use in different situations.

2.1.3. The open well "Casagrande"-type (Hydraulic) piezometer which consists of a porous tip connected to a small diameter riser tube surrounded by filter (Ottawa) sand (100 percent passing 0.850-mm (No. 20) sieve, 100 percent retained on 0.425-mm (No. 40) sieve) and sealed in the bottom of a drilled hole. The tips are available in various sizes and porosities and may be made of ceramic filter stone, porous plastic, or porous metals. The riser tube may be plastic and for convenience in reading should have an inside diameter no smaller than 6.35 mm ($^1/_4$ in.).

2.2. *Closed Systems*—The following equipment may be used to obtain pore pressure in soils of low permeability (Note 2):

Note 2—This equipment is also satisfactory for high-permeability soils.

2.2.1. *Closed Casagrande-Type Piezometer*—This consists of a porous tip (as in Section 2.1.3) sealed into a soil layer and connected to the ground surface by a fluid filled tube (or tubes) connected to a gauge. The porous tip is installed at the bottom of a drilled hole and surrounded by filter (Ottawa) sand (100 percent passing 0.850-mm (No. 20) sieve, 100 percent retained on 0.425-mm (No. 40) sieve). The tubing may be 6.35 to 12.7 mm ($^1/_4$ to $^1/_2$ in.) or larger-diameter plastic or flexible metal. Clean water should be used to fill the tube. Where freezing is a problem, consider using a pneumatic or electrically operated piezometer. A Bourdon tube-type compound gauge (of sufficient capacity to accommodate the expected pore pressure change) should be used. The gauge should be calibrated for the conditions under which it will be used (position, temperature, etc.). This type system measures the differential water pressure between the surrounding groundwater table and the pressure within the soils system.

2.2.2. *Pneumatic Piezometer*—This consists of a pneumatic pressure transducer in a plastic or stainless steel case with a porous (ceramic, plastic, or metal) opening to allow the pore water to reach the transducer diaphragm. Two small-diameter plastic air leads are connected to the transducer. A supply of compressed air, bottle compressed, or liquified gas (clean and without moisture) is required to operate the transducer. An air pressure gauge of sufficient capacity to record the existing pressure at the depth of the piezometer tip plus the expected pore pressure is needed.

2.2.3. *Electrically Operated Piezometer*—This consists of a calibrated diaphragm (with a strain gauge attached) sealed in a plastic or stainless steel case, with one side open to the pore water through a porous filter. The strain gauge attached to the diaphragm may be resistance type or vibrating wire type. Pore pressure is obtained by use of an electrical readout system compatible with the type of strain gauge used.

3. INSTALLATION PROCEDURES

3.1. *Driven or Drilled in-Type Installations*:

3.1.1. *Open-Well Piezometers*:

3.1.1.1. *Open Hole*—Drive standard pipe (with disposable point) of suitable size and strength to reach the soil layer in which pore pressure is to be obtained. Pull back the pipe a sufficient distance to obtain pore pressure response and cap the pipe with a vented cap.

3.1.1.2. *Wellpoint*—Drive standard pipe (with suitable wellpoint attached) of suitable size and strength to reach the soil layer in which the pore pressure is obtained. The wellpoint may be of any size, length, and screen opening suitable for the soil in which it is installed. However, the largest diameter of the wellpoint shall not be greater than the diameter of the pipe coupling above it. Insert a suitable flexible hose through the pipe and into the wellpoint. Pump clean water through the hose to clean the wellpoint (and screen). Flushing should continue for about 5 minutes after the water flows clean out of the top of the pipe. Remove the hose and install a vented cap on the pipe.

3.1.1.3. *Low-Volume Change Wellpoint*—A small-diameter 9.5 to 12.7-mm ($^3/_8$ to $^1/_2$ in.) plastic tube is firmly sealed (by mechanical coupling or suitable glue) to a suitable wellpoint. The seal must be strong enough to withstand the total pore pressure without allowing leakage into the drive pipe. The wellpoint is attached to a standard pipe of sufficient size and strength to reach the soil layer in which pore pressure is to be measured. The pipe threads for the first 6.1 m (20 ft) of pipe shall be sealed with a suitable pipe sealing compound to prevent leakage through the pipe joints. The plastic tube is threaded through the pipe sections during driving. After driving, the tube is suspended (with sufficient tension to keep the tube straight) from the top of the pipe, and the pipe capped with a vented cap.

3.1.2. *Closed-System Piezometers*:

3.1.2.1. Closed-system piezometers may be driven into the proper soil layer in a manner similar to Section 3.1.1.3 above. Special filters and points may be used for special situations. Connections to standard pipe or standard drill rods are acceptable provided the seals are watertight for the pore pressures used and the diameter of the point does not exceed the diameter of the drill rod or the drive pipe. For Casagrande-type piezometers, the point and enough tubing to reach the ground surface shall be completely filled with clean water before start of driving. The upper end of the tube shall be sealed to prevent entrance or loss of water from the system during driving. No tubing connectors should be used in the vertical (Riser) tube.

3.1.2.2. *Surface Connections*—Closed-system piezometers which are to be extended vertically through the embankment fill may be extended in any manner suitable for the type of piezometer being installed provided that (1) adequate protection is provided, and (2) there is a method of recalibrating the pore pressure reading with each extension. Closed-system piezometers with remote readout shall be installed in the following manner:

- Excavate a trench 610 mm (2 ft) deep by 305 mm (1 ft) wide from the piezometer location to the readout protection box. The bottom of the trench shall be 610 mm (2 ft) min below future construction (ditches, pipes, etc.).
- The top of the drive pipe shall be removed to a point at least 1.52 m (5 ft) below ground surface. The tube (or leads) shall be centered over the pipe for at least 305 mm (1 ft) as sand is placed in the hole. The tube (or leads) shall then be coiled in a spiral approximately 610 mm (2 ft) diameter upwards to the bottom of a trench approximately 610 mm (2 ft) below ground surface as sand is placed loosely around it.
- The horizontal leads shall be layered in a zigzag pattern in the trench on a bed of 152 mm (6 in.) of clean sand. When more than one tube or lead is used in a trench, the lines shall not cross.
- All horizontal tubes or wires shall be checked for continuity, leakage, etc., before final connections are made to the vertical piezometer leads. If possible, the leads or tubes should be in one continual length with no connections, from the piezometer tip to the readout protection box.
- All electrical leads shall be immersed in clear water and the resistance checked. If there is any change in resistance upon immersion, the leads shall be discarded and replaced.
- The air leads for pneumatic piezometers shall be immersed in clear water and checked for leaks under pressures exceeding the expected pore pressure. Also, the air leads shall be flushed with high pressure air to clear any dust or moisture from the leads before final connections are made. The air used for flushing should come from a tank which holds only filtered air and which has been bled for excess moisture.
- The horizontal tubes for hydraulic piezometers shall be vacuum tested to 70 kPa (10 psi) of vacuum prior to filling the tubes with colored water. There shall be two horizontal tubes with

T connection to the vertical riser from the piezometer tip. The tubes shall be completely filled with colored fluid with the tubes in a configuration such that any air bubbles that occur during filling can be seen and removed. The preferable way of filling is to immerse one end in the colored fluid, seal the T at the rise with a plug, and apply a vacuum to the free end of the horizontal tube. Care must be taken to prevent the formation of air bubbles during filling operations. Once the tube is completely filled with fluid, the connections should be made at the readout box. The vertical riser from the piezometer tip shall then be filled with water and the plug removed from the horizontal tube T, and the connection between the vertical riser and the horizontal tubes shall be made underwater. The elevation of the T and the readout gauge must be determined prior to backfilling the trench.

3.2. *Piezometers Installed in Drill Holes*:

3.2.1. The following additional equipment is required for installation of drilled-in piezometers:

3.2.1.1. A tamping hammer, made of a 610-mm (2-ft) length of seamless steel tubing, 41.3-mm ($1^5/_8$-in.) O.D. and 15.9-mm ($^5/_8$-in.) I.D. or cast bronze of the same dimensions and having a mass of at least 11.3 kg (25 lb). These dimensions are for a 50.8-mm (2-in.) I.D. casing. Larger hammer dimensions are required for larger casing sizes. At the upper end, a loop of 3.2-mm ($^1/_8$-in.) diameter galvanized airplane cable should be firmly attached to the hammer and to a grooved ring. The inside surface of the hammer should be smooth and all edges that touch the tubing should be rounded. This hammer should be supplied with a 41.3-mm ($1^5/_8$-in.) diameter disc 12.7-mm ($^1/_2$-in.) thick which can be firmly attached to the bottom. This disc shall have a slot in the center (of suitable size to accommodate the size tubing or leads used) with rounded edges. This hammer-cable assembly is used for the following purposes:

- To tamp the bentonite layers and thereby assure a watertight seal between the casing and the risers.
- To center the risers while the bentonite seal is being tamped into place.
- To measure depths at various stages of the installation.

3.2.1.2. Galvanized preformed airplane cable 6.35-mm ($^1/_4$-in.) diameter of sufficient length to permit installation on the deepest piezometers. This should be securely fastened to one end of a snap-type swivel hook. Mark the cable at 1.52-m (5-ft) intervals, starting at the bottom face of the hammer.

3.2.1.3. A tripod and sheave for operating the tamping hammer.

3.2.1.4. Drive sample drilling equipment.

3.2.1.5. Ottawa sand or a thoroughly washed sand passing the 0.850-mm (No. 20) sieve and retained on 0.425-mm (No. 40) sieve.

3.2.1.6. Bentonite balls about 12.7 mm ($^1/_2$ in.) in diameter, which are formed at a water content somewhat above the plastic limit but below the sticky limit (i.e., at a putty-like consistency) rolled in talcum powder to prevent sticking, and stored in glass jars to protect them from drying, or the commercial pellets.

3.2.1.7. Rounded pebbles approximately 12.7 mm ($^1/_2$ in.) in diameter.

3.2.2. Drive casing, 50.8-mm (2-in.) I.D. or larger, to the approximate elevation of the bottom of the piezometer cell. The bottom 3.05-m (10-ft)-long section must be in one piece, without joints or couplings, and it is not to have a drive shoe on the lower end. The casing may be advanced by any means, except for the final 6.1 m (20 ft) of penetration. It shall then be advanced in 1.52-m (5-ft) increments, and the casing must be washed out after each 1.52-m (5-ft) advance. The casing shall be kept filled with water at all times and no washing below the casing will be permitted.

3.2.2.1. Obtain a spoon sample of the material for 305 mm (12 in.) below the bottom of the casing and deliver the samples in sealed jars to the engineer. Drive the casing 305 mm (12 in.) below the piezometer cell elevation and clean out the remaining soil to the bottom of the casing. Replace the water in the casing with clear water by reversing the flow of the pump and using the jet pipe as the intake, with the lower end of the pipe held a few centimeters above the bottom of the casing. Keep the casing filled with clean water and continue the operation until the return water becomes clear.

3.2.2.2. Pull the casing up 305 mm (1 ft) and pour clean sand into the casing to fill up the 305-mm (1-ft) hole. The top of the sand should be measured by a sounding device. Lower the assembly into the casing until the piezometer cell rests on the sand, and center the cell by lowering the tamping hammer to the top of the cell.

3.2.2.3. *Pneumatic piezometers*—Connect the air leads (in one continuous unspliced length, to extend 3.05 m (10 ft) above the ground surface) to the piezometer cell. The system should be checked for leaks and the air leads labeled or color coded before installation. The cell and readout gauge should be checked for accuracy by measuring the pore pressure (equal to the head of water in the casing) at several depths between the top of the casing and the installation depth. The leads should then be plugged to prevent entrance of dirt during the remainder of the installation.

- For electric piezometers: Connect the electric leads (in one continuous unspliced length to extend to 3.05 m (10 ft) above the ground surface) to the piezometer cell with watertight connections. The leads should be color coded or labeled before installation. The accuracy of the piezometer cell shall be checked as in Section 3.2.2.3 above.
- For hydraulic piezometers: Saturate the porous tip and fill the riser tube (in one continuous unspliced length to extend to 3.05 m (10 ft) above the ground surface) with clean water by immersing the porous tip in clean water and applying a vacuum to the tube. The tube should be checked for air bubbles and the top plugged. The porous tip shall only be removed from the clean water while being transferred to the filled casing.

3.2.3. Pull the casing up so that the bottom of the casing is 305 mm (1 ft) above the bottom of the cell (Note 3) and, at the same time, slowly (Note 4) pour a measured volume of clean sand into the casing so that the sand fills the space around the piezometer tip and to approximately 762 mm ($2^1/_2$ ft) above the bottom of the casing. Maintain tension on the tubing but do not permit any vertical movements of the piezometer tip.

Note 3—In areas where large foundation settlements are expected (over 914 mm (3 ft), the casing is not pulled above the piezometer tip, or the bottom of the casing can be perforated.

Note 4—If sand is poured too fast, it could fill the pipe such that when the pipe is pulled back, the tip would also move.

3.2.4. Form a 25.4-mm (1-in.) thick layer of 12.7-mm ($^1/_2$-in.) diameter pebbles on top of the sand in the casing and apply 20 blows to the pebble layer with a 152-mm (6-in.) drop of the hammer per blow.

3.2.5. Form a bentonite seal of five layers of bentonite balls, each 76.2-mm (3-in.)-thick layer placed and compacted as follows, while maintaining a constant tension on the tubing or leads.

3.2.5.1. Lower the water 76.2 mm (3 in.) below the top of the casing.

3.2.5.2. Drop bentonite balls individually into the casing until the water rises to the top of the casing and allow sufficient time for the balls to reach the bottom (about 1 minute for each 3.05 m (10 ft) of depth).

3.2.5.3. Drop enough 12.7-mm ($^1/_2$-in.)-diameter pebbles into the casing to form a layer 25.4-mm (1-in.) thick and allow sufficient time for the pebbles to reach the bottom.

3.2.5.4. Slip the tamping hammer over the plastic tubing and, keeping tensions on the tubing, apply 20 blows to the pebble layer with a 152-mm (6-in.) drop of the hammer per blow.

3.2.5.5. Repeat this procedure until a five-layer seal is formed. Whenever the tamper does not move freely, it should be immediately withdrawn and cleaned.

3.2.6. Pour enough sand into the casing to form a 610-mm (2-ft) layer of sand; cover with pebbles and compact with 20 blows of the hammer.

3.2.7. Repeat step in Section 3.2.5, forming another bentonite seal.

3.2.8. Disconnect the top section of the casing, so that the top of the casing is at least 1.52 m (5 ft) below the ground surface. This can be done by having the upper sections of casing tightened to a lesser degree than the lower sections of casing. Fill at least 3.05 m (10 ft) of the remainder of the casing with sand.

Note 5—An alternative to this would be complete withdrawal of the casing. In the event that it is decided to completely withdraw the casing, the following alterations will be necessary: casing must be pulled up enough to allow filling the space around the piezometer tip and to approximately 762 mm ($2^1/_2$ ft) above the piezometer tip (Section 3.2.3). Then the casing must be pulled up enough to allow forming the first five-layer bentonite seal (Sections 3.2.4 through 3.2.5.5), then pulled up enough to allow placing the 610-mm (2-ft) layer of sand atop the bentonite seal (Section 3.2.6), then pulled up enough to allow forming the second five-layer bentonite seal (Section 3.2.7). After completing the second bentonite seal, pull the casing up 305 mm (1 ft), add sand, and apply 20 blows with a 152-mm (6-in.) drop of the hammer per blow. Repeat 305 mm at a time until 1.52 m (5 ft) of sand has been placed above the second bentonite seal. Completely withdraw the casing.

Note 6—An alternative to forming the two five-layer bentonite seals is to backfill the piezometer hole with a flexible cement/bentonite grout.

3.2.9. Surface connections are made identical to those used for the driven installations for closed-system piezometers under Section 3.1.2.2.

3.3. *Pressed or Pushed in-Type Installation*:

3.3.1. Drill through any granular soil or very stiff clay overlying the clay layer in which the tip is to be installed with a casing or auger of a larger diameter than the drill rod or pipe to which the tip will be attached.

3.3.2. Fill the piezometer and enough tubing to extend from the tip elevation to above the ground surface with water.

3.3.3. Slowly press (use two pipe wrenches, hydraulic jack, etc.) the piezometer tip attached to drill rod or flush joint pipe into the clay, maintaining a slight flow of water through the tip with a small pump until within 6.1 m (20 ft) of tip elevation. At this point, disconnect the pump and continue pressing piezometer to desired tip elevation. Each time a section of drill rod must be added, the pump is disconnected and the end of the tubing plugged while tubing is threaded through next section of drill rod. This should be done as expeditiously as possible.

4. INTERPRETATION OF DATA

4.1. *Corrections to Pore Pressure Readings*:

4.1.1. *Open-well piezometers—water filled*:

4.1.1.1. The excess pore pressure is the difference between the elevation of the water in the well and the general water table elevation.

4.1.2. *Closed-system hydraulic Casagrande-type piezometers*.

4.1.2.1. The excess pore pressure is determined using the gauge reading and adding the differential water pressure between the elevation of the gauge and the elevation of the surrounding groundwater table.

4.1.3. *Pneumatic and electrical piezometers*—Most of these devices measure the total water pressure at a point, and therefore, the excess pore pressure in the soil is determined by subtracting the difference in elevation between the piezometer tip and the surrounding groundwater table from the gauge reading.

4.2. *Data Interpretation*:

4.2.1. Pore pressure measurements in soils are usually used to estimate the gain in shear strength or the settlement remaining under known conditions of loading. Since pore pressures are only an indirect measure of these characteristics, much care is needed to interpret the results with accuracy. The following information should be considered when interpreting pore pressures:

4.2.2. The total applied load and the rate of loading.

4.2.3. *The seasonal fluctuations of the surrounding groundwater table*—Observation wells (shallow and open-well piezometers) are required in the surrounding area. This is necessary where tidal waters are encountered. The number and location depends on the surrounding terrain.

4.2.4. The actual distribution of pore pressures in the soil deposit being monitored—both vertical and horizontal. This usually requires three or more piezometers at different levels and three or more at different distances from the center of loading.

4.2.5. *The soil parameters for the deposit being monitored*—This is usually obtained from extensive laboratory testing of undisturbed soil samples.

5. SPECIAL PROBLEMS

5.1. The following special problems occur with sufficient frequency to warrant discussion:

5.2. *Gas Lock*:

5.2.1. In many organic soils, the gas generated around the piezometer tip is sufficient to block entrance of the pore water through the filter into the measuring device. Where this is expected to be a problem, special piezometers are available with flushing devices to remove the gas from the piezometer tip.

5.3. *Large Settlements*:

5.3.1. In areas where large foundation settlements occur, numerous problems have developed.

5.3.1.1. Crimping of the riser tubes below the end of a permanent casing installation. This is eliminated by installing the piezometer inside the casing.

5.3.1.2. *Crimping of the riser at the top of the permanent casing*—This is eliminated by removing the top section of casing to about 1.52 m (5 ft) below ground surface and backfilling with sand.

5.3.1.3. *Stretching of the horizontal leads*—This is acceptable for most installations provided that no connections are made in the horizontal leads and the leads are made of materials having yield before rupture. Stretching of electrical leads may adversely affect the calibration of the circuits giving erroneous readings.

5.4. *Electronic Variations*:

5.4.1. The accuracy of electrical pore pressure measuring units may depend on the changes in temperature, elongation of the lead wires, and changes in diaphragm characteristics. Maintaining calibration is very difficult over long periods of time. Some special piezometer cells are available which reduce these problems.

5.5. *Closed System*:

5.5.1. Hydraulic piezometers often lose accuracy because of leaks in the tubing or gas generation (dissolved air). These conditions can be reduced by using “de-aired” water. Once air is in the system, it must be removed before accurate readings can be obtained. To remove the air, the two horizontal leads must be flushed with a different colored fluid (water) by applying a vacuum to one lead and providing a continuous fluid supply to the other lead. Air leaks on the readout device can be repaired, but air leaks underground can generally not be located or repaired.

Standard Method of Test for

Determining Expansive Soils

AASHTO Designation: T 258-81 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Expansive Soils

AASHTO Designation: T 258-81 (2008)

1. SCOPE

1.1. This standard covers a method to determine if a soil is expansive and methods to predict the amount of swell.

Note 1—Methods that are being used by various agencies to control the amount of swell are given in the appendix.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 100, Specific Gravity of Soils
- T 216, One-Dimensional Consolidation Properties of Soils
- T 273, Soil Suction

3. DETECTING EXPANSIVE SOILS

3.1. The potential expansiveness of a soil may be determined by using the Atterberg Limits of the soil and the natural soil suction.

3.2. Using AASHTO Test Methods, the Liquid Limit (LL), the Plasticity Index (PI) and the soil suction at natural water content (τ_{nat}) are determined on a soil. From Table 1, determine how potentially expansive the soil is using the Liquid Limit, Plasticity Index, and the soil suction at natural water content.

Table 1—Determining Degree of Expansion in Soil

Degree of Expansion	LL	PI	τ_{nat}, tsf
High	>60	>35	>383 kPa
Marginal	50–60	25–35	144 to 383 kPa
Low	<50	<25	<144 kPa

4. DETERMINING THE AMOUNT OF SWELL

4.1. The amount of swell to be expected in a stratum is determined by one of the following described methods. Where more exacting determination of the amount of swell is needed, the Overburden

Swell Test Procedure should be used. Due to the length of time and costs required to perform the Overburden Swell Test, an empirical procedure called the Potential Vertical Rise Method may be used to estimate the swell where conditions do not require the more exact determination.

4.2. *Overburden Swell Test and Prediction Procedure*:

4.2.1. *Method 1*—Prepare an undisturbed sample for consolidation testing according to the procedure in T 216. Extreme care should be taken to prevent moisture loss during the preparation stage. From the sample trimmings, determine the field moisture content and the specific gravity of the soil. The field moisture is determined as a percentage of the mass of oven-dried soil and shall be calculated as follows:

$$\text{Percentage of Moisture} = \frac{\text{Mass of Water}}{\text{Mass of Oven} - \text{Dried Soil}} \times 100 \qquad (1)$$

The specific gravity of the soil is determined as outlined in T 100. After the sample has been placed in the consolidometer, a load equal to the existing overburden pressure is applied on the sample. This load shall be maintained until the dial gage of the extensometer indicates that all adjustment to the applied load has ceased. During the application of this load and adjustment period, extreme care must be exercised to prevent desiccation. It is extremely important not to lose any moisture from this sample. This may be accomplished by covering the consolidometer with moist cotton. This loading procedure returns the sample, as closely as possible, to the actual field void ratio and field condition since extrusion allows undisturbed samples to immediately rebound elastically. Actual field conditions are defined as Point One (1) in Figure 1. The sample is then inundated and allowed to reach an equilibrium as indicated by the dial gage of the extensometer. This condition then is defined as Point Two (2) in Figure 1. The sample then is unloaded to the desired pressure, in decrements of load that a laboratory normally uses, thus producing a swell curve from Point Two (2) to Point Three (3) in Figure 1. From this point (Point 3, Figure 1), a normal consolidation-rebound test is conducted as outlined in T 216. The swell-curves form approximately straight lines on a semi-log plot; therefore, the No-Volume Change pressure is determined by extrapolating the swell curves between Points 2 and 3 until it intersects the Field Void Ratio as Point Four (4). The Field Void Ratio (e_f) is determined as follows:

$$e_f = \frac{\text{Percent Field Moisture} \times \text{Specific Gravity}}{\text{Percent Saturation}} \qquad (2)$$

4.2.2. *Method II*—This method is presented because there may be a need to expedite the work and the existing overburden load may be so small that obtaining swell curves directly may be meaningless. This method may be used only after running several tests by Method I and finding that the slope of the rebound curve, Points Five (5) and Six (6), is substantially the same as the slope of the swell curve, Points Two (2) and Three (3). Method II is the same as Method I to the point where the sample is inundated and the total swell is recorded. At this point, a normal consolidation-rebound load sequence is followed to produce the desired curves. Since the slope of the rebound and swell curves is substantially the same, the swell curve can be produced by passing a curve through Point Two (2), Figure 1 that is parallel to the rebound curve. The intersection of this curve with the Field Void Ratio gives the point of No-Volume Change or maximum swell pressure potential.

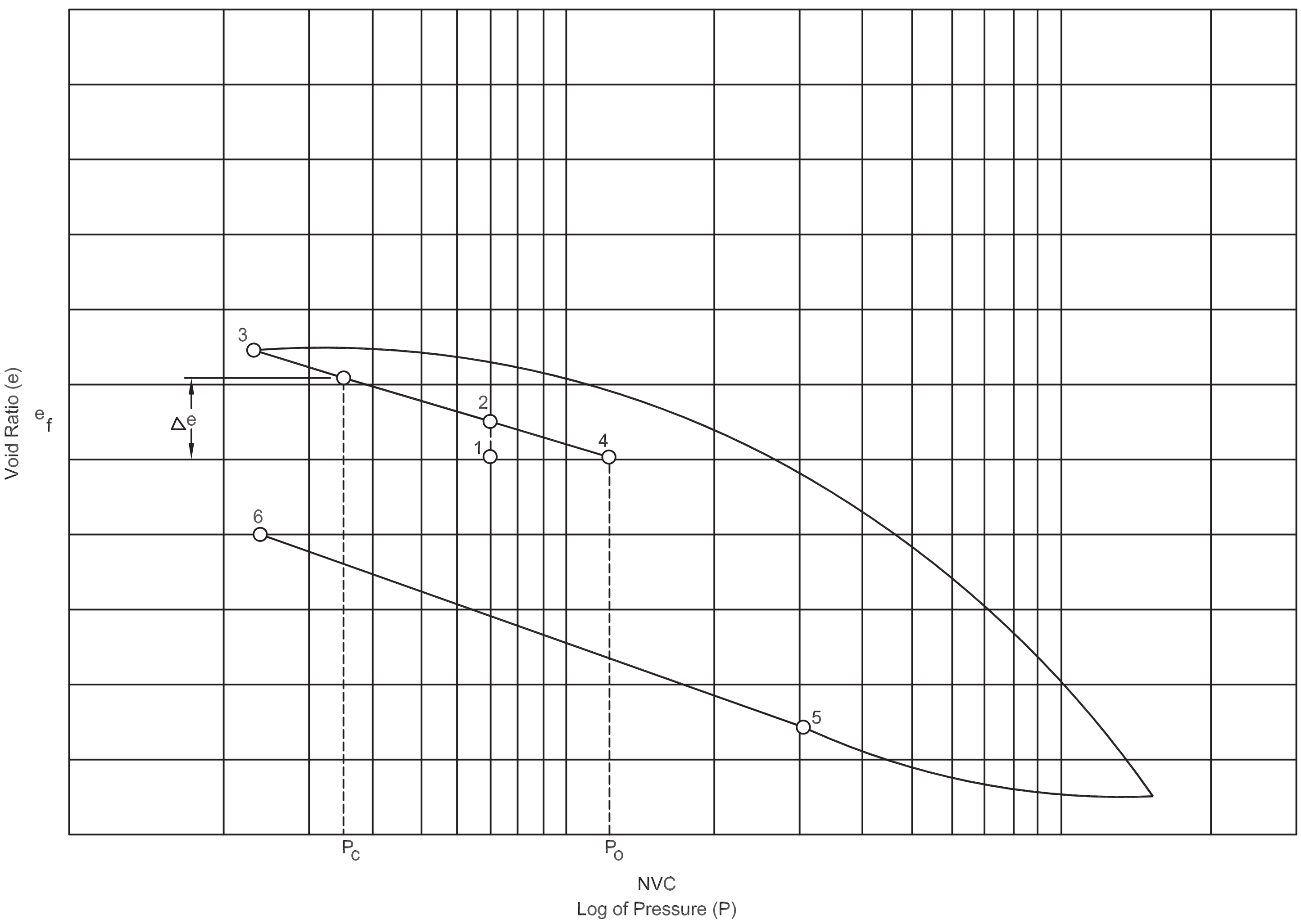


Figure 1—Design Example of Void Ratio Versus Log of Pressure

4.2.3. *Calculations*—Calculation for the amount of swell to be expected in a stratum can be made as follows:

$$S = \frac{eH}{1 + e_f} \tag{3}$$

where:

S = amount of swell in mm (in.),

e = difference in void ratio between existing overburden pressure (no-volume change load) and the desired overburden pressure,

H = thickness of stratum in mm (in.), and

e_f = field void ratio.

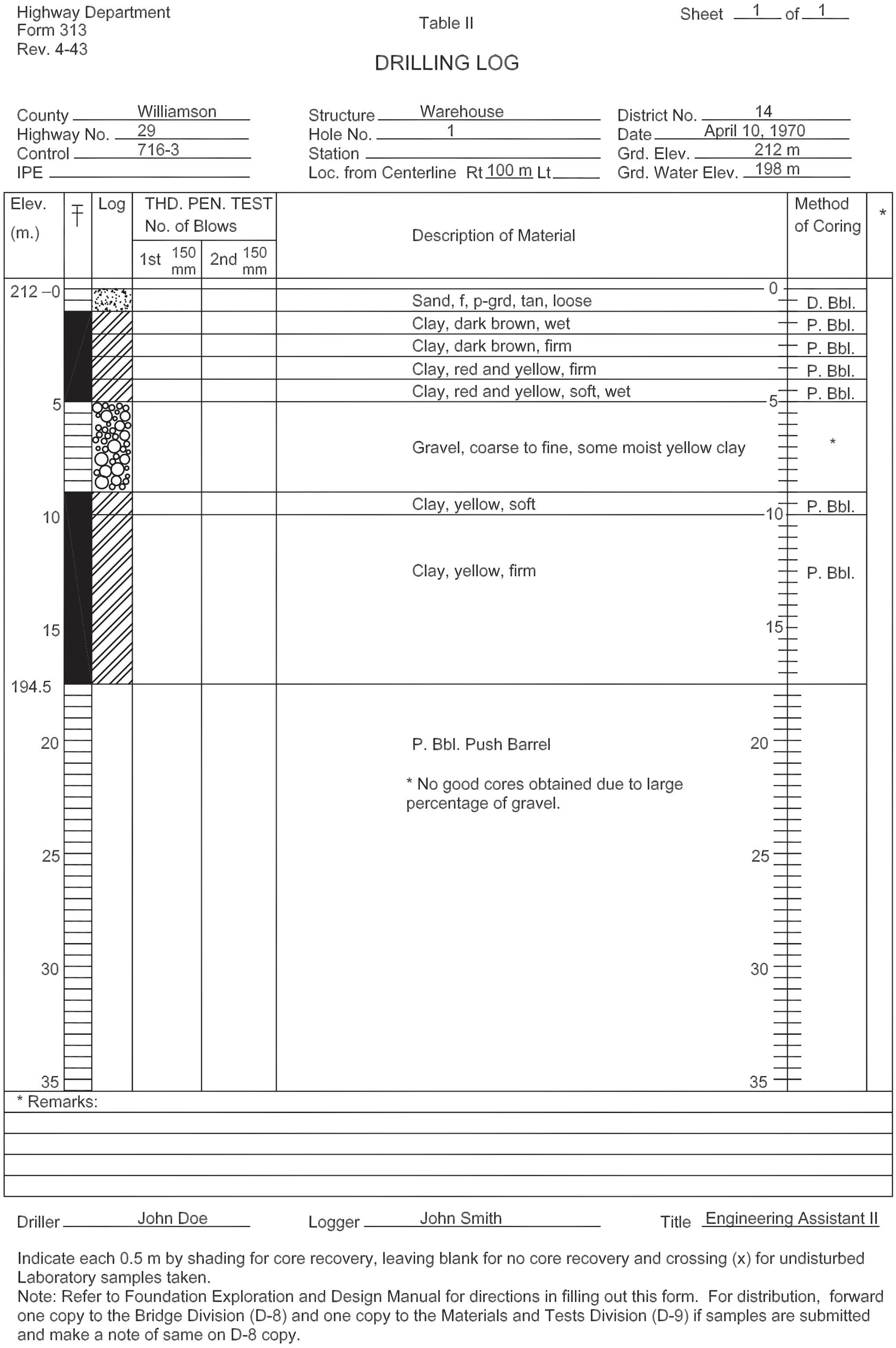
4.3. *Potential Vertical Rise (PVR) Test and Prediction Procedure*:

4.3.1. For this procedure, it is necessary to know the moisture content of each layer sampled. It is preferable that moisture samples be taken at the time of sampling. These moisture samples can be taken from cores that have been moisture sealed.

4.3.2. When cores have been taken, determine the wet density by trimming the cores to make right circular cylinders, measuring height and diameter, to the nearest 0.25 mm, determining the mass to the nearest estimated 0.5 g and calculating. When cuttings only are taken during sampling, use a wet density of 2002 kg/m^3, which is usually a reasonable value.

4.3.3. From representative portions of the cuttings or cores, determine the Liquid Limit, Plasticity Index, and percent soil binder [minus 0.425-mm (No. 40) sieve] in the soil layers. Record these results on Table 3 at the appropriate layer.

Table 2—Sample of Drilling Log Form



Highway Department
Form 313
Rev. 4-43

Table II

Sheet 1 of 1

DRILLING LOG

County Williamson
Highway No. 29
Control 716-3
IPE

Structure Warehouse
Hole No. 1
Station
Loc. from Centerline Rt 100 m Lt

District No. 14
Date April 10, 1970
Grd. Elev. 212 m
Grd. Water Elev. 198 m

Elev. (m.)	Ŧ	Log	THD. PEN. TEST No. of Blows 1st 150 mm	2nd 150 mm	Description of Material		Method of Coring	*
212 –0					Sand, f, p-grd, tan, loose	0	D. Bbl.	
					Clay, dark brown, wet		P. Bbl.	
					Clay, dark brown, firm		P. Bbl.	
					Clay, red and yellow, firm		P. Bbl.	
5					Clay, red and yellow, soft, wet	5	P. Bbl.	
					Gravel, coarse to fine, some moist yellow clay		*	
10					Clay, yellow, soft	10	P. Bbl.	
					Clay, yellow, firm		P. Bbl.	
15						15		
194.5								
20					P. Bbl. Push Barrel * No good cores obtained due to large percentage of gravel.	20		
25						25		
30						30		
35						35		

* Remarks:

Driller John Doe
Logger John Smith
Title Engineering Assistant II

Indicate each 0.5 m by shading for core recovery, leaving blank for no core recovery and crossing (x) for undisturbed Laboratory samples taken.
Note: Refer to Foundation Exploration and Design Manual for directions in filling out this form. For distribution, forward one copy to the Bridge Division (D-8) and one copy to the Materials and Tests Division (D-9) if samples are submitted and make a note of same on D-8 copy.

Table 3—Determining the Liquid Limit, Plasticity Index at the Appropriate Layer

											PVR, mm					
Depth, m	Avg load, kPa	LL	Dry 0.2 LL+9	Wet 0.47 LL+2	Percent moisture	Dry Avg Wet	Percent –0.425 mm	PI	Percent Vol Swell (Fig 1)	Percent Free Swell	Top of Layer	Bottom of Layer	Diff	Mod –0.425 mm Factor	Mod Density Factor	PVR in Layer mm
0–0.6	6.9	21	—	—	3.1	Dry	100	4	0.0	0.0	0.0	0.0	0.0	1.00	1.00	0.0
0.6–1.2	21	60	21.0	30.2	29.7	Wet	100	38	5.5	8.5	10.4	22.3	11.9	1.00	1.00	11.9
1.2–1.8	34	60	21.0	30.2	20.9	Dry	100	38	11.0	14.5	39.4	55.9	16.5	1.00	1.00	16.5
1.8–2.4	48	75	24.0	37.3	24.4	Dry	100	45	13.5	17.0	71.4	86.6	15.2	1.00	1.00	15.2
2.4–3.0	62	75	24.0	37.3	36.5	Wet	100	45	7.0	10.0	42.9	47.0	4.1	1.00	1.00	4.1
3.0–3.6	76	65	22.0	32.6	8.5	Wet	15	40	Less than 25 percent – 0.425 mm					1.00	1.00	0.0
3.6–4.2	90	65	22.0	32.6	8.5	Wet	15	40	Less than 25 percent – 0.425 mm					1.00	1.00	0.0
4.2–4.8	103	65	22.0	32.6	8.5	Wet	15	40	Less than 25 percent – 0.425 mm					1.00	1.00	0.0
4.8–5.4	117	65	22.0	32.6	8.5	Wet	15	40	Less than 25 percent – 0.425 mm					1.00	1.00	0.0
5.4–6.0	131	85	26.0	42.0	41.5	Wet	100	60	10.2	13.5	89.9	91.9	2.0	1.00	1.00	2.0
6.0–6.6	145	80	25.0	39.6	33.9	Avg	100	60	12.6	16.0	123.9	127.9	3.1	1.00	1.00	3.1
6.6–7.2	159	80	25.0	39.6	33.9	Avg	100	54	12.6	16.0	127.0	129.8	2.8	1.00	1.00	2.8
7.2–7.8	172	80	25.0	39.6	33.9	Avg	100	54	12.6	16.0	129.8	132.1	2.3	1.00	1.00	2.3
7.8–8.4	186	80	25.0	39.6	33.9	Avg	100	54	12.6	16.0	132.1	133.9	1.8	1.00	1.00	1.8
8.4–9.0	200	80	25.0	39.6	33.9	Avg	100	54	12.6	16.0	133.9	135.4	1.5	1.00	1.00	1.5
9.0–9.6	214	80	25.0	39.6	33.9	Avg	100	54	12.6	16.0	135.4	135.6	0.2	1.00	1.00	0.2
													Total PVR = 61.4[a]			
[b]6.0–9.6	131 to 214	80	25.0	39.6	33.9	Avg	100	54	12.6	16.0	123.9	135.6	11.7	1.00	1.00	11.7

[a] 2002 Kilograms per cubic meter wet density assumed for all layers. When greater accuracy is desired, use $\frac{2002}{\text{Actual Wet Density of Soil, kg/m}^3}$ as the modifier.

[b] Note: Since the 3.6-m layer from 6.0–9.6 m is uniform, the PVR may be determined in one reading by using the "top of the layer" as 131 kPa (as in 0.6-m layers) and reading the bottom of the layer at 214 kPa load as in the 9.0–9.6m layer. Readings of 123.9 mm and of 135.6 mm, respectively, or a difference of 11.7 mm will be obtained, which is the summation of increments (differences) as shown above for the bottom 3.6 m.

When layers of expensive clays of less than 0.6 m exist (example 1.2–1.4), it is preferable to enter the abscissa on the proper swell curve at 1.2 and 1.4 curve and use the difference in the respective ordinate readings as the unmodified swell in the 0.2-m thick layer.

[c] See example in Figure 2.

4.3.4. Beginning with the top layer at the surface of the ground from the drilling log (Table 2), start compilation of Table 3. Determine whether the layers are "wet," "dry," or "average."

Note 2—It has been determined that 0.2 LL + 9 is the "dry" condition from which little shrinkage is experienced, but where volumetric swell potential is greatest. It is the minimum moisture content swelling clays usually dry to 0.47 LL + 2, or "wet" condition, corresponds to the maximum capillary absorption by laboratory tests on specimens molded at optimum moisture and surcharged with a 7-kPa load. This is also analogous to moisture contents found beneath old pavements and other lightweight structures. This is the "optimum" condition.

4.3.5. Using Figure 2 and the wet, dry, or average moisture condition, find the PI of the first soil layer on the abscissa. Move vertically upwards to the appropriate swell curve (dry, average, or wet) and read the percent volumetric change on the ordinate. This percent volumetric change was determined for 7-kPa surcharge.

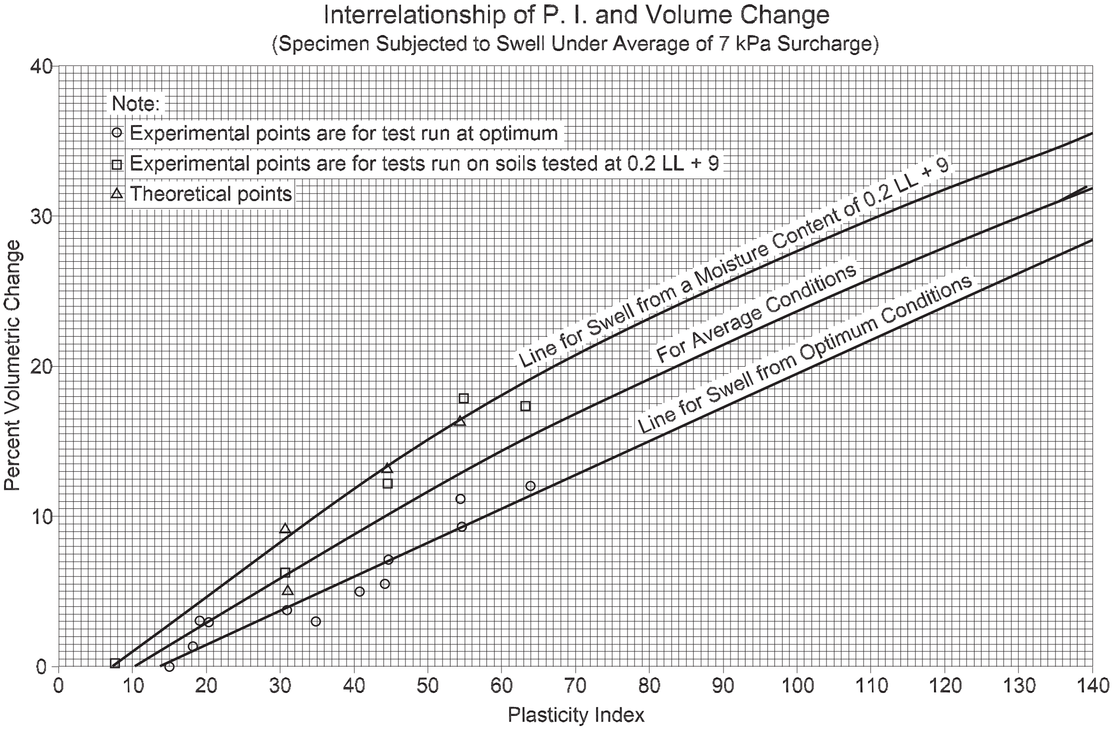


Figure 2—Interrelationship of Plasticity Index and Volume Change

Note 3—The PVR versus Load Curves in Figures 3 and 4 are for free swelling clays under no load and are based on a wet density of soil of 2002 kg/m^3. In order to use the curves in Figures 3 and 4, it has been determined that under the conditions of free swell and the percent volumetric swell at 7-kPa surcharge given in Figure 2, the following relationship exists:

Percent volumetric swell @

No load = percent volumetric swell @ [7 kPa (1 psi)] × (1.07) + 2.6

Example: From Figure 2, the swell @ 7 kPa = 10

Percent at no load or free swell = 10 × (1.07) + 2.6 = 10.7 + 2.6 = 13.3

These curves may have to be penciled in on Figures 3 or 4 for accurate readings.

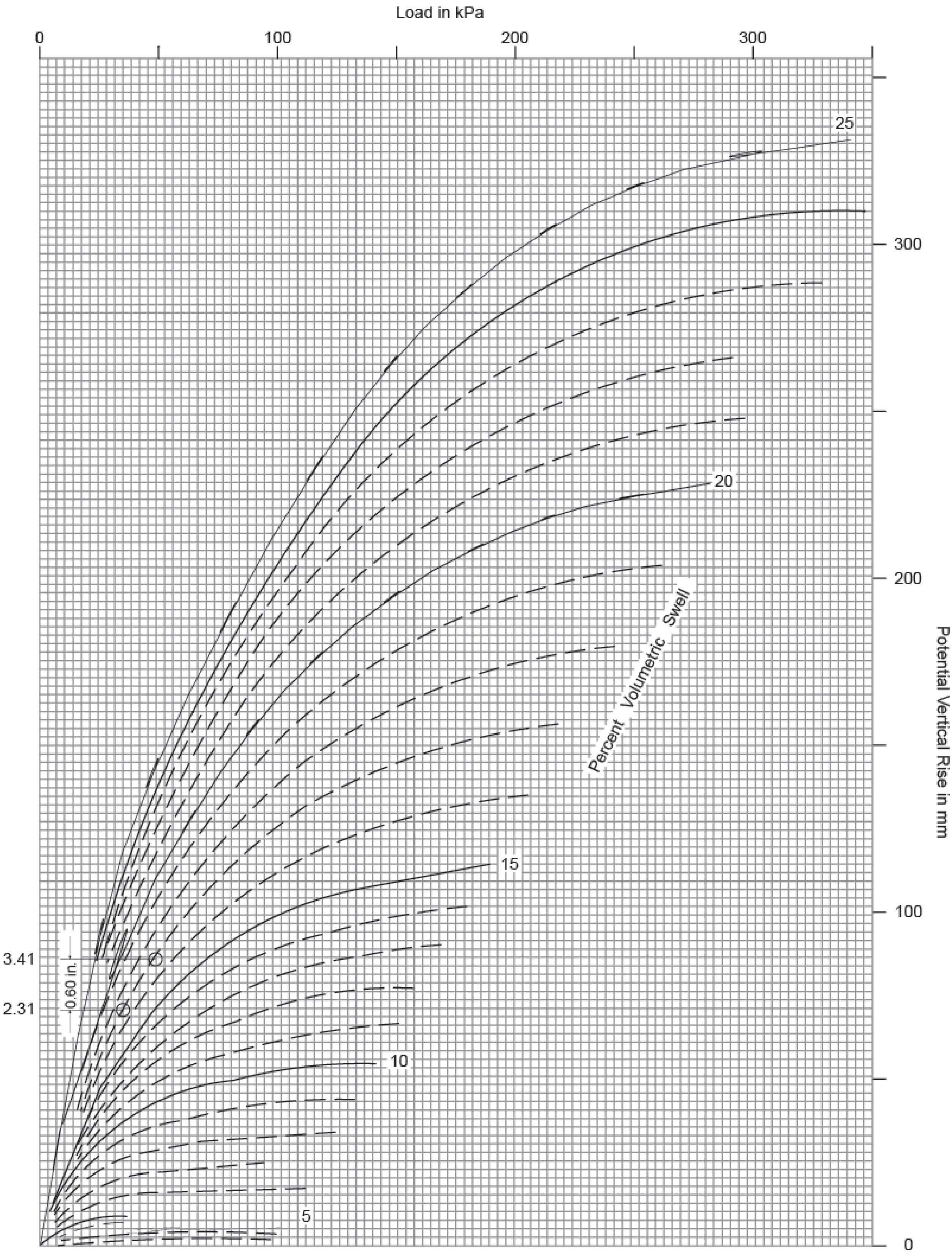


Figure 3—Potential Vertical Rise Versus Load Curves for Free Swelling Clays

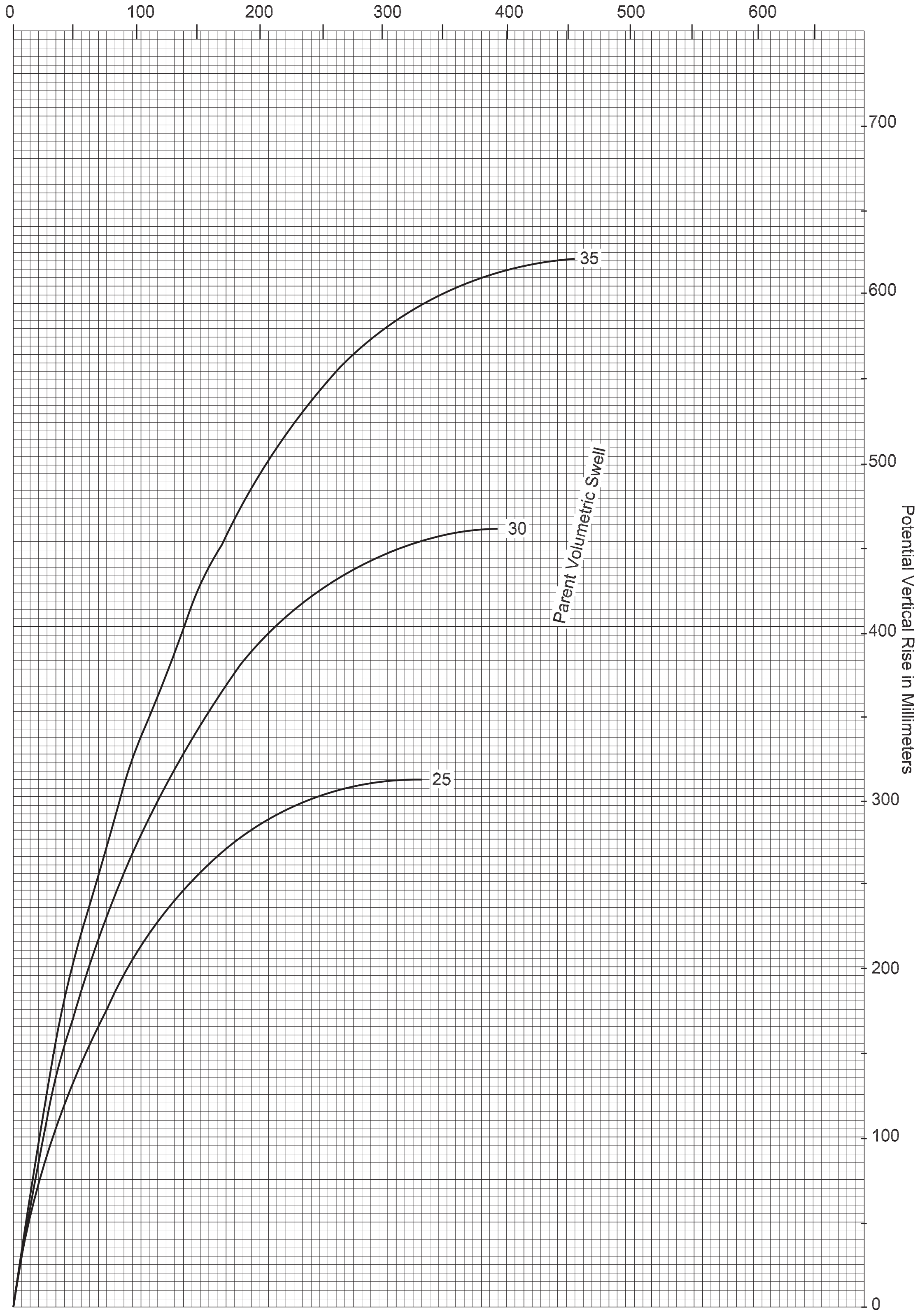


Figure 4—Potential Vertical Rise Versus Load Curves for Free Swelling Clays

4.3.6. In calculating the potential vertical rise, it is convenient or preferable to use 0.6-m elements or layers, provided the moisture contents and the log of the hole will permit. The use of 0.6-m layers and the assumption of 2002 kg/m^3 wet density, which is usually a reasonable wet density, make the tabulation simpler. The modification caused by using 2002 kg/m^3 rather than 2307 kg/m^3 for 7 kPa per meter has already been incorporated into the curves on Figures 3 and 4. Where wet densities vary from 2002 kg/m^3 and greater accuracy is desired, a modification factor should be applied to that layer equivalent to 2002 divided by the actual wet density.

Note 4—In the 0.6-m layer at the surface, the "average" load in the layer is 7 kPa; likewise, in the 0.6 to 1.2-m layer, the kPa load is 14 kPa for the top 0.6 m plus one-half of the 0.6 to 1.2-m layer, or 21 kPa total. Therefore, the average load in any 0.6-m layer is the average depth of the layer (subject to the correction factor as described above).

4.3.7. Using the percent minus 0.425-mm (No. 40) sieve column, PVR subsequently determined shall be modified as follows:

- Use zero swell where the percent minus 0.425 mm is less than 25 percent.
- Multiply the swell obtained for the layer by the percent minus 0.425 mm when the percentage exceeds 25 percent.

4.3.8. Then using Figure 2, determine the percent Volumetric Swell in the first layer (0 to 0.6 m). Since this swell is determined using 7 kPa surcharge, it must be modified for free swell, or no surcharge, as given in Note 3. Using Figures 3 and 4, and the percent free swell curve, just determined, begin to compile the swell in the layer.

- In the 0 to 0.6-m layer, read the ordinate (PVR) at the 7 kPa load from the swell curve and record on Table 3 as "bottom of layer."
- From the curve, read the "top of the layer" load of zero in the case of this layer, and record on Table 3.
- The difference in these two readings is the PVR in the first 0.6-m layer, subject to modification for density correction from Section 4.3.6 and for soil binder (minus 0.425-mm) correction from Section 4.3.7.

4.3.9. Take the 0.6 to 1.2-m layer and determine the percent Volumetric Swell by modifying the value determined from Figure 2. On this percent Volumetric Swell curve, or a sketched-in pencil curve if the line is not actually on Figures 3 or 4, read the PVR on the ordinate corresponding to 21 kPa (bottom of layer) and record on Table 3. Read the ordinate corresponding to 7 kPa (top of layer) from the same curve and record. The difference in the two readings is the swell in the 0.6 to 1.2-m layer subject to any density or soil binder (minus 0.425-mm) modifications.

4.3.10. Continue determination of PVR in each 0.6-m layer until each swelling layer has been determined as shown by the curves on Figures 3 and 4. Each curve should level out and indicate no difference when PVR is read from that curve. (Actually the swell is negligible or zero anywhere beyond the end of any given curve as shown on these two figures.) Thicker layers may be used in this calculation where they consist of uniform soil having a similar PI and moisture contents.

4.3.11. Check each layer for modification for density factor and soil binder.

4.3.12. Add the PVR in all layers to obtain the total PVR for the site.

Note 5—Table 3 has been calculated for no loading due to the structure. When unit loadings due to the structure are known, then simply add it in "Average load, kPa," and increase each figure in the column by the amount of the structure unit load, but note that the swell will be reduced because of increased loading.

4.3.13. To report the test results, submit a copy of Table 3 with appropriate job and site identifications.

Note 6—Often, during design, it is necessary to estimate PVR without knowing moisture contents anticipated at the time of construction. In cases of this kind, the design and planning of a job should influence the choice of line on Figure 2 to be selected for use. If the project exists in an arid to semiarid climate and the plans and specifications do not provide for moisture-density control or preservation of moisture, it is suggested that the line for 0.2 LL + 9 be used. If the plans and specifications do require moisture-density control and moisture preservation, the average line may be used.

In high rainfall areas, the average line may be used where moisture preservation is provided for, but if moisture-density-control and moisture preservation are provided for, the lower line (0.47 LL + 2) on Figure 1 may be used.

The term *moisture preservation* refers to the use of *blanket sections* with wide shoulders consisting of granular materials, stabilized soils, or where asphalt membranes are applied for this purpose.

APPENDIX

(Nonmandatory Information)

X1. PREVENTION OR REMEDIAL METHODS PRESENTLY BEING USED TO CONTROL THE AMOUNT OF SWELL

X1.1. All preventive methods are directed to keeping the moisture content of swelling soils constant. Without moisture change, these soils are generally stable. Four possible methods are as follows:

X1.1.1. *Membranes*—The most widely used membrane is a catalytically blown asphalt that is generally placed completely across the subgrade to the bottom of side ditches and up the back slope to a vertical distance of 457 mm. There are other waterproof membranes that have been used in the same mode as the asphalts. The most popular of these is a plastic sheet with joints sealed by some means such as liquid asphalts.

X1.1.2. *Ponding*—Ponding has been used successfully in soils that had fissures and cracks. The idea is to obtain all the swell possible before paving. Generally, lime stabilization is used in conjunction with ponding to provide a work platform and an impermeable barrier to prevent desiccation.

X1.1.3. *Lime Treatment*—It appears that lime continues to be the most effective and widely used additive for reducing swelling characteristics of expansive clays. In addition to conventional shallow mix-in-place or batch mix surface treatment drill-hole lime, LSPI, and deep-plow techniques have been used successfully. The benefits from drill-hole lime are the increase in moisture content of the surrounding subgrade and stress relief of lateral expansive pressures. The benefits obtained from Lime Slurry Pressure Injection (LSPI) are attributed to prewetting, development of soil-lime moisture barriers, and the formation of limited quantities of soil-lime reaction products.

X1.1.4. *Mix and Compact*—The mixing and compaction of the subgrade to various depths with moisture-compaction control has been effective. Generally, compaction is specified to be 95 percent of T 99. The moisture specified is optimum or above.

Note X1—The determination of PVR in deep-cut sections or deep side-hill cuts presents a special case of this test method. In the case of these two conditions, the material is surcharged in such a manner that the movement from swell is mostly in one direction, and in some high rainfall areas could be greater than that obtained by use of these procedures.

Note X2—When layers of expansive clays of less than 0.6 m exist (example: 1.2 to 1.4 m), it is preferable to enter the abscissa on the proper swell curve at 1.2 and 1.4, respectively, and use the difference in the respective ordinate readings as the unmodified swell in the 0.2-m thick layer.

Note X3—At optimum conditions, the following relationships are valid from Figure 2:

1. Percent volumetric swell @ 7 kPa surcharge = 0.217 (PI) – 2.9
2. Percent free swell = 0.232 (PI) – 0.5.

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Laboratory Determination of Moisture Content of Soils

AASHTO Designation: T 265-93 (2008)

American Association of State Highway and Transportation Officials
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Standard Method of Test for

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AASHTO Designation: T 265-93 (2008)

1. SCOPE

1.1. This method covers the laboratory determination of the moisture content of soils.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with E 29, Using Significant Digits in Test Data to Determine Conformance with Specifications.

2. DEFINITION

2.1. *moisture or water content of a soil*—the ratio, expressed as a percentage, of the mass of water in a given mass of soil to the mass of the solid particles. Practical application is to determine the mass of water removed by drying the moist soil to a constant mass in a drying oven controlled at 110 ± 5ºC (230 ± 9ºF) and to use this value as the mass of water in the given soil mass. The mass of soil remaining after oven-drying is used as the mass of the solid particles.

3. APPARATUS

3.1. *Drying Oven*—Thermostatically controlled, preferably of the forced-draft type, capable of being heated continuously at a temperature of 110 ± 5ºC (230 ± 9ºF).

3.2. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

3.3. *Containers*—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.

4. TEST SAMPLE

4.1. Select a representative quantity of moist soil in the amount indicated in the method of test. If no amount is indicated, the minimum mass of the sample shall be in accordance with the following table:

Maximum Particle Size	Minimum Mass of Sample, g
0.425-mm (No. 40) sieve	10
4.75-mm (No. 4) sieve	100
12.5-mm (1/2 in.)	300
25.0-mm (1 in.)	500
50-mm (2 in.)	1000

5. PROCEDURE

5.1. Weigh a clean, dry container with its lid and place the moisture content sample in the container. Replace the lid immediately and weigh the container, including the lid and the moist sample. Remove the lid and place the container with the moist sample in the drying oven maintained at a temperature of 110 ± 5ºC (230 ± 9ºF) and dry to a constant mass (Notes 1 and 2). Immediately upon removal from the oven, place the lid and allow the sample to cool to room temperature. Weigh the container including the lid and the dried sample (Notes 3 and 4).

Note 1—Checking every moisture content sample to determine that it is dried to a constant mass is impractical. In most cases, drying of a moisture content sample overnight (15 or 16 hours) is sufficient. In cases where there is doubt concerning the adequacy of overnight drying, drying should be continued until the mass after two successive periods of drying indicates no change in mass. Samples of sand may often be dried to constant mass in a period of several hours. Since dry soil may absorb moisture from wet samples, dried samples should be removed before placing wet samples in the oven.

Note 2—Oven-drying at 110 ± 5ºC (230 ± 9ºF) does not result in reliable moisture content values for soil containing gypsum or other minerals having loosely bound water from hydration or for soil containing significant amounts of organic material. Reliable moisture content values for these soils can be obtained by drying in an oven at approximately 60ºC (140ºF), or by vacuum desiccation at a pressure of approximately 10 mm Hg and at a temperature not lower than 23ºC (73ºF).

Note 3—A container without a lid may be used provided the moist sample is weighed immediately after being taken, and provided the dried sample is weighed immediately after being removed from the oven or after cooling in a desiccator.

Note 4—Moisture content samples should be discarded and should not be used in any other tests.

6. CALCULATION

6.1. Calculate the moisture content of the soil as follows:

$$w = \left[\left(\text{mass of moisture}\right)/\left(\text{mass of oven-dry soil}\right)\right] \times 100 = \left[\left(W_1 - W_2\right)/\left(W_2 - W_c\right)\right] \times 100 \quad (1)$$

where:

w = moisture content, percent;

W_1 = mass of container and moist soil, g;

W_2 = mass of container and oven-dried soil, g; and

W_c = mass of container, g.

6.2. Calculate the percent of moisture content to the nearest 0.1 percent.

Standard Method of Test for

Determination of Organic Content in Soils by Loss on Ignition

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AASHTO Designation: T 267-86 (2008)

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1. SCOPE

1.1. The "Loss on Ignition" method for the determination of organic content is most applicable to those materials identified as peats, organic mucks, and soils containing relatively undecayed or undecomposed vegetative matter or fresh plant materials such as wood, roots, or grass, or carbonaceous materials such as lignite, coal, etc. This method determines the quantitative oxidation of organic matter in these materials and gives a valid estimate of organic content. The Wet Combustion method (T 194) is recommended when it is desired to determine the humus-like easily oxidized organic material to provide information relating to the suitability of a soil for plant growth.

1.2. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 87, Dry Preparation of Disturbed Soil and Soil-Aggregate Samples for Test
- T 194, Determination of Organic Matter in Soils by Wet Combustion

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. APPARATUS

3.1. *Oven*—Drying oven capable of maintaining temperatures of 110 ± 5°C (230 ± 9°F). Gravity, instead of blower convection, may be necessary when drying lightweight material.

3.2. *Balance*—The balance shall have sufficient capacity and conform to M 231, Class G 1.

3.3. *Muffle Furnace*—The furnace shall be capable of maintaining a continuous temperature of 455 ± 10°C (833 ± 18°F) and have a combustion chamber capable of accommodating the designated container and sample. A pyrometer recorder shall indicate the temperature while in use.

3.4. *Crucibles or Evaporating Dishes*—High silica, alundum, porcelain, or nickel crucibles of 30 to 50-mL capacity or Coors porcelain evaporating dishes approximately 100-mm top diameter.

3.5. *Desiccator*—A desiccator of sufficient size containing an effective desiccant.

3.6. *Containers*—Suitable rustproof metal, porcelain, glass, or plastic-coated containers.

3.7. *Miscellaneous Supplies*—Asbestos gloves, tongs, spatulas, etc.

4. SAMPLE PREPARATION

4.1. A representative sample with a mass of at least 100 g shall be taken from the thoroughly mixed portion of the material passing the 2.00-mm (No. 10) sieve that has been obtained in accordance with T 87.

4.2. Place the sample in a container and dry in the oven at 110 ± 5°C (230 ± 9°F) to constant mass. Remove the sample from the oven, place in the desiccator, and allow to cool.

Note 1—This sample can be allowed to remain in the oven until ready to proceed with the remainder of the test.

5. IGNITION PROCEDURE

5.1. Select a sample with a mass of approximately 10 to 40 g, place into tared crucibles or porcelain evaporating dishes, and determine the mass to the nearest 0.01 g.

Note 2—Sample masses for lightweight materials such as peat may be less than 10 g but should be of sufficient amount to fill the crucible to at least $^3/_4$ depth. A cover may initially be required over the crucible during the initial phase of ignition to decrease the possibility of the sample being “blown out” from the container.

5.2. Place the crucible or dish containing the sample into the muffle furnace for 6 hours at a temperature of 455 ± 10°C. Remove the sample from the furnace, place into the desiccator, and allow to cool.

5.3. Remove the cooled sample from the desiccator and determine the mass to the nearest 0.01 g.

6. CALCULATION

6.1. The organic content shall be expressed as a percentage of the mass of the oven-dried soil and shall be calculated as follows:

$$\text{Percent Organic Matter} = \frac{A-B}{A-C} \times 100 \qquad (1)$$

where:

A = mass of crucible or evaporating dish and oven-dried soil, before ignition;

B = mass of crucible or evaporating dish and oven-dried soil, after ignition; and

C = mass of crucible or evaporating dish, to the nearest 0.01 g.

6.2. Calculate the percentage of organic content to the nearest 0.1 percent.

Standard Method of Test for

Family of Curves - One-Point Method

AASHTO Designation: T 272-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Family of Curves - One Point Method

AASHTO Designation: T 272-10

1. SCOPE

1.1. These methods of tests are for the rapid determination of the maximum density and optimum moisture content of a soil sample utilizing a family of curves and a one-point determination.

1.2. One-point determinations are made by compacting the soil in a mold of a given size with a 2.5-kg (5.5-lb) rammer dropped from a height of 305 mm (12 in.). Four alternate procedures are provided as follows:

- *Method A*—A 101.6-mm (4-in.) mold; soil material passing a 4.75-mm (No. 4) sieve. Sections 5 and 6.
- *Method B*—A 152.4-mm (6-in.) mold; soil material passing a 4.75-mm (No. 4) sieve. Sections 7 and 8.
- *Method C*—A 101.6-mm (4-in.) mold; soil material passing a 19.0-mm ($^3/_4$ in.) sieve. Sections 9 and 10.
- *Method D*—A 152.4-mm (6-in.) mold; soil material passing a 19.0-mm ($^3/_4$ in.) sieve. Sections 11 and 12.

1.3. The methods described herein correspond to the methods in T 99 and must be chosen accordingly; that is, when moisture-density relationships as determined by Method C of T 99 are used to form the family of curves, then Method C described in this procedure must be used for the one-point determination (Note 1).

Note 1—Direct reference to T 99 is made throughout these test methods, and most terminology, apparatus, and procedures are the same.

1.4. In addition, the concepts described herein are applicable to one-point determinations and moisture-density relationships as specified in T 180, with appropriate apparatus and method used as required.

1.5. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with the rounding-off method of ASTM E 29.

1.6. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 224, Correction for Coarse Particles in the Soil Compaction Test

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. DEFINITION

3.1. A family of curves is a group of typical soil moisture-density relationships determined using T 99, which reveal certain similarities and trend characteristic of the soil type and source. Soils sampled from one source will have many different moisture-density curves, but if a group of these curves are plotted together, certain relationships usually become apparent. In general, it will be found that higher unit mass soils assume steeper slopes with maximum dry densities at lower optimum moisture contents, while the lower unit mass soils assume flatter, more gently sloped curves with higher optimum moisture contents (Figure 1).

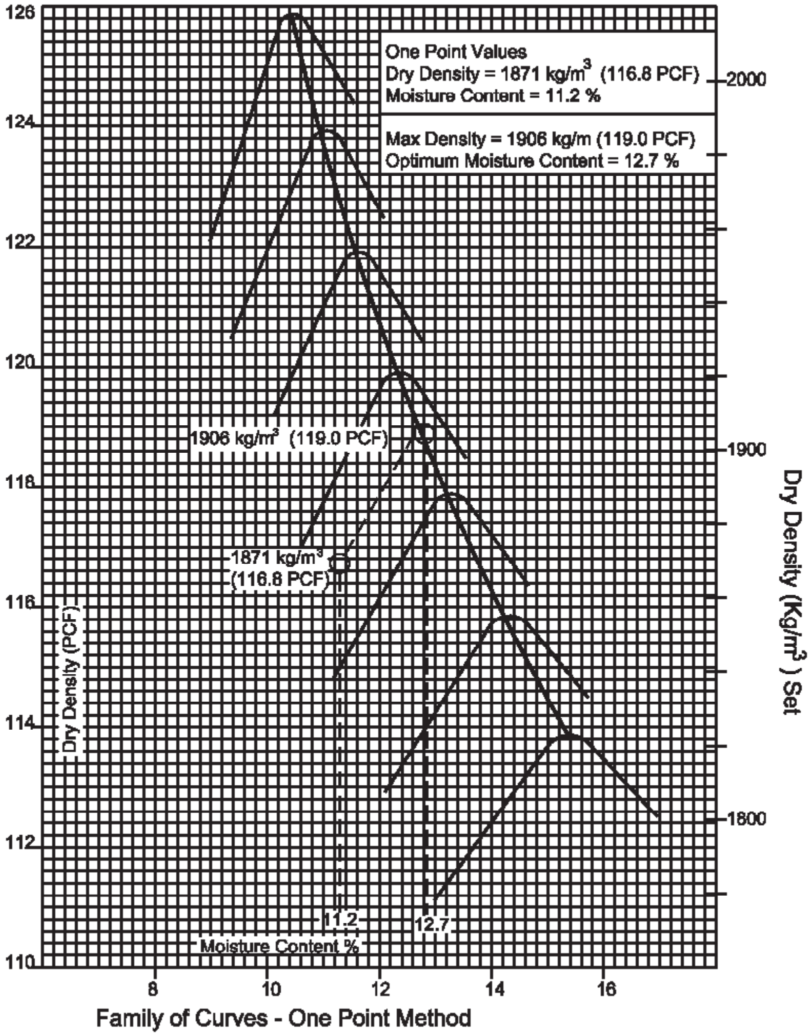


Figure 1—Example of Curves

4. APPARATUS

4.1. See T 99, Section 3.

METHOD A

5. SAMPLE

5.1. See T 99, Section 4.

6. PROCEDURE

6.1. Thoroughly mix the selected representative sample with sufficient water to dampen approximately 4 percentage points below optimum moisture content. Greater accuracy in the determination of the maximum density will result as the moisture content used approaches optimum moisture content. Moisture content of the sample should never exceed the optimum water content.

6.2. Form a specimen by compacting the prepared soil in the 101.6-mm (4-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5 in.). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm (12 in.) above the elevation of the soil when a sleeve-type rammer is used, or from 305 mm (12 in.) above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation (Note 2).

Note 2—Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil: a block of concrete, with a mass not less than 91 kg (200 lb) supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as are found in concrete box culverts, bridges, and pavements.

6.2.1. Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge, and determine the mass of the mold and moist soil in kilograms to the nearest 5 grams, or determine the mass in pounds to the nearest 0.01 pounds. For molds conforming to tolerances given in T 99 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 1060, and record the result as the wet density, W_1, in kilograms per cubic meter, of compacted soil. For molds conforming to tolerances given in T 99 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, W_1, in pounds per cubic foot, of compacted soil. For used molds out of tolerance by no more than 50 percent (T 99), use the factor for the mold as determined in accordance with T 19M/T 19.

6.3. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, determine the mass immediately, and dry in an oven at 110 ± 5ºC (230 ± 9ºF) for at least 12 hours, or to a constant mass to determine the moisture content. The moisture sample shall have a mass not less than 100 grams.

METHOD B

7. SAMPLE

7.1. Select the representative sample in accordance with Section 5, except that it shall have a mass of approximately 7 kg (16 lb).

8. PROCEDURE

8.1. Follow the same procedure as described for Method A in Section 6, except for the following: Form a specimen by compacting the prepared soil in the 152.4-mm (6-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5-in.), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming to tolerances given in T 99 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 471, and record the result as the wet density, W_1, in kilograms per cubic meter of compacted soil. For molds conforming to tolerances given in T 99 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.33, and record the result as the wet density, W_1, in pounds per cubic foot, of the compacted soil. For used molds out of tolerance by no more than 50 percent (T 99), use the factor for the mold as determined in accordance with T 19M/T 19.

METHOD C

9. SAMPLE

9.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus such that the temperature does not exceed 60ºC (140ºF). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

9.2. Sieve an adequate quantity of the representative pulverized soil over the 19.0-mm sieve. Discard the coarse material, if any, retained on the 19.0-mm sieve (Note 3).

Note 3—The discarded coarse material may be utilized in T 224.

9.3. Select a representative sample having a mass of approximately 5 kg (12 lb) or more of the soil prepared as described in Sections 9.1 and 9.2.

10. PROCEDURE

10.1. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 percentage points below optimum moisture content. Greater accuracy in the determination of the maximum density will result as the moisture content used approaches the optimum moisture content.

10.2. Form a specimen by compacting the prepared soil in the 101.6-mm (4-in.) mold (with collar attached) in three approximately equal layers to give total compacted depth of about 125 mm

(5 in.). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm (12 in.) above the elevation of the soil when a sleeve-type rammer is used or from 305 mm (12 in.) above the approximate elevation of each finely compacted layer when a stationary mounted type rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation (Note 2).

10.2.1. Following compaction, remove the extension collar and carefully trim the compacted soil even with the top of the mold by means of the straightedge. Holes developed in the surface by removal of coarse material shall be patched with smaller-size material. Determine the mass of the mold and moist soil in kilograms to the nearest 5 g, or determine the mass in pounds to the nearest 0.01 pounds. For molds conforming to tolerances given in T 99 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 1060, and record the result as the wet density, W_1, in kilograms per cubic meter of compacted soil. For molds conforming to tolerances given in T 99 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 30, and record the result as the wet density, W_1, in pounds per cubic foot, of compacted soil. For used molds out of tolerance by no more than 50 percent (T 99), use the factor for the mold as determined in accordance with Section 8 (Calibration of Measure) of T 19M/T 19.

10.3. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material from one of the cut faces, determine the mass immediately, and dry to a constant mass using a drying apparatus described in T 99 to determine the moisture content. The moisture sample shall have a mass no less than 500 g.

METHOD D

11. SAMPLE

11.1. Select the representative sample in accordance with Section 9.3 except that it shall have a mass of approximately 11 kg (25 lb).

12. PROCEDURE

12.1. Follow the same procedure as described for Method C in Section 10, except for the following: Form a specimen by compacting the prepared soil in the 152.4-mm (6-in.) mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm (5 in.), each layer being compacted by 56 uniformly distributed blows from the rammer. For molds conforming to tolerances given in T 99 and masses recorded in kilograms, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 471, and record the result as the wet density, W_1, in kilograms per cubic meter, of compacted soil. For molds conforming to tolerances given in T 99 and masses recorded in pounds, multiply the mass of the compacted specimen and the mold, minus the mass of the mold, by 13.33, and record the result as the wet density, W_1, in pounds per cubic foot, of the compacted soil. For used molds out of tolerance by no more than 50 percent (T 99), use the factor for the mold as determined in accordance with Section 8 (Calibration of Measure) of T 19M/T 19.

CALCULATIONS AND REPORT

13. CALCULATIONS

13.1. See T 99, Section 12.

14. MAXIMUM DENSITY AND OPTIMUM MOISTURE CONTENT DETERMINATION

14.1. The calculations in Section 13.1 shall be made to determine the moisture content and corresponding oven-dry mass (density) in kilograms per cubic meter (pounds per cubic foot) of the compacted specimen. The dry density (unit mass) of the soil shall be plotted as ordinate and the corresponding moisture content as the abscissa to define one-point within or on the family of curves (Figure 1).

14.2. If the one-point falls on one of the curves in the family of curves, the maximum dry density and optimum moisture content defined by that curve shall be used (Note 4).

14.3. If the one-point falls within the family but not on a curve, a new curve shall be drawn through the plotted one-point parallel and in character with the nearest existing curve in the family of curves. The maximum dry density and optimum moisture content as defined by the new curve shall be used (Note 4).

Note 4—If the one-point plotted within or on the family of curves does not fall in the 80 to 100 percent of optimum moisture range, compact another specimen, using the same material, at an adjusted moisture content that will place the one-point within this range.

14.3.1. If the family of curves is such that the profile of a new curve to be drawn through a one-point is not well defined or in any way questionable, then a full moisture-density relationship shall be made for the soil in question to correctly define the new curve and verify the applicability of the family of curves (Note 5).

Note 5—New curves drawn through plotted one-point determinations shall not become a permanent part of the family of curves until verified by a full moisture-density relationship.

15. REPORT

15.1. The report shall include the following:

15.1.1. The method used (Method A, B, C, or D).

15.1.2. The optimum moisture content as a percentage to the nearest whole number.

15.1.3. The maximum density to the nearest 0.5 kg/m^3 (1.0 lb/ft^3).

15.1.4. In Methods C and D, indicate if the material retained on the 19.0-mm sieve was removed or replaced.

15.1.5. Type of face if other than 50.8-mm (2-in.) circular.

Note 6—Inherent variability of soils places limitations on this method of test. The person using this test method must realize this and become thoroughly familiar with the material being tested. Knowledge of the AASHTO Soil Classification System and ability to recognize the gradation of soils are requirements for this work.

APPENDIX—DEVELOPING A MOISTURE-DENSITY FAMILY OF CURVES

The purpose of the family of curves is to represent the average moisture-density characteristics of the material. The family must, therefore, be based on moisture-density relationships that adequately represent the entire mass range and all types of material for which the family is to be used. It may be that particular soil types have moisture-density relationships that differ considerably and cannot be represented on one general family of curves; in this case, a separate family may be developed. Also, moisture-density relationships for material of widely varying geologic origins should be carefully examined to determine if separate families are required.

When a small number of moisture-density relationships are being used to develop a family of curves, plot the point representing the maximum density and optimum moisture content for each relationship on a single sheet of graph paper. Draw a smooth curve as close as possible to connect all the points. This line will define the maximum density and optimum moisture content of the material represented by this family of curves. At 1-kg (2-lb) increments, draw moisture-density curves with slopes similar to the slopes of the original moisture-density relationships. Slopes should gradually steepen, going from low to high maximum density material.

When a great number of moisture-density relationships are available, the above procedure can be modified by using average values. Tabulate the maximum density, optimum moisture content, and slope for all moisture-density relationships in each 1-kg (2-lb) increment of density. Average the maximum densities and optimum moisture contents for each increment and plot these values. As before, draw a smooth curve as close as possible to connect all the points. Determine the average slope for each increment, and at each 1-kg (2-lb) increment, draw a moisture-density curve using this average slope value. A computer may be used to accomplish this work.

The accuracy of a family of curves can be checked by comparing the maximum density and optimum moisture content from an individual moisture-density relationship with that obtained using the One-Point Method and family of curves. A point representing 80 percent of optimum moisture content is taken from the individual moisture-density relationship and used as described in the One-Point Method to determine the maximum density and optimum moisture content from the family of curves. These values are compared with the values from the individual moisture-density relationship. The difference represents the maximum variance expected when the One-Point Method and family of curves are used for material represented by that individual moisture-density relationship. This comparison should be made for all types of material over the mass range of the family. Based on these results, some adjustments may be necessary to the family, and/or it may be recognized that the family is not applicable to some types of material. Families based on relatively few moisture-density relationships will generally require the closest scrutiny, since it can be expected that a larger number of relationships will give better average conditions.

Standard Method of Test for

Soil Suction

AASHTO Designation: T 273-86 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Soil Suction

AASHTO Designation: T 273-86 (2008)

1. SCOPE

1.1. This method covers the procedure for determining total soil suction force using thermocouple psychrometers. The test results of this method are to be used in conjunction with T 258.

1.2. The thermocouple psychrometer measures the relative humidity in the soil by a technique called Peltier cooling. By causing a small direct current of approximately four to eight milliamperes to flow through the thermocouple junction for approximately 15 seconds in the correct direction, this junction will cool and water will condense on it when the dewpoint temperature is reached. Condensation of this water inhibits further cooling of the junction and the voltage difference developed between the thermocouple and the reference junctions can be measured using a microvoltmeter. With proper calibration, the thermocouple psychrometer output in microvolts can be coverted directly to soil suction in convenient units of pressure. Typical thermocouple psychrometer output voltages vary from less than one microvolt for relative humidities close to 100 percent or total soil suction less than 95.76 kPa (1 tsf) to about 25 microvolts for relative humidities of about 95 percent or total soil suctions of about 5746 kPa (60 tsf).

1.3. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

1.4. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 207, Thin-Walled Tube Sampling of Soils
- T 233, Density of Soil In-Place by Block, Chunk, or Core Sampling
- T 258, Determining Expansive Soils

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. DEFINITIONS

3.1. *matrix suction*—the matrix suction is the result of clay mineral surface attractive forces for water and cations (i.e., ion hydration) and the surface tension effects of water in soil. The matrix suction is both water content and surcharge pressure dependent.

3.2. *osmotic suction*—the osmotic suction arises from the presence of soluble salts in the pore water of the soil and is the result of the difference in the ion concentration between the pore water and the clay particles double-layer water. Osmotic suction is independent of water content and surcharge pressure.

3.3. *soil suction*—soil suction is a quantity that can be used to characterize the effect of moisture on the volume and strength properties of soils; that is, soil suction quantitatively describes the interaction between soil particles and water, which determines the physical behavior of the soil mass. Soil suction, expressed in units of pressure, is a measure of the pulling force exerted on water by the soil mass.

3.4. *total soil suction*—total soil suction, as determined by this method of test, is the force responsible for soil water retention and is the sum of the matrix and osmotic components.

4. APPARATUS

4.1. *Microvoltmeter*—Minimum range of 30 microvolts and readable to the nearest 0.01 microvolt.

4.2. *Milliammeter*—Minimum range 0 to 25 milliammeters.

4.3. *Thermocouple Psychrometers*—WESCOR Model PT 51-10, or equal.

4.4. *Polystyrene Thermal Containers*—Chest or box insulated with at least 38.1 mm (1.5 in.) of foamed polystyrene. One container approximately 304.8 mm by 304.8 mm by 381 mm (12 in. by 12 in. by 15 in.) will accommodate six samples.

4.5. *Sample Containers*—0.5 L (1-pint) metal sample containers with interior coated with melted wax to prevent corrosion. One-half liter paint cans are satisfactory.

4.6. *Rubber Stoppers*—Size $13^1/_2$ rubber stoppers with an approximately 6-mm (0.25-in.) diameter hole through the center.

4.7. *Electrical Supplies*—Switch box, selector switches, electrical connectors, two 1.5-volt dry cell batteries, and a 1 K ohm variable potentiometer.

4.8. *Calibration Standards*—Minimum of three WESCOR Osmolality Standards (290, 1000, and 1800 mOs/kg) (Note 1). Standard sodium chloride solutions of various molalities may be prepared in the laboratory.

4.9. *Stopwatch*.

4.10. *Tare Containers*.

4.11. *Specimen Cutting Equipment*—wire saw, knife, bandsaw, etc.

4.12. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

Note 1—mOs/kg is the abbreviation for milliosmos per kilogram.

5. ASSEMBLING EQUIPMENT

5.1. The assembled apparatus is as shown in Figure 1. The apparatus should be assembled to accommodate multiple samples to be tested simultaneously. The wiring diagram shown in Figure 2 permits the testing of twelve samples simultaneously by utilizing a 12-position selector switch.

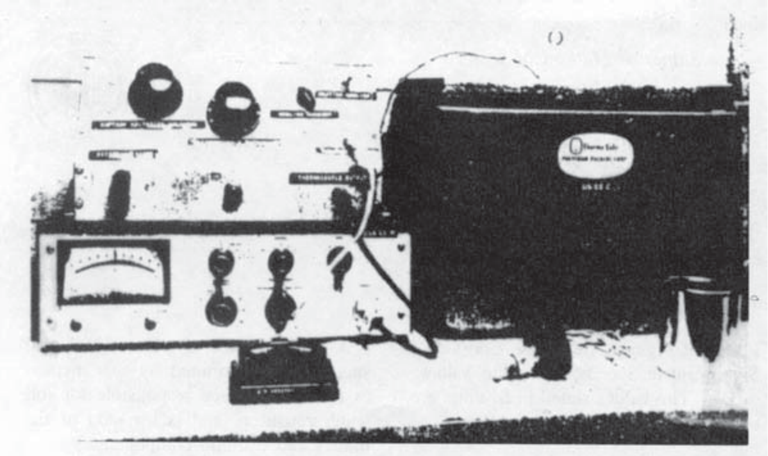


Figure 1—Soil Suction Apparatus

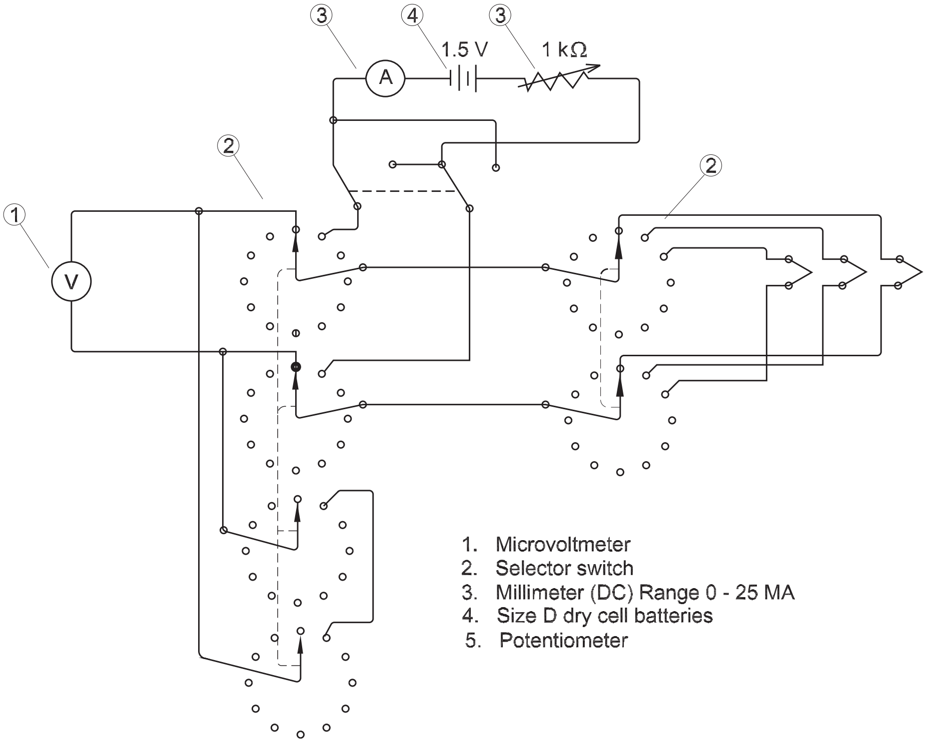


Figure 2—Wiring Diagram for Soil Suction Apparatus

5.2. The thermocouple psychrometer wires are fed through an approximately 12-mm (0.5-in.) diameter hole in the center of the thermal container cover. The thermocouple psychrometer wires are then fed through the hole in the rubber stoppers so the psychrometer tips extend approximately 25 mm (1 in.) from the bottom (small diameter end) of the stopper. The protective sheathing around the psychrometer tip must form an airtight seal in the hole in the rubber stopper.

5.3. The milliammeter, dry-cell batteries, and the variable potentiometer form the cooling circuit.

5.4. The electrical connectors are affixed to the psychrometer wires for easy connection to the switch box.

5.5. The switches are wired so the output voltages (temperature and soil suction) can be monitored on each of the psychrometers in turn.

5.6. The rubber stoppers are placed in the metal sample containers, which are placed in the thermal containers to minimize temperature variations. The temperature inside the thermal container is monitored by a thermometer placed through the container cover.

5.7. The equipment should be kept in a room where ambient temperature variations are minimal.

6. CALIBRATION OF EQUIPMENT

6.1. Place a small piece of filter paper (type and grade variable) in the bottom of each sample container along with 3 mL of the calibration standard. A minimum of three calibration standard concentrations should be used to adequately define the calibration line (i.e., 290, 1000, and 1800 mOs/kg).

6.2. Seal the sample containers, containing the standards, with the rubber stopper psychrometers installed and place them in the thermal containers. Allow the temperature to come to equilibrium, which requires approximately 24 hours.

6.3. After the temperature has come to equilibrium, begin taking temperature (millivolt) and soil suction (microvolt) output readings at least three times per day until the output readings stabilize. A cooling current of 8 mA is applied to the psychrometer for 15 seconds prior to reading the soil suction output reading. Time to stabilization varies with concentrations of the calibration standard but will generally be in the range of 7 to 10 days.

6.4. Obtain at least three stable output readings on each standard. Perform the following calculations on the average of the three readings.

6.4.1. Convert the thermocouple voltage output (millivolts) to temperature (ºC), using the equation in Section 9.1.

6.4.2. Convert the psychrometer (soil suction) voltage output, E_T (microvolts) to the equivalent output at the calibration temperature of 25ºC, E_{25}, using the equation in Section 9.2.

6.4.3. Calculate the equivalent moisture retention force or suction according to one of the following:

SI Units:

Multiply each concentration by 2.509 (i.e., 1800 mOs/kg × 2.509 = 4516 kPa).

U.S. Customary Units:

Multiply each concentration by 2.62×10^{-2} (i.e., 1800 mOs/kg × 0.0262 = 47.2 tsf).

6.5. Plot the calibration curve for each psychrometer using E_{25} (microvolts) as the abscissa and the soil suction, τ, kPa (tsf), for each calibration standard as the ordinate. Typical thermocouple psychrometer calibration curves (Figure 3) are linear and can be expressed using the following equation:

$$\text{Soil Suction, } \tau, \text{ kPa } (\text{or tsf}) = mE_{25} - n, \qquad (1)$$

where:

m = slope of the calibration curve, and

n = y-intercept of the calibration curve.

The slope of the calibration curve will always be positive and the y-intercept should be equal to or less than zero. The calibration curve is good for the useful life of the thermocouple psychrometer; however, under normal use, an annual check of the calibration by at least one point will assure that the equipment is operating properly.

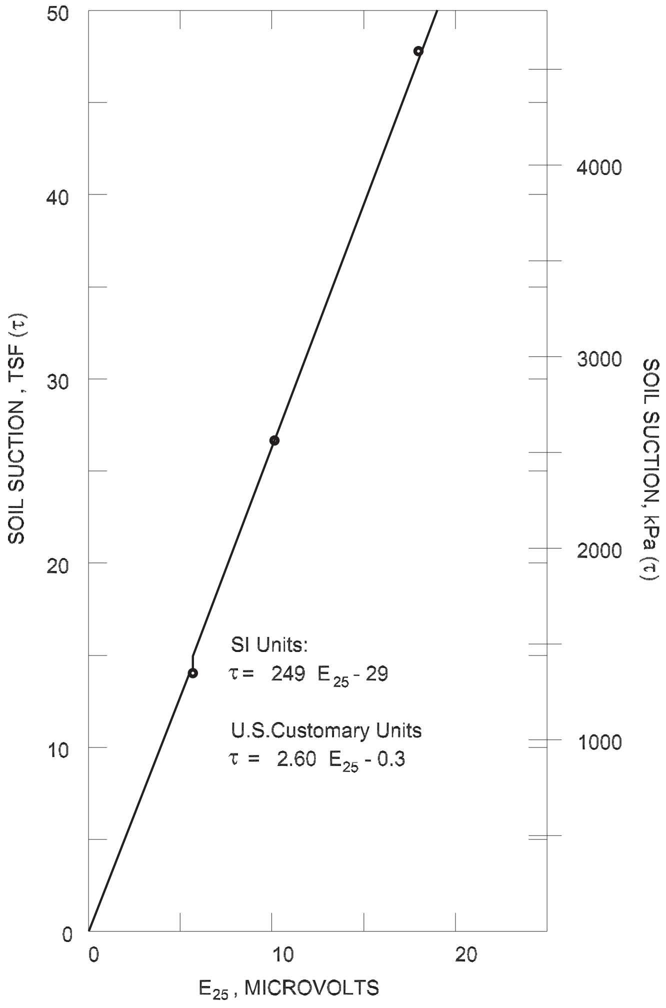


Figure 3—Typical Thermocouple Psychrometer Calibration Line

7. SAMPLING

7.1. Undisturbed samples shall be obtained, sealed, and protected in accordance with T 207.

8. TEST PROCEDURE

8.1. Set up apparatus according to Section 5.

8.2. Cut the sample selected for testing into nine (9) cubes approximately 38.1 mm by 38.1 mm (1.5 in. by 1.5 in.).

8.3. Place two of the specimens directly into the metal sample containers, seal with the rubber stoppers containing the thermocouple psychrometers, and place in the thermal containers. These two specimens represent the natural conditions of the soil.

8.4. The remaining seven specimens, depending on their natural water contents, are either wetted with varying amounts of distilled water or dried at room temperature for varying lengths of time to establish a range of water content conditions. For example, consider a soil that appears relatively dry (i.e., well below the plastic limit): To establish the necessary water content range, three of the specimens should be dried at room temperature (i.e., 1, 2, and 4 hours, respectively, would be reasonable times) and the remaining four specimens should be wetted with distilled water (i.e., 0.5, 1, 2, and 4 mL, respectively, would be reasonable amounts).

8.4.1. Place the specimen to be wetted into the metal sample containers; add varying amounts of water to the specimens as described above. Immediately seal the wetted specimens with the rubber stoppers containing the thermocouple psychrometers and place them in the thermal containers.

8.4.2. Allow the remaining specimens to dry at room temperature for varying lengths of time as described above. Place each dried specimen into the metal sample container and seal with a rubber stopper containing a thermocouple psychrometer and place in the thermal container.

8.5. Allow the specimens to come to equilibrium in the sealed containers. Temperature equilibrium is attained within a few hours after placing the cover of the thermal container. Equilibrium of the relative humidity of the air measured by the psychrometer and the relative humidity in the soil specimen is usually obtained within 48 to 72 hours.

8.6. Using the appropriate switch, read and record the temperature output of the thermocouple psychrometer in millivolts.

8.7. Change the switch from thermocouple to psychrometer, set the meter to zero, apply a cooling current of approximately 8 mA for 15 seconds, then read and record the psychrometer output in microvolts. The cooling currents and times should be identical to those used to determine the calibration curves.

8.8. Repeat Sections 8.6 and 8.7 for each of the thermocouple psychrometers in the equipment setup.

8.9. After the readings are completed, remove the specimens from the containers. Determine the dry density (volume displacement method) and the water content of each specimen in accordance with T 233. (A suggested data sheet that assures correct collection of the required data is shown in Figure 4.)

Soil, Suction, Water Content, and Specific Volume

Project ______________________________ Boring/Sample/Depth ______________________________ Date ____________________

Soil Suction	Psychrometer No.									
	Sample Container No.									
	Water Content Increment (0, +, –)									
	Thermocouple Output Psychrometer Output	†, Millivolts								
		T, °C								
		E_τ, Microvolts								
		E_{25}, Microvolts								
	Soil Suction, kPa		τ							
Water Content	Tare No.									
	Mass in Grams	Tare Plus Wet Soil								
		Tare Plus Dry Soil								
		Water	M_w							
		Tare								
		Dry Soil	M_s							
	Water Content, Percent		w							
Weight-Volume Relations	Test Temperature of Water, °C									
	Mass in Grams	Wet Soil and Wax in Air								
		Wet Soil	M							
		Wax								
		Wet Soil and Wax in Water								
		Dry Soil	M_s							
	Specific Gravity of Soil		G_s							
	Volume in cm^3	Wet Soil and Wax								
		Wax								
		Wet Soil	V							
		Dry Soil = M_s/G_s	V_s							
	Density g/cm^3	Wet Density = (M/V)	ρ_w							
		Dry Density = (M_s/V)	ρ_d							
	Specific Volume = $1/\rho_d$		V_T							

Figure 4—Suggested Data Sheet for Collection of Soil Suction Data

9. DATA REDUCTION AND INTERPRETATION

9.1. Convert the thermocouple voltage output (millivolts) to temperature (ºC) using the following equation:

$$T,\ ^\circ\mathrm{C}\ = \frac{\text{Output in Millivolts}}{0.0395\ \text{Millivolts}/^\circ\mathrm{C}} \qquad (2)$$

9.2. Convert the psychrometer voltage output, E_τ (microvolts) to the equivalent output at the calibration temperature of 25ºC, E_{25}, using the following equation:

$$E_{25} = \frac{E_\tau}{0.325 + 0.027T} \qquad (3)$$

9.3. Determine the Soil Suction, τ, of each individual specimen by entering the respective psychrometer calibration curve with E_{25} and reading the corresponding soil suction. The soil suction may also be calculated using the respective psychrometer calibration equation (Section 6).

9.4. Plot the soil suction (ordinate, log scale) versus the water content (abscissa) on a semilog plot to establish the log soil suction versus water content relationship, Figure 5, which is linear and can be expressed using the following equation:

$$\log\ \tau = A - Bw, \qquad (4)$$

where:

A = y-intercept;

B = slope; and

w = water content, percent.

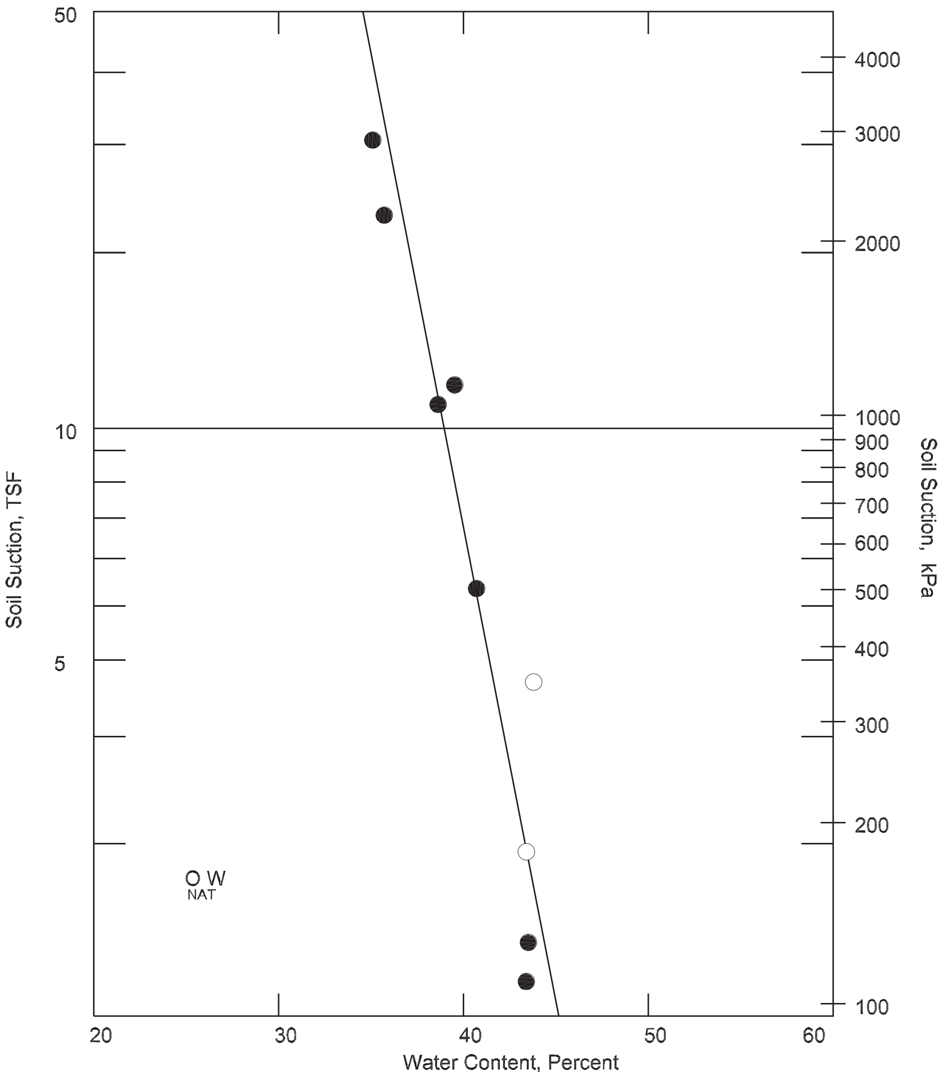


Figure 5—Typical Soil Suction Versus Water Content

9.4.1. All of the data points are used to establish the *τ–w* relationship. The points representing natural conditions should be identified on the plot. If some variation occurs at the upper or lower end of the curve because the limits of the measurement range are approached, the data points between soil suction values of 200 kPa (2 tsf) and 2000 kPa (20 tsf) should be used to establish the *τ–w* relationship.

9.4.2. The slope, *B*, of the line is determined by calculating the inverse of the change in water content over one cycle of the log scale.

9.4.3. The intercept, *A,* is calculated by applying the equation $\log \tau = A - Bw$, at a soil suction equal to 100 kPa (1 tsf) and solving for *A*.

9.5. Determine the specific volume of each specimen that is the inverse of its dry density. Plot the specific volume of each specimen (ordinate) versus its water content (abscissa), as in Figure 6.

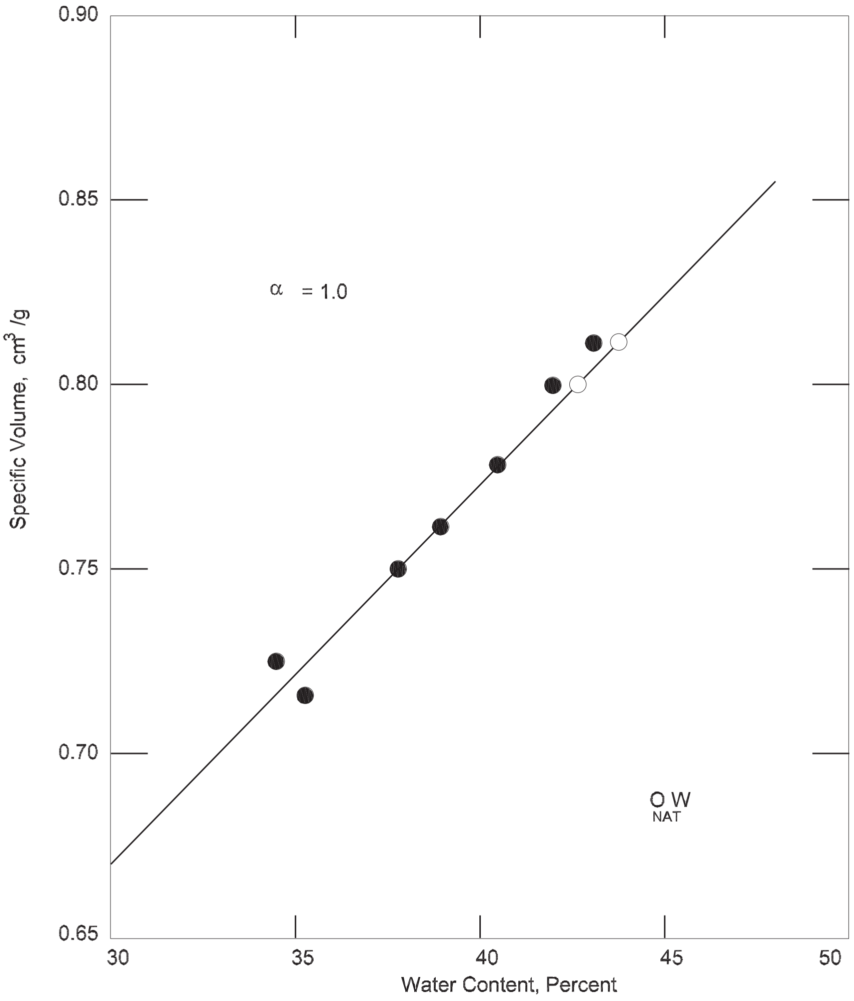


Figure 6—Typical Specific Volume vs. Water Content

9.6. Determine the volumetric compressibility factor, α, of the soil, which is the slope of the specific volume versus water content curve. The volumetric compressibility factor relates the change in volume to a corresponding change in water content. Occasionally, the slope of the curve may indicate an α greater than one, in which case α should be taken as one since the compressibility factor cannot be greater than one.

Standard Method of Test for

Determining Minimum Laboratory Soil Resistivity

AASHTO Designation: T 288-91 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Minimum Laboratory Soil Resistivity

AASHTO Designation: T 288-91 (2008)

1. SCOPE

1.1. This test method covers the laboratory determination for the minimum resistivity of a soil.

1.2. The principal use of this test method is to determine a soil's corrosivity and thereby identify the conditions under which the corrosion of metals in soil may be sharply accentuated. This standard is divided into two parts. The first part involves obtaining and preparing the sample to size for testing, and the second part describes the test method for determining the minimum laboratory soil resistivity.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

PART I—INITIAL PREPARATION OF TEST SAMPLES

3. SCOPE

3.1. This method covers the dry preparation of soil and soil-aggregate samples, as received from the field, for soil resistivity determination.

3.2. The following applies to all specified limits in this standard: for the purpose of determining conformance with these specifications, an observed value or calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

4. APPARATUS

4.1. *Balance*—The balance shall have sufficient capacity and be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

4.2. *Drying Apparatus*—Any suitable device capable of drying samples at a temperature not exceeding 60ºC (140ºF).

4.3. *Sieves*—A series of the following sizes: 6.3 mm ($^1/_4$ in.), 4.75 mm (No. 4), 2.00 mm (No. 10), and pan as required for preparing the sample for the minimum soil resistivity test. The sieves shall conform to M 92, Wire-Cloth Sieves for Testing Purposes (Note 1).

4.4. *Pulverizing Apparatus*—Either a mortar and rubber-covered pestle or any device suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains of soil (Note 2).

4.5. *Sample Splitter*—A suitable riffle sampler or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle sampler splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also permitted.

Note 1—The sieve sizes that have an opening size of 6.3 mm ($^1/_4$ in.) or larger shall conform to the requirements specified in M 92, excluding column No. 7. This exclusion permits the use of heavier screens in non-standard frames that are larger than the 203.2 mm (8 in.) round frames.

Note 2—Other types of apparatus are satisfactory if the aggregations of soil particles are broken up without reducing the size of the individual grains.

5. SAMPLE SIZE

5.1. The amount of soil material required to perform the minimum soil resistivity test is as follows:

Test	Approx Mass (g)	Sieve Size Finer Than:
Resistivity	1500	2.00 mm (No. 10)

6. INITIAL PREPARATION OF TEST SAMPLES

6.1. The sample as received from the field shall be dried in air or a drying apparatus not exceeding 60ºC (140ºF). A representative test sample of the amount required to perform the minimum soil resistivity test shall then be obtained with the sampler, or by splitting or quartering. The aggregations of soil particles shall then be broken up in the pulverizing apparatus until the aggregation of soil particles is separated into individual grains in such a way as to avoid reducing the natural size of the individual particles (Note 3).

Note 3—Samples dried in an oven or other drying apparatus at a temperature not exceeding 60ºC (140ºF) are considered to be air dried.

6.2. The portion of the dried sample selected for minimum soil resistivity testing shall be separated into fractions by one of the following methods:

6.2.1. *Alternate Method Using 2.0-mm (No. 10) Sieve*—The dried sample shall be separated into two fractions using a 2.00-mm sieve. The fraction retained on the sieve shall be ground with a pulverizing apparatus until the aggregations of the soil particles are broken into separate grains. The ground soil shall then be separated into two fractions using the 2.00-mm sieve.

6.2.2. *Alternate Method Using 4.75-mm and 2.00-mm (No. 4 and No. 10) Sieves*—The dried sample shall first be separated into two fractions using a 4.75-mm sieve. The fraction retained on this sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains and again separated on the 4.75-mm sieve. The fraction passing the 4.75-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve, and processed as in Section 6.2.1.

6.2.3. *Alternate Method Using 6.3-mm and 2.00-mm ($^1/_4$ in. and No. 10) Sieves*—The dried sample shall first be separated into two fractions using a 6.3-mm sieve. The fraction retained on this sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains and again separated on the 6.3-mm sieve. The fraction passing the 6.3-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve, and processed as in Section 6.2.1.

PART 2—MINIMUM SOIL RESISTIVITY DETERMINATION

7. SCOPE

7.1. This method covers the laboratory procedure for determining the minimum resistivity of soil samples. The values obtained from this method are relatable to the corrosion potential that a soil may exhibit.

8. APPARATUS AND MATERIALS

8.1. *Resistivity Meter*—An alternating current (AC) meter or a 12-volt direct current (DC) meter utilizing a Wien Bridge (AC bridge) with a phase sensitive detector and a square wave inverter that produces a nominal alternating signal at 97 Hz. (Note 4).

8.2. 100, 200, 500, and 900-ohm resistors with a 1 percent tolerance.

8.3. *Soil Box*—See Figure 1 and Figure 2.

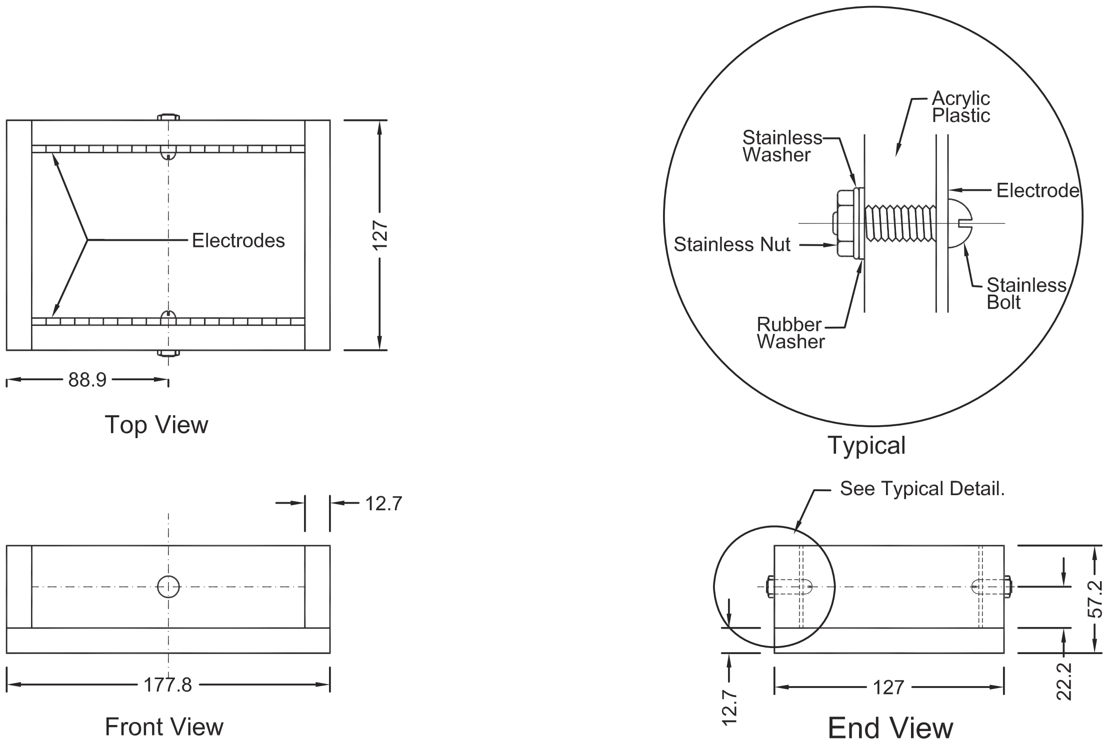
8.4. 2.00-mm (No. 10) sieve conforming to the requirements of M 92.

8.5. Mixing Pans (non-corrosive; e.g., stainless steel, plastic, etc.).

8.6. Graduated cylinder, 100 mL capacity.

8.7. Distilled water or deionized water that has a resistivity greater than 20000 (ohm) × (cm).

8.8. Straightedge, 305 mm (12 in.) length.

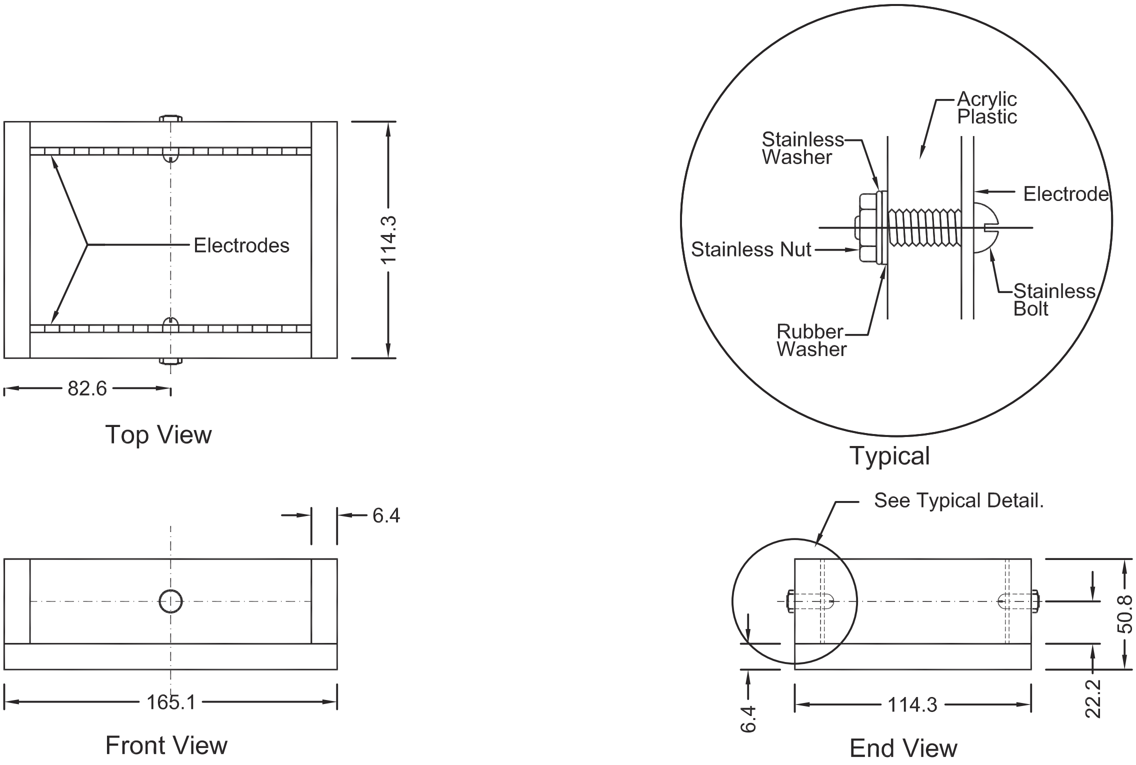


Materials

Bottom - 1 Pc 177.8 mm x 127 mm x 12.7 mm
Ends - 2 Pcs 127 mm x 44.45 mm x 12.7 mm
Sides - 2 Pcs 152.4 mm x 44.45 mm x 12.7 mm
Electrodes - 2 Pcs 0.9-mm stainless steel 152.4 mm x 44.45 mm
2 Each - M 4 x 0.5 x 19.0 mm (or longer)
Round head stainless steel
machine bolt with rubber
washer and stainless steel
washer and nut

Note: All dimensions in millimeters.

Figure 1—Soil Box for Laboratory Resistivity Determination (Not to Scale)



Materials

Bottom - 1 Pc 165.1 mm x 114.3 mm x 6.4 mm
Ends - 2 Pcs 114.3 mm x 44.45 mm x 6.4 mm
Sides - 2 Pcs 152.4 mm x 44.45 mm x 6.4 mm
Electrodes - 2 Pcs 0.9-mm stainless steel 152.4 mm x 44.45 mm
2 Each - M 4 x 0.5 x 19.0 mm (or longer)
Round head stainless steel
machine bolt with rubber
washer and stainless steel
washer and nut

Note: All dimensions in millimeters.

Figure 2—Soil Box for Laboratory Resistivity Determination (Not to Scale)

9. CALIBRATION OF RESISTIVITY METER

9.1. *Calibrate resistivity meter (follow manufacturer's instructions)*:

9.1.1. Zero the resistivity meter by clamping the two leads together, and adjusting the meter (if necessary).

9.1.2. Connect the leads of the resistivity meter to the 100-ohm resistor and read the meter. Repeat this process with the 200, 500, and 900-ohm resistors.

9.1.3. If the readings are within 10 percent of the resistance of the resistor, the meter is functioning satisfactorily.

10. SOIL RESISTIVITY DETERMINATION

10.1. Select the material for testing in accordance with T 248 and separate on a 2.00-mm (No. 10) sieve. Approximately 1500 grams of the material passing the 2.00-mm (No. 10) sieve will be required for testing.

10.2. Add 150 mL of distilled water to the prepared soil. Mix the sample thoroughly and cover the test sample with a damp cloth and allow the sample to stabilize until equilibrium has been reached, or allow to cure a minimum of 12 hours.

10.3. Zero the meter as per manufacturer's instructions.

10.4. Clean the soil box thoroughly with distilled water.

10.5. Thoroughly mix and place the sample in the soil box in layers and compact (moderate compaction with the fingers is sufficient). Trim off the excess material with the straightedge.

10.6. Measure the resistance and calculate the resistivity of the soil in accordance with the instructions furnished with the meter and record the test value.

10.7. Remove and retain the soil from the box, add 100 mL of distilled water to the sample, and mix thoroughly. Clean the soil box with distilled water prior to performing the next test.

10.8. Repeat the process of placing, compacting the soil in the box, then measure the resistance and calculate the soil resistivity (Note 5).

10.9. Repeat the steps in Sections 10.4 to 10.8 until a minimum value can be determined.

10.10. The minimum value is used for computing the minimum soil resistivity and reporting (Note 6).

11. REPORT

11.1. The minimum soil resistivity value determined above should be reported in units of (ohm) × (cm).

11.2. The Minimum Soil Resistivity utilizing the typical soil box is:

$$\text{Minimum Soil Resistivity} = \left[\text{minimum reading }\left(\text{ohms}\right)\right] \times \left[6.67\text{ cm}\right] \qquad (1)$$

(See Note 7.)

Note 4—Most resistance meters without an inverting circuit allow the sample under test to polarize during measurement causing the reading to vary (i.e., drift).

Note 5—In some soils, the minimum soil resistivity occurs when the specimen is in a slurry condition. When this occurs, it is necessary to thoroughly mix the soil slurry and then pour the slurry water into the soil box until full. If the soil box doesn't reach its capacity with the addition of the slurry water, add just enough of the mixed soil into the box until the soil box is filled; then take the reading.

Note 6—The minimum soil resistivity can occur at any moisture content.

Note 7—Multiplying Constant for each Soil Box is derived by:

$$\frac{\text{Surface Area of One Electrode}\left(\text{cm}^2\right)}{\text{Measured Average Distance between Electrodes}\left(\text{cm}\right) = \dfrac{\text{cm}^2}{\text{cm}} = \text{cm}} \qquad (2)$$

Typical Soil Box

$$\frac{15.24\ \text{cm} \times 4.445\ \text{cm}}{10.16\ \text{cm}} = 6.67\ \text{cm} \qquad (3)$$

The soil box may be constructed of either 6.4 or 12.7 mm ($^1/_4$ or $^1/_2$ in.) acrylic plastic. If other size soil boxes are used, it will be necessary to determine the correct multiplier. It should also be noted that it may be necessary to prepare extra soil for testing to fill the soil box.

12. PRECISION AND BIAS

12.1. Data not available at this time.

Standard Method of Test for

Determining pH of Soil for Use in Corrosion Testing

AASHTO Designation: T 289-91 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining pH of Soil for Use in Corrosion Testing

AASHTO Designation: T 289-91 (2008)

1. SCOPE

1.1. This test method describes procedures and apparatus for determining a pH value for corrosion testing by use of a pH meter.

1.2. The principal use of the test is to supplement soil-resistivity measurements and thereby identify conditions under which the corrosion of metals in the soil may be sharply accentuated. This standard is divided into two parts. The first part involves obtaining and preparing the sample to size for testing. The second part describes the test method for determining the pH of soil.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standard*:
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

PART I—INITIAL PREPARATION OF TEST SAMPLES

3. SCOPE

3.1. This method covers the dry preparation of soil and soil-aggregate samples for determining a soil's pH.

3.2. The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

4. APPARATUS

4.1. *Sieves*—A series of sieves of the following sizes: 6.3 mm ($^1/_4$ in.), 4.75 mm (No. 4), 2.00 mm (No. 10), and a pan. The sieve shall conform to M 92, Sieves for Testing Purposes (Note 1).

4.2. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

4.3. *Drying Apparatus*—Any suitable device capable of drying samples at a temperature not exceeding 60ºC (140ºF).

4.4. *Pulverizing Apparatus*—Either a mortar and rubber-covered pestle or any device suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains (Note 2).

4.5. *Sample Splitter*—A suitable riffle sampler or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle sampler splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also permitted.

Note 1—The sieve sizes that have an opening size of 6.3 mm ($^1/_4$ in.) or larger shall conform to the requirements specified in M 92, excluding Column No. 7. The exclusion of Column 7 permits the use of heavier screens in nonstandard frames that are larger than the 203.2 mm (8 in.) round frames.

Note 2—Other types of apparatus are satisfactory if the aggregations of soil particles are broken up without reducing the size of the individual grains.

5. SAMPLE SIZE

5.1. The amount of soil material required to perform the test is as follows:

Test	Approx Mass (g)	Sieve Size Finer Than:
pH	100	2.00 mm (No.10)

6. INITIAL PREPARATION OF TEST SAMPLES

6.1. The sample as received shall be in a moist condition for pH testing purposes. If the sample is too wet, it may be dried to a moist condition in air or a drying apparatus not exceeding 60ºC (140ºF) prior to sample selection (Note 3). A representative test sample to perform the pH test shall then be obtained with the sampler, or by splitting or quartering as per T 248.

Note 3—Samples dried in an oven or other drying apparatus at a temperature not exceeding 60ºC (140ºF) are considered to be air dried.

6.2. The portion of the sample selected for pH testing shall be separated into fractions by one of the following methods:

6.2.1. *Alternate Method Using 2.00-mm (No. 10) Sieve*—The sample shall be separated into two fractions using a 2.00-mm sieve. The fraction retained on the sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains. The ground soil shall then be separated into two fractions using the 2.00-mm sieve.

6.2.2. *Alternate Method Using 4.75-mm and 2.00-mm (No. 4 and No. 10) Sieves*—The sample shall first be separated into two fractions using a 4.75-mm sieve. The fraction retained on this sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains and again separated on the 4.75-mm sieve. The fraction passing the 4.75-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve and processed as in Section 6.2.1.

6.2.3. *Alternate Method Using 6.3-mm and 2.00-mm ($^1/_4$-in. and No. 10) Sieves*—The sample shall first be separated into two fractions using a 6.3-mm sieve. The fraction retained on this sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains and again separated on the 6.3-mm sieve. The fraction passing the 6.3-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve and processed as in Section 6.2.1.

PART 2—DETERMINATION OF SOIL PH

7. SCOPE

7.1. This section describes the procedure for determining soil pH.

8. APPARATUS

8.1. *pH Meter*—suitable for laboratory or field analysis, with either one or two electrodes.

8.2. A 50 mL wide-mouth glass beaker or other suitable container with a watch glass for cover. If lightweight material is to be tested, it may be necessary to increase the beaker size up to a maximum of 250 mL.

8.3. *Standard Buffer Solutions of Known pH Values*—standards to be used are pH of 4.0, 7.0, and 10.0.

8.4. Distilled water.

8.5. A teaspoon or small scoop.

8.6. A thermometer capable of reading 25 ± 10º C, to the nearest 0.1ºC.

8.7. *Sieves*—A 2.00 mm (No. 10) for preparing the sample and a pan. The sieve shall conform to M 92, Wire-Cloth Sieves for Testing Purposes.

8.8. A glass stirring rod.

9. PROCEDURE

9.1. Of the material selected for testing, place a mass of 30.0 ± 0.1 grams of soil into the glass beaker or other suitable container.

9.2. Add 30.0 ± 0.1 grams of distilled water to the soil sample. Stir to obtain a soil slurry and then cover with a watch glass.

9.3. The sample must stand for a minimum of 1 hour, stirring every 10 to 15 minutes. This is to allow the pH of the soil slurry to stabilize.

9.4. Measure the temperature of the sample and adjust the temperature controller of the pH meter to that of the sample temperature. This adjustment should be done just prior to testing. On meters with an automatic temperature control, follow the manufacturer's instructions.

9.5. Standardize the pH meter by means of the standard solutions provided. Temperature and adjustments must be performed as stated under Section 9.4 (see Note 4).

9.6. Immediately before immersing the electrode(s) into the sample, stir well with a glass rod. Place the electrode(s) into the soil slurry solution and gently turn the beaker or container to make good contact between the solution and the electrode(s). DO NOT place the electrode(s) into the soil; place them only into the soil slurry solution (see Note 5).

9.7. The electrode(s) require immersion for 30 seconds or longer in the sample before reading to allow the meter to stabilize. If the meter has an auto-read system, it will automatically signal when stabilized.

9.8. Read and record the pH value to the nearest tenth of a whole number. If the pH meter reads to the hundredth place, it is necessary to round off the result in accordance with the rounding-off method in ASTM E 29.

9.9. Rinse off the electrode(s) well with distilled water, then dab lightly with tissues to remove any film formed on the electrode(s). **Caution**—Do not wipe the electrode(s) as this may result in polarization of the electrode(s) and consequent slow response (see Note 6).

Note 4—To standardize the pH meter, use the 7.0 pH buffer standard solution plus the other standard solution that is nearest the estimated pH value of the sample to be tested. If the manufacturer's instructions indicate a method other than that noted above, then those instructions must be followed.

Note 5—When immersing electrode(s) into the glass beaker or container, care should be taken not to hit the bottom or side, causing damage to the electrode(s).

Note 6—If polarization does occur, as indicated by a slow response, rinse the electrode(s) and dab lightly again.

10. PRECAUTIONS

10.1. Periodically check for damage to the electrode(s).

10.2. The electrode tip should be kept moist during storage. Follow the manufacturer's instructions.

11. REPORT

11.1. As specified in Section 9.8, report the pH value to the nearest tenth of a whole number in accordance with ASTM E 29.

12. PRECISION AND BIAS

12.1. Data are not available at this time.

Standard Method of Test for

Determining Water-Soluble Sulfate Ion Content in Soil

AASHTO Designation: T 290-95 (2007)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Water-Soluble Sulfate Ion Content in Soil

AASHTO Designation: T 290-95 (2007)

1. SCOPE

1.1. This test method covers the determination of the water-soluble sulfate ion content in soil. This standard is divided into two parts. The first part specifies the procedure for sampling and preparing the sample to size for testing. The second part delineates two test procedures (Methods A or B) for the determination of the sulfate ion content in soils. The selection of the method is dependent on the concentration of sulfate ion and the accuracy desired. Two methods are given as follows:

	Section
Method A:	
(Gravimetric Method)	(1 to 7) and (8 to 16)
Method B:	
(Turbidimetric Method)	(1 to 7) and (17 to 26)

1.2. Method A is a primary measure of sulfate ion. Method B is less time-consuming, but often more liable to interference than Method A. It is particularly useful in the lower sulfate range and can be used as a screening test. This method is directly applicable over the range of 10 to 100 mg/kg.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:
- D 859, Standard Test Method for Silica in Water
- D 1129, Standard Terminology Relating to Water
- D 1193, Standard Specification for Reagent Water
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 60, Standard Practice for Analysis of Metals, Ores, and Related Materials by Molecular Absorption Spectrometry

- E 275, Standard Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers

3. DEFINITIONS

3.1. For definitions of terms used in these methods, refer to ASTM D 1129.

PART I—INITIAL PREPARATION OF TEST SAMPLES

4. SCOPE

4.1. This method covers the dry preparation of soil and soil-aggregate samples, as received from the field, for use in determining the sulfate ion content in soils.

4.2. The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

5. APPARATUS

5.1. The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231.

5.2. *Drying Apparatus*—Any suitable device capable of drying samples at a temperature not exceeding 60ºC (140ºF).

5.3. *Sieves*—A series of sieves of the following sizes: 6.3 mm ($^1/_4$ in.), 4.75 mm (No. 4), 2.00 mm (No. 10), and a pan. The sieve shall conform to M 92, Wire-Cloth Sieves for Testing Purposes (Note 1).

Note 1—The sieve sizes that have an opening size of 6.3 mm ($^1/_4$ in.) or larger shall conform to the requirements specified in M 92, excluding Column No. 7. This exclusion permits the use of heavier screens in non-standard frames that are larger than the 203.2 mm (8 in.) round frames.

5.4. *Pulverizing Apparatus*—Either a mortar and rubber-covered pestle or any device suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains (Note 2).

Note 2—Other types of apparatus are satisfactory if the aggregations of soil particles are broken up without reducing the size of the individual grains.

5.5. *Sample Splitter*—A suitable riffle sampler or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle sampler splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also permitted.

6. SAMPLE SIZE

6.1. The amount of soil material required to perform the individual test is as follows:

Test	Approx Mass (g)	Sieve Size Finer Than:
Sulfates	250	2.00 mm (No. 10)

7. INITIAL PREPARATION OF TEST SAMPLES

7.1. The sample as received from the field may be dried in air or a drying apparatus not exceeding 60ºC (140ºF) prior to sample selection (Note 3). A representative test sample of the amount required to perform the tests shall then be obtained with the sampler, or by splitting or quartering. The aggregations of soil particles shall then be broken up in the pulverizing apparatus in such a way as to avoid reducing the natural size of the individual particles.

Note 3—Samples dried in an oven or other drying apparatus at a temperature not exceeding 60ºC (140ºF) are considered to be air dried.

7.2. The portion of the sample selected for sulfate testing shall be separated into fractions by one of the following methods:

7.2.1. *Alternate Method Using 2.00-mm (No. 10) Sieve*—The dried sample shall be separated into two fractions using a 2.00-mm sieve. The fraction retained on the sieve shall be ground with the pulverizing apparatus until the aggregation of soil particles is separated into individual grains. The ground soil shall then be separated into two fractions using the 2.00-mm sieve.

7.2.2. *Alternate Method Using 4.75-mm and 2.00-mm (No. 4 and No. 10) Sieves*—The dried sample shall first be separated into two fractions using a 4.75-mm sieve. The fraction retained on this sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains and again separated on the 4.75-mm sieve. The fraction passing the 4.75-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve and processed as in Section 7.2.1.

7.2.3. *Alternate Method Using 6.3-mm and 2.00-mm ($^1/_4$ in. and No. 10) Sieves*—The dried sample shall first be separated into two fractions using a 6.3-mm sieve. The fraction retained on this sieve shall be ground with a pulverizing apparatus until the aggregations of soil particles are broken into separate grains and again separated on the 6.3-mm sieve. The fraction passing the 6.3-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve and processed as in Section 7.2.1.

PART 2—DETERMINATION OF SULFATE CONTENT

8. METHOD A—GRAVIMETRIC METHOD (SECTIONS 8 TO 16)

8.1. *Scope*:

8.2. This method is utilized to determine the amount of water-soluble sulfate ion in soil. It is directly applicable to samples containing approximately 20 to 100 mg/kg of sulfate ion. It can be extended to higher or lower ranges by adjusting the sample size.

8.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

9. SUMMARY OF METHOD

9.1. Sulfate ion is precipitated and the mass determined as barium sulfate after removal of silica and other insoluble matter.

10. INTERFERENCES

10.1. Sulfites and sulfides may oxidize and precipitate with the sulfate. Turbidity caused by silica or other insoluble material would interfere if allowed to be present, but removal of such interference is provided in this method.

10.2. Other substances tend to be occluded or adsorbed on the barium sulfate, but these do not significantly affect the precision and accuracy of the method.

11. PURITY OF REAGENTS

11.1. Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

11.2. Unless otherwise indicated, references to water shall be understood to mean Type II reagent water conforming to ASTM D 1193. In addition, reagent water used for these methods shall be sulfate-free.

12. REAGENTS

12.1. *Ammonium Hydroxide (sp gr 0.90)*—Concentrated ammonium hydroxide (NH_4OH).

12.2. *Barium Chloride Solution (100 g/L)*—Dissolve 100 g of barium chloride ($BaCl_2{\cdot}2H_2O$) in water and dilute to 1 L.

12.3. *Hydrochloric Acid (1 + 9)*—Mix one volume of hydrochloric acid (HCl, sp gr 1.19) with nine volumes of water.

12.4. *Hydrofluoric Acid (48 to 51 percent)*—Concentrated hydrofluoric acid (HF).

12.5. *Methyl Orange Indicator Solution (0.5 g/L)*—Dissolve 0.05 g of methyl orange in water and dilute to 100 mL.

12.6. *Nitric Acid (sp gr 1.42)*—Concentrated nitric acid (HNO_3).

12.7. *Picric Acid (saturated aqueous solution)*.

12.8. *Silver Nitrate Solution (100 g/L)*—Dissolve 10 g of silver nitrate ($AgNO_3$) in water and dilute to 100 mL.

12.9. *Sulfuric Acid (sp gr 1.84)*—Concentrated sulfuric acid (H_2SO_4).

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13. TEST PROCEDURE

13.1. Weigh 100 g of the soil sample for testing. Put the test sample into a 500-mL Erlenmeyer flask.

13.2. Add 300 mL of distilled water. Stopper the flask and shake the mix.

13.3. Centrifuge the sample; if the sample exhibits turbidity, filter the sample through a 0.45 micron membrane filter. A drop of concentrated nitric acid may be added, if needed, to precipitate finely divided suspended matter (Note 4).

13.4. Pipet 30.0 mL, or measure a quantity of the clear sample containing sulfate ion equivalent to 20 to 50 mg of barium sulfate ($BaSO_4$) into a 250 mL beaker. Adjust the volume by evaporation, or dilution with water, to approximately 200 mL. Adjust the acidity of the sample to the methyl orange end point and add 10 mL excess HCl (1 + 9). If a quantity other than 30 mL is used, substitute the volume of the aliquot into the calculation in place of 30 mL.

Note 4—Silica may be removed before applying this method by dehydration with HCl or perchloric acid ($HClO_4$) in accordance with the respective procedures in ASTM D 859. In this case, the ignition described in Section 13.8 need not be done in a platinum crucible.

13.5. Measure into the beaker a quantity of the clear sample containing sulfate ion equivalent to 20 to 50 mg of barium sulfate ($BaSO_4$). Adjust the volume by evaporation or dilution with water to approximately 200 mL. Adjust the acidity of the sample to the methyl orange end point and add 10 mL excess of HCl (1 + 9).

13.6. Heat the acidified solution to boiling and slowly add to it 5 mL of hot $BaCl_2$ solution (Note 5). Keep the temperature just below boiling until the liquid has become clear and the precipitate has settled out completely. In no case shall this settling period be less than 2 hours.

Note 5—Faster precipitation and a coarser precipitate can be obtained by adding 10 mL of saturated picric acid solution and boiling the sample 5 minutes before adding $BaCl_2$.

13.7. Filter the suspension of $BaSO_4$ on a fine, ashless filter paper and wash the precipitate with hot water until the washings are substantially free of chlorides, as indicated by testing the last portion of the washings with $AgNO_3$ solution (Note 6). Avoid excessive washing. If any $BaSO_4$ passes through the filter, pour the filtrate through the paper a second time (Note 7).

Note 6—Do not attempt to obtain a completely negative test for chloride. Discontinue washing when no more than a faint opalescence is produced in the test. Using a small amount of ashless filter paper pulp in the suspension will aid in filtration and reduce the tendency for $BaSO_4$ to pass through the filter.

Note 7—If the filtrate is poured through the paper a second time, $AgNO_3$ must not be present in the filtrate.

13.8. Place the filter paper and contents in a tared platinum crucible (Note 4), and char and consume the paper slowly without flaming. Ignite the residue at approximately 800ºC for one hour, or until it is apparent that all carbon has been consumed.

13.9. Add a drop of H_2SO_4 and a few drops of HF, and evaporate under a hood to expel silica as silicon tetrafluoride (SiF4). Reignite at about 800ºC, cool in a desiccator, and determine the mass of the $BaSO_4$.

14. CALCULATION

14.1. Calculate the concentration of sulfate ion (SO_4) in milligrams per kilogram, as follows:

$$\text{Sulfate, mg/kg} = (W \times 411500)/S \qquad (1)$$

where:

W = grams of $BaSO_4$ and

S = grams of sample used, e.g.,

$$\frac{100 \text{ g soil}}{S} = \frac{300 \text{ mL water}}{30 \text{ mL aliquot}}$$

$$S = 10 \text{ g}$$

14.2. *Sulfate Ion Content in Soil*:

$$(\text{mg/kg moisture free}) = [\text{Sulfates (mg/kg as determined above)} \times 100]/(100 - \text{percent moisture}) \qquad (2)$$

15. REPORT

15.1. Report the sulfate content as computed in Section 14.2 on a moisture-free basis in units of milligrams per kilogram (mg/kg). Report this value to the nearest whole number in accordance with the rounding-off method ASTM E 29.

16. PRECISION AND BIAS

16.1. Data are not available at this time.

METHOD B—TURBIDIMETRIC METHOD (SECTIONS 17 TO 26)

17. SCOPE

17.1. This method is intended for rapid routine or control tests for the water-soluble sulfate ion in soil where extreme accuracy and precision are not required. It is directly applicable over the range of 10 to 100 mg/kg of sulfate ion (SO_4).

18. SUMMARY OF METHOD

18.1. Sulfate ion is converted to a barium sulfate suspension under controlled conditions. Glycerin solution and a sodium chloride solution are added to stabilize the suspension and minimize interferences. The resulting turbidity is determined by a photoelectric colorimeter or spectrophotometer and compared to a curve prepared from standard sulfate solutions.

19. INTERFERENCES

19.1. Insoluble suspended matter in the sample must be removed. Dark colors that cannot be compensated for in the procedure interfere with the measurement of suspended barium sulfate ($BaSO_4$).

19.2. Although other ions normally found in water do not appear to interfere, the formation of the barium sulfate suspension is very critical. This method is more suitable as a control procedure where concentration and type of impurities present in the water are relatively constant. Determinations that are in doubt should be checked by Method A in some cases, or by the procedure suggested in Note 10.

20. APPARATUS

20.1. *Photometer*—A filter photometer or spectrophotometer suitable for measurements between 350 and 425 nm, the preferable wavelength range being 380 to 400 nm. The cell for the instrument should have a light path through the sample of approximately 40 mm, and should hold about 50 mL of sample. Filter photometers and photometric practices prescribed in this method shall conform to ASTM E 60; spectrophotometers shall conform to ASTM E 275.

21. REAGENTS

21.1. *Barium Chloride*—Crystals of barium chloride ($BaCl_2 \cdot 2H_2O$) screened to 20 to 30-mesh.

21.2. *Glycerin Solution (1 + 1)*—Mix one volume of glycerin with one volume of water.

Note 8—A stabilizing solution containing sodium carboxymethylcellulose (10 g/L) may be used instead of the glycerin solution.

21.3. *Sodium Chloride Solution (240 g/L)*—Dissolve 240 g of sodium chloride (NaCl) in water containing 20 mL of concentrated hydrochloric acid (HCl, sp gr 1.19), and dilute to 1 L with water. Filter the solution if turbid.

21.4. *Sulfate, Standard Solution (1 mL = 0.100 mg SO_4)*—Dissolve 0.1479 g of anhydrous sodium sulfate (Na_2SO_4) in water, and dilute with water to 1 L in a volumetric flask. Standardize by the procedure prescribed in Section 13.

22. CALIBRATION

22.1. Follow the procedure given in Section 23, using appropriate amounts of the standard sulfate solution prepared in accordance with Section 21.4, and prepare a calibration curve showing sulfate ion content in mg/L plotted against the corresponding photometer readings (Note 9). Prepare standards by diluting with water 0.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, 40.0, and 50.0 mL of standard sulfate solution to 50-mL volumes in volumetric flasks. These solutions will have sulfate ion concentrations of 0.0, 4.0, 10.0, 20.0, 30.0, 40.0, 60.0, 80.0, and 100.0 mg/L (ppm), respectively.

Note 9—A separate calibration curve must be prepared for each photometer and a new curve must be prepared if it is necessary to change the cell, lamp, or filter, or if any other alterations of instrument or reagents are made. Check the curve with each series of tests by running two or more solutions of known sulfate concentrations.

23. TEST PROCEDURE

23.1. Weigh 100 g of the soil sample for testing. Put the test sample into a 500-mL Erlenmeyer flask.

23.2. Add 300 mL of distilled water. Stopper the flask and shake the mix.

23.3. Centrifuge the sample; if the sample exhibits turbidity then filter the sample through a 0.45 micron membrane filter. A drop of concentrated nitric acid may be added, if needed, to precipitate finely divided suspended matter (Note 4).

23.4. Pipet into a 200-mL beaker 50 mL of the clear sample containing between 0.5 and 5 mg of sulfate ion (Note 10). Dilute to 50 mL with water, if required, and add 10.0 mL of glycerin solution (Note 8) and 5.0 mL of NaCl solution. If less than 50 mL of sample is used, use the appropriate dilution factor.

Note 10—The solubility of $BaSO_4$ is such that difficulty may be experienced in the determination of sulfate concentrations below 10 mg/kg. This can be overcome by concentrating the sample or by adding 5 mL of standard sulfate solution (1 mL = 0.100 mg SO_4) to the sample before diluting to 50 mL. This will add 0.5 mg SO_4 to the sample, which must be subtracted from the final result.

23.5. Fill a 40-mm sample cell with sample solution, wipe it with a clean, dry cloth, and place it in the cell compartment. Set the colorimeter to zero absorbance (100 percent transmission) for a blank. This compensates for any acid-insoluble matter that has not been filtered out, or for color present, or for both.

23.6. Pour the sample solution from the cell back into the beaker and add, with stirring, 0.3 g of $BaCl_2 \cdot 2H_2O$ crystals (Note 11). Continue gently stirring the solution for 60 seconds. Let it stand for 4 minutes, and stir again for 15 seconds. Fill the sample cell as before, and immediately make a reading with the photometer.

Note 11—The stirring should be at a constant rate in all determinations. The use of a magnetic stirrer has been found satisfactory for this purpose.

23.7. If interferences are suspected, dilute the sample with an equal volume of water and determine the sulfate concentration again. If the value so determined is one-half that in the undiluted sample, interferences may be assumed to be absent.

24. CALCULATION

24.1. Convert the photometer readings obtained with the sample to mg/L sulfate ion (SO_4) by use of the calibration curve described in Section 22.

$$\text{Sulfate Ion Content in Soil}\left(\text{mg/kg not corrected for moisture}\right) = \frac{50\ \text{mL solution}\ \left(\text{ppm curve}\right)}{S} \qquad (3)$$

where:

S = grams of samples used, e.g.,

$$\frac{100}{S} = \frac{300\ \text{mL water}}{50\ \text{mL aliquot}}$$

$$S = 16.6666\ \text{g}$$

24.2. *Sulfate Ion Content in Soil*:

(mg/kg moisture free) = [Sulfates (mg/kg with moisture) × 100]/
(100 – percent moisture) *(4)*

25. REPORT

25.1. Report the sulfate content as computed in Section 24.2 on a moisture-free basis in units of milligram per kilogram (mg/kg). Report this value to the nearest whole number in accordance with the rounding-off method in ASTM E 29.

26. PRECISION AND BIAS

26.1. Data are not available at this time.

Standard Method of Test for

Determining Water-Soluble Chloride Ion Content in Soil

AASHTO Designation: T 291-94 (2008)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Water-Soluble Chloride Ion Content in Soil

AASHTO Designation: T 291-94 (2008)

1. SCOPE

1.1. This test method describes the procedures for sampling and testing a soil for chloride ion content. This standard is divided into two parts. The first part specifies the procedure for sampling and preparing the sample to size for testing. The second part delineates two test procedures (Methods A or B) for the determination of the water-soluble chloride ion content in soil. Two methods are given as follows:

	Section
Method A:	
(Mohr Titration Method)	(1 to 7) and (8 to 16)
Method B:	
(pH/mV Meter Method)	(1 to 7) and (17 to 28)

1.2. Method A is based upon the Mohr procedure for determining chloride ion with silver nitrate. Method B utilizes a pH/mV Meter. By comparing the mV readings to the calibration curve, determine the chloride ion content.

1.3. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- D 1129, Standard Terminology Relating to Water
- D 1193, Standard Specification for Reagent Water
- D 2777, Standard Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water
- D 3370, Standard Practices for Sampling Water from Closed Conduits
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. DEFINITIONS

3.1. For definitions of terms used in this test method, refer to ASTM D 1129.

PART 1—INITIAL PREPARATION OF TEST SAMPLES

4. SCOPE

4.1. This method covers the dry preparation of soil and soil-aggregate samples, as received from the field, for use in determining the chloride content.

4.2. The following applies to all specified limits in this standard: For the purpose of determining conformance with these specifications, an observed value or calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E 29.

5. APPARATUS

5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2. *Drying Apparatus*—Any suitable device capable of drying samples at a temperature not exceeding 60ºC (140ºF).

5.3. *Sieves*—A series of sieves of the following sizes: 6.3-mm ($^1/_4$-in.), 4.75-mm (No. 4), 2.00-mm (No. 10) sieve, and a pan. The sieve shall conform to M 92, Wire-Cloth Sieves for Testing Purposes (Note 1).

Note 1—The sieve sizes that have an opening size of 6.3 mm ($^1/_4$ in.) or larger shall conform to the requirements specified in M 92, excluding Column No. 7. This exclusion permits the use of heavier screens in non-standard frames that are larger than the 203.2 mm (8 in.) round frames.

5.4. *Pulverizing Apparatus*—Either a mortar and rubber-covered pestle or any device suitable for breaking up the aggregations of soil particles without reducing the size of the individual grains (Note 2).

Note 2—Other types of apparatus are satisfactory if the aggregations of soil particles are broken up without reducing the size of the individual grains.

5.5. *Sample Splitter*—A suitable riffle sampler or sample splitter for proportional splitting of the sample and capable of obtaining representative portions of the sample without appreciable loss of fines. The width of the container used to feed the riffle sampler splitter should be equal to the total combined width of the riffle chutes. Proportional splitting of the sample on a canvas cloth is also permitted.

6. SAMPLE SIZE

6.1. The amount of soil material required to perform the individual test is as follows:

Test	Approx Mass (g)	Sieve Size Finer Than:
Chlorides	250	2.00 mm (No. 10)

7. INITIAL PREPARATION OF TEST SAMPLES

7.1. The sample as received from the field may be dried in air or a drying apparatus not exceeding 60ºC (140ºF) prior to sample selection (Note 3). A representative test sample of the amount required to perform the tests shall then be obtained with the sampler, or by splitting or quartering. The aggregations of soil particles shall then be broken up in the pulverizing apparatus in such a way as to avoid reducing the natural size of the individual particles.

Note 3—Samples dried in an oven or other drying apparatus at a temperature not exceeding 60ºC (140ºF) are considered to be air dried.

7.2. The portion of the sample selected for chloride testing shall be separated into fractions by one of the following methods:

7.2.1. *Alternate Method Using 2.00-mm (No. 10) Sieve*—The dried sample shall be separated into two fractions using a 2.00-mm sieve. The fraction retained on this sieve shall be ground with the pulverizing apparatus until the aggregation of soil particles is separated into individual grains. The ground soil shall then be separated into two fractions using the 2.00-mm sieve.

7.2.2. *Alternate Method Using 4.75-mm and 2.00-mm (No. 4 and No. 10) Sieves*—The dried sample shall be separated into two fractions using a 4.75-mm sieve. The fraction retained on this sieve shall be ground with the pulverizing apparatus until the aggregation of soil particles is separated into individual grains and again separated on the 4.75-mm sieve. The fraction passing the 4.7-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve and processed as in Section 7.2.1.

7.2.3. *Alternate Method Using 6.3-mm and 2.00-mm ($^1/_4$-in. and No. 10) Sieves*—The dried sample shall be separated into two fractions using a 6.3-mm sieve. The fraction retained on this sieve shall be ground with the pulverizing apparatus until the aggregations of soil particles are separated into individual grains and again separated on the 6.3-mm sieve. The fraction passing the 6.3-mm sieve shall be mixed thoroughly and, by the use of the sampler or by splitting and quartering, a representative portion adequate for testing shall be obtained. This split-off portion shall then be separated on the 2.00-mm sieve and processed as in Section 7.2.1.

PART 2—DETERMINATION OF WATER-SOLUBLE CHLORIDE ION CONTENT BY MOHR TITRATION METHOD (METHOD A)

8. SCOPE

8.1. This method covers the test procedure for the determination of water-soluble chloride content of soils.

8.2. Samples containing from 10 to 150 mg/kg of chloride can be analyzed by this test method. These levels are achieved by dilution as described in the test method.

8.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

9. SUMMARY OF METHOD

9.1. This test method is based upon the Mohr procedure for determining chloride ion with silver nitrate. The chloride reacts with the silver ion before any silver chromate forms, due to the lower solubility of silver chloride. The potassium chromate indicator reacts with excess silver ion to form a red silver chromate precipitate. The end point is the appearance of the first permanent orange color.

9.2. This test method is suitable for analyzing solutions with a pH between 6.0 and 8.5.

10. INTERFERENCES

10.1. Sulfide, bromide, iodide, thiocyanate, cyanide, phosphate, sulfite, carbonate, hydroxide, and iron interfere in this test method. Sulfide, sulfite, and thiosulfate can be removed with a peroxide treatment, but usually no attempt is made to remove bromide and iodide because they are usually present in insignificant quantities compared to chloride. If necessary, the pH can be raised and the hydroxides of several metals, including iron, can be filtered off. Iron, barium, lead, and bismuth precipitate with the chromate indicator.

11. APPARATUS

11.1. Buret, 25 mL capacity.

11.2. Hot plate.

11.3. Magnetic stirrer and TFE-fluorocarbon-coated stirring bars.

11.4. Buret, 50 mL capacity, 0.1 mL gradations.

11.5. Pipets, 1, 5, 10, 25, 30, and 50 mL.

11.6. Beaker, 250 mL.

11.7. Erlenmeyer flask, 500 mL.

11.8. Centrifuge with tubes capable of holding at least 50 mL.

11.9. Phydrion papers covering pH 1 through 11 in 1 pH units. A pH meter is preferable, if available.

11.10. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

12. REAGENTS

12.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specification of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

12.2. *Nitric Acid Solution (1 + 19)*—Add one volume of HNO_3 (sp. gr. 1.42) to 19 volumes of water.

12.3. *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to ASTM D 1193, Type III.

12.4. *Silver Nitrate Solutions*:

12.4.1. Silver nitrate solution (1 mL of solution is equivalent to 1 mg of chloride). Dissolve 4.79 grams of $AgNO_3$ in distilled water. Dilute to one liter. Add one drop concentrated nitric acid (HNO_3) and dilute to 1 L in a volumetric flask. The HNO_3 will eliminate any precipitation of silver hydroxide that would change the concentration. Standardize against sodium chloride (NaCl). Store in an amber-brown bottle to protect the solution from light.

12.4.2. *Silver Nitrate Solution, Standard (equivalent to 2 mg Cl/mL)*—For chloride concentrations slightly higher than specified in Section 12.4.1, this is a more concentrated standard. Dissolve 9.5834 g of $AgNO_3$ in approximately 700 mL of water. Add one drop concentrated nitric acid (HNO_3) and dilute to 1 L in a volumetric flask. Standardize against sodium chloride (NaCl). Store in an amber-brown bottle to protect the solution from light.

12.4.3. *Silver Nitrate Solution, Standard (equivalent to 5 mg Cl/mL)*—For chloride concentrations higher than specified in Section 12.4.2, dissolve 23.9582 g of $AgNO_3$ in approximately 700 mL of water. Add one drop concentrated nitric acid (HNO_3) and dilute to 1 L in a volumetric flask. The HNO_3 will eliminate any precipitation of silver hydroxide which would change the concentration. Standardize against sodium chloride (NaCl) by procedure described below. Store in an amber-brown bottle to protect the solution from light.

12.5. *Sodium Chloride Solution*:

12.5.1. Dry 2 to 6 g of high purity (minimum 99.5 percent) sodium chloride crystals at 110 ± 5ºC for 1 hour and cool in a desiccator to room temperature.

12.5.2. Weigh 1.6484 g of the NaCl crystals. Transfer the crystals into a 1-L volumetric flask, dissolve, dilute, and mix well. A quantity of 1 mL of this solution provides 1 mg of Cl.

12.5.3. A 0.2 mL blank can be utilized or determine the indicator blank by substituting 100 mL of reagent grade water for the sample and perform the following:

12.5.3.1. Check the pH with a meter, if available, or with phydrion paper. If the pH is in the range of six through eight, proceed immediately to the step in Section 12.5.3.2. If the pH is below six, add sodium bicarbonate to adjust to the above range; if the pH is above eight, add nitric acid to adjust to the above range.

12.5.3.2. Add two drops of potassium chromate solution.

12.5.3.3. Titrate with silver nitrate solution until the indicator begins to turn from yellow to red.

12.5.3.4. Indicator blank is the volume of $AgNO_3$ required to the end point. Record this value as the blank.

12.5.4. The titre (T) of the silver nitrate solution is given in the following equation:

$$T = \frac{\text{mg CL used}}{\text{mL AgNO}_3\text{ required} - \text{Blank}} \qquad (1)$$

12.5.5. If the titre (T) of the solutions are not exactly 1.0, 2.0, or 5.0 mg of Cl per mL $AgNO_3$, it may be desirable to dilute the solutions if they are too concentrated or add more silver nitrate if they are too weak. In either case, restandardize the resulting solution.

12.6. *Potassium or Sodium Chromate, Indicator Solution*—Prepare a 5 percent solution (5 g/100 mL) and adjust the pH to 7.0 with HNO_3 (1 + 19) or $NaHCO_3$ powder described in Sections 12.2 and 12.7.

12.7. *Sodium Bicarbonate ($NaHCO_3$)*—Powder to adjust the sample pH to 8.3.

12.8. *Standardization of Silver Nitrate Solutions*:

12.8.1. Pipet 25 mL aliquots of NaCl solution to standardize the $AgNO_3$ solution (1 mg Cl/mL) and dilute to 100 mL with water. For the higher concentrations use 50 mL aliquots of the NaCl solution to standardize the $AgNO_3$ solution (2 mg Cl/mL) and dilute to 100 mL with water. Use 100 mL of the NaCl solution to standardize the more concentrated $AgNO_3$ solution (5 mg of Cl/mL).

12.8.2. Add 1 mL of 5 percent indicator solution (see Section 12.6), 1 g of sodium bicarbonate powder, and titrate to the appearance of a permanent orange color preceding a red precipitate. The analyst must practice this titration to become familiar with this color.

13. TEST PROCEDURE

13.1. Weigh 100 g of soil into a 500-mL Erlenmeyer flask. Add 300 mL of distilled water. Stopper and shake vigorously for 20 seconds. After 1 hour repeat shaking. Centrifuge the sample. If the sample exhibits turbidity, then filter the sample through a 0.45 micron membrane filter.

13.2. Check the pH and titrate a 30 mL aliquot for chlorides as follows:

13.2.1. Check the pH with a meter, if available, or with phydrion paper. If the pH is in the range of six through eight, proceed immediately to the step in Section 13.2.2. If the pH is below six, add sodium bicarbonate to adjust to the above range; if the pH is above 8, add nitric acid to adjust to the above range.

13.2.2. Add two drops of potassium chromate solution.

13.2.3. Titrate with silver nitrate solution until the indicator begins to turn from yellow to red. If the titration is over 30 mL, take a smaller sample so as to keep the titration under this value. Dilute any smaller sample to about 50 mL with distilled water before titrating.

13.2.4. Record the volume of $AgNO_3$ required to the end point and calculate the chloride content.

13.2.5. Deduct the 0.2 blank or the blank volume as determined in Section 12.5.5.

14. CALCULATIONS

14.1. Calculate the chloride content as follows:

$$\text{Chloride content (mg/kg)} = (\text{mL } AgNO_3 \text{ used} - \text{B}) \times \text{T} \times 1000/S \qquad (2)$$

where:

T = titre, mg Cl/mL of $AgNO_3$;

B = indicator blank, 0.2 or as determined in Section 12.5.5; and

S = g of sample titrated as diluted in steps described in Sections 13.1 and 13.2, e.g.:

$$\frac{100 \text{ g soil}}{S} = \frac{300 \text{ mL water}}{30 \text{ mL aliquor}}$$

$$S = 10 \text{ gr}$$

14.2. Chloride content on a moisture-free basis: Determine percent moisture by drying at 110 ± 5°C and adjust above result as:

Chloride content mg/kg (moisture-free basis) = [mg/kg (as received) × 100]/
(100 – percent moisture)

15. REPORT

15.1. The chloride content will be reported as in Section 14.2 on a moisture-free basis in milligrams per kilogram (mg/kg). This result will be reported to the nearest whole number in accordance with ASTM E 29.

16. PRECISION AND BIAS

16.1. Data are not available at this time.

DETERMINATION OF WATER-SOLUBLE CHLORIDE ION CONTENT UTILIZING A PH/MV METER (METHOD B)

17. SCOPE

17.1. This method covers the test procedure and apparatus for the determination of water-soluble chloride ion content of soils by the use of a pH/mV meter equipped with chloride ion electrode(s).

17.2. Samples containing from 10 to 1000 mg/kg of chloride can be analyzed by this test method. The range is based on the calibration curve that is developed (Note 5).

17.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

18. SUMMARY OF METHOD

18.1. This test method utilizes a pH/mV meter equipped with chloride ion selective electrode(s). This apparatus can be used directly to measure concentrations after the addition of mV ionic strength adjustment buffer to sample(s) and standards. This procedure brings all solutions to the same ionic strength so the activity coefficients are equal in all cases. The activity of an ion is a function of the change and concentration of all ions present.

19. INTERFERENCES

19.1. Sulfide, bromide, iodide, thiocyanate, cyanide, phosphate, sulfite, carbonate, hydroxide, and iron interfere in this test method. Sulfide, sulfite, and thiosulfate can be removed with a peroxide treatment, but usually no attempt is made to remove bromide and iodide because they are usually present in insignificant quantities compared to chloride.

20. APPARATUS

20.1. pH/mV Meter.

20.2. Electrodes.
(a) Reference Electrode Ag/AgCl Double Junction.
(b) Chloride Electrode.

20.3. Centrifuge with tubes capable of holding at least 50 mL.

20.4. *Glassware, Assorted*—As required in the procedure.

20.5. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

20.6. *Drying Apparatus*—An oven capable of drying samples at a temperature of 110 ± 5ºC.

21. REAGENTS/SOLUTIONS

21.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specification of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

21.1.1. 4 M KC1 Solution saturated with AgCl (purchased, reference electrode internal chamber fill solution).

21.1.2. 1 M KNO_3 Solution. Dissolve 101.11 g of reagent grade potassium nitrate in deionized water and dilute to 1 liter. (Reference electrode external chamber fill solution).

21.1.3. 0.2 M potassium nitrate (KNO_3) buffer. Dissolve 20.22 g of potassium nitrate in deionized water and dilute to 1 liter (Note 4).

Note 4—Other strengths of the buffer solution may be substituted in lieu of the 0.2 M buffer. However, it should be noted that the buffer solution being substituted must be used to develop the calibration curve as well as for performing the test.

21.1.4. *Potassium Chloride Stock Solution*—Dry the potassium chloride in an oven at 110 ± 5ºC for a minimum of 12 hours and allow to cool in a desiccator before determining the mass. Dissolve 2.103 g of reagent potassium chloride in deionized water and dilute to 1 liter (Note 5). This produces a stock solution of 1000 mg/L.

Note 5—Other strengths of stock solution may be prepared that will span the range of the material being tested.

21.1.5. *Standard Solutions*—Standard solutions are prepared by diluting potassium chloride stock solution.

22. SAMPLE PREPARATION

22.1. Select a representative portion of the material passing the 2.00-mm (No. 10) sieve and dry a minimum of 12 hours at 110 ± 5ºC.

22.2. To 100 g of the prepared soil, add 100 mL of deionized water and agitate for 15 minutes on a small paint shaker. If less vigorous means of agitation is used, a longer period of time is necessary.

22.3. Centrifuge a 50-mL portion of the mixture at approximately 10000 r/min for 10 to 15 minutes and then transfer 20 mL or 25 mL aliquot into a 100-mL beaker. If the sample is turbid, then filter the sample through a 0.45 micron membrane filter.

23. CALIBRATION OF METER-MILLIVOLT MEASUREMENT

23.1. *Calibrate the pH/mV Meter*—Follow the instructions supplied with the meter and the electrodes.

24. PROCEDURE

24.1. *Preparation of Calibration Curves*:

24.1.1. Calibration solutions should be prepared by serial dilution of the potassium chloride stock solution. The range of the standards should be from 10 to 1000 mg/L. Solutions of other strengths may be prepared that span the range of the material being tested.

24.1.2. Standards and samples should be ionic strength buffered.

24.1.3. Construct a calibration graph on semi-log paper by plotting the value of the concentration standards on the long axis (mg/L) versus the mV reading obtained with these standards on the linear axis. (Ion selective electrodes give a logarithmic response to the activities of ions rather than to their concentrations. With the addition of an ionic strength adjustment buffer, the electrodes can be used directly to measure concentrations or millivolts.)

25. CHLORIDE CONCENTRATION MEASUREMENT

25.1. Transfer an aliquot (25 mL to 40 mL) of liquid from the centrifugation of the sample into a 100-mL beaker.

25.2. Buffer the samples (or standards) by the addition of an equal volume of the 0.2 M KNO_3 solution (one to one by volume).

25.3. Rinse the electrodes with deionized water and blot off excess liquid.

25.4. Immerse the electrodes into the solution—stir gently.

25.5. Allow the electrodes to remain in the solution until the meter reading stabilizes. Refer to the instructions supplied with the meter and the electrode(s).

25.6. After stabilization, read and record the displayed reading (see manufacturer's operating instructions).

25.7. Before removing the electrode(s) from the solution refer to the proper operating instructions supplied with the meter and electrode(s) so as not to damage the meter.

25.8. Remove the electrodes from the solution, rinse, and blot dry.

25.9. Consult the calibration curve to determine the concentration to which the displayed value in mV corresponds.

26. PRECAUTIONS

26.1. Periodically check the electrodes for any damage.

26.2. The temperature of the solution used to develop the calibration curve must be the same temperature as the sample being tested.

27. REPORT

27.1. Report the values (mg/kg) to the nearest whole number in accordance with ASTM E 29.

28. PRECISION AND BIAS

28.1. Data are not available at this time.

Standard Method of Test for

Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression

AASHTO Designation: T 296-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression

AASHTO Designation: T 296-10

1. SCOPE

1.1. This test method covers the determination of unconsolidated strength and stress-strain relationships for a cylindrical specimen of either an undisturbed or remolded cohesive soil sheared undrained in compression at a constant rate of axial deformation (strain controlled).

1.2. The test method provides for the calculation of total stresses on, and axial compression of, the test specimen by measurement of axial load and axial deformation.

1.3. The test provides data useful in determining strength and deformation properties of cohesive soils much as Mohr strength envelopes and Young's modulus.

1.4. The determination of strength envelopes and the development of relationships to aid in interpreting and evaluating test results are left to the engineer or office requesting the test.

1.5. The values stated in SI units are to be regarded as standard.

1.6. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils
- T 100, Specific Gravity of Soils
- T 207, Thin-Walled Tube Sampling of Soils
- T 208, Unconfined Compressive Strength of Cohesive Soil
- T 297, Consolidated, Undrained Triaxial Compression Test on Cohesive Soils

2.2. *ASTM Standards*:

- D 422, Standard Test Method for Particle-Size Analysis of Soils
- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids

- D 2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 4220, Standard Practices for Preserving and Transporting Soil Samples

2.3. *Other Standards and References*:

- USBR 5754 Procedure for Unconsolidated-Undrained Triaxial Shear Testing of Soils. (See Earth Manual, Part 2.)
- Joseph E. Bowles, *Engineering Properties of Soils and their Measurement*, McGraw-Hill Book Company, New York, p. 158, 3rd Edition.

3. TERMINOLOGY

3.1. *Definitions*—The definitions of terms used in this test method shall be in accordance with Terminology D 653.

3.2. *Description of Terms Specific to This Standard*:

3.2.1. *failure*—the stress condition at failure for a test specimen. Failure is often taken to correspond to the maximum principal stress difference (maximum deviator stress) attained or the principal stress difference (deviator stress) at 15 percent axial strain, whichever is obtained first during the performance of a test. Depending on soil behavior and field application, other suitable failure criteria may be defined, such as the principal stress difference (deviator stress) at a selected axial strain other than 15 percent.

3.2.2. *principal stress difference (deviator stress)*—the difference in magnitude between the major principal stress and minor principal stress; in a triaxial compression test, the stress due to the axial load that is applied in excess of the confining pressure.

3.2.3. *total stress,* σ—the total force per unit area acting within a soil mass. It is the sum of neutral and effective stresses ($\sigma' + \mu$).

4. SIGNIFICANCE AND USE

4.1. The strength in this test is measured under undrained conditions and is applicable to field conditions where soils are subjected to a change in stress without time for consolidation to take place (unconsolidated condition), and the field stress conditions are similar to those in the tests.

4.2. The shear strength determined from the test expressed in terms of total stresses or effective stresses is commonly used in embankment stability analyses, earth pressure calculations, and foundation design.

5. APPARATUS

5.1. The requirements for equipment needed to perform satisfactory tests are given in the following sections.

5.2. *Axial Loading Device*—The axial compression device may be a screw jack driven by an electric motor through a geared transmission, a hydraulic or pneumatic loading device, or any other compression device with sufficient capacity and control to provide the rate of axial strain (loading) described in Section 8.2.6. The rate of advance of the loading device should not deviate by more than ±1 percent from the selected value. Vibration due to the operation of the loading device shall be sufficiently small to not cause dimensional changes in the specimen or to produce changes in pore-water pressure when the drainage valves are closed.

Note 1—A loading device may be judged to produce sufficiently small vibrations if there are no visible ripples in a glass of water placed on the loading platform when the device is operating.

5.3. *Axial Load-Measuring Device*—The axial load-measuring device may be a load ring, electronic load cell, hydraulic load cell, or any other load-measuring device capable of the accuracy prescribed in this paragraph and may be a part of the axial loading device. The axial load-measuring device shall be capable of measuring the axial load to an accuracy of within ±1 percent of the axial load at failure. If the load-measuring device is located inside the triaxial compression chamber, it shall be insensitive to horizontal forces and to the magnitude of the chamber pressure.

5.4. *Triaxial Compression Chamber*—The triaxial chamber must be able to withstand a chamber pressure equal to the sum of the effective confining pressure and back pressure. It shall consist of a top plate and a baseplate separated by a cylinder. The cylinder may be constructed of any material capable of withstanding the applied pressures. It is desirable to use a transparent material or have a cylinder provided with viewing ports so the behavior of the specimen may be observed. The top plate shall have a vent valve such that air can be forced out of the chamber as it is filled. The baseplate shall have an inlet through which pressure liquid is supplied to the chamber.

Note 2—Although the confining fluid for this test is typically a liquid, compressed air or other gases may be successfully used. Use of air or other gases is a safety concern, however, about which the user must be aware and take reasonable safeguards.

5.5. *Axial Load Piston*—The piston passing through the top of the chamber and its seal must be designed so the variation in axial load due to friction does not exceed 0.1 percent of the axial load at failure and so there is negligible lateral bending of the piston during loading.

Note 3—The use of two linear ball bushings to guide the piston is recommended to minimize friction and maintain alignment.

Note 4—A minimum piston diameter of one-sixth the specimen diameter has been used successfully in many laboratories to minimize lateral bending.

5.6. *Chamber Pressure Control Device*—The chamber pressure control device shall be capable of applying and controlling pressure to within 2 kPa (±0.25 psi) for chamber pressures less than 200 kPa (28 psi) and to within ±1 percent for chamber pressures greater than 200 kPa (28 psi). The device may consist of self-compensating mercury pots, pneumatic pressure regulator, or any other device capable of applying and controlling pressures to the required tolerances.

5.7. *Chamber Pressure Measurement Device*—The chamber pressure measuring device shall be capable of measuring pressures to the tolerances given in Section 5.6. It may be a Bourdon gauge, pressure manometer, electronic pressure transducer, or any other device capable of measuring pressures to the stated tolerances.

5.8. *Deformation Indicator*—The vertical deformation of the specimen is usually determined from the travel of the piston acting on the top of the specimen. The piston travel shall be measured with an accuracy of at least ±0.02 percent of the initial specimen height. The deformation indicator shall have a travel range of at least 20 percent of the initial height of the specimen and may be a dial indicator, linear variable differential transformer (LVDT), extensiometer, or other measuring device meeting the requirements for accuracy and range.

5.9. *Specimen Cap and Base*:

5.9.1. *For Total Stress Determination*—An impermeable rigid cap and base shall be used to prevent drainage of the specimen. The specimen cap and base shall be constructed of a noncorrosive impermeable material and each shall have a circular plane surface of contact with the specimen and a circular cross section. The weight of the specimen cap shall produce an axial stress on the specimen of less than 1 kN/m^2 (0.145 psi). The diameter of the cap and base shall be equal to the initial diameter of the specimen. The specimen base shall be coupled to the triaxial compression chamber so as to prevent lateral motion or tilting and the specimen cap shall be designed to receive the piston such that the piston-to-cap contact area is concentric with the cap. The specimen cap during shear shall not tilt more than 5 degrees. The cylindrical surface of the specimen base and cap that contacts the membrane to form a seal shall be smooth and free of scratches.

Note 5—The stress produced by the specimen cap can exceed 1 kN/m^2 (0.145 psi) provided the test data is corrected for the effects of that stress.

5.10. *Rubber Membrane*—The rubber membrane used to encase the specimen shall provide reliable protection against leakage. To check a membrane for leakage, the membrane shall be placed around a cylindrical form, sealed at both ends with rubber O-rings, subjected to a small air pressure on the inside, and immersed in water. If air bubbles appear from any point on the membrane it shall be rejected. To offer minimum restraint to the specimen, the unstretched membrane diameter shall be between 90 and 95 percent of that of the specimen. The membrane thickness shall not exceed 1 percent of the diameter of the specimen. The membrane shall be sealed to the specimen cap and base with rubber O-rings for which the unstressed inside diameter is between 75 and 85 percent of the diameter of the cap and base, or by other means that will provide a positive seal. An equation for correcting the principal stress difference (deviator stress) for the effect of the stiffness of the membrane is given in Section 10.4.3.

5.11. *Specimen-Size Measurement Devices*—Devices used to determine the height and diameter of the specimen shall measure the respective dimensions to within ±0.1 percent of the total dimension and shall be constructed such that their use will not disturb the specimen.

Note 6—Circumferential measuring tapes are recommended over calipers for measuring the diameter.

5.12. *Recorders*—Specimen behavior may be recorded manually or by electronic digital or analog recorders. If electronic recorders are used, it shall be necessary to calibrate the measuring devices through the recorder using known input standards.

5.13. *Sample Extruder*—Hand-operated, mechanical, and hydraulic extruders are acceptable provided the device (1) is capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube, (2) has a length of travel at least equal to the required untrimmed test length of the sample and permits the extrusion to occur in one operation without resetting the piston or extrusion mechanism, (3) can be operated at a relatively uniform rate, and (4) causes negligible disturbance of the sample.

5.14. *Weighing Device*—The specimen weighing device shall determine the mass of the specimen to an accuracy of within ±0.05 percent of the total mass of the specimen.

5.15. *Testing Environment*—The shear portion of the test shall be performed in an environment where temperature fluctuations are less than ±4ºC (±7.2ºF) and there is no direct contact with sunlight.

5.16. *Miscellaneous Apparatus*—Specimen trimming and carving tools including a wire saw, steel straightedge, miter box, and vertical trimming lathe, apparatus for preparing compacted specimens, membrane and O-ring expander, water content cans, and data sheets shall be provided as required.

6. TEST SPECIMEN PREPARATION

6.1. *Specimen Size*—Specimens shall be cylindrical and have a minimum diameter of 3.3 cm (1.3 in.). The height-to-diameter ratio shall be between 2 and 2.5. The largest particle size shall be smaller than one-sixth the specimen diameters. If, after completion of a test, it is found based on visual observation that oversize particles are present, indicate this information in the report of test data (Section 11.1.20).

Note 7—If oversize particles are found in the specimen after testing, a particle-size analysis may be performed in accordance with ASTM D 422 to confirm the visual observation and the results provided with the test report (Section 11.1.4).

6.2. *Undisturbed Specimens*—Prepare undisturbed specimens from large undisturbed samples or from samples secured in accordance with T 207 or other acceptable undisturbed tube sampling procedures and preserved and transported in accordance with the practices for Group C samples in ASTM D 4220. Specimens obtained by tube sampling may be tested without trimming except for cutting the end surfaces plane and perpendicular to the longitudinal axis of the specimen, provided soil characteristics are such that no significant disturbance results from sampling. Handle specimens carefully to minimize disturbance, changes in cross section, or change in water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut the tube in suitable sections to facilitate removal of the specimen with minimum disturbance. Prepare trimmed specimens, in an environment such as a controlled high-humidity room where soil water content change is minimized. Where removal of pebbles or crumbling resulting from trimming causes voids on the surface of the specimen, carefully fill the voids with remolded soil obtained from the trimmings. Where the sample condition permits, a vertical trimming lathe that will accommodate the total sample may be used as an aid in preparing the specimen to the required diameter. After obtaining the desired diameter, place the specimen in a miter box and cut the specimen to the final length with a wire saw or other suitable device. Trim the surfaces with the steel straightedge. Perform one or more water content determinations on material trimmed from the specimen in accordance with ASTM D 2216. Determine the mass and dimensions of the specimen using the devices described in Sections 5.13 and 5.16. A minimum of three height measurements (120° apart) and at least three diameter measurements at the quarter points of the height shall be made to determine the average height and diameter of the specimen.

6.3. *Remolded Specimens*—Prepare the specimen by first thoroughly working the previously undisturbed specimen, which has been tested and is still encased in the rubber membrane, with the fingers. Then reform the specimen by forming within a mold having dimensions such that the remolded specimen dimensions will be equal to those of the undisturbed specimen. Exercise care to avoid entrapping air in the specimen. This will aid in obtaining a uniform unit mass, in remolding to the same void ratio as the undisturbed specimen, and in preserving the natural water content of the soil.

6.4. *Compacted Specimens*—Prepare specimens using the compaction method, predetermined water content, and unit mass prescribed by the individual assigning the test. Compacted specimens may be prepared by compacting material in at least six layers, using a pressing or kneading action, into a split mold of circular cross section having dimensions meeting the requirements of Section 6.1. Material required for the specimen shall be batched by thoroughly mixing soil with sufficient water to produce the desired water content. After batching, store the material in a covered container for at least 16 hours prior to compaction. Specimens may be molded to the desired density by either: (1) kneading or tamping each layer until the accumulative mass of the soil placed in the mold is compacted to a known volume or (2) by adjusting the number of layers, the number of tamps per layer, and the force per tamp. Scarify the top of each layer prior to the addition of material for the next layer. The tamper used to compact the material shall have an area in contact with the soil equal to or less than one-half the area of the mold. After a specimen is formed, with the ends perpendicular to the longitudinal axis, remove the mold and determine the mass and dimensions of the specimen using the devices described in Sections 5.13 and 5.16. Perform one or more water content determinations on excess material used to prepare the specimen in accordance with ASTM D 2216.

Note 8—It is common for the unit mass of the specimen after removal from the mold to be less than the value based on the volume of the mold. This occurs as a result of the specimen swelling after removal of the lateral confinement due to the mold.

Note 9—Experience indicates that it is difficult to compact, handle, and obtain valid results with specimens that have a degree of saturation that is greater than about 90 percent.

7. MOUNTING SPECIMEN

7.1. *Preparations*—Before mounting the specimen in the triaxial chamber, make the following preparations:

7.1.1. If deemed necessary, check the rubber membrane for leaks. (See Section 5.11.)

7.1.2. Place the membrane on the membrane expander or, if it is to be rolled onto the specimen, roll the membrane on the cap or base.

7.1.3. Attach the pressure-control device to the chamber base.

7.2. Place the rubber membrane around the specimen and seal it at the cap and base with two rubber O-rings or other positive seal at each end. A thin coating of silicon grease on the vertical surfaces of the cap and base will aid in sealing the membrane.

8. PROCEDURE

8.1. *For total stress determination*:

8.1.1. With the specimen encased in the rubber membrane, which is sealed to the specimen cap and base and positioned in the chamber, assemble the triaxial chamber. Bring the axial load piston into contact with the specimen cap several times to permit proper seating and alignment of the piston with the cap. When the piston is brought into contact the final time, record the reading on the deformation indicator. During this procedure, take care not to apply an axial stress to the specimen exceeding approximately 0.5 percent of the estimated compressive strength. If the mass of the piston is sufficient to apply an axial stress exceeding approximately 0.5 percent of the estimated compressive strength, lock the piston in place above the specimen cap after checking the seating and alignment and keep locked until application of the chamber pressure.

8.1.2. Place the chamber in position in the axial loading device. Be careful to align the axial loading device, the axial load-measuring device, and the triaxial chamber to prevent the application of a lateral force to the piston during testing. Attach the pressure-maintaining and measurement device and fill the chamber with the confining liquid. Adjust the pressure-maintaining and measurement device to the desired chamber pressure and apply the pressure to the chamber fluid. If it is determined to be necessary to stabilize the specimen under the chamber pressure prior to application of the axial load, wait approximately 10 minutes after applying chamber pressure before continuing the test.

Note 10—In some cases the chamber will be filled and the chamber pressure applied before placement in the axial loading device.

Note 11—Make sure the piston is locked or held in place by the axial loading device before applying the chamber pressure.

Note 12—The purpose of the waiting period is to allow the specimen to stabilize under the chamber pressure prior to application of the axial load.

8.1.3. If the axial load-measuring device is located outside of the triaxial chamber, the chamber pressure will produce an upward force on the piston that will react against the axial loading device. In this case, start the test with the piston slightly above the specimen cap, and before the piston comes in contact with the specimen cap, either: (1) measure and record the initial piston friction and upward thrust of the piston produced by the chamber pressure and later correct the measured axial load, or (2) adjust the axial load-measuring device to compensate for the friction and thrust. If the axial load-measuring device is located inside the chamber, it will not be necessary to correct or compensate for the uplift force acting on the axial loading device or for piston friction. In both cases record the initial reading on the deformation indicator when the piston contacts the specimen cap.

8.1.4. Apply the axial load to produce axial strain at a rate of approximately 1 percent/min for plastic materials and 0.3 percent/min for brittle materials that achieve maximum deviator stress at approximately 3 to 6 percent strain. At these rates, the elapsed time to reach maximum deviator stress will be approximately 15 to 20 minutes. Continue the loading to 15 percent axial strain, except loading may be stopped when the deviator stress has peaked, then dropped 20 percent, or the axial strain has reached 5 percent beyond the strain at which the peak in deviator stress occurred.

8.1.5. Record load and deformation values at about 0.1, 0.2, 0.3, 0.4, and 0.5 percent strain; then at increments of about 0.5 percent strain to 3 percent; and, thereafter, at every 1 percent. Take sufficient readings to define the stress-strain curve; hence, more frequent readings may be required in the early stages of the test and as failure is approached.

Note 13—Alternate intervals for the readings may be used provided sufficient points are obtained to define the stress-strain curve.

8.1.6. For completion of the total stress determination, proceed to Section 9 and applicable portions of Section 10.

9. REMOVING SPECIMEN

9.1. When shear is completed, perform the following steps:

9.1.1. Remove the axial load and reduce the chamber and back pressures to zero.

9.1.2. With the specimen drainage valves remaining closed, quickly remove the specimen from the apparatus so the specimen will not have time to absorb water from the porous discs.

9.1.3. Remove the rubber membrane and determine the water content of the total specimen in accordance with the procedure outlined in ASTM D 2216. (Free water remaining on the specimen after removal of the membrane should be blotted away before obtaining the water content.) In cases where there is insufficient material from trimmings for index property tests, that is, where specimens have the same diameter as the sampling tube, the mass of the specimen should be determined prior to removing material for index property tests and a representative portion of the specimen used to determine its final water content. Prior to placing the specimen (or portion thereof) in the oven to dry, sketch a picture or take a photograph of the specimen showing the mode of failure (shear plane, bulging, etc.).

10. CALCULATIONS

10.1. *Initial Specimen Properties*—Using the dry mass of the total specimen, calculate and record on the appropriate data sheet the initial water content, volume of solids, initial void ratio, initial degree of saturation, and initial dry unit mass. Calculate the specimen volume from values measured in Section 6.2 or 6.3. Calculate the volume of solids by dividing the dry mass of the specimen by the specific gravity of the solids (Note 14) and dividing by the density of water. Calculate the void ratio by dividing the volume of voids by the volume of solids where the volume of voids is assumed to be the difference between the specimen volume and the volume of the solids. Calculate dry density by dividing the dry mass of the specimen by the specimen volume.

Note 14—The specific gravity of solids can be determined in accordance with Test Method T 100 or it may be assumed based on previous test results.

10.2. Calculate the axial strain, $\in$ (expressed as a decimal), for a given applied axial load, as follows:

$$\in = \Delta L/L_o \qquad (1)$$

where:

ΔL = change in length of specimen as read from deformation indicator, and

L_o = initial length of test specimen minus any change in length prior to loading.

10.3. Calculate the average cross-sectional area, A, for a given applied axial load as follows:

$$A = A_o/(1 - \in) \qquad (2)$$

where:

A_o = initial average cross-sectional area of the specimen, and

$\in$ = axial strain for the given axial load (expressed as a decimal).

Note 15—In the event that the application of the chamber pressure results in a change in the specimen length, A_o should be corrected to reflect this change in volume. Frequently, this is done by assuming that lateral strains are equal to vertical strains. The diameter after volume change would be given by $D = D\sigma\ (1 - \Delta L/L)$.

10.4. For determination of total stress:

10.4.1. Calculate the principal stress difference (deviator stress), $\sigma_1 - \sigma_3$, for a given applied axial load as follows:

$$\sigma_1 - \sigma_3 = P/A \qquad (3)$$

where:

P = measured applied axial load (corrected for uplift and piston friction; if required, see Section 8.2.5.1.3), and

A = corresponding average cross-sectional area.

10.4.2. *Stress-Strain Curve*—Prepare a graph showing the relationship between principal stress difference (deviator stress) and axial strain, plotting deviator stress as ordinate and axial strain (in percent) as abscissa. Select the compressive strength and axial strain at failure in accordance with the definitions in Sections 3.2.3 and 3.2.6.

10.4.3. *Correction of Strength Due to Stiffness of Rubber Membrane*—Assuming units are consistent, the following equation, or other acceptable equations, shall be used to correct the principal stress difference or deviator stress for the effect of the rubber membrane if the error in principal stress difference due to the stiffness of the membrane exceeds 5 percent:

$$\Delta(\sigma_1 - \sigma_3) = \frac{4E_m t \in_1}{D} \quad (4)$$

where:

$\Delta(\sigma_1 - \sigma_3)$ = correction to be subtracted from the measured principal stress difference,

D = $\sqrt{\frac{4A}{\pi}}$ = diameter of specimen,

E_m = Young's modulus for the membrane material,

t = thickness of the membrane, and

$\in_1$ = axial strain.

10.4.3.1. The Young's modulus of the membrane material may be determined by hanging a 12.5-mm (0.5-in.) wide strip of membrane over a thin rod, placing another rod along the bottom of the hanging membrane, and measuring the force per unit strain obtained by stretching the membrane. The modulus value may be computed using the following equation assuming units are consistent:

$$E_m = \frac{FL}{A_m \Delta L} \quad (5)$$

where:

E_m = Young's modulus of the membrane material,

F = force applied to stretch the membrane,

L = unstretched length of the membrane,

A_m = twice the initial thickness of the membrane multiplied by the width of the membrane strip, and

ΔL = change in length of the membrane due to application of F.

A typical value of E_m for latex membrane is 200 psi (1400 kPa).

Note 16—The effect of the stiffness of the membrane on the lateral stress is usually assumed to be negligible.

Note 17—The correction for rubber membranes is based on simplified assumptions concerning their behavior during shear. Their actual behavior is complex and there is not a consensus on more exact corrections.

10.4.4. Calculate the major and minor principal total stresses at failure as follows:

σ_3 = minor principal total stress = chamber pressure, and

σ_1 = major principal total stress = deviator stress at failure plus chamber pressure.

10.4.4.1. Calculate the initial degree of saturation of the test specimen using the initial mass and dimensions.

Note 18—The specific gravity determined in accordance with Test Method T 100 is required for calculation of the degree of saturation, or an assumed value may be used provided it is noted in the test report that an assumed value was used.

11. REPORT

11.1. The report shall include the following (as applicable):

11.1.1. Identification data and visual description of specimen, including soil classification and whether the specimen is undisturbed, compacted, or otherwise prepared.

11.1.2. Values of plastic limit and liquid limit, if determined in accordance with Test Methods T 89 and T 90.

11.1.3. Value of specific gravity of solids and notation if the value was determined in accordance with Test Method T 100 or assumed.

11.1.4. Particle-size analysis, if determined in accordance with ASTM D 422.

11.1.5. Initial specimen dry unit weight, void ratio, water content, and percent saturation.

11.1.6. Initial height and diameter of specimen.

11.1.7. Failure criterion used.

11.1.8. The value of the principal stress difference (deviator stress) at failure and the values of the effective minor and major principal stresses at failure.

11.1.9. Axial strain at failure, percent.

11.1.10. Rate of strain, percent/min.

11.1.11. Stress-strain curve as described in Section 10.4.2.

11.1.12. Failure sketch or photograph of the specimen.

11.1.13. Remarks and notations regarding any unusual conditions or other information necessary to properly interpret the results obtained, including any departures from the procedure outlined.

12. PRECISION AND BIAS

12.1. The variability of soil and resultant inability to determine a true reference value prevent development of a meaningful statement of bias. Data are being evaluated to determine the precision of this test method. In addition, the subcommittee is seeking pertinent data from users of this test method.

13. KEYWORDS

13.1. Back pressure saturation; unconsolidated-undrained triaxial compression test; effective stress; pore pressure; shear strength; strength envelope; total stress.

Standard Method of Test for

Consolidated, Undrained Triaxial Compression Test on Cohesive Soils

AASHTO Designation: T 297-94 (2007)
ASTM Designation: D 4767-88$^{\in 1}$

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Consolidated, Undrained Triaxial Compression Test on Cohesive Soils

AASHTO Designation: T 297-94 (2007)

ASTM Designation: D 4767-88$^{\in 1}$

AASHTO T 297-94 (2007) is identical to ASTM D 4767-88$^{\in 1}$ except that all references to the ASTM standards contained in ASTM D 4767-88$^{\in 1}$, listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standards

ASTM	AASHTO
D 854	T 100
D 1587	T 207
D 2166	T 208
D 2435	T 216
D 4318	T 89 and T 90

Standard Method of Test for

High-Strain Dynamic Testing of Piles

AASHTO Designation: T 298-99 (2006)[1]

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Standard Method of Test for

High-Strain Dynamic Testing of Piles

AASHTO Designation: T 298-99 (2006)[1]

1. SCOPE

1.1. This test method covers the procedure for testing vertical or batter piles individually to determine the force and velocity response of the pile to an impact force applied axially by a pile-driving hammer to the top of the pile. This test method is applicable to deep foundation units that function in a manner similar to foundation piles, regardless of their method of installation, provided that they are receptive to high-strain impact testing. These elements can include drilled shafts, micropiles, and continuous flight auger cast piles.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*. For a specific precautionary statement, see Note 7.

Note 1—High-strain dynamic testing requires a strain at impact which is representative of a force in the pile having the same order of magnitude, or greater, than the ultimate pile-soil resistance.

Note 2—This standard method may be applied to the high-strain dynamic testing of piles with the use of only force or strain transducers and/or acceleration, velocity or displacement transducers as long as the test results clearly state how the testing deviates from the standard, i.e., what combination of instruments was used.

Note 3—A suitable follower may be required for testing existing cast-in-place concrete piles. This follower should have an impedance within 50 percent of the impedance of the pile. However, additional caution and analysis may be required if the impedance is not within 10 percent.

Note 4—For mandrel-driven piles, the mandrel may be instrumented in a similar way to a driven pile. However, results from a mandrel that is more than two pieces, one that has joints, will require additional analysis.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- C 469, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression[2]
- D 198, Standard Test Methods of Static Tests of Lumber in Structural Sizes[3]
- D 653, Standard Terminology Relating to Soil, Rock, and Contained Fluids[4]
- D 1143, Standard Test Methods for Deep Foundations Under Static Axial Compressive Load[4]

3. TERMINOLOGY

3.1. Except as defined in Section 3.2, the terminology used in this test method conforms with Terminology ASTM D 653.

3.2. *Descriptions of Terms Specific to This Standard*:

3.2.1. *capblock*—the material inserted between the hammer striker plate and the drive cap on top of the pile (also called the hammer cushion).

3.2.2. *cushion*—the material inserted between the drive cap and top of the pile (also called the pile cushion).

3.2.3. *impact event*—the period of time during which the pile is moving in a positive and/or negative direction of penetration due to a single impact force application. (See Figure 1.)

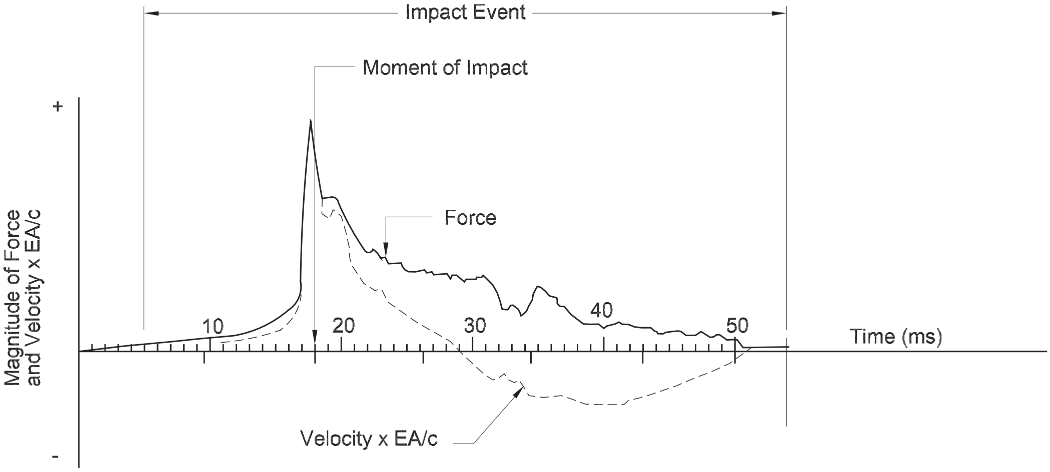


Figure 1—Typical Force and Velocity Traces Generated by the Apparatus for Obtaining Dynamic Measurements

3.2.4. *moment of impact*—the first moment of time after the start of the impact event when the acceleration is zero, i.e., first major velocity peak. (See Figure 1.)

3.2.5. *strain wave speed (or wave speed)*—the speed with which a strain wave propagates through a pile. It is a property of the pile material.

3.2.6. *particle velocity*—the velocity of a particle in the pile as a strain wave passes by.

3.2.7. *pile impedance*—indicates the resistance a pile has to a sudden change in velocity. It can be calculated by multiplying Young's Modulus of Elasticity by the cross-sectional area and dividing the product by the strain wave speed (proportionality constant):

$$Z = AE/c = \rho cA \quad (1)$$

where:

Z = impedance,

A = cross-sectional area,

E = Young's Modulus of Elasticity,

c = wave speed of the pile, and

ρ = unit mass density of the pile material.

3.2.8. *restriking*—the redriving of a previously driven pile after a waiting period of from 15 minutes to 30 days or more. The length of the waiting period is dependent upon the type of pile and the soil.

3.2.9. *transducer attachment area (TAA)*—an extension of non-driven elements used to attach the instruments the minimum distance from the top of the column. The minimum length of the TAA is two element diameters. This length can be achieved by using a buildup to extend the column height and/or by excavation of the soil, from around the existing column.

4. SIGNIFICANCE AND USE

4.1. This test method is used to provide data on strain or force and acceleration, velocity or displacement of a pile under impact force. The data may be used to estimate the bearing capacity and the integrity of the pile, as well as hammer performance, pile stresses, and soil dynamics characteristics such as soil damping coefficients and quake values.

5. APPARATUS

5.1. *Apparatus for Applying Impact Force*:

5.1.1. *Impact Force Application*—Any conventional pile-driving hammer or similar device is acceptable for applying the impact force. The hammer or device should be capable of generating:

- A net measurable pile penetration, or
- An estimated mobilized static resistance in the bearing strata which, for a minimum period of three minute, exceeds to a sufficient degree the working load assigned to the pile, as judged by the engineer.

The device shall be positioned so that the impact is applied axially to the head of the pile and concentric with the pile. For non-driven piles the concrete should be level with or above any casing. The top should be fitted with a cushioning material with a thickness of 50 to 150 mm. The final thickness shall be determined from a wave equation study. A steel striker plate, minimum thickness of 50 mm, and an area between 70 and 90 percent of the shaft area, but not less than the area of the impact weight.

Note 5—If protruding reinforcing bars are present, the contractor has the option to incorporate the reinforcing bars inside the TAA, or use a pedestal follower (see Note 3).

5.2. *Apparatus for Obtaining Dynamic Measurements*:

5.2.1. *Measurement Transducer Requirements*—The apparatus shall include transducers that are capable of independently measuring strain and acceleration versus time at a specific location along the pile axis during the impact event. The transducers should have a natural frequency in excess of 2000 Hz once they are attached to the pile. A minimum of two each of these devices shall be attached securely to the pile so that they do not slip. Bolt-on, glue-on or weld-on transducers are acceptable. The transducers shall have been calibrated to an accuracy of two percent throughout the applicable measurement range. If damage is suspected during use, the transducers shall be replaced or recalibrated.

5.2.2. *Location of Transducers*—The measurement transducers shall be located at equal radial distances on diametrically opposite sides of the pile. They shall be located the same axial distance from the bottom of the pile, so that measurements are not affected by bending of the pile. When near the upper end of the pile, they shall be attached at least one and one-half pile diameters from the head; where practicable this distance should be three diameters. When testing large diameter piles or non-driven elements it is recommended to use four transducers, if practicable. Attaching transducers to a TAA, created with a casing, will require cutting windows in the casing to access the concrete. The windows should be a minimum of 15 cm square. This is illustrated in Figures 4 through 7.

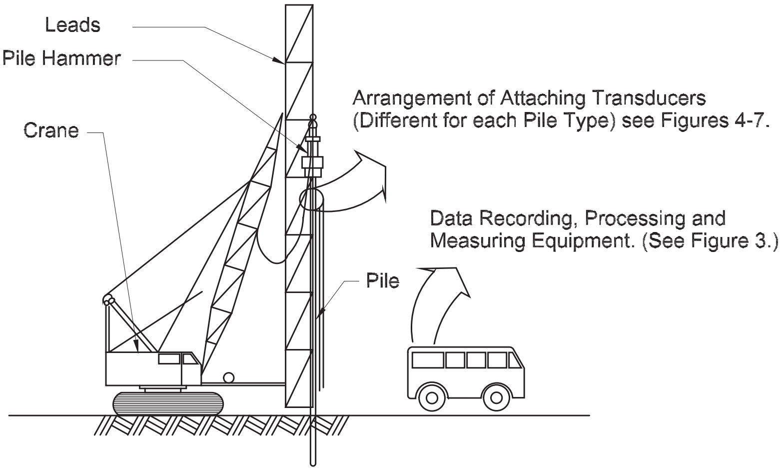


Figure 2—Typical Arrangement for High-Strain Testing

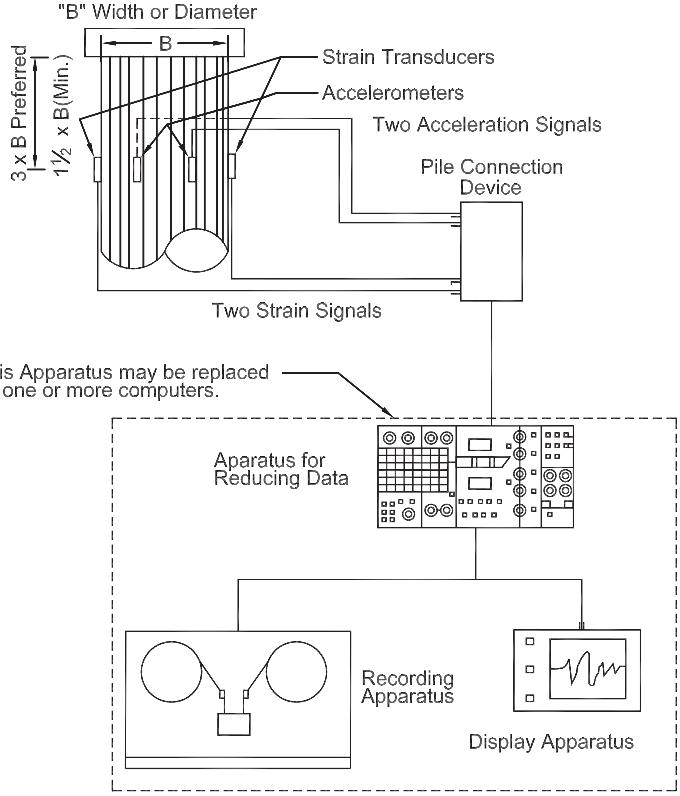
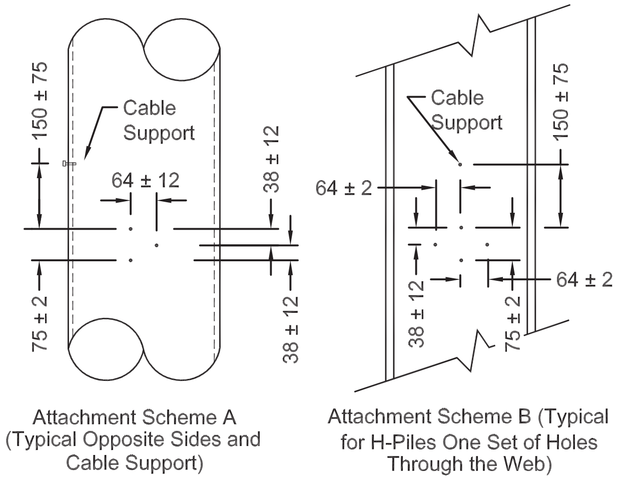


Figure 3—Schematic Diagram of Apparatus for Dynamic Monitoring of Piles



Note: All dimensions shown in millimeters unless otherwise noted.

Figure 4—Instrument Attachment Schemes and Dimensions

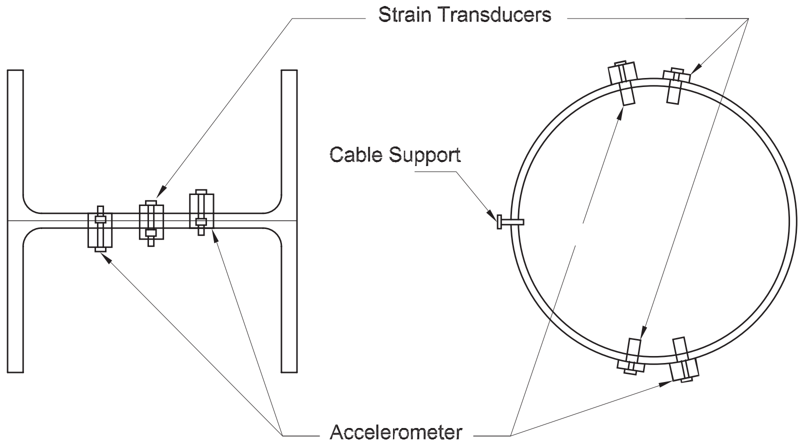


Figure 5—Typical Attachment for H-Piles and Pipe Piles

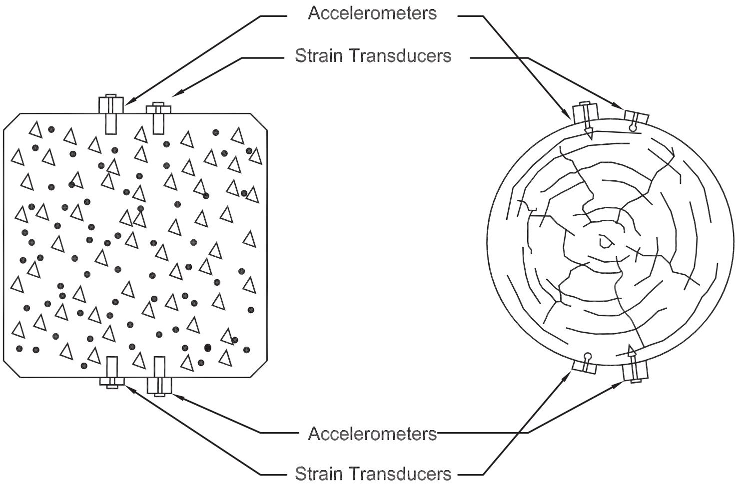


Figure 6—Typical Attachment for Concrete and Timber Piles

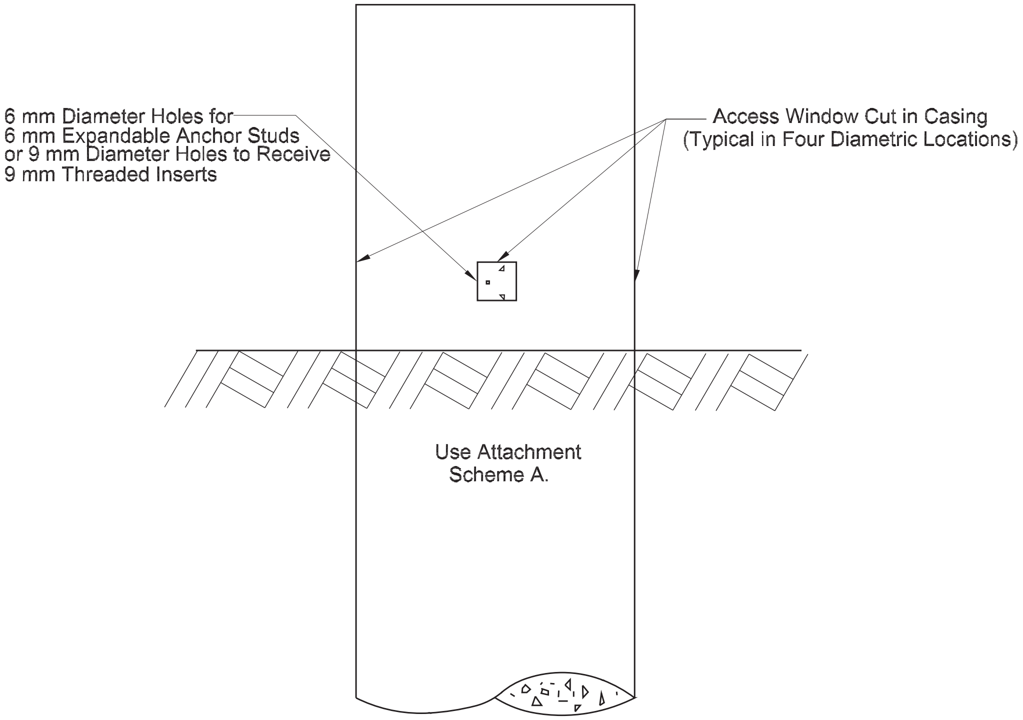


Figure 7—Typical Arrangement for Attaching Transducers to a Non-Driven Pile

5.2.3. *Force or Strain Transducers*—The strain transducers shall have a linear output over the range of possible pile strains. The measured strain shall be converted to force using the pile cross-section area and dynamic modulus of elasticity at the measuring location. The dynamic modulus of elasticity may be assumed to be 200 to 207 GPa for steel. The dynamic modulus of elasticity for concrete and wood piles may be calculated from the wave speed determined as indicated in Section 6.2. The dynamic modulus of elasticity is equal to the product of the strain wave speed squared and the unit weight of the pile divided by gravity.

$$E = c^2 \gamma / g = c^2 \rho \qquad (2)$$

where:

E = dynamic modulus of elasticity,

c = wave speed of pile,

γ = unit weight of pile material,

g = gravity, and

ρ = unit mass density of the pile material.

Alternatively, the dynamic modulus of elasticity may be estimated from the static modulus of elasticity by measurement during a compression test in accordance with ASTM C 469 and D 198, for concrete and wood, respectively.

5.2.3.1. Force measurements also can be made by a force transducer, an instrumented unit, placed between the pile head and the driving hammer, although it should be recognized that such a transducer may alter the dynamic characteristics of the driving system. Force transducers shall have an impedance between 50 percent and 200 percent of the pile impedance. The output signal must be linearly proportional to the axial force, even under eccentric load application. The connection between the force transducers and the pile shall have the smallest possible mass and least possible cushion necessary to prevent damage.

5.2.4. *Acceleration, Velocity, or Displacement Transducers*—Velocity data shall be obtained with accelerometers, provided the signal can be processed by integration in the apparatus for reducing data. The accelerometers shall be linear to at least 1000 g and 1000 Hz for satisfactory results on concrete and timber piles. For steel piles, it is advisable to use accelerometers that are linear up to 2000 g and 2000 Hz. Either ac or dc accelerometers can be used. If ac devices are used, the resonant frequency shall be above 50,000 Hz and the time constant shall be at least 1.0 second. Alternatively, velocity or displacement transducers may be used to obtain velocity data, provided they are equivalent in performance to the specified accelerometers.

5.3. *Signal Transmission*—The signals from the transducers shall be transmitted to the apparatus for recording, reducing, and displaying the data (see Section 5.4) by means of a cable or equivalent. The means of signal transmission shall limit electronic or other interference to less than three percent of the maximum signal expected. The signals arriving at the apparatus shall be linearly proportional to the measurements at the pile over the frequency range of the equipment.

5.4. *Apparatus for Recording, Reducing, and Displaying Data*:

5.4.1. *General*—The signals from the transducers (see Section 5.2) during the impact event shall be transmitted to an apparatus for recording, reducing, and displaying data to allow determination of the force and velocity versus time. It may be desirable to also determine the acceleration and displacement of the pile head, and the energy transferred to the pile. The apparatus shall include an oscilloscope, oscillograph, or LCD screen for displaying the force and velocity traces; a tape recorder, digital disk, or equivalent for obtaining a record for future analysis; and a means to reduce the data. The apparatus for recording, reducing, and displaying data shall have the capability of making an internal calibration check of strain, acceleration, and time scales. No error shall exceed two percent of the maximum signals expected. A typical schematic arrangement for this apparatus is illustrated in Figure 3.

5.4.2. *Recording Apparatus*—Signals from the transducers shall be recorded electronically in either analog or digital form so that frequency components have a low pass cut-off frequency of 1500 Hz (–3 dB). When digitizing, the sample frequency shall be at least 5000 Hz for each data channel.

5.4.3. *Apparatus for Reducing Data*—The apparatus for reducing signals from transducers shall be an analog or digital computer capable of at least the following functions:

5.4.3.1. *Force Measurements*—The apparatus shall provide signal conditioning, amplification, and calibration for the force measurements system. If strain transducers are used (see Section 5.2.3), the apparatus shall be able to compute the force. The force output shall be continuously balanced to zero except during the impact event.

5.4.3.2. *Velocity Data*—If accelerometers are used (see Section 5.2.4), the apparatus shall integrate the acceleration over time to obtain velocity. If displacement transducers are used, the apparatus shall differentiate the displacement over time to obtain velocity. If required, the apparatus shall zero the velocity between impact events and shall adjust the velocity record to account for transducers' zero drift during the impact event.

5.4.3.3. *Signal Conditioning*—The signal conditioning for force and velocity shall have equal frequency response curves to avoid relative phase shifts and relative amplitude differences.

5.4.4. *Display Apparatus*—Signals from the transducers specified in Section 5.2 shall be displayed by means of an apparatus, such as an oscilloscope, oscillograph, or LCD screen on which the force and the product of velocity and impedance versus time can be observed for each hammer blow. This apparatus may receive the signals from the transducers directly or after they have been processed by the apparatus for reducing the data. The apparatus shall be adjustable to reproduce a signal having a duration of between 5 and 160 ms. Both the force and velocity data can be reproduced for each blow and the apparatus shall be capable of holding and displaying the signal from each selected blow for a minimum period of 30 seconds.

6. PROCEDURE

6.1. *General*—Record applicable project information (Section 7). Attach the transducers (see Section 5.2) to the pile, perform the internal calibration check and take the dynamic measurements for the impacts during the interval to be monitored together with routine observations of penetration resistance. Determine properties during initial driving. The recommended minimum for determining dynamic properties is 10 blows. However, concrete piles in an easy driving condition may preclude striking the pile this many times. If a restrike is necessary to determine the bearing capacity of the piling, the data from the first one or two blows should normally be used to determine the bearing capacity of the piling. The force and velocity versus time signals may be reduced by the apparatus for reducing data or by a computer or may be reduced manually to calculate the developed force, velocity, acceleration, displacement, and energy over the impact event.

6.2. *Determination of Strain Wave Speed for Concrete and Wood Piles (See Figure 8)*—Wave speeds should be determined for each concrete or timber pile tested. The strain wave speed should be determined from the impact event if a tensile reflection wave from the pile toe is clearly identified. Alternatively, place the pile on supports or level ground free and clear from neighboring piles and obstructions. Attach accelerometer to one end of the pile and strike the end of the pile with a sledge hammer of suitable weight. Take care not to damage or dent the pile. Record (see Section 5.4.2) and display (see Section 5.4.4) the accelerometer signal. Measure the time between acceleration peaks of as many cycles of reflection as possible. However, the first impact should not be counted. Divide this time by the appropriate travel length of the strain waves during this interval to determine the wave speed.

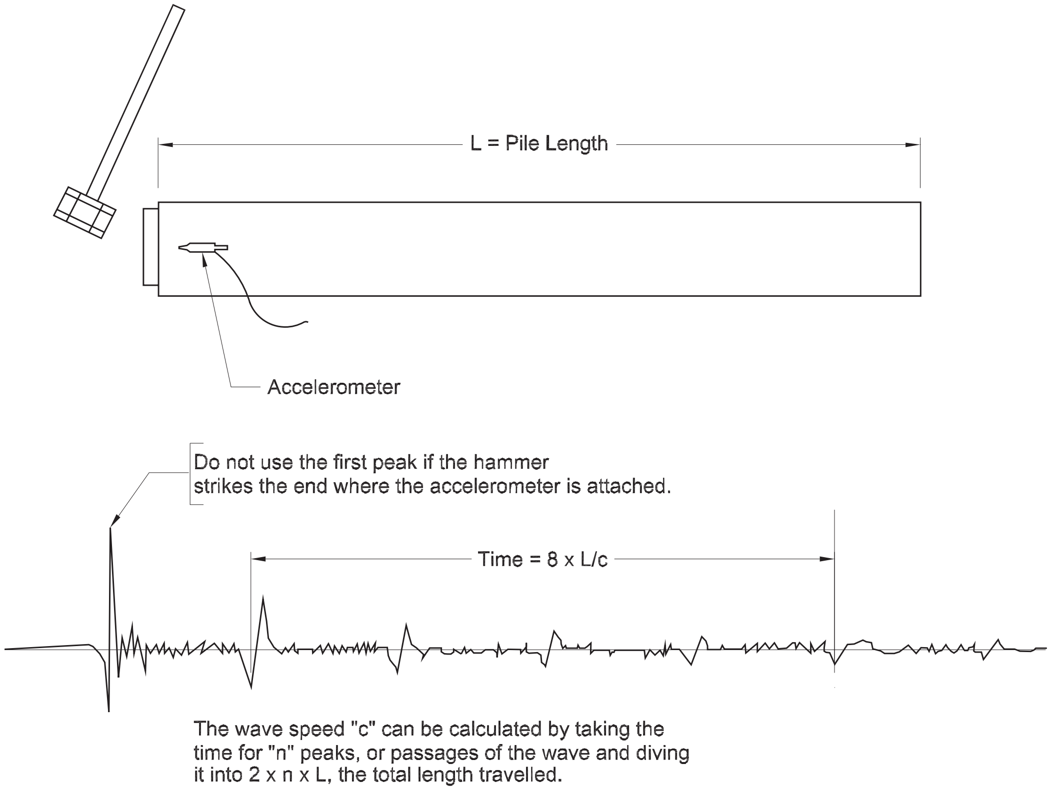


Figure 8—Wave Speed Determination for Concrete and Timber Piles

6.3. *Preparation*—Mark the piles clearly at appropriate intervals. Attach the transducers securely to the piles by bolting, gluing, or welding. For pile materials other than steel, determine the wave speed (see Section 6.2). Position the apparatus for applying the impact force so that the force is applied axially and concentrically with the pile. Set up the apparatus for recording, reducing, and displaying data so that it is operational and the force and velocity signals are zeroed.

6.4. *Taking Measurements*—Record the number of impacts for a specific penetration. For drop hammers and single acting diesel and air/steam hammers, record the drop of the ram or ram travel length. For double-acting diesel hammers, measure the bounce chamber pressure and, for double-acting steam or compressed-air hammers, measure the steam or air pressure in the pressure line to the hammer. For all movements record the number of blows per minute delivered by the hammer. Take, record, and display a series of force and velocity measurements. Compare the force and the product of velocity and impedance (see Section 3.2.7) at the moment of impact.

Note 6—If the dynamic measurements are to be used for bearing capacity computations, take the dynamic measurements during restriking of the pile at time periods sufficiently long after the end of initial driving to allow pore water pressure and soil strength changes to occur. The capacity of the pile is the pile-soil resistance. It does not address pile settlement due to underlying compressible layers.

Note 7—**Warning**: Before approaching a pile being driven, check that no material or other appurtenances can break free and jeopardize the safety of people in the vicinity.

6.5. *Data Quality Checks*—For confirmation of data quality, periodically compare the force and the product of the velocity and pile impedance at the moment of impact for proportionality agreement. The force and the product of velocity and pile impedance versus time should be checked for consistency and proportionality over a series of selected and generally consecutive impact events.

Consistent and proportional signals from the force or strain transducers and the acceleration, velocity, or displacement transducers are the result of the transducer systems and the apparatus for recording, reducing, and displaying data being properly calibrated. If the signals are not in proportionality agreement, investigate the cause and correct the situation if necessary. If the cause is determined to be a transducer, it must be recalibrated before further use. Perform internal calibration checks at the beginning and end of each data set.

Note 8—For purposes of calibration, the apparatus for obtaining dynamic measurements and the apparatus for recording, reducing, and displaying data can be placed in three categories:
(a) Those which can be checked by the user.
(b) Those which can be checked and calibrated by the user.
(c) Those which can only be checked and calibrated by the manufacturer.

It is recommended that types a and b be checked before each trip to a site and calibrated as necessary. It is recommended that type c apparatus be calibrated at least once every two years.

6.6. *Analysis of Measurements*:

6.6.1. Obtain force and velocity from the readout of the apparatus for reducing data (see Section 5.4.3) or from the display apparatus (see Section 5.4.4). Record the impact force and velocity and the maximum and minimum forces for the selected representative blows. Obtain the maximum acceleration directly from the accelerometer signal or by differentiation of the velocity versus time record. Obtain the displacement from the pile-driving record or from the displacement transducer, if used in accordance with Section 5.2.4, or by integration of the velocity versus time record. Obtain the maximum energy transferred to the location of the transducers.

6.6.2. The recorded data may be subjected to analysis by a computer. The results of the analysis may include an assessment of integrity of the pile, the driving system performance, and the maximum dynamic driving stresses. The results may also be used for evaluation of static soil resistance and its distribution on the pile at the time of the testing. Such further use of the data is a matter of proper engineering judgment.

Note 9—Normally, there is better correlation between mobilized resistance and bearing capacity where there is a measurable net penetration per impact. In a majority of cases, blow counts should not exceed 35 blows per decimeter, so as to achieve the best correlation.

Note 10—Evaluation of static soil resistance and its distribution can be based on a variety of analytical methods and is the subject of individual engineering judgment. The input into the analytical methods may or may not result in the dynamic evaluation matching static load test data. It is desirable and sometimes necessary to calibrate the result of the dynamic analysis with those of a static pile load test carried out according to ASTM D 1143.

7. REPORT

7.1. The report of the dynamic testing shall include all the following information, as applicable to the type of pile being tested. Any required information that could not be obtained should be indicated in the testing report as “not available.”

7.1.1. *General*:

7.1.1.1. Project identification;

7.1.1.2. Project location;

7.1.1.3. Test site location;

7.1.1.4. Log of nearest test boring;

7.1.2. *Pile Installation Equipment*:

7.1.2.1. Make and model of the equipment used for either driving or drilling the test pile(s) and/or the testing of the pile(s).

7.1.2.2. Weight of hammer and ram;

7.1.2.3. Rated and actual stroke of ram;

7.1.2.4. Rated energy of hammer;

7.1.2.5. Rated capacity of boiler or compressor;

7.1.2.6. Type, dimensions, and stiffness values of hammer cushion and pile cushion;

7.1.2.7. Weight and dimensions of drive cap;

7.1.2.8. Description of the lead type (fixed, semifixed, or swinging); and

7.1.2.9. Description of any special installation equipment such as followers, mandrels, augering, or jetting.

7.1.3. *Test Piles*:

7.1.3.1. Identification and location of test pile(s),

7.1.3.2. Working load and safety factor (or required ultimate resistance) of pile(s),

7.1.3.3. Type and dimensions of pile(s) including cross-sectional area, length, and diameter (as a function of the length for timber and composite piles),

7.1.3.4. Description of pile tip reinforcement or protection,

7.1.3.5. Description and location of splices, if applicable.

7.1.3.6. Description of special coating used, if applicable.

7.1.3.7. Which piles were vertical or batter,

7.1.3.8. Degree of batter,

7.1.3.9. For concrete piles, cast-in-place pipe piles (tested after filling) and drilled shafts:

- dates that the test piles were cast or installed
- design concrete strength
- description of internal reinforcement used in test pile (size, length, number longitudinal bars, arrangement, spiral, or tie steel)

- condition of precast piles including spalled areas, cracks, head surface, and straightness of piles
- the effective prestress, if applicable

7.1.3.10. For steel piles:

- steel grade
- yield strength
- type of pile (seamless or spiral welded pipe, with wall thickness of pipe or H section)

7.1.3.11. For timber piles:

- general quality of the test pile(s) including type of timber, occurrence of knots, splits, checks and shakes, and straightness of pile(s)
- the density of the material
- preservative treatment, if any
- description of banding, if any

7.1.4. *Pile Installation*:

7.1.4.1. Date driven (installed),

7.1.4.2. Date concreted (cast-in-place),

7.1.4.3. Cause and duration of interruptions in pile installation, and,

7.1.4.4. Notation of any unusual occurrences during installation,

7.1.4.5. For drilled shafts or micropiles:

- nominal size of auger or casing used
- volume of concrete or grout placed in the pile (volume versus depth, if available)
- a description of special installation procedure such as casing installation or removal
- grout pressure used, if applicable

7.1.4.6. For driven piles:

- when hammer and pile cushions were replaced, if applicable
- description of pre-excavation or jetting (depth, size, pressure, duration)
- driving records, including blow counts, hammer stroke, and/or operating level, especially for final penetration and/or restrike

7.1.5. *Dynamic Testing*:

7.1.5.1. Description, calibration data, and date of calibration of all components of the apparatus for obtaining dynamic measurements and apparatus for recording, reducing, and displaying data,

7.1.5.2. Date tested,

7.1.5.3. Test pile identification,

7.1.5.4. The modulus of elasticity, density, and wave speed of test pile, and how determined, 7.1.5.5. Where in the sequence of pile-driving operations the test was carried out, such as end of initial driving, beginning of restrike,

7.1.5.6. Length of pile, as being driven, the length embedded and the length below apparatus for obtaining dynamic measurements,

7.1.5.7. Penetration resistance during dynamic testing,

7.1.5.8. The range, average, and standard deviation of the measurements of maximum and minimum compression force,

7.1.5.9. The range, average, and standard deviation of the impact velocity data,

7.1.5.10. The range, average, and standard deviation of the measurements of maximum acceleration,

7.1.5.11. The range, average, and standard deviation of the measurements of final penetration of the pile,

7.1.5.12. The range, average, and standard deviation of the maximum and final energy data,

7.1.5.13. Which one-dimensional wave theory was used for the analysis of the pile driving; give reference (i.e., program name and version),

7.1.5.14. The variable entered into the wave theory, such as damping, quake, and resistance,

7.1.5.15. When applicable, the computed soil resistance acting on the pile at the time of testing and how computed, and

7.1.5.16. Comments on the integrity of the pile.

Note 11—Data on the forces, velocity, acceleration, penetration, and energy can be recorded at any point of interest during the pile driving. The standard deviation of these values should be calculated for a minimum of 20 consecutive hammer blows.

8. PRECISION AND BIAS

8.1. *Precision*—The precision of the procedure in this test method for direct measurements of strain and acceleration is difficult to determine because of the variability of the pile-driving hammer and the materials in which the pile is located. Information is being gathered on the precision of the procedure.

8.2. *Bias*—No justifiable statement of bias can be made on the procedure in this test method because there are no standard values to which the measured values can be referenced.

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[1] Except for Section 5.2, this standard is in general conformance to ASTM D 4945.
[2] *Annual Book of ASTM Standards*, Vol. 04.02.
[3] *Annual Book of ASTM Standards*, Vol. 04.09.
[4] *Annual Book of ASTM Standards*, Vol. 04.08.

Standard Method of Test for

Progressing Auger Borings for Geotechnical Explorations

AASHTO Designation: T 306-98 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Progressing Auger Borings for Geotechnical Explorations

AASHTO Designation: T 306-98 (2006)

1. SCOPE

1.1. This practice covers equipment and procedures for the use of earth augers in geotechnical subsurface explorations.

1.2. This procedure is applicable in soils that permit auger drilling to obtain representative or *in situ* samples and when information concerning resistance to driving casing or drive pipe is not necessary.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 206, Penetration Test and Split-Barrel Sampling of Soils
- T 207, Thin-Walled Tube Sampling of Soils

3. SIGNIFICANCE AND USE

Auger borings provide a simple method of soil investigations and sampling. They are used for collecting representative, split-spoon or undisturbed tube samples, determining groundwater levels, observing changes in earth strata, and setting of slope inclinometers. Depths of auger investigations are, however, limited by groundwater conditions, soil characteristics, and the equipment used.

4. APPARATUS AND DEFINITIONS

4.1. *Hand-Operated Augers for Obtaining Soil Samples*:

4.1.1. *helical augers*—small lightweight augers generally available in sizes from 25.4 through 76.2 mm (1 through 3 in.) in diameter.

4.1.1.1. *spiral type*—a flat, thin metal strip, machine twisted to a spiral configuration of uniform pitch having at one end, a sharpened or hardened point, with a means of attaching a shaft or extension at the opposite end.

4.1.1.2. *ship type*—similar to a carpenter's wood bit. It is generally forged from steel and machined to the desired size and configuration. It is normally provided with sharpened and hardened nibs at the point end and with an integral shaft extending through its length for attachment of a handle or extension at the opposite end.

4.1.2. *open tubular augers*—ranging in size from 38 through 200 mm (1.5 through 8 in.) in diameter and having the common characteristic of appearing tubular when viewed from the digging end.

4.1.2.1. *orchard-barrel type*—a tube having cutting lips or nibs hardened and sharpened on one end to penetrate the formation and an adaptor fitting for an extension or handle on the opposite end.

4.1.2.2. *open-spiral type*—a flat, thin metal strip that has been helically wound around a circular shank to form a spiral in which the flat faces of the strip are parallel to the axis of the augered hole. The lower helix edges are hard-faced to improve wear characteristics. The drive end is fitted with an adaptor for extension.

4.1.2.3. *closed-spiral type*—nearly identical to the open-spiral type, except the pitch of the helically wound spiral is much less than that of the open-spiral type.

4.1.3. *post-hole augers*—generally 50 through 200 mm (2 through 8 in.) in diameter, and having a means of blocking the escape of soil from the auger.

4.1.3.1. *clam-shell type*—consisting of two halves, hinged to allow opening and closing for alternatively digging and retrieving. Generally, it is not used deeper than about 1.5 m (5 ft).

4.1.3.2. *Iwan type*—consisting of two tubular steel segments, connected at the top to a common member to form a nearly complete tube, but with diametrically opposed openings. It is connected at the bottom by two radial blades pitched to serve as cutters, which also block the escape of contained soil. Attachment of handle or extension is at the top connector.

4.2. *Machine-Operated Augers for Obtaining Disturbed Soil Samples*:

4.2.1. *continuous-flight augers*—a boring device that has a solid center shank with a flat, metal strip helically wound around itself to form a continuous spiral or flight to bore into and convey or store cut soil. The drive end is fitted with a socket for applying power. The cutting head is affixed with replaceable carbide teeth of various styles to penetrate hard soil formations.

Auger sections generally come in 0.6- and 1.5-m (2- and 5-ft) lengths with other lengths available on special request. When coupled together, the sections provide a continuous flight to convey the soil throughout the full length of the borehole.

4.2.1.1. *available sizes*—generally, these augers come in nominal sizes ranging from 100- through 300-mm (4- through 12-in.) outside diameter.

4.3. *Machine-Operated Augers for Obtaining Split-Barrel and Tube Samples*:

4.3.1. *continuous hollow-stem augers*—basically the same as Continuous Flight Augers except the center shank is a hollow tube whose inside diameter is large enough to allow the passage of split barrel and tube samplers.

4.3.1.1. *available sizes*—inside diameters shall be 57, 82, and 95 mm (2.25, 3.25, and 3.75 in.). Additional and larger sizes are acceptable, provided the sampler clearance requirement of Section 4.3.1.2 is met.

4.3.1.2. Sampler clearance shall be such that no sampler or core barrel will be operated in or through a hollow-stem auger whose bore diameter is less than 108 percent of the sampler outside diameter.

4.3.1.3. The hollow-stem auger may be advanced and sampling or coring conducted by any power-operated drilling machine having sufficient torque and ram range to rotate and force the auger to the desired depth, provided the machine is equipped with the accessory equipment needed to take the required sample or core.

4.4. *Casing (when needed)*—Pipe of slightly larger diameter than the auger used.

4.5. *Accessory Equipment*—Labels, field log sheets, sample jars, sealing wax, sample bags, and other necessary tools and supplies.

5. DRILLING PROCEDURES

5.1. *Progressing Hand- and Machine-Operated Solid Shaft Auger Borings*:

5.1.1. Progress the boring by rotating and advancing the auger the desired distance into the soil. If continuous flight augers are not used, withdraw the auger from the hole and remove the soil for examination and tests. Return the empty auger into the hole and repeat the procedure. Continue the sequence until the required depth is reached.

5.1.2. Casing is required in unstable soil in which the borehole fails to stay open, and especially when the boring is extended below the groundwater level. The inside diameter of the casing must be slightly larger than the diameter of the auger used. The casing shall be driven to a depth not greater than the top of the next sampling location and shall be cleaned out by means of the auger. The auger can then be inserted into the borehole and turned below the bottom of the casing to obtain a sample.

5.1.3. The continuous flight auger can be used both for boring the hole and for bringing up disturbed samples of the soil encountered. The structure of a cohesive soil is completely destroyed and the moisture content may be changed by the auger. The samples may be contaminated with soils from the overlying strata, especially when the cohesive soil is overlain by a sand and casing has not been placed through the sandy strata. Seal all samples in a jar or other airtight container and label appropriately. If more than one type of soil is picked up in the sample, prepare a separate container for each type of soil.

5.1.4. *Field Observations*—Record complete groundwater information in the field logs. Where casing is used, measure groundwater levels before and after the casing is pulled. In sands, determine the water level at least 30 minutes after boring completion; in silts, after at least 24 hours. In clays, no accurate water level determination is possible unless pervious seams are present. As a precaution, however, water levels in clays should be checked after at least 24 hours.

5.2. *Progressing Machine-Operated, Hollow-Stem Auger Borings*:

5.2.1. *Method A*:

Advance the hollow-stem auger with plug or pilot bit in place to the desired sampling depth. Retract the plug or pilot bit by withdrawing the center drill rods. Remove the plug or pilot bit from the drill rods and replace with the desired sampling or coring tool. Lower and seat the sampling tool through the hollow-stem auger into the exposed undisturbed material at the bottom of the hole. Proceed with the sampling operation by rotating, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool. Retract the loaded sampler by withdrawing the center rods. Replace the sampler with the plug or pilot bit and return to the bottom of the hole. Add an additional auger and lock the plug or pilot bit in place and advance the hollow-stem auger to the next desired sample depth. Repeat the sequence for each sample desired.

5.2.2. *Method B*:

Advance the hollow-stem auger with plug or pilot bit in place to the desired sampling depth. Retract the plug by reeling in the wire line and attached in-hole hammer and auger plug. Remove the auger plug from the in-hole hammer and replace it with the desired drive sampler. Lower the wire line and attached in-hole hammer and sampler through the hollow-stem to seat the sampler into the exposed undisturbed material at the bottom of the hole. Proceed with the sampling operation in accordance with the standard or approved method governing use of the sampler and hammer. Free the loaded sampler by overaugering until the auger mouth is at the sampler shoe depth, or by bumping back. Retrieve the sampler by reeling in the wire line and attached in-hole hammer and sampler. Remove the sampler from the hammer and replace with the auger plug or pilot bit or, in the case of continuous sampling, with another sampler. Lower the in-hole hammer with plug or sampler attached and again advance the auger or begin sampling as appropriate to the incremental or continuous sampling being conducted. Repeat or continue the sequence to the desired completion.

5.2.3. *Method C*:

5.2.3.1. The small hollow-stem auger, approximately 57 mm (2.25 in.) or less, may be used without the plug or pilot bit. When so used, a plug of soil may be expected to form at the mouth of the auger. This plug will seldom exceed 100 to 150 mm (4 to 6 in.) in thickness. Samplers can normally be pressed or driven through this plug. However, the plug of soil then becomes the upper part of the sample. Accordingly, samplers for use in the hollow-stem auger should be fitted with spoil reservoirs or spoil barrels, if the auger is to be used without a plug or pilot bit.

5.2.3.2. The hollow-stem auger may be utilized with a constantly positive liquid head within the center tube of the auger when working without the center plug. Liquid may be water or drilling mud weighted as necessary to preclude entry of saturated free-flowing formation into the auger. Care shall be taken to avoid blow out of the formation by excessive pressure or weight of liquid in the center tube. Normally weighted liquid shall be introduced into the auger only by gravity flow and only as necessary to maintain the level within the auger center tube above the formation water level. Sampling within the liquid-filled auger shall be conducted in the normal manner prescribed for use of the particular sampler in a liquid-filled borehole.

5.2.3.3. In the event of inflow of the formation into the auger from loss of positive internal head or other cause, the center tube is to be washed out in the same manner as prescribed for casing cleanout. Sampling may then be conducted as prescribed for use of the particular sampler in the liquid-filled borehole; however, the boring report should always indicate that loss of formation occurred before sampling was conducted.

Note 1—The inflow of cohesionless materials into the bottom of any type of borehole normally results in the loosening of natural material at or below the bottom, and thus a sample or *N* value taken may not be truly representative of the undisturbed condition of the material.

6. REPORTING

6.1. The data obtained in Section 5 shall be recorded in the field logs and shall include the following:

6.1.1. Date of start and completion of boring.

6.1.2. Identifying number of boring.

6.1.3. Reference datum including direction and distance of boring relative to reference line of project or other suitable reference points.

6.1.4. Type and size of auger used in boring.

6.1.5. Depth of changes in strata.

6.1.6. Description and classification of soil in each major stratum.

6.1.7. Groundwater elevation and location of seepage zones, when found.

6.1.8. Condition of augered hole upon removal of auger, that is, whether the hole remains open or the sides cave in, when such can be observed.

6.2. In addition, the data obtained in Section 6.2 shall be reported as required in accordance with T 206 and/or T 207.

7. PRECISION AND BIAS

7.1. This standard provides qualitative data only; hence, precision and bias are not applicable.

Standard Method of Test for

Determining the Resilient Modulus of Soils and Aggregate Materials

AASHTO Designation: T 307-99 (2007)

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Determining the Resilient Modulus of Soils and Aggregate Materials

AASHTO Designation: T 307-99 (2007)

1. SCOPE

1.1. This method covers procedures for preparing and testing untreated subgrade soils and untreated base/subbase materials for determination of resilient modulus (M_r) under conditions representing a simulation of the physical conditions and stress states of materials beneath flexible pavements subjected to moving wheel loads.

1.2. The methods described are applicable to undisturbed samples of natural and compacted subgrade soils, and to disturbed samples of subgrade soils and untreated base/subbase prepared for testing by compaction in the laboratory.

1.3. In this method, stress levels used for testing specimens for resilient modulus are based upon the location of the specimen within the pavement structure. Samples located within the base and subbase are subjected to different stress levels as compared to those specimens that are from the subgrade. Generally, specimen size for testing depends upon the type of material based upon the gradation and the plastic limit of the material as described in a later section.

1.4. The value of resilient modulus determined from this procedure is a measure of the elastic modulus of untreated base and subbase materials and subgrade soils recognizing certain nonlinear characteristics.

1.5. Resilient modulus values can be used with structural response analysis models to calculate the pavement structural response to wheel loads, and with pavement design procedures to design pavement structures.

1.6. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 1—Test specimens and equipment described in this method may be used to obtain other useful and related information such as the Poisson's ratio and rutting characteristics of subgrade soils and base/subbase materials. Procedures for obtaining these are not covered in this standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 88, Particle Size Analysis of Soils
- T 89, Determining the Liquid Limit of Soils
- T 90, Determining the Plastic Limit and Plasticity Index of Soils

- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 100, Specific Gravity of Soils
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 190, Resistance R-Value and Expansion Pressure of Compacted Soils
- T 191, Density of Soil In-Place by the Sand-Cone Method
- T 233, Density of Soil In-Place by Block, Chunk, or Core Sampling
- T 265, Laboratory Determination of Moisture Content of Soils
- T 296, Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression
- T 310, In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

2.2. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *untreated granular base and subbase materials*—these include soil-aggregate mixtures and naturally occurring materials. No binding or stabilizing agent is used to prepare untreated granular base or subbase layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined in Sections 3.3 and 3.4.

3.2. *subgrade*—subgrade soils are prepared and compacted before the placement of subbase and/or base layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined in Sections 3.3 and 3.4.

3.3. *Material Type 1*—for the purposes of resilient modulus testing, Material Type I includes all untreated granular base and subbase material and all untreated subgrade soils that meet the criteria of less than 70 percent passing the 2.00-mm (No. 10) sieve and less than 20 percent passing the 75-µm (No. 200) sieve, and that have a plasticity index of 10 or less. Soils classified as Type 1 will be molded in a 150-mm diameter mold.

3.4. *Material Type 2*—for the purpose of resilient modulus testing, Material Type 2 includes all untreated granular base/subbase and untreated subgrade soils not meeting the criteria for material Type 1 given in Section 3.3. Thin-walled tube samples of untreated subgrade soils fall into this Type 2 category.

3.5. *resilient modulus of untreated materials*—the modulus of an untreated material is determined by repeated load triaxial compression tests on test specimens of the untreated material samples. Resilient modulus (M_r) is the ratio of the amplitude of the repeated axial stress to the amplitude of the resultant recoverable axial strain.

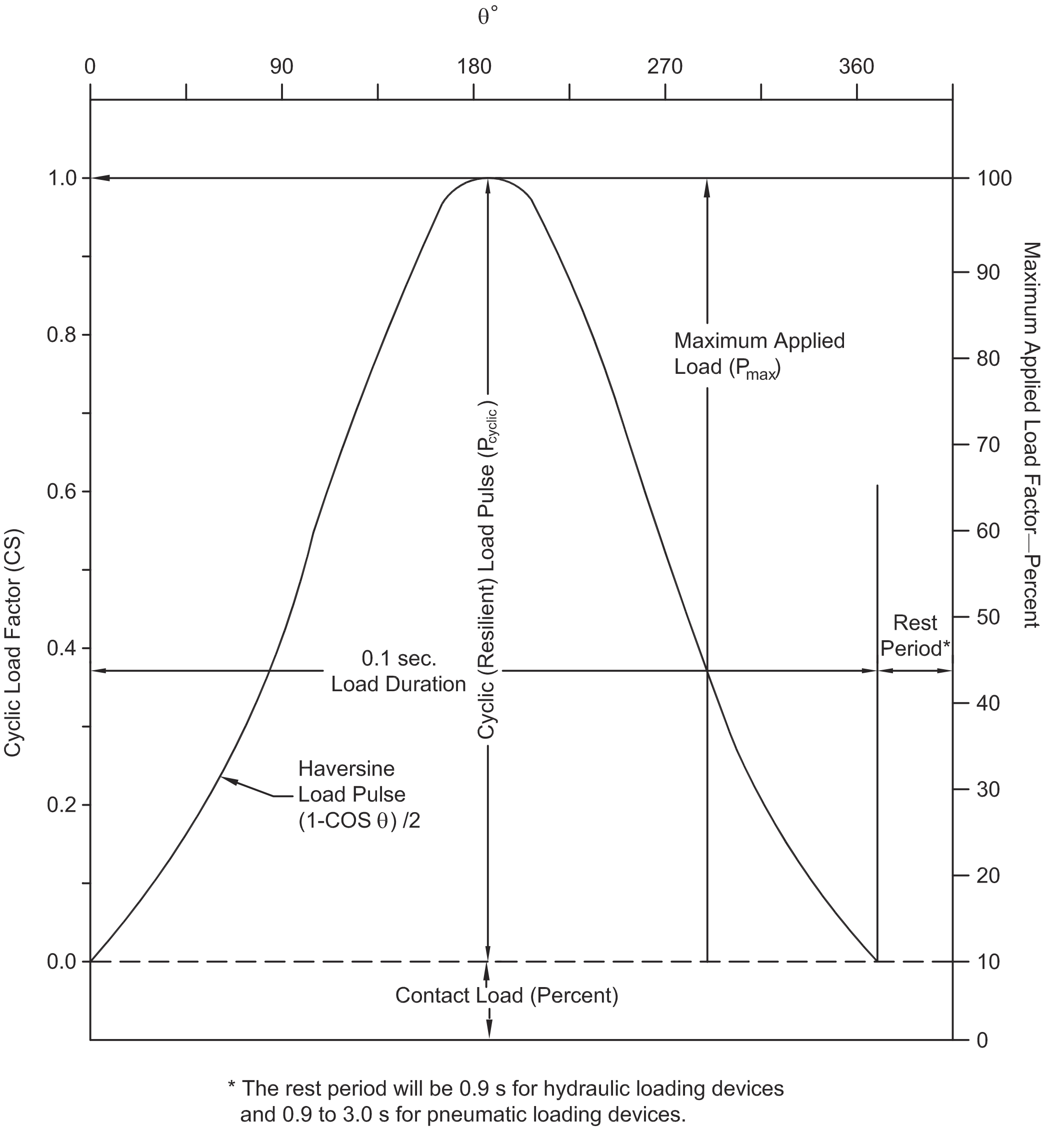
3.6. *haversine-shaped load form*—the required load pulse form. The load pulse is in the form $(1 - \cos \theta)/2$ as shown in Figure 1.

3.7. *maximum applied axial load* ($P_{\max}$)—the total load applied to the sample, including the contact and cyclic (resilient) loads.

$$P_{\text{max}} = P_{\text{contact}} + P_{\text{cyclic}} \qquad (1)$$

3.8. *contact load* (P_{contact})—vertical load placed on the specimen to maintain a positive contact between the specimen cap and the specimen.

$$P_{\text{contact}} = 0.1P_{\text{max}} \qquad (2)$$



* The rest period will be 0.9 s for hydraulic loading devices and 0.9 to 3.0 s for pneumatic loading devices.

Figure 1—Definition of Resilient Modulus Terms Cyclic Axial Load (Resilient Vertical Load, P_{cyclic})—Repetitive Load Applied to a Test Specimen

$$P_{\text{cyclic}} = P_{\text{max}} - P_{\text{contact}} \qquad (3)$$

3.9. *maximum applied axial stress* (S_{max})—the total stress applied to the sample including the contact stress and the cyclic (resilient) stress.

$$S_{\text{max}} = P_{\text{max}}/A \qquad (4)$$

where:

A = initial cross-sectional area of the specimen.

3.10. *cyclic axial stress* (resilient stress, S_{cyclic})—Cyclic (resilient) applied axial stress.

$$S_{\text{cyclic}} = P_{\text{cyclic}}/A \tag{5}$$

3.11. *contact stress* (S_{contact})—axial stress applied to a test specimen to maintain a positive contact between the specimen cap and the specimen.

$$S_{\text{contact}} = P_{\text{contact}}/A \tag{6}$$

Also,

$$S_{\text{contact}} = 0.1S_{\text{max}} \tag{7}$$

3.12. S_3 is the total radial stress; that is, the applied confining pressure in the triaxial chamber (minor principal stress).

3.13. e_r is the resilient (recovered) axial deformation due to S_{cyclic}.

3.14. $\in_r$ is the resilient (recovered) axial strain due to S_{cyclic}.

$$\in_r = e_r/L \tag{8}$$

where:

L = original specimen length.

3.15. Resilient Modulus (M_r) is defined as $S_{\text{cyclic}}/\in_r$.

3.16. Load duration is the time interval the specimen is subjected to a cyclic stress (usually 0.1 s).

3.17. Cycle duration is the time interval between the successive applications of a cyclic stress (usually 1.0 to 3.1 s, depending on type of loading device. See Section 6.2).

4. SUMMARY OF METHOD

4.1. A repeated axial cyclic stress of fixed magnitude, load duration (0.1 s), and cycle duration (1.0 to 3.1 s) is applied to a cylindrical test specimen. During testing, the specimen is subjected to a dynamic cyclic stress and a static-confining stress provided by means of a triaxial pressure chamber. The total resilient (recoverable) axial deformation response of the specimen is measured and used to calculate the resilient modulus.

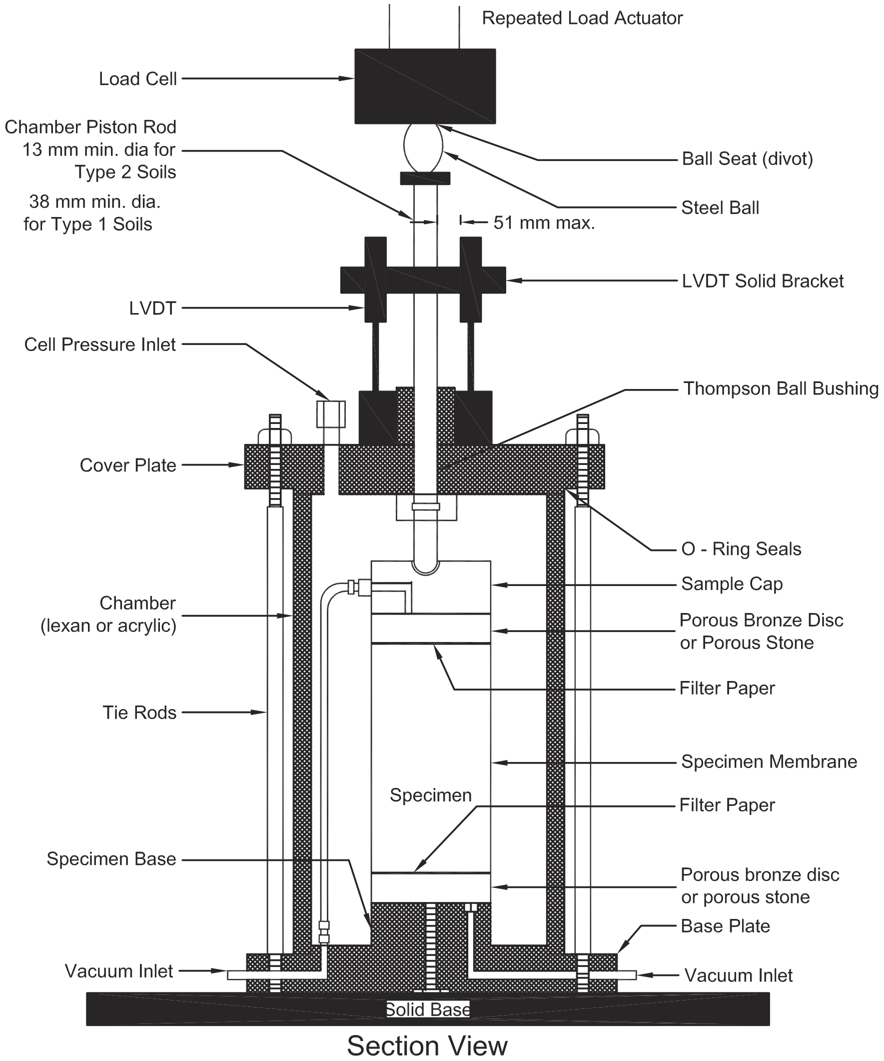
5. SIGNIFICANCE AND USE

5.1. The resilient modulus test provides a basic relationship between stress and deformation of pavement materials for the structural analysis of layered pavement systems.

5.2. The resilient modulus test provides a means of characterizing pavement construction materials, including subgrade soils, under a variety of conditions (i.e., moisture, density, etc.) and stress states that simulate the conditions in a pavement subjected to moving wheel loads.

6. APPARATUS

6.1. *Triaxial Pressure Chamber*—The pressure chamber is used to contain the test specimen and the confining fluid during the test. A typical triaxial chamber suitable for use in resilient testing of soils is shown in Figure 2. The deformation is measured *externally* with two spring-loaded linear variable differential transducers (LVDT) as shown in Figure 2.



Note: LVDT tips shall rest on the triaxial cell itself or on a plate/bracket that is rigidly attached to the triaxial cell.

Figure 2—Typical Triaxial Chamber with Eternal LVDTs and Load Cell (Not to Scale)

6.1.1. Air shall be used in the triaxial chamber as the confining fluid.

6.1.2. The chamber shall be made of polycarbonate, acrylic or other suitable “see through” material to facilitate the observation of the specimen during testing.

6.2. *Loading Device*—The loading device shall be a top-loading, closed loop, electrohydraulic or electropneumatic testing machine with a function generator that is capable of applying repeated cycles of haversine-shaped load pulse of the following durations.

Type of Loading Device	Load Pulse (s)	Rest Period (s)
pneumatic	0.1	0.9 to 3.0
hydraulic	0.1	0.9

6.2.1. The haversine-shaped load pulse shall conform to Section 3.6. All preconditioning and testing shall be conducted using a haversine-shaped load pulse. The system-generated haversine waveform and the response waveform shall be displayed to allow the operator to adjust the gains to ensure that they coincide during preconditioning and testing.

6.3. *Load and Specimen Response Measuring Equipment*:

6.3.1. The axial load-measuring device should be an electronic load cell located between the actuator and the chamber piston rod as shown in Figure 2. The following load-cell capacities are required:

Specimen Dia. (mm)	Max. Load Cap. (kN)	Req. Accuracy (N)
71	2.2	±4.5
100	8.0	±10.0
152	22.24	±22.24

The above requirements for load capacity and accuracy are approximately linear when plotted versus specimen cross-section area. Requirements for load cells used with other specimen diameters should be approximately on the same linear relationships.

Note 2—During periods of resilient modulus testing, the load cell shall be monitored and checked once every 2 weeks or after every 50 resilient modulus tests with a calibrated proving ring to assure that the load cell is operating properly. An alternative to using a proving ring is to insert an additional calibrated load cell and independently measure the load applied by the original load cell to ensure accurate loadings. Additionally, the load cell shall be checked at any time if the laboratory's in-house QA/QC testing indicates non-compliance or there is a suspicion of a load-cell problem. Resilient modulus testing shall not be conducted if the testing system is found to be out of calibration or if the load cell does not meet the manufacturer's tolerance requirements stated above for accuracy, whichever of the two is of the higher accuracy.

6.3.2. Test chamber pressures shall be monitored with conventional pressure gages, manometers, or pressure transducers accurate to 0.7 kPa.

6.3.3. *Axial Deformation*—Measuring system for all materials shall consist of 2 LVDTs fixed to opposite sides of the piston rod outside the test chamber as shown in Figure 2. These two transducers shall be located equidistant from the piston rod and shall bear on hard, fixed surfaces, which are perpendicular to the LVDT axis. Spring-loaded LVDTs are required. The following LVDT ranges are required:

Specimen Dia. (mm)	Range (mm)
71	±1
100	± 2.5
152	±6

Both LVDTs shall meet the following minimum specifications:

- *Linearity*, ±0.25 percent of full scale
- *Repeatability*, ±1 percent of full scale

- *Minimum Sensitivity*, 2 mv/v (AC) or 5 mv/v (DC)

The above requirement for range is approximately linear when plotted vs. specimen cross-section area. Requirements for LVDTs used with other specimen diameters are approximately on the same linear relationships. A digital or other type of deformation measurement system with equivalent linearity and repeatability specifications may be used in place of LVDTs.

6.3.3.1. A positive contact between the vertical LVDTs and the surface on which the tips of the transducers rest shall always be maintained during the test procedure. In addition, the two LVDTs shall be wired so that each transducer can be read and reviewed independently and the results averaged for calculation purposes.

Note 3—Misalignment or dirt on the shaft of the transducer can cause the "sticking" of the shafts of the LVDT. The laboratory technician shall depress and release each LVDT prior to each test to assure that there is no sticking. An acceptable cleaner/lubricant (as specified by the manufacturer) shall be applied to the transducer shafts on a regular basis.

6.3.3.2. The response of the LVDTs shall be checked daily with the laboratory's in-house QA/QC program. Additionally, the LVDTs shall be calibrated every 2 weeks, or after every 50 resilient modulus tests, whichever comes first, using a micrometer with compatible resolution or a set of specially machined gauge blocks. Resilient modulus testing shall not be conducted if the LVDTs do not meet the manufacturer's tolerance requirements for accuracy.

6.3.4. Suitable signal excitation, conditioning, and recording equipment are required for simultaneous recording of axial load and deformations. The signal shall be clean and free of noise. Use shielded cables for connections. If a filter is used, it shall have a frequency that cannot attenuate the signal. The LVDTs shall be wired separately so each LVDT signal can be monitored independently. A minimum of 200 data points from each LVDT shall be recorded per load cycle.

6.4. *Specimen Preparation Equipment*—A variety of equipment is required to prepare undisturbed samples for testing and to obtain compacted specimens that are representative of field conditions. Use of different methods of compaction is necessary to prepare specimens of different materials and to simulate desired field conditions. See Annexes A, B, and C for specimen preparation (Annex A), specimen compaction equipment and compaction procedures for Type 1 (Annex B), and Type 2 materials (Annex C or Appendix A), respectively.

6.5. Equipment for trimming test specimens from undisturbed thin-walled tube samples of subgrade soils shall be as described in T 296.

6.6. *Miscellaneous Apparatus*—This includes calipers, micrometer gauge, steel rule calibrated to 0.5 mm, rubber membranes 0.25 to 0.79 mm thick, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones (subgrade), porous bronze discs (base/subbase), scales, moisture content cans, and report forms, as required.

6.7. *System Calibration and Periodic Checks*—The entire system (transducer, conditioning, and recording devices) shall be calibrated every 2 weeks or after every 50 resilient modulus tests using the laboratory's in-house QA/QC program. Daily and other periodic checks of the system shall also be performed in accordance with the laboratory's in-house QA/QC program.

7. PREPARATION OF TEST SPECIMENS

7.1. *Specimen Size*—The following guidelines, based on the sieve analysis test results, shall be used to determine the test specimen size.

7.1.1. Use 71-mm or 86-mm diameter specimens for tests on undisturbed cohesive specimens of Type 2 materials. For Type 1 materials, or compacted specimens of Type 2 materials, select mold sizes to fabricate specimens of a minimum diameter equal to five times the maximum particle size. If the maximum particle size exceeds 25 percent of the largest mold diameter available, these particles will be scalped. Length for all specimens will be at least two times the diameter.

7.2. *Undisturbed Subgrade Soil Specimens*—Undisturbed subgrade soil specimens are trimmed and prepared. The natural moisture content, *w,* of the tube sample shall be determined after triaxial resilient modulus testing following the procedure outlined in T 265, and recorded in the test report.

7.2.1. To be suitable for testing, a specimen of sufficient length, being at least twice the diameter of the specimen, shall be cut from the tube sample. The specimen shall be free from defects. Such defects include cracks in the specimen, broken corners that cannot be repaired during preparation, or presence of particles much larger than that typical for the material. For example, the presence of plus 19.0 mm stones in a fine-grained soil or presence of “foreign objects” such as large roots, wood particles, organic material, and gouges due to gravel hanging on the edge of the tube constitute damaged specimens that are unacceptable.

7.3. *Laboratory Compacted Specimens*—Reconstituted test specimens of both Type 1 and Type 2 materials shall be prepared to approximate the *in situ* wet density, Υ_w, and moisture content, *w*. These laboratory-compacted specimens shall be prepared for all unbound granular base and subbase material and for all subgrade soils for which undisturbed tube specimens could not be obtained.

7.3.1. *Moisture Content*—The moisture content of the laboratory-compacted specimen shall be the *in situ* moisture content obtained in the field using T 310. If data are not available on *in situ* moisture content, then refer to Section 7.3.3. The moisture content of the laboratory-compacted specimen shall not vary by more than ±1.0 percent for Type 1 materials or ±0.5 percent for Type 2 materials from the *in situ* moisture content obtained.

7.3.2. *Compacted Density*—The density of the compacted specimen shall be the in-place wet density obtained in the field using T 310 or T 191. If these data are not available on *in situ* density, then refer to Section 7.3.3. The wet density of the laboratory-compacted specimen shall not vary by more than ±3 percent of the in-place wet density for that layer.

7.3.3. If either the *in situ* moisture content or the in-place density data are not available, then use the percentage of maximum dry density and the corresponding optimum moisture content by T 99 or T 180 as is specified by the individual testing or transportation agency. The moisture content of the laboratory-compacted specimen shall not vary by more than ±1.0 percent for Type 1 materials or ±0.5 percent for Type 2 materials from the target moisture content. Also, the wet density of the laboratory-compacted specimen shall not vary by more than ±3 percent of the target wet density.

Example: If the desired density is 1950 kg/m^3 and the desired moisture content is 8.0 percent for a Type 1 material, then a moisture content between 7.0 and 9.0 percent would be acceptable. For the same desired moisture content and density for a Type 2 material, acceptable moisture contents are between 7.5 and 8.5 percent. Acceptable densities for either material are between 1892 and 2009 kg/m^3.

7.3.4. *Sample Reconstitution*—Reconstitute the specimen for Type 1 and Type 2 materials in accordance with the provisions given in Annex A. The target moisture content and density to be used in determining needed material quantities are given in Section 7.3. Annex A provides guidelines for reconstituting the material to obtain a sufficient amount of material to prepare the appropriate specimen type at the designated moisture content and density. After this step is completed, specimen compaction can begin.

7.4. *Compaction Methods and Equipment for Reconstituting Specimens*:

7.4.1. *Compacting Specimens for Type 1 Materials*—The general method of compaction for Type 1 materials will be that of Annex B.

7.4.2. *Compacting Specimens for Type 2 Materials*—The general method of compaction for Type 2 materials will be that of Annex C or Appendix A. If it is desired to investigate specimen density gradient, the method is that of Appendix B.

7.4.3. The prepared specimens shall be protected from moisture change by applying the triaxial membrane and testing within 5 days of completion. Prior to storage, and directly after removal from storage, weigh the specimen to determine if there was any moisture loss. If moisture loss exceeds 1 percent for Type 1 materials or 0.5 percent for Type 2 materials, then the prepared specimen will not be tested. However, a new specimen will be needed to be prepared for testing. Material from the specimens not tested may be reused.

8. PROCEDURE—RESILIENT MODULUS TEST FOR SUBGRADE SOILS

8.1. The procedure described in this section is used for undisturbed or laboratory-compacted specimens of subgrade soils. This can include specimens of 150-mm diameter or Type 2 specimens of 70 mm diameter.

8.2. *Assembly of Triaxial Chamber*—Specimens trimmed from undisturbed samples and laboratory-compacted specimens are placed in the triaxial chamber and loading apparatus in the following steps:

8.2.1. Place a moist porous stone and moist paper filter on the top of the specimen base of the triaxial chamber as shown in Figure 2.

8.2.2. Carefully place the specimen on the porous stone. Place the membrane on a membrane expander, apply vacuum to the membrane expander, then carefully place the membrane on the specimen and remove the vacuum and the membrane expander. Seal the membrane to the pedestal (or bottom plate) with an O-ring or other pressure seal.

8.2.3. Place a moist paper filter and the top platen containing a moist porous stone on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some other pressure seal.

8.2.4. If the specimen has been compacted or stored inside a rubber membrane and the porous stones and sample are already attached to the rubber membrane in place, Sections 8.2.1, 8.2.2, and 8.2.3 are omitted. Instead, the “specimen assembly” is placed on the base plate of the triaxial chamber.

8.2.5. Connect the specimen’s bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 7 kPa. If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap of the base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.

8.2.6. When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly.

8.2.7. Slide the assembly apparatus into position under the axial loading device. Positioning of the chamber is extremely critical in eliminating all possible side forces in the piston rod. Couple the loading device to the triaxial chamber piston rod.

8.3. *Conduct the Resilient Modulus Test*—The following steps are required to conduct the resilient modulus test on a subgrade specimen that has been installed in the triaxial chamber and placed under the loading frame.

8.3.1. Open all drainage valves leading into the specimen to atmospheric pressure. This will simulate drained conditions. Simulation of undrained conditions will require saturation of specimens. Such procedures are not contained in this method.

8.3.2. If it is not already connected, connect the air pressure supply line to the triaxial chamber and apply the specified pre-conditioning confining pressure of 41.4 kPa to the test specimen. A contact stress of 10 percent ± 0.7 kPa of the maximum applied axial stress during each sequence number shall be maintained.

8.3.2.1. Loads applied to the top of the triaxial cell piston rod must be adjusted to apply stresses shown in Table 1 after accounting for a net upward or downward resultant calculated as follows:

$$F = (A \times P) - W \qquad (9)$$

where:

F = resultant force,

A = piston rod cross-section area,

P = confining pressure, and

W = weight of piston rod and exterior-mounted specimen deformation measurement system.

Table 1—Testing Sequence for Subgrade Soil

Sequence No.	Confining Pressure, S_3		Max. Axial Stress, $S_{\max}$		Cyclic Stress, S_{cyclic}		Constant Stress, $0.1S_{\max}$		No. of Load Applications
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
0	41.4	6	27.6	4	24.8	3.6	2.8	0.4	500–1000
1	41.4	6	13.8	2	12.4	1.8	1.4	0.2	100
2	41.4	6	27.6	4	24.8	3.6	2.8	0.4	100
3	41.4	6	41.4	6	37.3	5.4	4.1	0.6	100
4	41.4	6	55.2	8	49.7	7.2	5.5	0.8	100
5	41.4	6	68.9	10	62.0	9.0	6.9	1.0	100
6	27.6	4	13.8	2	12.4	1.8	1.4	0.2	100
7	27.6	4	27.6	4	24.8	3.6	2.8	0.4	100
8	27.6	4	41.4	6	37.3	5.4	4.1	0.6	100
9	27.6	4	55.2	8	49.7	7.2	5.5	0.8	100
10	27.6	4	68.9	10	62.0	9.0	6.9	1.0	100
11	13.8	2	13.8	2	12.4	1.8	1.4	0.2	100
12	13.8	2	27.6	4	24.8	3.6	2.8	0.4	100
13	13.8	2	41.4	6	37.3	5.4	4.1	0.6	100
14	13.8	2	55.2	8	49.7	7.2	5.5	0.8	100
15	13.8	2	68.9	10	62.0	9.0	6.9	1.0	100

Note: Load sequences 14 and 15 are not to be used for materials designed as Type 1.

8.3.3. *Conditioning*—Begin the test by applying a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 27.6 kPa and corresponding cyclic stress of 24.8 kPa using a haversine-shaped load pulse with durations as described in Section 6.2. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing as outlined in sequence No. 0, Table 1.

Note 4—The laboratory/technician shall conduct appropriate QA/QC comparative checks of the individual deformation output from the two vertical transducers during the conditioning phase of each resilient modulus test in order to recognize specimen misplacement and misalignment. During the preconditioning phase, the two vertical deformation curves shall be viewed to ensure that acceptable vertical deformation ratios are being measured. The vertical deformation ratio R_v is defined as $R_v = Y_{\max}/Y_{\min}$, where $Y_{\max}$ equals the larger of the two vertical deformations and $Y_{\min}$ equals the smaller of the two vertical deformations. Every effort shall be made to achieve R_v values of 1.10 or less. Acceptable R_v values are 1.30 or less. If unacceptable vertical deformation ratios are obtained (i.e., R_v is greater than 1.30), then the test shall be discontinued and specimen placement/alignment difficulties alleviated. Once acceptable vertical deformation values are obtained, then the test shall be continued to completion. It is emphasized that the specimen alignment is critical for proper resilient modulus results. This note also applies to Section 9.3.3.

8.3.3.1. The above stress sequence constitutes sample conditioning; that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and the test specimen.

8.3.3.2. If the total vertical permanent strain reaches 5 percent during conditioning, the conditioning process shall be terminated. For recompacted samples, a review shall be conducted of the compaction process to identify any reason(s) why the sample did not attain adequate compaction. If this review does not provide an explanation, the material shall be refabricated and tested a second time. If the sample again reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and a notation added to the report form.

8.3.4. *Testing Specimen*—The testing is performed following the loading sequence shown in Table 1. Begin by decreasing the maximum axial stress to 13.8 kPa (Sequence No. 1, Table 1) and set the confining pressure to 41.4 kPa.

8.3.5. Apply 100 repetitions of the corresponding cyclic axial stress using a haversine-shaped load pulse with durations as described in Section 6.2. Record the average recovered deformations for each LVDT separately for the past five cycles on the Report Form C4.1 (Table C3.1).

8.3.6. Increase the maximum axial stress to 27.6 kPa (Sequence No. 2) and repeat Step 8.3.5 at this new stress level.

8.3.7. Continue the test for the remaining load sequences in Table 1 (3 to 15), recording the vertical recovered deformation. If at any time the permanent strain of the sample exceeds 5 percent, stop the test and report the result on the appropriate worksheet.

8.3.8. After completion of the resilient modulus test procedure, check the total vertical permanent strain the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, and if strength information is desired, continue with the quick shear test procedure (Section 8.3.9). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen, other than in Section 8.3.11.

8.3.9. *Quick Shear Test*—Apply a confining pressure of 27.6 kPa to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute under a strain-controlled loading procedure. Continue loading until either (1) the load values decrease with increasing strain, (2) 5 percent strain is reached, or (3) the capacity of the load cell is reached. Data from the internally mounted deformation transducer in the actuator shaft and from the load cell shall be used to record specimen deformation and loads at a maximum of 3-s intervals.

8.3.10. At the completion of the triaxial shear test, reduce the confining pressure to zero and remove the sample from the triaxial chamber.

8.3.11. Remove the membrane from the specimen and use the entire specimen to determine moisture content in accordance with T 265.

8.3.12. Plot the stress-strain curve for the specimen for the triaxial shear test procedure.

9. PROCEDURE—RESILIENT MODULUS TEST FOR BASE/SUBBASE MATERIALS

9.1. The procedure described in this section applies to all unbound granular base and subbase materials. This can include specimens classified as Type 1 or Type 2 material.

9.2. *Assembly of the Triaxial Chamber*—When compaction is completed, place the porous bronze disc and specimen cap on the top surface of the specimen. Roll the rubber membrane off the rim of the mold and over the sample cap. If the sample cap projects above the rim of the mold, the membrane shall be sealed tightly against the cap with the O-ring seal. If it does not, the seal can be applied later. Install the specimen in the triaxial chamber as in Sections 8.2.1 through 8.2.7.

9.2.1. Connect the chamber pressure supply line and apply a confining pressure of 103.4 kPa.

9.2.2. Remove the vacuum supply from the vacuum saturation inlet and open the top and bottom head drainage ports to atmospheric pressure.

9.3. *Conduct the Resilient Modulus Test*—After the test specimen has been prepared and placed in the loading device as described in Section 8.2.1, the following steps are necessary to conduct the resilient modulus testing:

9.3.1. If not already done, adjust the position of the axial loading device or triaxial chamber base support as necessary to couple the load-generation device piston and the triaxial chamber piston. The triaxial chamber piston should bear firmly on the load cell. A contact stress of 10 percent ±0.7 kPa of the maximum applied axial stress during each sequence number shall be maintained.

9.3.1.1. Loads applied to the top of the triaxial cell piston rod must be adjusted to apply the stresses shown in Table 2 after accounting for a net upward or downward resultant calculated as follows:

$$F = (A \times P) - W \qquad (10)$$

where:

F = resultant force,

A = piston rod cross-section area,

P = confining pressure, and

W = weight of piston rod and exterior-mounted specimen deformation measurement system.

Table 2—Testing Sequences for Base/Subbase Materials

Sequence No.	Confining Pressure, S_3		Max. Axial Stress, $S_{\max}$		Cyclic Stress, S_{cyclic}		Constant Stress, $0.1S_{\max}$		No. of Load Applications
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
0	103.4	15	103.4	15	93.1	13.5	10.3	1.5	500–1000
1	20.7	3	20.7	3	18.6	2.7	2.1	0.3	100
2	20.7	3	41.4	6	37.3	5.4	4.1	0.6	100
3	20.7	3	62.1	9	55.9	8.1	6.2	0.9	100
4	34.5	5	34.5	5	31.0	4.5	3.5	0.5	100
5	34.5	5	68.9	10	62.0	9.0	6.9	1.0	100
6	34.5	5	103.4	15	93.1	13.5	10.3	1.5	100
7	68.9	10	68.9	10	62.0	9.0	6.9	1.0	100
8	68.9	10	137.9	20	124.1	18.0	13.8	2.0	100
9	68.9	10	206.8	30	186.1	27.0	20.7	3.0	100
10	103.4	15	68.9	10	62.0	9.0	6.9	1.0	100
11	103.4	15	103.4	15	93.1	13.5	10.3	1.5	100
12	103.4	15	206.8	30	186.1	27.0	20.7	3.0	100
13	137.9	20	103.4	15	93.1	13.5	10.3	1.5	100
14	137.9	20	137.9	20	124.1	18.0	13.8	2.0	100
15	137.9	20	275.8	40	248.2	36.0	27.6	4.0	100

9.3.2. Adjust the recording devices for the LVDTs and load cell as needed.

9.3.3. *Conditioning*—Set the confining pressure to 103.4 kPa and apply a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 103.4 kPa and corresponding cyclic axial stress of 93.1 kPa according to sequence 0, Table 2, using a haversine-shaped load pulse with durations as described in Section 6.2. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing.

9.3.3.1. The above stress sequence constitutes sample conditioning; that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and base plate and the test specimen. The drainage valves should be open to atmospheric pressure throughout the resilient modulus testing. This will simulate drained conditions. Simulation of undrained conditions will require saturation of specimens. Such procedures are not contained in this method.

9.3.3.2. If the total vertical permanent strain reaches 5 percent during conditioning, the conditioning process shall be terminated. A review shall be conducted of the compaction process to identify any reason(s) why the sample did not attain adequate compaction. If this review does not provide an explanation, the material shall be refabricated and tested a second time. If the sample again reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and a notation added to the report form.

9.3.4. *Testing Specimen*—The testing is performed following the loading sequences in Table 2 using a haversine-shaped load pulse as described above. Decrease the maximum axial stress to 21.0 kPa and set the confining pressure to 21.0 kPa (Sequence No. 1, Table 2).

9.3.5. Apply 100 repetitions of the corresponding cyclic stress using a haversine-shaped load pulse with durations as described in Section 6.2. Record the average recovered deformations for each LVDT separately for the past five cycles on the report form.

9.3.6. Continue with sequence No. 2 increasing the maximum axial stress to 41.0 kPa and repeat Step 8.2.2.5 at this new stress level.

9.3.7. Continue the test for the remaining load sequences in Table 2 (sequences 3 to 15), recording the vertical recovered deformation. If at any time the total vertical permanent strain deformation exceeds 5 percent, stop the test and make a notation on the report form.

9.3.8. After completion of the resilient modulus test procedure, check the total vertical permanent strain that the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, and if strength information is desired, continue with the quick shear test procedure (Section 9.3.9). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen, other than in Section 9.3.11.

9.3.9. *Quick Shear Tests*—Apply a confining pressure of 34.5 kPa to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute under a strain-controlled loading procedure. Continue loading until either (1) the load values decrease with increasing strain, (2) 5 percent strain is reached, or (3) the capacity of the load cell is reached. Data from the internally mounted deformation transducer in the actuator shaft and from the load cell shall be used to record specimen deformation and loads at a maximum of 3-s intervals.

9.3.10. At the completion of the triaxial shear test, reduce the confining pressure to zero and remove the sample from the triaxial cell.

9.3.11. Remove the membrane from the specimen and use the entire sample to determine the moisture content in accordance with T 265.

9.3.12. Plot the stress-strain curve for the specimen for the triaxial shear test procedure.

10. CALCULATIONS

10.1. Perform the calculations to obtain resilient modulus values using the tabular arrangement shown on Report Form C4.1 (Table C3.1). The resilient modulus value is computed for each of the past five cycles of each load sequence. These values are subsequently averaged on the data sheet.

11. REPORT

11.1. *The report shall consist of the following*:

11.1.1. Report Form C4.1 (Table C3.1).

11.1.2. Report Form C4.2 (Table C3.2) (recompacted specimens) or Report Form C4.3 (Table C3.3) (thin-walled tube specimens).

11.2. *The following general information is to be recorded on all of the Report Forms*:

11.2.1. The specimen identification, the material type (Type 1 or Type 2), and test date.

11.3. *Report the following information on the appropriate data sheet*:

11.3.1. Report Form C4.2 (Table C3.2) shall be used to record general information concerning the specimen being tested. This form shall be completed only for those specimens that are recompacted from bulk samples. This form shall not be used to record information for thin wall tube samples.

11.3.1.1. *Item 4*—Record a "Y" (Yes) or "N" (No) to denote whether the sample reached a 5 percent total vertical permanent strain during the conditioning stage of the test procedure (Sections 8.3.3 and 9.3.3). Also, note with a "Y" (Yes) or "N" (No) whether or not the sample reached 5 percent total vertical permanent strain during the testing sequence. Record the number of test sequences completed, either partially or completely, for the given sample.

11.3.1.2. *Item 5*—Record the specimen dimensions and perform the area and volume calculations.

11.3.1.3. *Item 6*—Record the compaction masses as outlined in Annex B (Type 1) or Annex C or Appendix A (Type 2).

11.3.1.4. *Item 7*—Record the *in situ* moisture content/density values used as the basis for compaction of the specimen as per Sections 7.3.1 and 7.3.2. These values were obtained from nuclear methods in the field. If these values are not available, record the optimum moisture content, maximum dry density, and 95 percent maximum dry density values used as the basis for compaction of the specimen as per Section 7.3.3.

11.3.1.5. *Item 8*—Record the moisture content of the compacted material as per Section B1.3.16 (Type 1) or Sections C1.3.12 or D1.6.3 (Type 2). Record the moisture content of the material after the resilient modulus test as per Section 8.3.11 (Subgrade) or Section 9.3.11 (Base/Subbase). Also, record the target density used for specimen recompaction.

11.3.1.6. *Item 9*—Record the results and accompanying information for the quick-shear test procedure as per Section 8.3.9 (Subgrade) or Section 9.3.9 (Base/Subbase).

11.3.2. Report Form C4.3 (Table C3.3) shall be used to record general information concerning the specimen being tested. This form shall be completed only for thin-walled tube specimens. This form shall not be used to record information for recompacted samples.

11.3.2.1. *Item 4*—Record the approximate distance from the top of the subgrade to the top of the specimen (if known).

11.3.2.2. *Item 5*—Record a "Y" (Yes) or "N" (No) to denote whether the sample reached 5 percent total vertical permanent strain during the preconditioning stage of the test procedure (Sections 8.3.3 and 9.3.3). Also, note with a "Y" (Yes) or "N" (No) whether or not the sample reached a 5 percent total vertical permanent strain during the testing sequence. Record the number of test sequences completed, either partially or completely, for the given sample.

11.3.2.3. *Item 6*—Record the specimen dimensions and perform the area and volume calculations. Record the mass of the specimen.

11.3.2.4. *Item 7*—Record the moisture content (*in situ*) prior to resilient modulus testing. Record the moisture content at the completion of resilient modulus testing as per Section 8.3.11. Record the wet and dry density of the thin-walled tube samples.

11.3.2.5. *Item 8*—Record the results and accompanying information for the quick-shear test procedure as per Section 8.3.9 (Subgrade).

11.3.3. Record the test data for each specimen in a format similar to Report Form C4.1 (Table C3.1) and attach with Report Form C4.2 (Table C3.2) or Report Form C4.3 (Table C3.3). The following information shall be recorded on Report Form C4.1 (Table C3.1):

11.3.3.1. *Column 1*—Record the chamber confining pressure for the testing sequence. Only one entry need be made for the past five load cycles. This entry should correspond exactly with the confining pressure levels shown in Table 1 (Subgrade) or Table 2 (Base/Subbase).

11.3.3.2. *Column 2*—Record the nominal axial cyclic stress for the testing sequence. Only one entry need be made for the past five load cycles. This entry should correspond exactly with the nominal axial cyclic stress required in Table 1 (Subgrade) or Table 2 (Base/Subbase).

11.3.3.3. *Columns 4 through 9*—Record the actual applied loads and stresses for each of the past five load cycles as shown on the worksheet.

11.3.3.4. *Columns 10 through 12*—Record the recoverable axial deformation of the sample for each LVDT independently for each of the past five load cycles. Average the response from the two LVDTs and record this value in Column 12. This value will be used to calculate the axial strain of the material.

11.3.3.5. *Column 13*—Compute the axial strain for each of the past five load cycles. This value is computed by dividing Column 12 by the original length of the specimen, L_o, which was recorded on Report Form C4.2 (Table A3.2) (recompacted specimens) or Report Form C4.3 (Table C3.3) (thin-walled tube specimens).

11.3.3.6. *Column 14*—Compute the resilient modulus for each of the past five load cycles. This value is computed by dividing Column 8 by Column 13.

11.3.3.7. *Average*—Compute the average of the past five load cycles for each column.

11.3.3.8. *Standard Deviation*—Compute the standard deviation of the values for each column for the past five load cycles using the equation:

$$s = \sqrt{\frac{\sum\left(x_i - \bar{x}\right)^2}{n-1}} = \sqrt{\frac{\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}} \qquad (11)$$

ANNEX A—SAMPLE PREPARATION

(Mandatory Information)

A1. SCOPE

A1.1. The following procedure provides guidelines for reconstituting the material to be tested so as to produce a sufficient amount of material needed to prepare the appropriate sample type (Type 1 or Type 2 sample) at the designated moisture content and density.

A1.1.1. *Sample Conditioning*—If the sample is damp when received from the field, dry it until it becomes friable. Drying may be in air or by use of a drying apparatus as long as the temperature does not exceed 60ºC. Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles. Moderate pressure using a rubber-covered implement to push the particles through a 4.75-mm (No. 4) sieve has been found to be adequate to break down clay lumps.

A1.1.2. *Sample Preparation*—Determine the moisture content, w_1, of the sample as per T 265. The mass of the moisture content specimen shall be at least 200 g for samples with a maximum particle size smaller than the 4.75-mm (No. 4) sieve and at least 500 g for samples with a maximum particle size greater than the 4.75-mm (No. 4) sieve.

A1.1.2.1. Determine the appropriate total volume V of the compacted specimen to be prepared. The total volume must be based on a height of the compacted specimen slightly greater than that required for resilient testing to allow for trimming of the specimen ends, if necessary. Compacting to a height/diameter ratio of 2.1 to 2.2 will provide adequate material for this purpose.

A1.1.2.2. Determine the mass of oven-dry soil solids W_s required to obtain the desired dry density γ_d and moisture content w as follows:

$$W_s = 453.59\ \gamma_d\ V \qquad (A1.1)$$

where:

W_s = mass of oven-dry solids, g;

γ_d = desired dry density, lb/ft^3; and

V = total volume of compacted specimen, ft^3.

A1.1.2.3. Determine the mass of the dried sample, W_{ad}, with the moisture content, w_1, required to obtain W_s plus an additional amount, W_{as}, of at least 500 g to provide material for the determination of moisture content at the time of compaction.

$$W_{ad} = (W_s + W_{as})(1 + w_1/100) \qquad (A1.2)$$

where:

W_{ad} = mass of sample at water content w_1, g;

W_{as} = mass of moisture content specimen (usually 500 g), g; and

w_1 = water content of prepared material, percent.

A1.1.2.4. Determine the mass of water (W_{aw}) required to change the water content from the existing water content, w_1, to the desired compaction water content, w. (See Section 7.3.3)

$$W_{aw} = (W_s + W_{as})[(w - w_1)/100] \qquad (A1.3)$$

where:

W_{aw} = mass of water needed to obtain water content, w, g; and

w = desired water content of compacted material, percent.

A1.1.2.5. Place a sample of mass W_{ad} into a mixing pan.

A1.1.2.6. Add the mass of water (w_{aw}) needed to change the water content from w_1 to w, to the sample in small amounts and mix thoroughly after each addition.

A1.1.2.7. Place the mixture in a plastic bag. Seal the bag, place it in a second bag and seal it. Cure the sample for 16 to 48 hours, determine the mass of the wet soil and container to the nearest gram and record this value on Report Form C4.2 (Table A3.2).

A1.1.2.8. The material is now ready for compaction.

ANNEX B—VIBRATORY COMPACTION OF TYPE 1 AND TYPE 2 SOILS

(Mandatory Information)

B1. SCOPE

B1.1. Soils will be recompacted using a split mold and vibratory compaction. Select mold sizes to fabricate specimens of a minimum diameter equal to five times the maximum particles size. If the maximum particle size exceeds 25 percent of the largest mold diameter available, these particles shall be scalped. Length of all specimens will be at least two times the diameter.

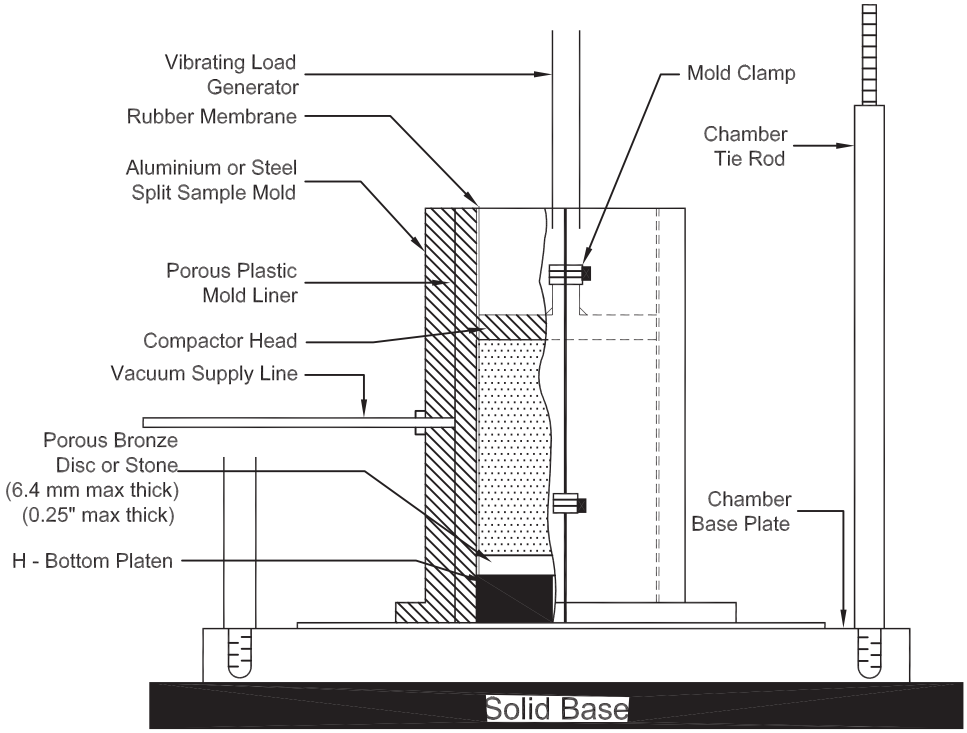
B1.2. Specimens shall be compacted in six lifts in a split mold mounted on the base of the triaxial cell as shown in Figure B2.1. Compaction forces are generated by a vibratory impact hammer without kneading action powered by air or electricity and of sufficient size to provide the required laboratory densities while minimizing damage to the sample membrane.

B2. APPARATUS

B2.1. A split mold, with an inside diameter of 152 mm, having a minimum height of 381 mm (or a sufficient height to allow guidance of the compaction head for the final lift).

B2.2. *Vibratory Compaction Device*—Vibratory compaction shall be provided using electric rotary or demolition hammers with a rated input of 750 to 1250 watts and capable of 1800 to 3000 blows per minute.

B2.3. The compactor head shall be at least 13-mm thick and have a diameter of not less than 146 mm.



Note: Compactor head should be 6.35 ± 0.5 mm (0.25 ± 0.02 in.) smaller than specimen diameter.

Figure B2.1—Typical Apparatus for Vibratory Compaction of Type 1 Untreated Materials

B3. PROCEDURE

B3.1. For removable platens, tighten the bottom platen into place on the triaxial cell base. It is essential that an airtight seal is obtained and that the bottom platen interface constitutes a rigid body because calculations of strain assume zero movement of the bottom platen under load.

B3.2. Place the two porous stones and the top platen on the bottom platen. Determine the total height of the top and bottom platens and stones to the nearest 0.25 mm.

B3.3. Remove the top platen and bronze disc, if used. Measure the thickness of the rubber membrane with a micrometer.

B3.4. Place the rubber membrane over the bottom platen and lower bronze disc. Secure the membrane to the bottom platen using an O-ring or other means to obtain an airtight seal.

B3.5. Place the split mold around the bottom platen and draw the membrane up through the mold. Tighten the split mold firmly in place. Exercise care to avoid pinching the membrane.

B3.6. Stretch the membrane tightly over the rim of the mold. Apply a vacuum to the mold sufficient to draw the membrane in contact. If wrinkles are present in the membrane, release the vacuum, adjust the membrane, and reapply the vacuum. The use of a porous plastic forming jacket line helps to ensure that the membrane fits smoothly inside the mold. The vacuum is maintained throughout the compaction procedure.

B3.7. Measure, to the nearest 0.25 mm, the inside diameter of the membrane-lined mold and the distance between the top of the lower porous stone and the top of the mold.

B3.8. Determine the volume, V, of the specimen to be prepared using the diameter determined in Step B3.7 and a value of height between 305 to 318 mm.

B3.9. Determine the mass of material, at the prepared water content, to be compacted into the volume, V, to obtain the desired density.

B3.10. For 152-mm diameter specimens (specimen height of 305 mm) six layers of 50 mm per layer are required for the compaction process. Determine the mass of wet soil, W_L, required for each layer.

$$W_L = W_t / N \qquad (B3.1)$$

where:

W_t = total mass of test specimen to produce the appropriate density, and

N_t = number of layers to be compacted.

B3.11. Place the total required mass of soil for all lifts, W_{ad}, into a mixing pan. Add the required amount of water, W_{aw}, and mix thoroughly.

B3.12. Determine the mass of the wet soil and the mixing pan.

B3.13. Place the amount of wet soil, W_L, into the mold. Avoid spillage. Using a spatula, draw soil away from the inside edge of the mold to form a small mound at the center.

B3.14. Insert the vibrator and vibrate the soil until the distance from the surface of the compacted layer to the rim of the mold is equal to the distance measured in B3.7 minus the thickness of the layer selected in Step B3.10. This may require removal and reinsertion of the vibrator several times until experience is gained in gauging the vibration time that is required.

B3.15. Repeat Steps B3.13 and B3.14 for each new layer after first scarifying the top surface of the previous layer to a depth of 6.4 mm. The measured distance from the surface of the compacted layer to the rim of the mold is successively reduced by the layer thickness selected in Step B3.10. The final surface shall be a smooth horizontal plane. As a recommended final step where porous bronze discs are used, the top plate shall be placed on the sample and seated with the vibrator head. If necessary, due to degradation of the first membrane, a second membrane can be applied to the sample at the conclusion of the compaction process.

B3.16. When the compaction process is completed, determine the mass of the mixing pan and the excess soil. This mass subtracted from the mass determined in Step B3.12 is the mass of the wet soil used (mass of specimen). Verify the compaction water, W_c, of the excess soil using care in covering the pan of wetted soil during compaction to avoid drying and loss of moisture. The moisture content of this sample shall be conducted using T 265.

B3.17. Proceed with Section 9 of this method.

Note B1—As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as in Appendix B, may be used.

ANNEX C—COMPACTION OF TYPE 2 SOILS

(Mandatory Information)

C1. SCOPE

C1.1. This method covers the compaction of Type 2 soils for use in resilient modulus testing.

C1.2. The general method of compaction of Type 2 soils will be that of static loading (a modified version of the double plunger method). If testable thin-walled tubes are available, specimens shall not be recompacted.

C1.3. The process is one of compacting a known mass of soil to a volume that is fixed by the dimensions of the mold assembly. The minimum mold diameter shall be 71 mm. Select mold sizes to fabricate specimens of a minimum diameter equal to five times the maximum particle size. If the maximum particle size exceeds 25 percent of the largest mold diameter available, these particles shall be scalped. Length of all specimens will be at least two times the diameter. A typical mold assembly is shown in Figure C3.1. As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as in Annex B, may be used. Several steps are required for static compaction, as follows in Section C3 of this Annex and as illustrated in Figures C3.2 to C3.6.

C2. APPARATUS

C2.1. The apparatus is as shown in Figure C3.1.

C3. PROCEDURE

C3.1. Five layers of equal mass shall be used to compact the specimens using this procedure. Determine the mass of wet soil, W_L, to be used per layer where $W_L = W_t/5$.

C3.2. Place one of the spacer plugs into the specimen mold.

C3.3. Place the mass of soil, W_L, determined in Step C3.1, into the specimen mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

C3.4. Insert the second plug and place the assembly in the static loading machine. Apply a small load. Adjust the position of the mold with respect to the soil mass, so the distances from the mold ends to the respective spacer plugs are equal. Soil pressure developed by the initial loading will serve to hold the mold in place. By having both spacer plugs reach the zero volume change simultaneously, more uniform layer densities are obtained.

C3.5. Slowly increase the load until the plugs rest firmly against the mold ends. Maintain this load for a period of not less than 1 minute. The amount of soil rebound depends on the rate of loading and load duration. The slower the rate of loading and the longer the load is maintained, the less the rebound (Figure C3.2).

Note C1—To obtain uniform densities, extreme care must be taken to center the first soil layer exactly between the ends of the specimen mold. Checks and any necessary adjustments should be made after completion of Steps C3.4 and C3.5.

Note C2—Use of compaction by measuring the plunger movements to determine that the desired volume has been reached for each layer is an acceptable alternative to the use of the spacer plugs.

C3.6. Decrease the load to zero and remove the assembly from the loading machine.

C3.7. Remove the loading ram. Scarify the top surface of the compacted layer to a depth of 3.2 mm and put the mass of wet soil, W_L, for the second layer in place and form a mound. Add a spacer plug of the height shown in Figure C3.3.

C3.8. Slowly increase the load until the plugs rest firmly against the top of the mold end. Maintain load for a period of not less than 1 minute (Figure C3.3).

C3.9. Remove the load, flip the mold over, and remove the bottom plug keeping the top plug in place. Scarify the bottom surface of layer one and put the mass of wet soil W_L for the third layer in place and form a mound. Add a spacer ring of the height shown in Figure C3.4.

C3.10. Place the assembly in the loading machine. Increase the load slowly until the spacer plugs firmly contact the ends of the specimen mold. Maintain this load for a period of not less than 1 minute.

C3.11. Follow the steps presented in Figures C3.5 and C3.6 to compact the remaining two layers.

C3.12. After compaction is completed, determine the moisture content of the remaining soil using T 265. Record this value on Report Form C4.2 (Table C3.2).

C3.13. Using the extrusion ram, press the compacted soil out of the specimen mold and into the extrusion mold. Extrusion should be done slowly to avoid impact loading the specimen.

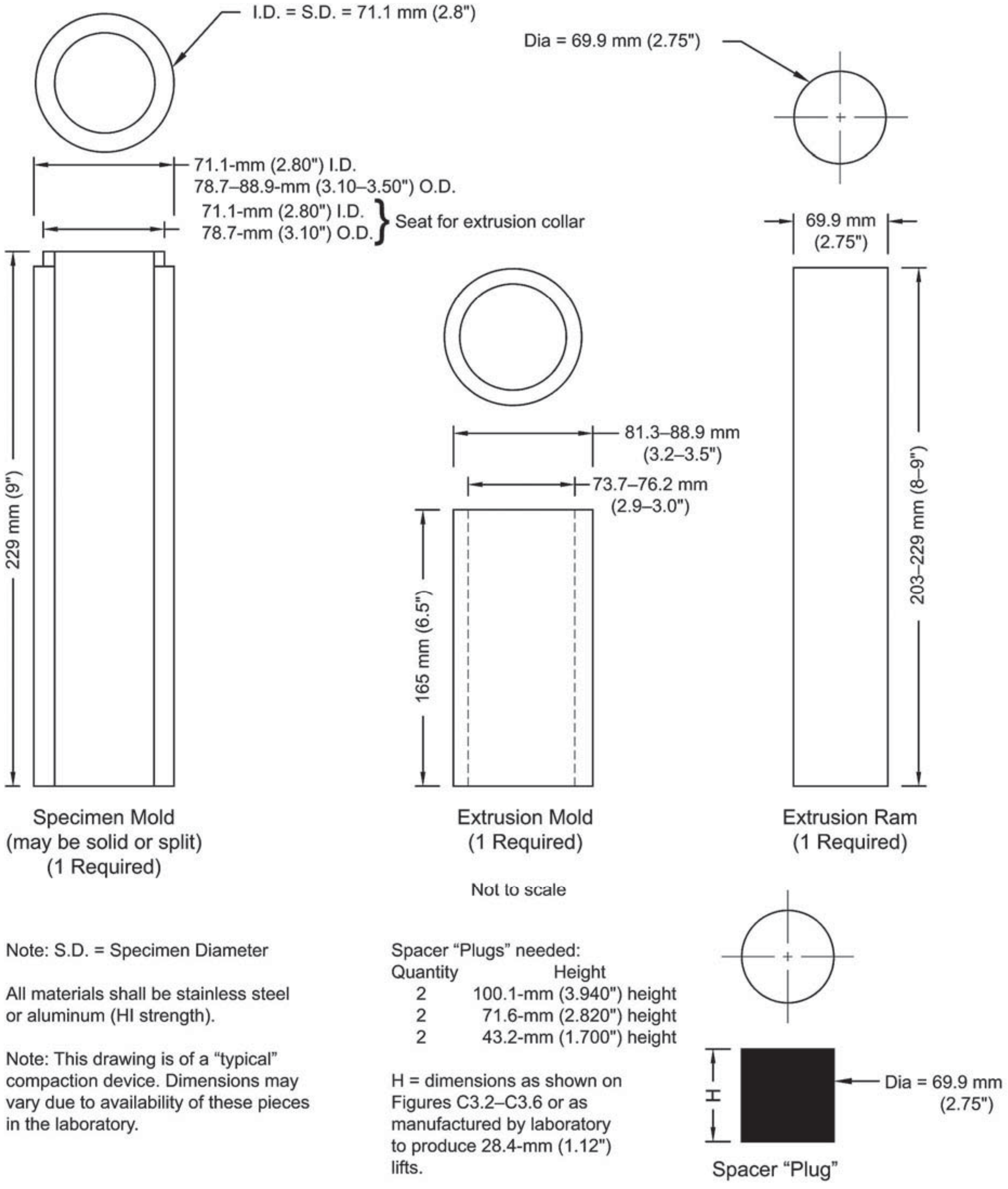
C3.14. Using the extrusion mold, carefully slide the specimen off the ram onto a solid end platen. The platen should be circular with a diameter equal to that of the specimen and have a minimum thickness of 13 mm. Platens shall be of a material that will not absorb soil moisture.

C3.15. Determine the mass of the compacted specimen to the nearest gram. Measure the height and diameter to the nearest 0.25 mm. Record these values on Report Form C4.1 (Table C3.1).

C3.16. Place a platen similar to the one used in Step C3.13 on top of the specimen.

C3.17. Using a vacuum membrane expander, place the membrane over the specimen. Carefully pull the ends of the membrane over the end platens. Secure the membrane to each platen using O-rings or other means to provide an airtight seal.

C3.18. Proceed with Section 8 of this method.



Note: S.D. = Specimen Diameter

All materials shall be stainless steel or aluminum (HI strength).

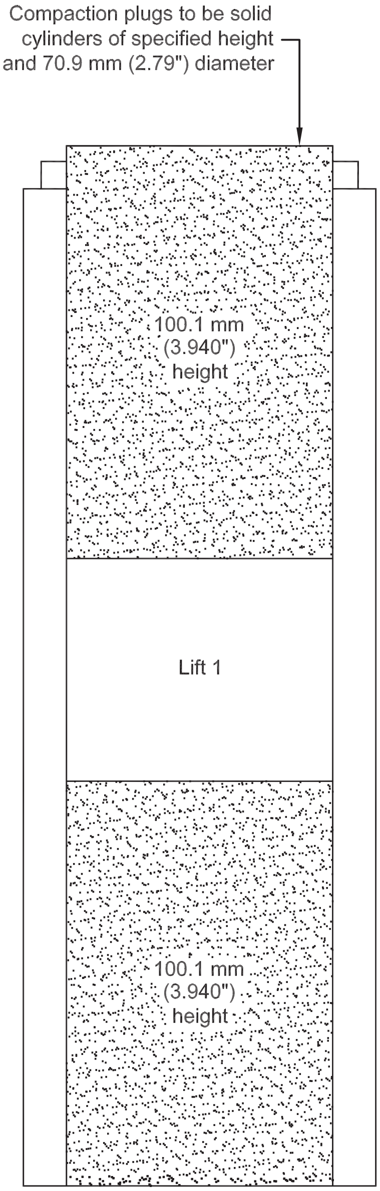
Note: This drawing is of a "typical" compaction device. Dimensions may vary due to availability of these pieces in the laboratory.

Spacer "Plugs" needed:

Quantity	Height
2	100.1-mm (3.940") height
2	71.6-mm (2.820") height
2	43.2-mm (1.700") height

H = dimensions as shown on Figures C3.2–C3.6 or as manufactured by laboratory to produce 28.4-mm (1.12") lifts.

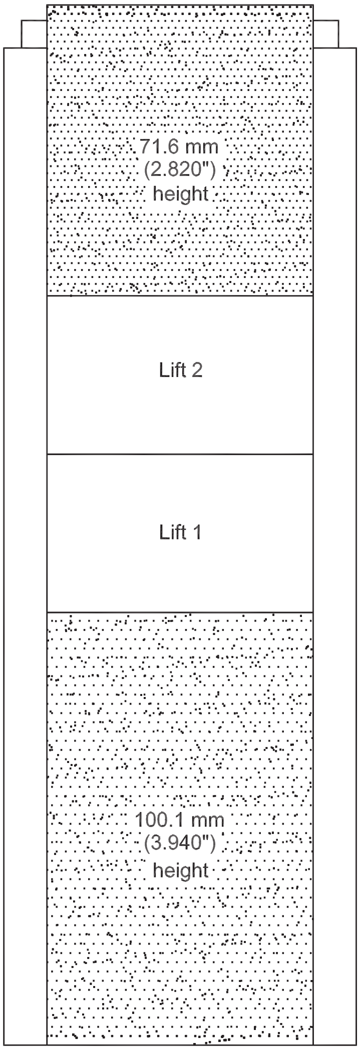
Figure C3.1—Typical Apparatus for Static Compaction of Type 2 Materials



Step 3.5—Lift 1:

- * Measure correct wet weight of soil to use for a layer.
- * Place in mold, spade.
- * Insert plugs of given height.
- * Double plunge until plugs are flush with top and bottom of mold.
- * Remove top plug.
- * Scarify the exposed surface of Lift 1.
- * Proceed with next step.

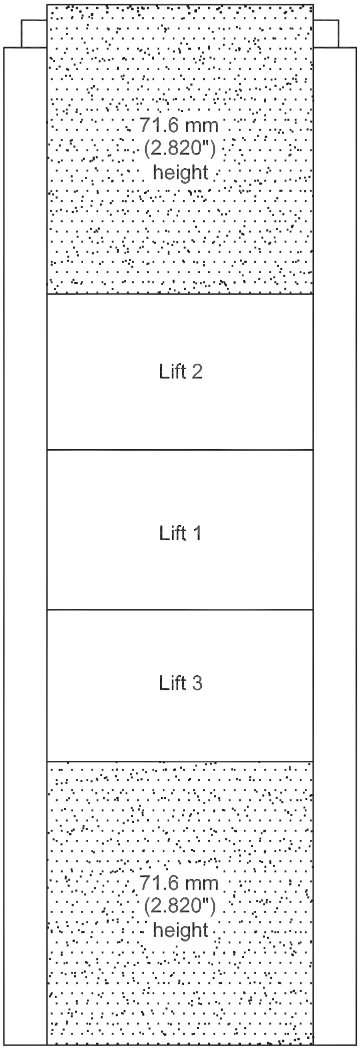
Figure C3.2—Compaction of Type 2 Soil, Lift 1



Step 3.7—Lift 2:

* Measure correct wet weight of soil to use for a layer.
* Place in mold, spade.
* Insert 71.6 mm (2.820") plug.
* Plunge until plugs are flush with top and bottom of mold.
* Flip mold over and remove 100.1 mm (3.940") plug, keeping the 71.6 mm (2.820") plug in place.
* Scarify the exposed surface of Lift 1.
* Proceed with next step.

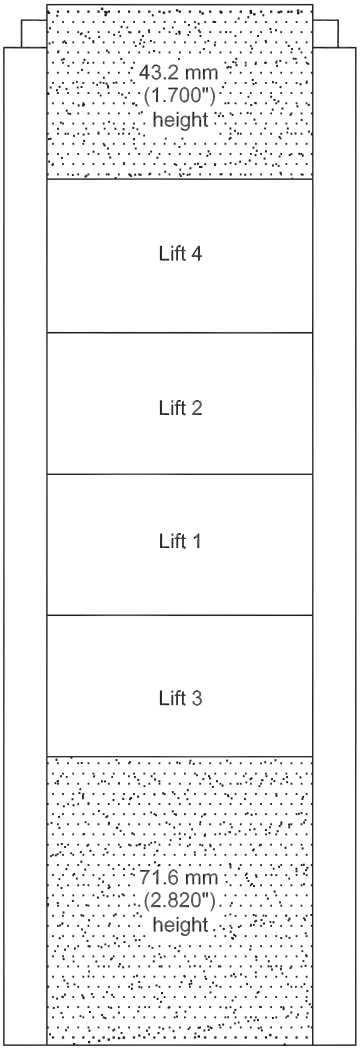
Figure C3.3—Compaction of Type 2 Soil, Lift 2



Step 3.9—Lift 3:

- * Measure correct wet weight of soil to use for a layer.
- * Place in mold, spade.
- * Insert 71.6 mm (2.820") plug.
- * Plunge until plugs are flush with top and bottom of mold.
- * Flip mold over and remove 71.6 mm (2.280") plug, from the top of Lift 2, keeping the 71.6 mm (2.820") plug (on Lift 3) in place.
- * Scarify the exposed surface of Lift 2.
- * Proceed with next step.

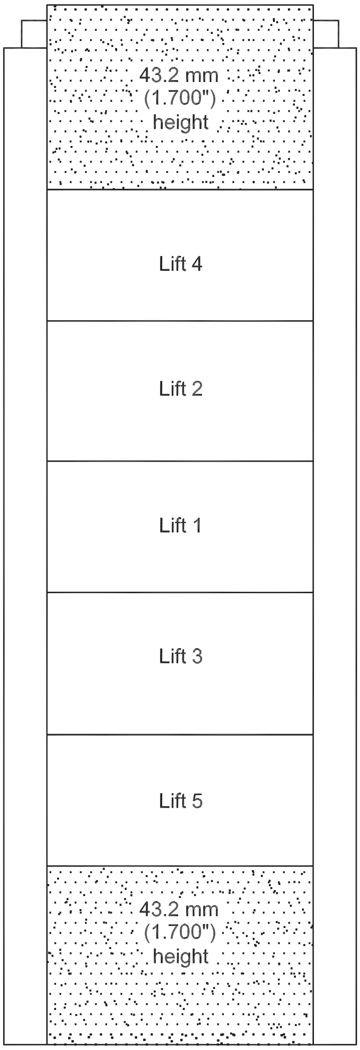
Figure C3.4—Compaction of Type 2 Soil, Lift 3



Step 3.11—Lift 4:

* Measure correct wet weight of soil to use for a layer.
* Place in mold, spade.
* Insert 43.2 mm (1.700") plug.
* Plunge until plugs are flush with top and bottom of mold.
* Flip mold over and remove 71.6 mm (2.820") plug, keeping the 43.2 mm (1.700") plug in place.
* Scarify the exposed surface of Lift 3.
* Proceed with next step.

Figure C3.5—Compaction of Type 2 Soil, Lift 4



Step 3.13—Lift 5:

* Measure correct wet weight of soil to use for a layer.
* Place in mold, spade.
* Insert 43.2 mm (1.700") plug.
* Plunge until plugs are flush with top and bottom of mold.
* Extrude compacted sample from mold using extruding apparatus or extrusion mold.
* Place in rubber membrane.
* Test for M_r.

Figure C3.6—Compaction of Type 2 Soil, Lift 5

C4. REPORT FORMS

(Nonmandatory Information)

Table C4.1—Report Form C4.1

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials

1. SAMPLE NUMBER __ __ __ __
2. MATERIAL TYPE __ __ __ __
3. TEST DATE __ __-__ __-__ __
4. RESILIENT MODULUS TESTING

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PARAMETER	Chamber Confining Pressure	Nominal Maximum Axial Stress	Cycle No.	Actual Applied Max. Axial Load	Actual Applied Cycle Load	Actual Applied Contact Load	Actual Applied Max. Axial Stress	Actual Applied Cycle Stress	Actual Applied Contact Stress	Recov Def. LVDT #1 Reading	Recov Def. LVDT #2 Reading	Average Recov Def. LVDT 1 and 2	Resilient Strain	Resilient Modulus
DESIGNATION	S_3	S_{max}	c_1	P_{max}	P_{cyclic}	$P_{contact}$	S_{max}	S_{cyclic}	$S_{contact}$	H_1	H_2	H_{avg}	$\in_r$	M_r
UNIT	kPa	kPa	----	N	N	N	N	kPa	kPa	mm	mm	mm	mm/mm	MPa
PRECISION	_ _ _ ._	_ _ _._	_	_ _ _._	_ _ _._	_ _ _._	_ _ _._	_ _ _._	_ _._	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_ _ _.
SEQUENCE 1			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

Note: Repeat the gray shaded area for Sequences 2 to 15.

Table C4.2—Report Form C4.2

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
(RECOMPACTED SAMPLES)

1. SAMPLING DATE: __ __-__ __ -20 __ __

2. SAMPLE NUMBER __ __ __ __

3. MATERIAL TYPE (Type 1 or Type 2) __

4. TEST INFORMATION
   PRECONDITIONING – GREATER THAN 5 PERCENT PERM.STRAIN? (Y = YES OR N = NO) __
   TESTING – GREATER THAN 5 PERCENT PERM. STRAIN? (Y = YES OR N = NO) __
   TESTING – NUMBER OF LOAD SEQUENCES COMPLETED (0 – 15) __ __

5. SPECIMEN INFO.:
   SPEC. DIAM., mm __ __ __.__
      TOP __ __ __.__
      MIDDLE __ __ __.__
      BOTTOM __ __ __.__
      AVERAGE __.__ __
      MEMBRANE THICKNESS (1), mm __.__ __
      MEMBRANE THICKNESS (2), mm __ __ __.__
   NET DIAM, mm __ __ __.__
   HEIGHT OF SPECIMEN, CAP AND BASE, mm __ __ __.__
   HEIGHT OF CAP AND BASE, mm __ __ __.__
   INITIAL LENGTH L_O, mm __ __ __ __ __.
   INITIAL AREA, A_O, mm^2 __ __ __ __ __ __ __.
   INITIAL VOLUME, $A_O L_O$, mm^3 __ __ __ __ __ __ __.

6. SOIL SPECIMEN WEIGHT:
   INITIAL WEIGHT OF CONTAINER AND WET SOIL, grams __ __ __ __ __.__ __
   FINAL WEIGHT OF CONTAINER AND WET SOIL, grams __ __ __ __ __.__ __
   WEIGHT OF WET SOIL USED, grams __ __ __ __ __.__ __

7. SOIL PROPERTIES:
   IN SITU MOISTURE CONTENT (NUCLEAR), PERCENT __ __.__
   IN SITU WEIGHT DENSITY (NUCLEAR), kg/m^3 __ __ __ __.__
   or
   OPTIMUM MOISTURE CONTENT, PERCENT __ __.__
   MAX DRY DENSITY, kg/m^3 __ __ __ __.__
   95 PERCENT MAX DRY DENSITY, kg/m^3 __ __ __ __.__

8. SPECIMEN PROPERTIES:
   COMPACTION MOISTURE CONTENT, PERCENT __ __.__
   MOISTURE CONTENT AFTER RESILIENT MODULUS TESTING, PERCENT __ __.__
   COMPACTION DRY DENSITY, γ_d, kg/m^3 __ __ __ __.__

9. QUICK SHEAR TEST
   STRESS-STRAIN PLOT ATTACHED (Y = YES OR N = NO) __
   TRIAXIAL SHEAR MAXIMUM STRENGTH
      (MAX. LOAD/X-SECTION AREA), kPa __ __ __ __.
   SPECIMEN FAIL DURING TRIAXIAL SHEAR? (Y = YES, N = NO) __

10. TEST DATE __ __.__ __.__ __

GENERAL REMARKS:____
____

TESTED BY ___________________ DATE _______________

Table C4.3—Report Form C4.3

Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
(THIN-WALL TUBE SAMPLES)

1. SAMPLING DATE: __ __-__ __ -20 __ __

2. SAMPLE NUMBER __ __ __ __

3. MATERIAL TYPE (Type 1 or Type 2) __

4. APPROX. DISTANCE FROM TOP OF SUBGRADE TO SAMPLE, m __.__ __

5. TESTING INFORMATION
PRECONDITIONING – GREATER THAN 5 PERCENT PERM. STRAIN? (Y = YES OR N = NO) __
TESTING – GREATER THAN 5 PERCENT PERM. STRAIN? (Y = YES OR N = NO) __
TESTING – NUMBER OF LOAD SEQUENCES COMPLETED (0 – 15) __ __

6. SPECIMEN INFO.:
SPEC. DIAM., mm
TOP __ __ __.__
MIDDLE __ __ __.__
BOTTOM __ __ __.__
AVERAGE __ __ __.__
MEMBRANE THICKNESS (1), mm __.__ __
MEMBRANE THICKNESS (2), mm __.__ __
NET DIAM, mm __ __ __.__
INITIAL LENGTH, L_O, mm __ __ __.__
INITIAL AREA, A_O, mm^2 __ __ __ __ __.
INITIAL VOLUME, A_OL_O, mm^3 __ __ __ __ __ __ __.
INITIAL WEIGHT, gram __ __ __ __ __.__

7. SOIL PROPERTIES:
IN SITU MOISTURE CONTENT, PERCENT __ __.__
MOISTURE CONTENT AFTER RESILIENT MODULUS TESTING, PERCENT __ __.__
WEIGHT DENSITY, γ_W, kg/m^3 __ __ __ __.__
DRY DENSITY, γ_d, kg/m^3 __ __ __ __.__

8. QUICK SHEAR TEST
STRESS-STRAIN PLOT ATTACHED (Y = YES OR N = NO) __
TRIAXIAL SHEAR MAXIMUM STRENGTH
(MAX. LOAD/X-SECTION AREA), kPa __ __ __ __
SPECIMEN FAIL DURING TRIAXIAL SHEAR? (Y = YES, N = NO) __

9. TEST DATE __ __.__ __.__ __

GENERAL REMARKS:____
____

TESTED BY ___________________ DATE ________________

APPENDIX A—KNEADING COMPACTION OF TYPE 2 SOILS

(Nonmandatory Information)

X1. SCOPE

X1.1. This method covers kneading compaction of Type 2 soils for use in resilient modulus testing.

X1.2. Specimens shall be compacted in five lifts (layers) in a split mold. Either a pneumatic manual compactor or a hydraulic mechanical compactor provides the compactive effort. The number of tamps per lift and the compaction pressure are constant for all lifts. The compaction pressure is adjusted to achieve the required laboratory density.

X2. SIGNIFICANCE AND USE

X2.1. Kneading compaction will yield a structure in Type 2 soils that is characteristically obtained by field compaction methods. Thus, when compacted dry of the optimum moisture content, the soil structure is mostly flocculated; and when compacted wet of the optimum, it is mostly dispersed.

X2.2. This procedure may result in a gradient of soil density within the specimen, which may affect the resilient modulus, M. Where it is important to achieve a uniform density in all specimen layers, the procedure described in Appendix B should be used.

X3. APPARATUS

X3.1. *Test Specimen Mold*—A split mold with a removable collar, as shown in Figure X6.1, shall be used. The minimum mold inside diameter shall be 71 mm. The mold shall have a minimum inside diameter not less than five times the maximum particle size. The trimmed length of all specimens shall be at least two times the diameter.

Note X1—As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as described in Annex B, may be used.

X3.2. *Manual Compactor*—A pneumatic manual compactor, as shown in Figure X6.2, may be used. The volume of the air reservoir shall be a minimum of 200 times the volume of the compactor at full piston extension. The compactor rod shall be threaded to receive tamping feet of various diameters from 13 to 19 mm. The reservoir pressure regulator and gauge shall be capable of adjusting and reading air pressure from zero to 400 kPa. Calibration shall be checked annually using a calibrated proving ring or load cell.

Note X2—This device is modeled after the Harvard miniature compactor. A pneumatically operated compactor is preferred to a spring-loaded compactor due to the more consistent compactive effort and reduced operator variability.

X3.3. *Mechanical Compactor*—A hydraulic mechanical compactor capable of applying a foot pressure from 250 to 2000 kPa and meeting the requirements of T 190 may be used. When a mechanical compactor is used, the split mold inside diameter shall be chosen as required to work with the compactor, provided that the requirements of Section X3.1 are met.

X4. MANUAL COMPACTION PROCEDURE

X4.1. Specimen material shall be prepared in accordance with Annex A. If the maximum particle size exceeds 25 percent of the mold inside diameter, the oversize particles shall be scalped. The specimen will be fabricated 6 to 8 mm over height to allow trimming to a square end. Increase the quantity of material prepared to allow for the trimming.

X4.2. Specimens shall be compacted in five lifts of equal mass. Determine the mass of soil, W_L, required for each lift according to:

$$W_L = W_T/5 \qquad (X4.1)$$

where:

W_T = total mass of test specimen to produce the target density, including the allowance for trimming.

Note X3—In most cases, the target density will be determined by field conditions. Where this is not the case, an appropriate target density can be determined by performing a laboratory moisture-density test according to the procedure of T 99 or T 180.

X4.3. Adjust the air reservoir pressure to the level to be used in the first trial. Thread the desired diameter tamper foot onto the compactor piston. Determine the required number of tamps for one coverage of each lift according to Table X4.1.

Table X4.1—Number of Tamps for One Coverage of a Lift-Manual Procedure

Specimen Diameter	Tamper Foot Diameter			
	13 mm	15 mm	17 mm	19 mm
71 mm	30	22	17	14
86 mm	44	33	26	20
102 mm	62	46	36	29
152 mm	137	103	80	64

Note X4—Maintaining a database of compaction variables, soil types and moisture-density conditions will assist with selection of starting air pressure to achieve the desired specimen density.

X4.4. Place the mass of wet soil, W_L, for one lift in the mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

X4.5. Holding the compactor vertically, apply the required number of tamps to the soil. Tamps should be distributed evenly over the specimen cross section. Each tamp should be applied slowly with just enough force to move the piston approximately 5 to 10 mm in the compactor.

Note X5—**Caution**: The piston should not be moved all the way to the end of the compactor, as this will cause an unregulated force to be applied.

X4.6. Lightly scarify the top surface of the compacted lift to a depth of 3 mm prior to placing soil in the mold for the next lift.

X4.7. Repeat Steps X4.5 and X4.6 until five lifts have been compacted. Continue with Section X6.1.

X5. MECHANICAL COMPACTION PROCEDURE

X5.1. Specimen material shall be prepared and weighed in accordance with Sections X4.1 and X4.2.

X5.2. Adjust the foot pressure to the level to be used in the first trial.

X5.3. Place the mass of wet soil, W_L, for one lift in the mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

X5.4. Apply one revolution of tamps to the first lift (normally five to seven tamps per revolution, according to T 190) to achieve one coverage over the specimen cross section.

X5.5. Lightly scarify the top surface of the compacted lift to a depth of 3 mm prior to placing soil in the mold for the next lift.

X5.6. Repeat Steps X5.3 through X5.5 until five lifts have been compacted.

X6. SPECIMEN TRIMMING AND CALCULATIONS

X6.1. Remove the collar and carefully screed off the specimen to the top of the mold. Small depressions in the screeded surface, caused by removal of larger particles, shall be filled with fines. Remove the split mold from the base and the mold halves from the specimen.

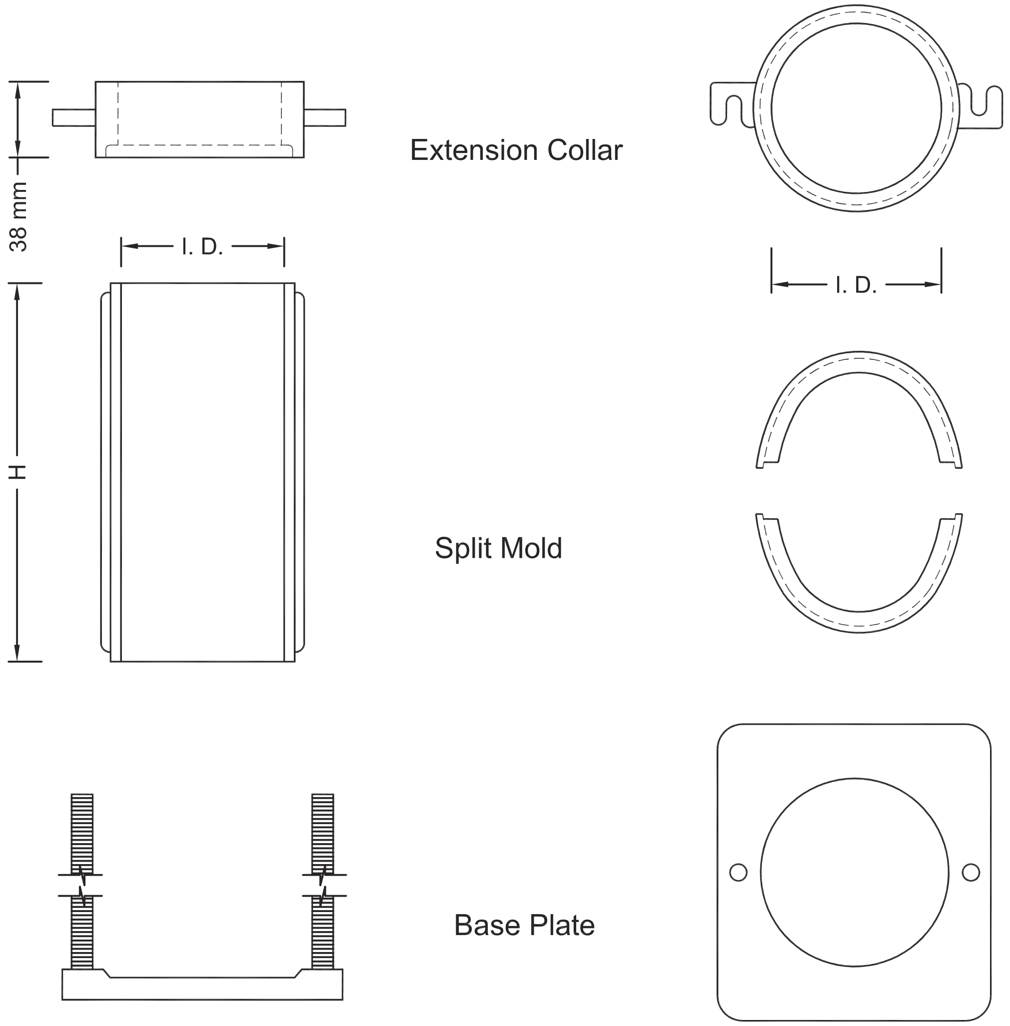
X6.2. Determine and record the mass of the entire specimen to the nearest gram. Use a tabular form, as in Figure X6.2, to record the data.

X6.3. Determine and record the moisture content of the remaining soil according to T 265.

X6.4. Calculate and record the average bulk (wet) density of the entire specimen, γ_s. If the average density differs from the target density by *less* than the tolerance allowed in Section 7.3.2 or 7.3.3, then proceed with Section 7.4.3 of this method.

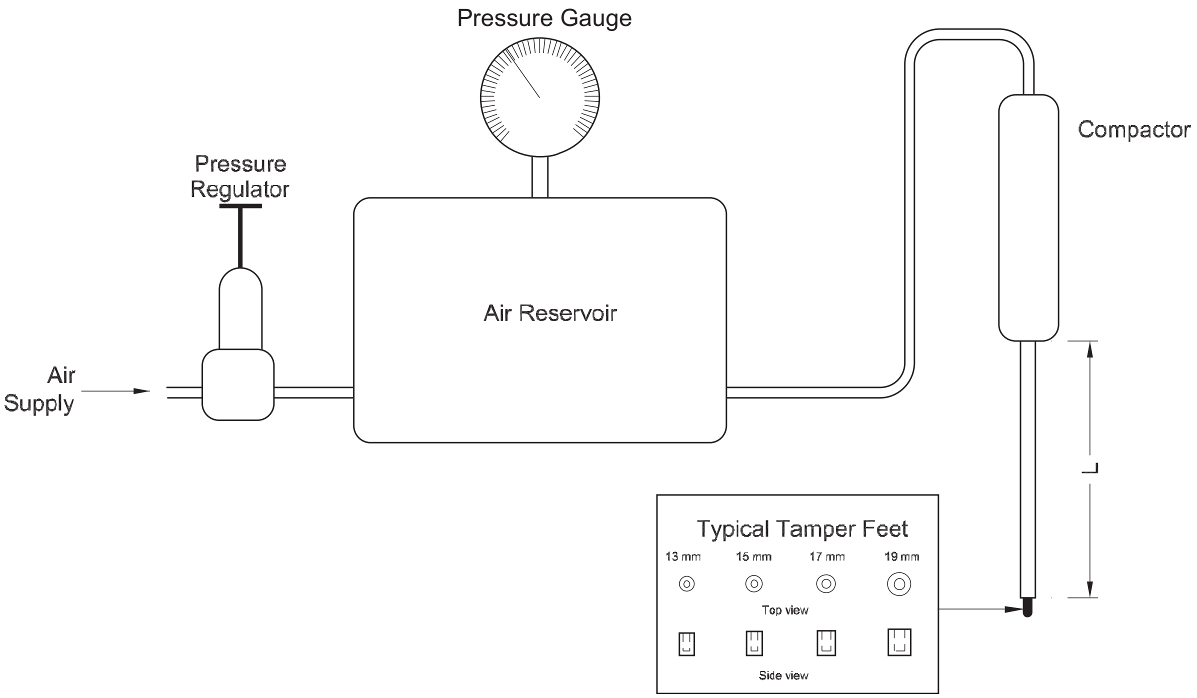
X6.5. If the average density differs from the target density by *more* than the tolerance allowed in Section 7.3.2 or 7.3.3, then the compaction pressure shall be adjusted to increase or decrease the average density toward the target density. Repeat X4 or X5.

Note X6—If a sufficient quantity of material is available, it is preferable to use new material for each subsequent specimen. If the old material is reused, this will have an effect on the structure of subsequently compacted specimens.



Notes: 1. Mold halves are connected with 2 hose clamps.
2. H = I.D. × 2

Figure X6.1—Specimen Mold



Notes:
1. L = Specimen ht. + Collar ht. – Layer HL + 12 mm
2. Minimum Reservoir Volume = 200 × Compactor Volume
3. Minimum gauge accuracy is 0.5 kPa.
4. Compactor air cylinder is rolling diaphragm type.

Figure X6.2—Pneumatic Kneading Compaction System

KNEADING COMPACTION OF TYPE 2 SOILS

PROJECT	

Target Moisture (%)		Target Dry Density (kg/m^3)	

Mold Dimensions – diam. X ht. (mm)		Mold Volume (cm)		Mold Wt. (gm)	

Specimen No.				
Wt. of Scalped Soil (gm)				
No. Tamps per Layer				
Air or Tamper Foot Pressure (Pa)				
Wt. Specimen & Mold (gm)				
Wt. Mold Assembly (gm)				
Wt. Moist Soil (gm)				
Wt. Dry Soil (gm)				
Moisture Content (%)				
Dry Density (kg/m^3)				
Wet Density (kg/m^3)				

PERCENT DIFFERENCES

Target & Specimen Dry Density (%)				
Target & Specimen Moisture (%)				

Specimen No.	Soil Description

REMARKS

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Figure X6.3—Kneading Compaction of Type 2 Soils

APPENDIX B—OBTAINING A UNIFORM DENSITY IN TYPE 2 SOILS

(Nonmandatory Information)

X7. SCOPE

X7.1. This method provides procedures for measuring and minimizing or eliminating density gradients in a specimen of Type 2 soil for use in resilient modulus testing.

X7.2. Specimens shall be compacted in five lifts (layers) in a density gradient mold. Kneading compaction (Appendix A) shall be used. The number of tamps per lift shall be adjusted for each lift to avoid imparting a density gradient to the specimen.

X8. SIGNIFICANCE AND USE

X8.1. A specimen fabricated in layers, with each lift receiving equal compactive effort, will typically exhibit a density gradient with the first lift compacted being more dense than the last. To measure this effect, the density gradient mold is used to determine the density of each lift. A trial and error process is used to adjust the compactive effort for each lift until the desired specimen density is obtained with a minimum gradient.

X8.2. Density gradients can occur with kneading (Appendix A), static double plunger (Annex C), or vibratory (Annex B) compaction methods. The density gradient mold can be used in conjunction with any of the three compaction methods to measure density gradients from top to bottom within the specimen.

X8.3. For the most accurate characterization of resilient modulus, the density gradient within the test specimen should be minimized. The test specimen should have a structure that closely approximates the one that will be obtained in field compaction. The use of kneading compaction can help to achieve the proper structure.

X9. APPARATUS

X9.1. *Density Gradient Mold*—The density gradient mold is shown in Figure X10.1. This is a split mold with the inside milled to receive five interchangeable solid rings that have been permanently numbered from one through five. The ring I.D. shall be equal to the mold I.D. The mold height and diameter shall be the same as those used in preparing specimens for resilient modulus testing (Appendix A).

X9.2. *Compactor*—To measure the density gradient (using Section X10), the same type of compactor shall be used as is used in preparing specimens for resilient modulus testing, as described in Annex B, Annex C, or Appendix A. To minimize the density gradient (using Section X11), either a manual or a mechanical kneading compactor, as described in Appendix A, shall be used.

X10. PROCEDURE FOR COMPACTING SPECIMENS TO MEASURE DENSITY GRADIENTS

X10.1. Specimen material shall be prepared in accordance with Annex A. If the maximum particle size exceeds 25 percent of the mold inside diameter, the oversize particles shall be scalped. The specimen will be fabricated 6 to 8 mm over height to allow trimming to a square end. Increase the quantity of material prepared to allow for the trimming.

X10.2. Specimens shall be compacted to the same diameter, and using the same apparatus and procedure, as is used in preparing specimens for resilient modulus testing, as described in Annex B, Annex C, or Appendix A.

X10.3. Remove the collar and carefully screed off the specimen to the top of the mold. Small depressions in the screeded surface, caused by removal of larger particles, shall be filled with fines. Remove the split mold from the base and the mold halves from the specimen. Leave the five rings on the specimen.

X10.4. Determine and record the net mass of the entire specimen to the nearest gram. To do this, subtract the mass of the rings from the mass of the specimen with rings attached.

X10.5. Determine and record the moisture content of the remaining soil according to T 265.

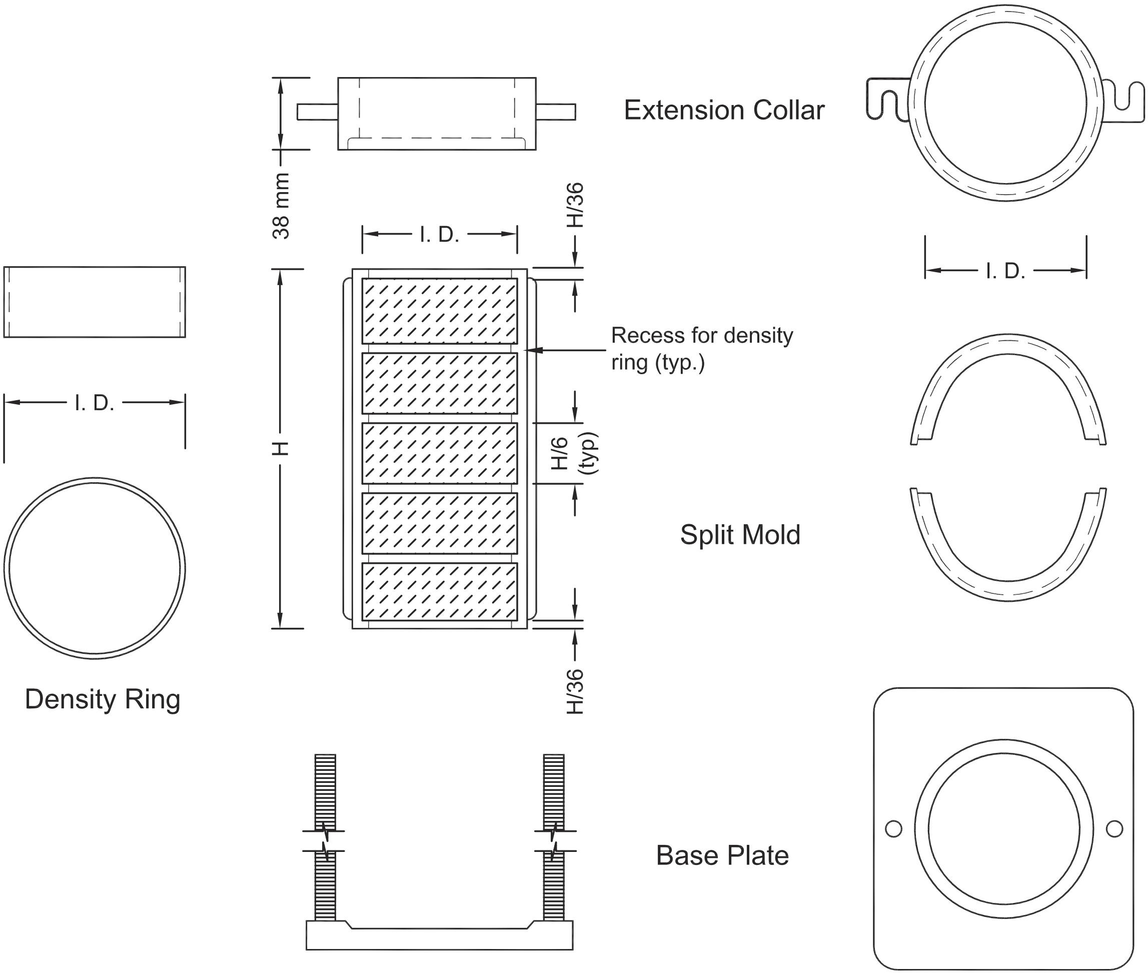
X10.6. Using a hacksaw or other abrasive device, carefully cut the specimen into five pieces. Each cut should be made midway between the rings. Screed off each piece to form square ends at the top and bottom of each ring. Small depressions in the screeded surface, caused by removal of larger particles, shall be filled with fines.

X10.7. Determine and record the net mass of each numbered piece to the nearest gram. Use a tabular form, as in Figure X10.2, to record the data.

X10.8. Determine and record the moisture content of each numbered piece.

X10.9. Calculate and record the average bulk (wet) density of the entire specimen, γ_s, and the densities of each of the five pieces, γ_1 to γ_5.

X10.10. If the maximum difference between the density of each individual piece and the average density is 1.0 percent or less, report the density gradient as being uniform. If the maximum difference between the density of each individual piece and the average density is more than 1.0 percent, report the density gradient as being non-uniform.



Notes: 1. L = Specimen ht. + Collar ht. – Layer HL + 12 mm
2. Minimum Reservoir Volume = 200 × Compactor Volume
3. Minimum gauge accuracy is 0.5 kPa.
4. Compactor air cylinder is rolling diaphragm type.

Figure X10.1—Density Gradient Mold

PROJECT	

Sample No.		Soil Description	

Target Moisture (%)	Target Density (kg/m^3)		*Air Tamper Foot Pressure (Pa)	

Was Sample Scalped?	Wt Scalped Soil (gm)		Mold Dimensions – diam. x ht. (mm)	

Ring Volume (cm^3)

Layer Position in Mold	Order of Compaction[a]	Ring No.	No. of Temps per Layer[b]	Weight (gm)					Moisture (%)	Layer Dry Density (kg/m^3)	Percent Difference Between Average Density & Layer density
				Ring	Ring + Soil (wet)	Soil (wet)	Soil (dry)	Water			
1 (top)											
2											
3											
4											
5 (bottom)											

Average Layer Density (kg/m^3)	Average Moisture (%)	Percent Difference Between Target Density & Average Density (%)	Percent Difference Between Target Moisture & Average Moisture (%)

[a] For static compaction, middle layer is usually first.
For kneading compaction, bottom layer is first.

[b] Required for kneading compaction (Annex A4).

REMARKS

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Figure X10.2—Check for Density Gradient

X11. PROCEDURE FOR COMPACTING TEST SPECIMENS TO ACHIEVE A UNIFORM DENSITY

X11.1. Follow the procedure in Sections X10.1 through X10.9, using either the manual or mechanical kneading compaction procedure (Appendix A).

Note X7—The requirement in Appendix A that the number of tamps per lift be constant is waived. However, it is recommended that the number of tamps per lift be constant for each lift in the first trial specimen in order to establish that a density gradient does exist.

X11.2. If the average bulk density differs from the target density by more than the tolerance allowed in Section 7.3.2 or 7.3.3, then the compaction pressure shall be adjusted, holding the number of tamps per lift constant, to increase or decrease the average density toward the target density. Repeat Step X11.1.

X11.3. After the target average density is achieved, check the density uniformity according to Section X10. If the density is non-uniform, hold the compaction pressure constant and adjust the number of tamps per lift until a uniform density gradient is achieved.

Note X8—If a sufficient quantity of material is available, it is preferable to use new material for each subsequent specimen. If the old material is reused it will have an effect on the structure of subsequently compacted specimens.

X11.4. Use the compaction pressure and number of tamps per lift thus determined to prepare specimens for resilient modulus testing using the procedure in Appendix A.

Standard Method of Test for

In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

AASHTO Designation: T 310-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

AASHTO Designation: T 310-10

1. SCOPE

1.1. This test method describes the procedure for determining the in-place density and moisture of soil and soil-aggregate by use of nuclear gauge. The density of the material may be determined by either direct transmission, backscatter, or backscatter/air-gap ratio method. The moisture of the material is determined only from measurements taken at the surface of the soil (i.e., backscatter).

1.2. *Density*—The total or wet density of soil and soil-rock mixtures is determined by the attenuation of gamma radiation where the source or detector is placed at a known depth up to 300 mm (12 in.) while the detector(s) or source remains on the surface (Direct Transmission Method) or the source and detector(s) remain on the surface (Backscatter Method).

1.2.1. The density in mass per unit volume of the material under test is determined by comparing the detected rate of gamma radiation with previously established calibration data.

1.3. *Moisture*—The moisture content of the soil and soil-rock mixtures is determined by thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector both remain at the surface.

1.3.1. The water content in mass per unit volume of the material under test is determined by comparing the detection rate of thermalized or slow neutrons with previously established calibration data.

1.4. *SI Units*—The values stated in SI units are to be regarded as the standard. The inch-pound equivalents may be approximate. It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two systems of units, that is, the absolute system and the gravitational system.

1.4.1. This standard has been written using the absolute system for water content (kilograms per cubic meter) in SI units. Conversion to the gravitational system of unit weight in lbf/ft^3 may be made. The recording of water content in pound-force per cubic foot should not be regarded as nonconformance with this standard, although the use is scientifically incorrect.

1.4.2. In the English system, the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm) or recording of density (lbm/ft^3) should not be regarded as nonconformance with this standard.

1.5. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and* *health practices and determine the applicability of regulatory limitations prior to use.* See Section 6, Hazards.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
- T 191, Density of Soil In-Place by the Sand-Cone Method
- T 217, Determination of Moisture in Soils by Means of a Calcium Carbide Gas Pressure Moisture Tester
- T 224, Correction for Coarse Particles in the Soil Compaction Test
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 265, Laboratory Determination of Moisture Content of Soils
- T 272, Family of Curves—One-Point Method

2.2. *ASTM Test Methods*:

- D 2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D 2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 2937, Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method
- D 4253, Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
- D 4254, Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
- D 7013, Standard Guide for Nuclear Surface Moisture and Density Gauge Calibration Facility Setup

3. SIGNIFICANCE

3.1. The test method described is useful as a rapid, nondestructive technique for the in-place determination of the wet density and water content of soil and soil-aggregate.

3.2. The test method is used for quality control and acceptance testing of compacted soil and rock for construction and for research and development. The nondestructive nature allows for repetitive measurements at a single test location and statistical analysis of the results.

3.3. *Density*—The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material under test is homogeneous.

3.4. *Moisture*—The fundamental assumptions inherent in the test method are that the hydrogen present is in the form of water as defined by ASTM D 2216 and that the material under test is homogeneous.

3.5. Test results may be affected by chemical composition, sample heterogeneity, and to a lesser degree, material density and the surface texture of the material being tested. The technique also exhibits spatial bias in that the gauge is more sensitive to water contained in the material in close proximity to the surface and less sensitive to water at deeper levels.

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4. INTERFERENCES

4.1. *In-Place Density Interferences*:

4.1.1. The chemical composition of the sample may affect the measurement, and adjustments may be necessary.

4.1.2. The gauge is more sensitive to the density of the material in close proximity to the surface in the Backscatter Method.

Note 1—The nuclear gauge density measurements are somewhat biased to the surface layers of the soil being tested. This bias has largely been corrected out of the Direct Transmission Method, and any remaining bias is insignificant. The Backscatter Method is still more sensitive to the material within the first several inches from the surface. Density measurements with direct transmission is the preferred method.

4.1.3. Oversize rocks or large voids in the source-detector path may cause higher or lower density determination. Where lack of uniformity in the soil due to layering, rock, or voids is suspected, the test site should be excavated and visually examined to determine if the test material is representative of the full material in general, and if rock correction is required.

4.1.4. The sample volume is approximately 0.0028 m^3 (0.10 ft^3) for the Backscatter Method and 0.0057 m^3 (0.20 ft^3) for the Direct Transmission Method when the test depth is 150 mm (6 in.). The actual sample volume is indeterminate and varies with the gauge and the density of the material. In general, the higher the density, the smaller the volume.

4.1.5. Other radioactive sources must not be within 10 m (30 ft) of the gauge in operation.

4.2. *In-Place Moisture Content Interferences*:

4.2.1. The chemical composition of the sample may dramatically affect the measurement and adjustments may be necessary. Hydrogen in forms other than water, as defined by ASTM D 2216, and carbon will cause measurements in excess of the true value. Some chemical elements, such as boron, chlorine, and minute quantities of cadmium, will cause measurements lower than the true value.

4.2.2. The water content determined by this test method is not necessarily the average water within the volume of the sample involved in the measurement. The measurement is heavily influenced by the water content of the material closest to the surface. The volume of soil and rock represented in the measurement is indeterminate and will vary with the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. At 160 kg/m^3 (10 lb/ft^3), approximately 50 percent of the typical measurement results from the water content of the upper 50 to 75 mm (2 to 3 in.).

4.2.3. Other neutron sources must not be within 10 m (30 ft) of the gauge in operation.

5. APPARATUS

5.1. *Nuclear Density/Moisture Gauge*—While exact details of construction of the gauge may vary, the system shall consist of:

5.1.1. A sealed source of high-energy gamma radiation such as cesium or radium.

5.2. *Gamma Detector*—Any type of gamma detector such as a Geiger-Mueller tube(s).

5.3. *Fast Neutron Source*—A sealed mixture of a radioactive material such as americium, radium, or californium-252 and a target material such as beryllium.

5.4. *Slow Neutron Detector*—Any type of slow neutron detector such as boron trifluoride or helium-3 proportional counter.

5.5. *Reference Standard*—A block of material used for checking gauge operation, correction of source decay, and to establish conditions for a reproducible reference count rate.

5.6. *Site Preparation Device*—A plate, straightedge, or other suitable leveling tool which may be used for planing the test site to the required smoothness, and in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.

5.7. *Drive Pin*—A pin not to exceed the diameter of the rod in the Direct Transmission gauge by more than 6 mm ($^1/_4$ in.), or as recommended by the gauge manufacturer, used to prepare a hole in the material under test for inserting the rod.

5.7.1. A slide hammer, with a drive pin attached, may also be used both to prepare a hole in the material to be tested and to extract the pin without distortion to the hole.

5.8. *Drive Pin Extractor*—A tool that may be used to remove the drive pin in a vertical direction so that the pin will not distort the hole in the extraction process.

6. HAZARDS

6.1. The gauge utilizes radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of the gauge must become familiar with applicable safety procedures and government regulations.

6.2. Effective user instructions together with routine safety procedures, such as source leak tests, recording and evaluation of film badge data, etc., are a recommended part of the operation and storage of this gauge.

7. CALIBRATION

7.1. Calibration of the gauge will be in accordance with Annexes A1 and A2. (See also ASTM D 7013).

8. STANDARDIZATION

8.1. All nuclear density/moisture gauges are subject to long-term aging of the radioactive sources, detectors, and electronic systems, which may change the relationship between count rates and the material density and water content. To offset this aging, gauges are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard or to an air-gap count (for the backscatter/air-gap ratio method). The reference count rate should be in the same or higher order of magnitude than the range of measurement count rates over the useful range of the gauge.

8.2. Standardization of the gauge on the reference standard is required at the start of each day's use and a permanent record of these data shall be retained. The standardization shall be performed with the gauge at least 10 m (30 ft) away from other nuclear density/moisture gauges and clear of large masses of water or other items which may affect the reference count rates. Standard counts should be taken in the same environment as the actual measurement counts.

8.2.1. Turn on the gauge and allow for stabilization according to the manufacturer's recommendations. If the gauge is to be used either continuously or intermittently during the day, it is best to leave it in the "power on" condition to prevent having to repeat the stabilization (refer to manufacturer recommendations). This will provide more stable, consistent results.

8.2.2. Using the reference standard, take at least four repetitive readings at the normal measurement period and obtain the mean. If available on the gauge, one measurement of four or more times the normal period is acceptable. This constitutes one standardization check.

Use the procedure recommended by the gauge manufacturer for determining compliance with the gauge calibration curves. Without specific recommendations for the gauge manufacturer, use the procedure in Section 8.2.3.

8.2.3. If the mean of the four repetitive readings is outside the limits set by Equation 1, repeat the standardization check. If the second standardization check satisfies Equation 1, the gauge is considered in satisfactory operating condition. If the second standardization check does not satisfy Equation 1, the gauge should be checked and verified according to Annexes A1 and A2, Sections A1.8 and A2.5. If the verification shows that there is no significant change in the calibration curve, a new reference standard count, N_o, should be established. If the verification check shows that there is a significant difference in the calibration curve, repair and recalibrate the gauge.

$$N_s = N_o \pm 1.96\sqrt{(N_o/F)} \qquad (1)$$

where:

N_s = value of current standardization count;

N_o = average of the past four values of N_s taken for prior usage; and

F = factory pre-scale factor (contact gauge manufacturer for the factor).

9. PROCEDURE

9.1. Select a test location where the gauge will be at least 150 mm (6 in.) away from any vertical mass. If closer than 600 mm (24 in.) to a vertical mass, such as in a trench, follow gauge manufacturer correction procedures.

9.2. *Prepare the test site in the following manner*:

9.2.1. Remove all loose and disturbed material and additional material as necessary to expose the top of the material to be tested.

Note 2—The spatial bias should be considered in determining the depth at which the gauge is to be seated.

9.2.2. Prepare a horizontal area sufficient in size to accommodate the gauge by planing the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

9.2.3. The maximum void beneath the gauge shall not exceed 3 mm ($^1/_8$ in.). Use native fines or fine sand to fill the voids and smooth the surface with a rigid plate or other suitable tool. The depth of the filler should not exceed approximately 3 mm ($^1/_8$ in.).

Note 3—The placement of the gauge on the surface of the material to be tested is critical to the successful determination of density. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. When optimal conditions are not present, correct surface irregularities by the use of sand or similar filler material. The total area filled should not exceed 10 percent of the bottom area of the gauge. Several trial seatings may be required to achieve these conditions.

9.3. Turn on and allow the gauge to stabilize (warm up) according to the manufacturer's recommendations (see Section 8.2.1).

9.4. *Backscatter or Backscatter/Air-Gap Ratio Method of In-Place Nuclear Density and Moisture Content*:

9.4.1. Seat the gauge firmly.

9.4.2. Keep all other radioactive sources at least 10 m (30 ft) away from the gauge to avoid affecting the measurement.

9.4.3. Set the gauge into the Backscatter (BS) position (see Note 4).

9.4.4. Secure and record one or more 1-minute readings (see Note 5). When using the backscatter/air-gap ratio method, follow the manufacturer's instructions regarding gauge setup. Take the same number of readings for the normal measurement period in the air-gap position as in the standard backscatter position. Determine the air-gap ratio by dividing the counts per minute obtained in the air-gap position by the counts per minute obtained in the standard position. Many gauges have built-in provisions for automatically calculating the air-gap ratio and wet density.

9.4.5. Determine the in-place wet density by use of the calibration curve previously established or read the gauge directly if so equipped.

9.4.6. *Direct Transmission Method of In-Place Nuclear Density and Moisture Content:*

9.4.6.1. Select a test location where the gauge in test position will be at least 150 mm (6 in.) away from any vertical projection.

9.4.7. Make a hole perpendicular to the prepared surface using the guide and the hole-forming device (Section 5). The hole shall be a minimum of 50 mm (2 in.) deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area.

9.4.8. Mark the test area to allow the placement of the gauge over the test site and to allow the alignment of the source rod to the hole. Follow manufacturer recommendations if applicable.

9.4.9. Remove the hole forming device carefully to prevent the distortion of the hole, damage to the surface, or loose material to fall into the hole.

9.4.10. Place the gauge on the material to be tested, making sure of maximum surface contact as described above.

9.4.11. Lower the source rod into the hole to the desired test depth. Pull gently on the gauge in the direction that will bring the side of the probe to face the center of the gauge so that the probe is in intimate contact with the side of the hole in the gamma measurement path.

Note 4—As a safety precaution, do not extend a rod containing radioactive sources out of its shielded position prior to placing on the test site. Always align the gauge so as to allow placing the rod directly into the test hole from the shielded position.

9.4.12. Keep all other radioactive sources at least 10 m (30 ft) away from the gauge to avoid affecting the measurement.

9.4.13. If the gauge is so equipped, set the depth selector to the same depth as the probe before recording the automated (gauge computed densities, moisture contents, and weights) values.

9.4.14. Secure and record one or more 1-minute readings (see Note 5).

9.4.15. Determine the in-place wet density by use of the calibration curve previously established or read the gauge directly if so equipped.

Note 5—The gauge may be rotated about the axis of the probe to obtain additional readings.

10. CALCULATION OF RESULTS

10.1. If dry density is required, the in-place water content may be determined by using the nuclear methods described herein, gravimetric samples and laboratory determination, or other approved instrumentation.

10.1.1. If the water content is determined by nuclear methods, use the gauge readings directly, or subtract the kg/m^3 (lbm/ft^3) of moisture from the kg/m^3 (lbm/ft^3) of wet density, and obtain dry density in kg/m^3 (lbm/ft^3).

10.1.2. If the water content is determined by other methods, and is in the form of percent, proceed as follows:

$$d = \frac{100}{100 + w}(m) \tag{2}$$

where:

d = dry density in kg/m^3 (lbm/ft^3);

m = wet density in kg/m^3 (lbm/ft^3); and

w = water as a percent of dry mass.

10.2. *Percent Density:*

10.2.1. It may be desired to express the in-place density as a percentage of some other density, for example, the laboratory densities determined in accordance with T 99 and T 180. This relation can be determined by dividing the in-place density by the laboratory density and multiplying by 100. Calculations for determining relative density are provided in ASTM D 4253 or D 4254. Corrections for oversize material, if required, should be performed in accordance with T 224 or ASTM D 4718.

10.2.2. If representative samples of material are to be taken for purposes of correlation with other test methods or rock correction, the volume measured can be approximated by a 200-mm (8-in.)-diameter cylinder located directly under the center line of the radioactive source and detector(s). The height of the cylinder to be excavated will be the depth setting of the source rod when using the Direct Transmission method or approximately 75 mm (3 in.) when using the Backscatter method.

10.2.3. An alternate to the correction for oversize particles that can be used with mass density methods or minimal oversize situations involves multiple tests. Three tests may be taken at adjacent locations and the results averaged to get a representative value.

Comparisons need to be made to evaluate whether the presence of a single large rock or void in the soil is producing unrepresentative values of density. Whenever values obtained are questionable, the test volume site should be excavated and visually examined.

11. REPORT

11.1. The report shall include the following:

11.1.1. Standardization and adjustment data for the date of the tests.

11.1.2. Make, model, and serial number of the test gauge.

11.1.3. Name of the operator(s).

11.1.4. Date of last instrument calibration or calibration verification.

11.1.5. Test site identification.

11.1.6. Visual description of material tested.

11.1.7. Test mode (backscatter or direct transmission) and test depth (if applicable).

11.1.8. Wet and dry densities in kg/m^3 or unit weights in lb/ft^3.

11.1.9. Water content in percent of dry mass or dry unit weight.

11.1.10. Any adjustments made in the reported values and reasons for adjustments (i.e., offset, oversize particles, etc.).

12. PRECISION AND BIAS

12.1. *Precision*:

12.1.1. *Wet Density*—Criteria for judging the acceptability of wet density test results obtained by this test method are given in Table 1. The figure in Column 3 represents the standard deviations that have been found to be appropriate for the materials tested in Column one. The figures given in

Column 4 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. The figures given are based upon an inter-laboratory study in which five test sites containing soils, with wet densities as shown in Column 2, were tested by eight different devices and operators. The wet density of each test site was determined three times by each device.

Table 1—Results of Statistical Analysis (Wet Density)[a]

	Soil Type (Column 1)	Average, lb/ft^3 (kg/m^3) (Column 2)	Standard Deviation (Column 3)	Acceptable Range of Two Results,[b] lb/ft^3 (kg/m^3) (Column 4)
Single-Operator Precision				
Direct Transmission:				
	CL	114.7 (1837.3)	0.34 (5.45)	0.94 (15.06)
	SP	120.9 (1936.6)	0.27 (4.32)	0.74 (11.85)
	ML	130.1 (2084.0)	0.46 (7.37)	1.28 (20.50)
Backscatter:				
	ML	124.6 (1995.9)	1.21 (19.38)	3.39 (54.30)
Multilaboratory Precision				
Direct Transmission:				
	CL	114.7 (1837.3)	0.66 (10.57)	1.86 (29.79)
	SP	120.9 (1936.6)	0.68 (10.89)	1.91 (30.59)
	ML	130.1 (2084.0)	0.77 (12.23)	2.15 (34.44)
Backscatter:				
	ML	124.6 (1995.9)	2.38 (38.12)	6.67 (106.84)

[a] The data used to establish the density and moisture content precision statements are contained in ASTM Research Report RR:D18-1004. Similar soil types using other classification systems should reflect similar precision values.

[b] Two separate readings at a singular site with constant gate orientation and settings.

12.1.2. *Moisture Content*—Criteria for judging the acceptability of the moisture content results obtained by this test method are given in Table 2. The value in Column 2 is in the units actually measured by the nuclear gauge. The figures in Column 3 represent the standard deviations that have been found to be appropriate for the materials tests in Column 1. The figures given in Column 4 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. The figures given are based upon an inter-laboratory study in which five test sites containing soils, with moisture content as shown in Column 2, were tested by eight different devices and operators. The moisture content of each test site was determined three times by each device.

Table 2—Results of Statistical Analysis (Moisture Content)

	Soil Type (Column 1)	Average, lb/ft^3 (kg/m^3) (Column 2)	Standard Deviation (Column 3)	Acceptable Range of Two Results,[a] lb/ft^3 (kg/m^3) (Column 4)
Single-Operator Precision				
	CL	12.1 (193.8)	0.35 (5.6)	0.97 (15.5)
	SP	18.7 (299.5)	0.46 (7.4)	1.29 (20.7)
	ML	19.6 (314.0)	0.35 (5.6)	0.99 (15.8)
Multilaboratory Precision				
	CL	12.1 (193.8)	0.52 (8.3)	1.44 (23.1)
	SP	18.7 (299.5)	0.75 (12.0)	2.10 (33.6)
	ML	19.6 (314.0)	0.58 (9.3)	1.63 (26.1)

[a] Two separate readings at a singular site with constant gauge orientation and settings.

12.2. *Bias*:

12.2.1. There are no accepted reference values for these test methods; therefore, bias cannot be determined.

13. KEYWORDS

13.1. Compaction test; construction control, density; moisture content; nuclear methods; quality control; water content.

ANNEXES

(Mandatory Information)

A1. WET DENSITY CALIBRATION AND VERIFICATION

A1.1. *Calibration*—Newly acquired gauges shall be calibrated initially. Existing gauges shall be calibrated after repairs that may affect the gauge geometry. Existing gauges shall be calibrated to re-establish calibration curves, tables, or equivalent coefficients if the gauge does not meet the specified tolerances in the verification process. If the owner does not establish a verification procedure, the gauge shall be calibrated at a minimum frequency of 24 months.

A1.2. *Verification*—Existing gauges shall be verified at a minimum frequency of 12 months. The verification process and resultant tolerances obtained over the depths that the gauge shall be formally recorded and documented. If the verification process indicates a variance beyond the specified tolerances, the gauge shall be calibrated.

A1.3. The calibration response of the gauge shall be within ±16 kg/m^3 (±1.0 lb/ft^3) on the blocks on which the gauge was calibrated. This calibration may be done by the manufacturer, the user, or an independent vendor. Nuclear gauge response is influenced by the chemical composition of measured materials. This response must be taken into account in establishing the assigned standard block density. The blocks used for calibration shall be capable of generating a general and reliable curve covering the entire density range of materials tested in the field. The density of these standard blocks shall be determined to an accuracy of ±0.2 percent.

A1.4. Sufficient data shall be taken on each density standard block to ensure a gauge count precision (see Annex A3) of at least one half the gauge count precision required for field use assuming field use measurement of 1-minute duration and 4-minute duration used for calibration, or an equivalent relationship. The data may be presented in the form of a graph, table, equation coefficients, or stored in the gauge, to allow converting the count rate data to density.

A1.5. The method and test procedures used in establishing the calibration count rate data shall be the same as those used for obtaining the field count rate data.

A1.6. The material type, actual density, or assigned standard block density of each calibration standard used to establish or verify the gauge calibration shall be stated as part of the calibration data for each measurement depth.

A1.7. The standards should be sufficient in size to not change the count rate if enlarged in any dimension.

Note A1—Minimum surface dimensions of approximately 610 mm by 430 mm (24 by 17 in.), have proven satisfactory. For the Backscatter Method, a minimum depth of 230 mm (9 in.) is adequate, while for the Direct Transmission Method the depth should be at least 50 mm (2 in.) deeper than the deepest rod penetration depth. A larger surface area should be considered for the backscatter air-gap method. For blocks with width and length smaller than the sizes specified, follow block manufacturers' recommendations for proper installation and use.

A1.8. The most successful standards that have been established for calibration have been made of magnesium, aluminum, aluminum/magnesium, granite, and limestone. These standards have been used in combination with each other, with historical curve information, and with other prepared block(s) to produce accurate and reliable calibration.

A1.8.1. Standards of soil, rock, and concrete that have stable characteristics for reproducibility and uniformity are difficult to prepare. These standards may be of use for specialty verification or field calibration where local site material chemistry or background situation require special adaptation.

A1.9. *Verify an existing calibration* by taking a sufficient number of counts at each measurement depth on one or more blocks of established density to ensure the accuracy of the existing calibration within ±32 kg/m^3 (±2.0 lb/ft^3) at each measurement depth.

A1.9.1. Sufficient data shall be taken to ensure a gauge count precision of at least one half the gauge count precision required for field use assuming field use measurement of 1-minute duration and 4-minute duration used for calibration, or an equivalent relationship.

A1.9.2. Calibration blocks, which are used for calibration of the gauge, or prepared block(s), which are capable of generating a general and reliable curve covering the range of densities of the materials to be tested in the field, can be used to verify the gauge calibration.

A1.9.2.1. Blocks prepared of soil, rock, concrete, asphalt, and engineered blocks that have characteristics of reproducible uniformity may be used, but care must be taken to minimize changes in density and water content over time.

A1.9.2.2. Density values of prepared blocks shall be determined to an accuracy of ±0.5 percent at each measurement depth.

A1.9.3. The assigned block density for each calibration depth used to verify the gauge calibration shall be stated as part of the verification data.

A2. WATER CONTENT CALIBRATION AND VERIFICATION

A2.1. *Calibration*—Newly acquired gauges shall be calibrated initially. Existing gauges shall be calibrated after repairs that may affect the gauge geometry. Existing gauges shall be calibrated to re-establish calibration curves, tables, or equivalent coefficients if the gauge does not meet the specified tolerances in the verification process. If the owner does not establish a verification procedure, the gauge shall be calibrated at a minimum frequency of 24 months.

A2.2. *Verification*—Existing gauges shall be verified at a minimum frequency of 12 months. The verification process and resultant tolerances obtained over the depths the gauge shall be formally recorded and documented. If the verification process indicates a variance beyond the specified tolerances, the gauge shall be calibrated.

A2.3. The calibration response of the gauge shall be within ±16 kg/m^3 (±1.0 lb/ft^3) on the blocks on which the gauge was calibrated. This calibration may be done by the manufacturer, the user, or an independent vendor. The blocks used for calibration should be capable of generating a general curve covering the entire water content range of the materials to be tested in the field. The calibration curve can be established using counts and water contents of standard blocks, previous factory curve information, or historical data. Due to the effect of chemical composition, the calibration supplied by the manufacturer with the gauge will not be applicable to all materials. It shall be accurate for silica and water; therefore, the calibration must be verified and adjusted, if necessary, in accordance to Section A2.5.

A2.4. Calibration standards may be established using any of the following methods. Prepared containers or standards must be large enough to not change the observed count rate if made larger in any dimension.

Note A2—Dimensions of approximately 610-mm long by 460-mm wide by 360-mm deep (approximately 24 in. by 18 in. by 14 in.) have proven satisfactory. For blocks with width and length smaller than the sizes specified, follow block manufacturers' recommendations for proper installation and use.

A2.4.1. Prepare a homogeneous standard of hydrogenous materials having an equivalent water content determined by comparison (using a nuclear gauge) with a saturated silica sand standard prepared in accordance with Section A.2.4. Metallic blocks used for wet density calibration, such as magnesium or aluminum, are convenient zero water content standard.

A2.4.2. Prepare containers of compacted material with a percent water content determined by oven dry (ASTM D 2216) and a wet density calculated from the mass of the material and the inside dimensions of the container. The water content may be calculated as follows:

$$M_m = \frac{\rho \times w}{100 + w} \qquad (A2.1)$$

where:

M_m = water content, kg/m^3 or lbm/ft^3;

ρ = wet (total) density, kg/m^3 or lbm/ft^3; and

w = water content, percent of dry mass.

A2.4.3. Where neither of the previous calibration standards are available, the gauge may be calibrated by using a minimum of four selected test sites in an area of a compaction project where material has been placed at several different water contents. The test sites shall represent the range of water contents over which the calibration is to be used. At least four replicate nuclear measurements shall be made at each test site. The density at each site shall be measured by making four closely spaced determinations with calibrated equipment in accordance with AASHTO T 191 or ASTM D 2937. The water content of each of the density tests shall be determined by ASTM Test Method D 2216. Use the mean value of the replicate readings as the calibration point value for each site.

A2.5. *Calibration Adjustments*:

A2.5.1. The calibration of newly acquired or repaired gauges shall be verified and adjusted prior to use. Calibration curves shall be checked prior to performing tests on materials that are distinctly different from material types previously used in obtaining or adjusting the calibration. Sample materials may be selected by either Section A2.5.1.1 or Section A2.5.1.2. The amount of water shall be within ±2 percent of the water content established as optimum for compaction. Determine the water content in kg/m^3 or lb/ft^3 by Equation A2.1. A microwave oven or direct heater may be utilized for drying materials which are not sensitive to temperature, in addition to the methods listed in Section A2.4.3. A minimum of four comparisons is required and the mean of the observed differences used as the correction factor.

A2.5.1.1. Container(s) of compacted material taken from the test site may be prepared in accordance with Section A2.4.2.

A2.5.1.2. Test site(s) or the compacted material may be selected in accordance with Section A2.4.3.

A2.5.2. The method and test procedures used in obtaining the count rate to establish the error must be the same as those used for measuring the water content of the material to be tested.

A2.5.3. The mean value of the difference between the moisture content of the test samples as determined in Section A2.5.1.1 or Section A2.5.1.2 and the values measured with the gauge shall be used as a correction to measurements made in the field. Some gauges utilizing a microprocessor may have provision to input a correction factor that is established by the relative values of water content as a percentage of dry density, thus eliminating the need to determine the difference in mass units of water.

A2.6. *Verify an existing calibration* by taking sufficient number of counts on one or more blocks of established water content to ensure the accuracy of the existing calibration within ±16 kg/m^3 (±1 lb/ft^3). The water content block(s) should be prepared in accordance with Sections A2.4.1 and A2.4.2.

A2.6.1. Sufficient data shall be taken to ensure a gauge count precision (see Annex A3) of at least one half the gauge count precision required for field use assuming field use measurement of 1-minute duration and 4-minute duration used for calibration, or an equivalent relationship.

A2.6.2. Calibration blocks used to establish calibration parameters and prepared block(s) that are capable of generating a general and reliable curve covering the range of densities of the materials that are to be tested in the field can be used to verify calibration.

A2.6.3. Prepared block(s) that have characteristics of reproducible uniformity may be used, but care must be taken to minimize changes in density and water content over time.

A2.6.4. The assigned water content of the block(s) used for verification of the gauge shall be stated as part of the verification data.

A3. GAUGE COUNT PRECISION

A3.1. Gauge count precision is defined as the change in density or water content that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The density of the material and time period of the count must be stated. It may be determined using calibration data (Equation A3.1) or Sections A3.2 and A3.3.

A3.2. Determine the gauge count precision of the system, P, from the slope of the calibration curve, S, and the standard deviation, σ, of the signals (detected gamma rays or detected neutrons) in counts per minute (cpm), as follows:

$$P = \sigma / S \qquad (A3.1)$$

where:

P = precision;

σ = standard deviation, cpm; and

S = slope, $cpm/kg/m^3$ ($cpm/lb/ft^3$).

Note A3—Displayed gauge counts may be scaled. Contact the manufacturer to obtain the appropriate pre-scale factor.

A3.3. *Density*—Determine the slope of the calibration curve at the 2000-kg/m^3 (125-lb/ft^3) point in counts per minute per kilogram per cubic meter (counts per minute per pound per cubic foot). Determine the standard deviation of a minimum of 20 per pound repetitive readings of 1 minute each (gauge is not moved after seating for the first count) taken on material having a density of 2000 ± 80 kg/m^3 (125.0 ± 5.0 lb/ft^3). The value of P is typically less than 10 kg/m^3 (0.6 lb/ft^3) in the backscatter method and 5 kg/m^3 (0.3 lb/ft^3) in the direct transmission method at 6-in. depth.

A3.4. *Moisture*—Where the slope of the calibration curve is determined at the 160-kg/m^3 (10-lb/ft^3) point and the standard deviation is determined from a minimum of 20 repetitive readings of 1 minute each (the gauge is not moved after the first count) taken on material having a moisture content of 160 ± 10 kg/m^3 (10.0 ± 0.6 lb/ft^3) the value of P is typically less than 4.8 kg/m^3 (0.30 lb/ft^3).

Standard Method of Test for

Grain-Size Analysis of Granular Soil Materials

AASHTO Designation: T 311-00 (2010)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Grain-Size Analysis of Granular Soil Materials

AASHTO Designation: T 311-00 (2010)

1. SCOPE

1.1. This method covers the determination of the particle size distribution of granular soil material. This method utilizes the 6.3-mm sieve size for separation purposes. However, the sample tester may use an alternative sieve size (i.e., 4.75 mm, 2.00 mm, etc.). In this case, the alternative sieve size used must replace the 6.3-mm size throughout this procedure.

1.2. Specifications for granular soil material, which reference this method, usually contain grading requirements that include both coarse and fine fractions in sizes between 100 mm and 0.075 mm.

1.3. *The standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes (Excluding Column 7 in Table No. 1)
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates

2.2. *ASTM Standard*:

- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

3. SUMMARY OF METHOD

3.1. A weighed sample of dry granular soil material is separated through a series of sieves with progressively smaller openings. Particle size distribution is determined by weighing the material retained on each of the sieves and dividing these weights by the total dry weight of the sample. This method requires drying, washing, and a series of separations.

4. SIGNIFICANCE AND USE

4.1. This method is used primarily to determine the gradation of granular soil material for use as fill material in subbase, pipe, or structural backfill. Granular soil material used in these applications generally necessitates a well-graded material. This results in samples that contain material that is retained on a wide range of sieve sizes. The results are used to determine the compliance of grain size distribution of granular soil material with applicable specification requirements, and to provide the necessary data in order to determine the acceptability of this select granular material for the stated uses. This procedure is intended for use in quality assurance testing where large numbers of samples are processed.

5. APPARATUS

5.1. *Platform Scale*—The platform scale shall conform to the requirements of M 231 for the class of general purpose scale required for the principal sample weight being tested.

5.2. *Balance*—The balance shall conform to the requirements of M 231 for the class of general purpose balance required for the sample weight of fine granular material being tested.

5.3. *Sieves*—The sieves shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The sieves shall conform to M 92 (Note 1).

Note 1—It is recommended that sieves mounted in frames larger than standard 203-mm diameter frames be used for testing coarse aggregate. Also, it may be desirable to use a heavy duty screen meeting the required opening tolerances but with a larger wire diameter.

5.4. *Mechanical Sieve Shaker*—A mechanical sieve shaker, if used, shall impact a vertical or lateral and vertical motion to the sieve, causing the particles thereon to bounce and turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 7.4 is met in a reasonable time period.

Note 2—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg or greater, and may be used for smaller samples, including fine granular material. Excessive time (more than approximately 5 minutes) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse granular material very likely could result in loss of a portion of the sample if used for a smaller sample of coarse granular or fine granular material.

5.5. *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of 110 ± 5ºC.

5.6. *Miscellaneous*—Spoons, spatulas, brushes, and containers (non-corroding and not subject to weight change).

6. SAMPLING AND PREPARATION

6.1. Sample the aggregate in accordance with T 2.

6.2. *Sample Size*:

6.2.1. For granular construction items, the sample(s) shall be transported to the testing facility in a clean, approved container. Assure that the sample size meets a minimum mass requirement of 20 kg.

6.2.2. For materials other than granular construction items, i.e., design testing, the sample(s) shall be transported to the testing facility in a clean, approved container and be large enough to be representative of the material being tested. In general, the larger the nominal maximum particle size is, the larger the sample should be in order to be considered representative. The following may be considered a guide (not a requirement) for sample masses on particle size:

Nominal Maximum Particle Size	Sample Mass
50 mm	20 kg
19 mm	7 kg
6.3 mm	1 kg

7. PROCEDURE

Note 3—Due to ease of operation, the following Procedure, Calculation, and Sieve Analysis Data Sheet utilizes a 6.3-mm sieve for separation. Depending on the sample type and size, or the tester's preference, or both, alternative sieve sizes can be used for separation (i.e., 4.75 mm, 2.00 mm). When an alternative sieve size is used, then that size must replace the 6.3-mm size as outlined in this method. In addition, a new Sieve Analysis Data Sheet must be developed for the alternative sieve size utilized.

7.1. Screen the sample on a 6.3-mm sieve in order to divide it into plus 6.3-mm and minus 6.3-mm portions. If an excessive amount of silt or clay adheres to the plus 6.3-mm material, it should be screened again after additional drying. If the sample does not have any plus 6.3-mm particles, proceed in accordance with Section 7.4.

Note 4—During this initial and subsequent sieving, care should be exercised to prevent "overloading" the 6.3 mm and any other sieve. This condition exists when an excessive amount of soil is placed on the sieve, leaving an insufficient amount of sieve openings for the material to pass through. To avoid "overloading," the sample must be divided into smaller portions and sieved separately.

Note 5—In some soils a significant amount of the particles will adhere together and form silt or clay balls, or both, that may be mistaken for plus 6.3-mm particles. Care must be taken to ensure that such balls pass through the 6.3-mm screen. It may be necessary to run a wood mallet over the material on the screen for this purpose; but be careful not to pulverize the actual particles or damage the sieve.

7.2. Once the plus 6.3-mm portion has fully dried (to the point where there is no visible sign of moisture), weigh the sample to the nearest 5 g and record this value (line A).

Note 6—Prior to weighing the plus 6.3-mm portion, check for particles larger than 100 mm. Remove such material and weigh it to the nearest 5 g and make a note of it on the data sheet. These particles should not be included in the test. (See Figures 1 and 2.)

Project
PIN Contract No.
Region County
Material Source
Location Offset Depth
Item No.
Sample No.

PROJECT STAMP

LINE	SAMPLE WEIGHTS			LINE	MOISTURE CONTENT		
A	Wt. of Dry Plus 6.3 mm After Separation	g		G	Container Number		
B	Wt. of "Pan" Material from Plus 6.3 mm	g		H	Wt. of Sample & Container Before Drying	g	
C	Wt. of Dry Plus 6.3 mm Material (A – B)	g		I	Wt. of Sample & Container After Drying	g	
D	Wt. of Moist Minus 6.3 mm Material	g		J	Wt. of Container	g	
E	Wt. of Dry Minus 6.3 mm D / (1 + (M / 100))	g		K	Wt. of Water (H – I)	g	
F	Wt. of Total Dry Sample (C + E)	g		L	Wt. of Dry Sample (I – J)	g	
				M	Moisture Content (K / L) × 100		

SIEVE DESIGNATION		1	2	3	4	SPECIFICATION REQUIREMENT
		WEIGHT RETAINED	% RETAINED	% OF TOTAL SAMPLE PASSING	WHOLE NO. % PASSING	
mm	in.					
100	4					
75	3					
50	2					
37.5	$1\frac{1}{2}$					
25.0	1					
19.0	$\frac{3}{4}$					
12.5	$\frac{1}{2}$					
9.5	$\frac{3}{8}$					
6.3	$\frac{1}{4}$					
TOTAL						

N. Wt. of Dry Minus 6.3 mm Before Wash ____________ g

O. Wt. of Dry Minus 6.3 mm After Wash ____________ g

SIEVE DESIGNATION		5	6	7	8	9	SPECIFICATION REQUIREMENT
		WEIGHT RETAINED	% RETAINED	% PASSING BASED ON MINUS 6.3 mm	% OF TOTAL SAMPLE PASSING	WHOLE NO. % PASSING	
mm	No.						
4.75	4						
2.00	10						
0.850	20						
0.425	40						
0.250	60						
0.150	100						
0.075	200						
PAN							
TOTAL							

REMARKS

TESTED BY: DATE: CHECKED BY: DATE:

Figure 1—Sieve Analysis Data Sheet

Project
PIN Contract No.
Region County
Material Source
Location Offset Depth
Item No.
Sample No.

PROJECT STAMP

LINE	SAMPLE WEIGHTS			LINE	MOISTURE CONTENT		
A	Wt. of Dry Plus 6.3 mm After Separation	g	11340	G	Container Number		AA
B	Wt. of "Pan" Material from Plus 6.3 mm	g	10	H	Wt. of Sample & Container Before Drying	g	642.4
C	Wt. of Dry Plus 6.3 mm Material (A – B)	g	11330	I	Wt. of Sample & Container After Drying	g	628.3
D	Wt. of Moist Minus 6.3 mm Material	g	13605	J	Wt. of Container	g	89.1
E	Wt. of Dry Minus 6.3 mm D / (1 + (M / 100))	g	13260	K	Wt. of Water (H – I)	g	14.1
F	Wt. of Total Dry Sample (C + E)	g	24590	L	Wt. of Dry Sample (I – J)	g	539.2
				M	Moisture Content (K / L) × 100		2.6

SIEVE DESIGNATION		1	2	3	4	SPECIFICATION REQUIREMENT
mm	in.	WEIGHT RETAINED	% RETAINED	% OF TOTAL SAMPLE PASSING	WHOLE NO. % PASSING	
100	4					
75	3					
50	2	0	0.0	100.0	100	
37.5	1½					
25.0	1	730	3.0	97.0	97	
19.0	¾					
12.5	½	6100	24.8	72.2	72	
9.5	⅜					
6.3	¼	4500	18.3	53.9	54	
TOTAL		11330	46.1			

N. Wt. of Dry Minus 6.3 mm Before Wash 301.4 g

O. Wt. of Dry Minus 6.3 mm After Wash 280.2 g

SIEVE DESIGNATION		5	6	7	8	9	SPECIFICATION REQUIREMENT
mm	No.	WEIGHT RETAINED	% RETAINED	% PASSING BASED ON MINUS 6.3 mm	% OF TOTAL SAMPLE PASSING	WHOLE NO. % PASSING	
4.75	4						
2.00	10	67.6	22.4	77.6	41.8	42	
0.850	20						
0.425	40	161.1	53.4	24.2	13.0	13	
0.250	60						
0.150	100	26.4	8.8	15.4	8.3	8	
0.075	200	24.8	8.2	7.2	3.9	4	
PAN		0.3					
TOTAL		280.2	92.8				

REMARKS

TESTED BY: DATE: CHECKED BY: DATE:

Figure 2—Sample Completed Sieve Analysis Data Sheet

7.3. Sieve the material retained on the 6.3-mm sieve during initial separation of coarse and fine material. The series of sieves used shall comply with the particle size requirements of the material being tested. The sieves shall be arranged such that the largest opening sieve is on top, with the sizes progressively decreasing. The last sieve shall be the 6.3 mm, followed by a "pan." During the sieving process, some additional material will pass through the 6.3-mm sieve into the "pan." Weigh this "pan" material to the nearest 5 g and record on line B of the data sheet. Incorporate this material to the minus 6.3-mm material obtained in Section 7.1. Weigh the material retained on each sieve to the nearest 5 g and record these values in Column 1 of the data sheet. Sum the values in Column 1 and record this value at the bottom of the column. Compute the total mass of plus 6.3-mm material by subtracting line B from line A, and record this value on line C.

Note 7—If the sieving is performed using a mechanical shaker, the sieves shall be shaken no less than 3 minutes and no more than 5 minutes. If performed manually, the sieve shall be shaken no less than 5 minutes. Very often particles will get stuck in the openings of a sieve. Such material shall be removed from the openings and weighed as being retained on that sieve. Do not force particles through the sieves.

7.4. Weigh the portion of the minus 6.3-mm sample to the nearest 5 g and record this value on the data sheet (line D). Immediately mix the portion of minus 6.3-mm sample thoroughly. By quartering or using a sample splitter, obtain a minimum 500 g sample of this material, and place it into a container of known weight for a moisture content determination. The weight of the container and the weight of the soil and container should be recorded respectively to the nearest 0.1 g (lines J and H). Dry the sample to a constant mass as noted below. After drying, allow the sample to cool and re-weigh it to the nearest 0.1 g and record (line I).

Note 8—If the sample being tested is a recycled material, or if it contains any bituminous material (asphalt, etc.), it shall be dried to a *constant weight* by air drying or in an oven not exceeding 60ºC.

Note 9—If a hot plate or stove is used, place the container holding the sample on a pan containing a thin layer of sand to prevent spattering and/or fracturing of the soil particles during the drying process.

Note 10—If an oven is used, maintain the temperature of the sample at 110º ± 5ºC for a minimum of 12 hours or until it maintains a constant weight.

Note 11—When a sample contains less than 500 g of minus 6.3-mm particles, moisture content and gradation may be performed on the smaller amount only if the sample is considered to be representative.

7.5. Obtain a 300 ± 5 g portion of the moisture content sample (from Section 7.4) and record this mass to the nearest 0.1 g (line N). Wash this sample on a 0.075-mm sieve to remove all material finer than the 0.075-mm sieve from the sample. It is suggested to wash the sieve sample over a white basin to make it easier to see when the wash water is clean. After the sample is thoroughly washed, carefully transfer the sample from the sieve to a container for drying. Dry the sample in accordance with the provisions of Section 7.4. Weigh the dried sample to the nearest 0.1 g and record this value (line O).

Note 12—Examine the 0.075-mm sieve prior to each washing to determine its condition. Replace the sieve if any holes or cracks are noticed in the solder or mesh, or if the sieve's mesh is stretched excessively. A new 0.075-mm sieve should be washed with soap and water prior to initial use.

Note 13—The 0.075-mm sieves are delicate. Fingertips may be used to agitate the sample during washing, but do not apply pressure to the mesh itself.

Note 14—Do not allow water to overflow or splash out of the sieve. This may cause a loss of material and lead to inaccurate results. Tapping the side of the sieve will help break the surface tension as well as eliminate clogging.

7.6. Sieve the dry washed sample remaining from Section 7.5. The series of sieves used shall comply with the particle size requirements of the material being tested. The sieves shall be arranged such that the largest mesh sieve is on top, with the mesh sizes progressively decreasing. The last sieve should be the 0.075 mm, followed by a "pan." Weigh the material retained on each sieve and the "pan," and record the weights to the nearest 0.1 g in Column 5. Sum the values (Column 5) of the masses retained on each sieve and pan, and record this value at the bottom of that column.

8. CALCULATION

8.1. Calculate the mass of minus 6.3-mm material for moisture content.

8.1.1. Determine the moisture content.

Compute the mass of water by subtracting line *I* from line *H* and record this value on line *K*. Compute the mass of dry material by subtracting line *J* from line *I* and record this value on line *L*. Compute moisture content by dividing mass of water (line K) by the mass of dry material (line L) and multiplying this value by 100 and record to the nearest 0.1 percent on line *M*.

$$\text{\% Moisture Content:} \quad M = \frac{H - I}{I - J} \times 100 \qquad (1)$$

8.1.2. Compute the dry mass of the minus 6.3-mm material.

Divide the total mass of minus 6.3-mm material (line D) by the quantity 1 plus the moisture content (line M) divided by 100 and record this value on line *E*.

$$\text{Mass of Dry minus 6.3 mm:} \quad E = \frac{D}{1 + \left(\frac{M}{100}\right)} \qquad (2)$$

8.2. Compute the total dry mass of the sample.

Compute the total dry mass by adding the dry mass of the plus 6.3-mm material (line C) to the dry mass of the minus 6.3-mm material (line E) and record this value on line *F*.

Total Dry Mass, $F = C + E$ *(3)*

8.3. Compute the particle size distribution of plus 6.3-mm material.

8.3.1. Compute the percent retained.

Divide the mass retained on each sieve (in Column 1) by the total dry mass of the sample (line F). Multiply each value by 100 and record the results to the nearest 0.1 percent in Column 2 opposite the respective sieve. Sum the values in Column 2 and record this value at the bottom of Column 2.

8.3.2. Compute the percent of total sample passing.

The smallest sieve in which all of the sample passes will have 100 percent total sample passing. For the rest of the sieve sizes, compute the percent total sample passing by subtracting the percent retained (in Column 2) from the percent of total sample passing computed for the previous sieve size. This makes it necessary to work from the top down. Record each of the values computed to the nearest 0.1 percent in Column 3 of the data sheet. For checking specification criteria, round the values in Column 3 to the nearest 1 percent and record these values in Column 4.

8.4. Compute the particle size distribution of minus 6.3-mm material.

8.4.1. Compute the percent retained.

Divide the mass retained on each sieve (in Column 5) by the mass of the minus 6.3-mm sample prior to washing (line N). Multiply each value by 100 and record the results to the nearest 0.1 percent in Column 6. Sum the values in Column 6 and record this value at the bottom of the column.

8.4.2. Compute the percent passing based on minus 6.3-mm material.

Subtract the percent retained, on the largest sieve used on the minus 6.3-mm material, from 100 percent to determine the percent for that sieve. For the rest of the sieves, compute the percent sample passing by subtracting the percent retained from the percent sample passing computed for the previous sieve size. Record these values as percents to the nearest 0.1 percent in Column 7.

8.4.3. Compute the percent passing based on total mass.

Multiply the percents passing, computed in Section 8.4.2. (Column 7), by the percent of the total sample passing the 6.3-mm sieve, (last value in Column 3), for each sieve size. Divide each value by 100 to get percent and record to the nearest 0.1 percent in Column 8. For checking specification criteria, round the values in Column 8 to the nearest 1 percent and record these values in Column 9.

9. CHECKS AND BALANCES

9.1. Check the computed percent retained.

9.1.1. For the plus 6.3-mm material:

The total mass retained (Total of Column 1) divided by the total dry mass of the sample (line F) and multiplied by 100, should be no more than ±0.2 percent from the sum of the percents retained (Total of Column 2).

9.1.2. For the minus 6.3-mm material:

The total mass retained (Total of Column 5) minus the "pan" material, divided by the mass of dry minus 6.3-mm material before wash (line N) and multiplied by 100, should be no more than ±0.2 percent from the sum of the percents retained (Total of Column 6).

9.2. Check the computed percent passing.

9.2.1. For the plus 6.3-mm material:

The sum of the percent retained (Total of Column 2) plus the percent of total sample passing the 6.3-mm sieve (last value of Column 3) must equal 100 percent.

9.2.2. For the minus 6.3-mm material:

The sum of the percent retained (Total of Column 6) plus the percent passing the 0.075-mm sieve, based on minus 6.3 mm, (last value of Column 7) must equal 100 percent.

As an aid to the user of this volume, the following tabulation shows equivalencies between AASHTO and ASTM specifications. Where an asterisk (*) follows the ASTM number, there is a difference between the two specifications. These differences are explained in the endnote accompanying each individual specification.

AASHTO ***Specifications***	**ASTM** ***Equivalent***	**AASHTO** ***Specifications***	**ASTM** ***Equivalent***
T 2-91 (2006)	D 75-03	T 119M/T 119-10	C 143/C 143M-08
T 11-05 (2009)	C 117-04*	T 121M/T 121-09	C 138/C 138M-08
T 19M/T 19-09	C 29/C 29M-07	T 127-04 (2008)	C 183-02
T 21-05 (2009)	C 40-04*	T 129-06	C 187-04
T 22-10	C 39/C 39M-05*	T 131-10	C 191-08
T 23-08	C 31-06*	T 133-98 (2006)	C 188-95e
T 24M/T 24-07	C 42/C 42M-04	T 137-04 (2008)	C 185-02
T 27-06	C 136-05*	T 141-05 (2009)	C 172-04*
T 32-10	C 67-09*	T 143-04 (2009)	D 345-02*
T 37-07	D 546-05*	T 148-07	C 174/C 174M-06
T 40-02 (2006)	D 140-01*	T 152-10	C 231-08c
T 42-10	D 545-08*	T 153-09	C 204-07
T 44-03 (2007)	D 2042-01*	T 154-10	C 266-08
T 48-06	D 92-05a*	T 155-08	C 156-05
T 49-07	D 5-06$^{\in 1}$*	T 157-06	C 233-04
T 50-09	D 139-07	T 158-09	C 232-07
T 51-09	D 113-07*	T 160-09	C 157/C 157M-06
T 53-09	D 36-06*	T 161-08	C 666/C 666M-03
T 55-02 (2006)	D 95-05$^{\in 1}$	T 162-09	C 305-06
T 65M/T 65-08	A 90/A 90M-07*	T 164-10	D 2172-05*
T 68M/T 68-09	E 8/E 8M-08	T 165-02 (2006)	D 1075-96
T 71-08	C 87-04*	T 168-03 (2007)	D 979-01 (2006)$^{\in 1}$*
T 84-10	C 128-07a*	T 170-00 (2009)	D 1856-95a (2003)*
T 85-10	C 127-04*	T 177-10	C 293-08
T 96-02 (2006)	C 131-01*	T 178-10	C 1084-02
T 97-10	C 78-08	T 179-05 (2009)	D 1754-97 (2002)*
T 98-99 (2008)	C 115-96a	T 185-09	C 359-08
T 100-06	D 854-00	T 186-09	C 451-08
T 105-09	C 114-07	T 190-09	D 2844-07
T 106M/T 106-09	C 109/C 109M-07	T 192-99 (2007)	C 430-96
T 107-07	C 151-05	T 195-67 (2007)	D 2489-02
T 110-03 (2007)	D 1461-85 (2006)*	T 196M/T 196-09	C 173/C 173M-08
T 112-00 (2008)	C 142-97*	T 197M/T 197-08	C 403/C 403M-06
T 113-06	C 123-03	T 198-09	C 496/C 496M-04

AASHTO ***Specifications***	**ASTM** ***Equivalent***	**AASHTO** ***Specifications***	**ASTM** ***Equivalent***
T 200-79 (2006)	E 70-97 (2002)	T 244-10	A 370-09a
T 201-10	D 2170-07*	T 246-10	D 1560-09*
T 202-10	D 2171-07*	T 247-10	D 1561-92
T 206-09	D 1586-99*	T 248-02 (2006)	C 702-98 (2003)*
T 207-03 (2007)	D 1587-00	T 255-00 (2008)	C 566-97 (2004)*
T 208-10	D 2166-00	T 266-08	E 23-07a*
T 210-10	D 3744-03*	T 269-97 (2007)	D 3203-05
T 213M/T 213-08	A 428/A 428M-06*	T 276-10	C 918-02
T 215-70 (2007)	D 2434-68 (1994)$^{\epsilon1}$	T 277-07	C 1202-05
T 216-07	D 2435-04	T 278-90 (2007)	E 303-93 (2003)*
T 221-90 (2008)	D 1195-93 (2004)	T 279-96 (2006)	D 3319-90
T 226-90 (2008)	D 2664-86	T 280-06	C 497-05*
T 227-02 (2006)	D 1298-99 (2005)	T 281-06	C 301-04*
T 228-09	D 70-08*	T 282-01 (2006)	E 556-95 (2000)
T 231-05 (2009)	C 617-98 (2003)	T 295-08	D 3142-05
T 236-08	D 3080-72 (2003)*	T 297-94 (2007)	D 4767-88$^{\epsilon1}$
T 240-09	D 2872-04*	T 309M/T 309-10	C 1064/C 1064M-05*
T 242-96 (2009)	E 274-97*	T 327-09	D 6928-03
T 243M/T 243-08	A 673/A 673M-07	T 331-10	D 6752-03$^{\epsilon1}$

ASTM *Specifications*	**AASHTO** *Equivalent*	**ASTM** *Specifications*	**AASHTO** *Equivalent*
A 90/A 90M-07*	T 65M/T 65-08	C 231-08c	T 152-10
A 370-09a	T 244-10	C 232-07	T 158-09
A 428/A 428M-06*	T 213M/T 213-08	C 233-04	T 157-06
A 673/A 673M-07	T 243M/T 243-08	C 266-08	T 154-10
C 29/C 29M-07	T 19M/T 19-09	C 293-08	T 177-10
C 31-06*	T 23-08	C 301-04*	T 281-06
C 39/C 39M-05*	T 22-10	C 305-06	T 162-09
C 40-04*	T 21-05 (2009)	C 359-08	T 185-09
C 42/C 42M-04	T 24M/T 24-07	C 403/C 403M-06	T 197M/T 197-08
C 67-09*	T 32-10	C 430-96	T 192-99 (2007)
C 78-08	T 97-10	C 451-08	T 186-09
C 87-04*	T 71-08	C 496/C 496M-04	T 198-09
C 109/C 109M-07	T 106M/T 106-09	C 497-05*	T 280-06
C 114-07	T 105-09	C 566-97 (2004)*	T 255-00 (2008)
C 115-96a	T 98-99 (2008)	C 617-98 (2003)	T 231-05 (2009)
C 117-04*	T 11-05 (2009)	C 666/C 666M-03	T 161-08
C 123-03	T 113-06	C 702-98 (2003)*	T 248-02 (2006)
C 127-04*	T 85-10	C 918-02	T 276-10
C 128-07a*	T 84-10	C 1064/C 1064M-05*	T 309M/T 309-10
C 131-01*	T 96-02 (2006)	C 1084-02	T 178-10
C 136-05*	T 27-06	C 1202-05	T 277-07
C 138/C 138M-08	T 121M/T 121-09	D 5-06$^{\epsilon1}$*	T 49-07
C 142-97*	T 112-00 (2008)	D 36-06*	T 53-09
C 143/C 143M-08	T 119M/T 119-10	D 70-08*	T 228-09
C 151-05	T 107-07	D 75-03	T 2-91 (2006)
C 156-05	T 155-08	D 92-05a*	T 48-06
C 157/C 157M-06	T 160-09	D 95-05$^{\epsilon1}$	T 55-02 (2006)
C 172-04*	T 141-05 (2009)	D 113-07*	T 51-09
C 173/C 173M-08	T 196M/T 196-09	D 139-07	T 50-09
C 174/C 174M-06	T 148-07	D 140-01*	T 40-02 (2006)
C 183-02	T 127-04 (2008)	D 345-02*	T 143-04 (2009)
C 185-02	T 137-04 (2008)	D 545-08*	T 42-10
C 187-04	T 129-06	D 546-05*	T 37-07
C 188-95e	T 133-98 (2006)	D 854-00	T 100-06
C 191-08	T 131-10	D 979-01 (2006)$^{\epsilon1}$*	T 168-03 (2007)
C 204-07	T 153-09	D 1075-96	T 165-02 (2006)

ASTM ***Specifications***	**AASHTO** ***Equivalent***	**ASTM** ***Specifications***	**AASHTO** ***Equivalent***
D 1195-93 (2004)	T 221-90 (2008)	D 2664-86	T 226-90 (2008)
D 1298-99 (2005)	T 227-02 (2006)	D 2844-07	T 190-09
D 1461-85 (2006)*	T 110-03 (2007)	D 2872-04*	T 240-09
D 1560-09*	T 246-10	D 3080-72 (2003)*	T 236-08
D 1561-92	T 247-10	D 3142-05	T 295-08
D 1586-99*	T 206-09	D 3203-05	T 269-97 (2007)
D 1587-00	T 207-03 (2007)	D 3319-90	T 279-96 (2006)
D 1754-97 (2002)*	T 179-05 (2009)	D 3744-03*	T 210-10
D 1856-95a (2003)*	T 170-00 (2009)	D 4767-88$^{\in 1}$	T 297-94 (2007)
D 2042-01*	T 44-03 (2007)	D 6752-03$^{\in 1}$	T 331-10
D 2166-00	T 208-10	D 6928-03	T 327-09
D 2170-07*	T 201-10	E 8/E 8M-08	T 68M/T 68-09
D 2171-07*	T 202-10	E 23-07a*	T 266-08
D 2172-05*	T 164-10	E 70-97 (2002)	T 200-79 (2006)
D 2434-68 (1994)$^{\in 1}$	T 215-70 (2007)	E 274-97*	T 242-96 (2009)
D 2435-04	T 216-07	E 303-93 (2003)*	T 278-90 (2007)
D 2489-02	T 195-67 (2007)	E 556-95 (2000)	T 282-01 (2006)

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Revisions for 30th Edition of Standard Specifications for Transportation Materials and Methods of Sampling and Testing—Part 2

The balloted technical and editorial changes listed below are also indicated in the specifications by a change bar in the left margin. Non-balloted editorial changes do not receive a change bar.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
T 11-05 (2009)	Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing	1c	Reconfirmed in 2009.
T 21-05 (2009)	Organic Impurities in Fine Aggregates for Concrete	1c	Reconfirmed in 2009.
T 22-10	Compressive Strength of Cylindrical Concrete Specimens	3c	Revised extensively.
T 30-10	Mechanical Analysis of Extracted Aggregate	2c	Revised the requirements for mechanical washing.
T 32-10	Sampling and Testing Brick	4a	Updated to reference ASTM C 67-09.
T 42-10	Preformed Expansion Joint Filler for Concrete Construction	4e	Revised to maintain equivalency with ASTM D 545-08.
T 67-08	Standard Practices for Force Verification of Testing Machines	4f	Deleted in 2009.
T 68-05	Tension Testing of Metallic Materials	4f	Deleted in 2009.
T 68M/T 68-09	Tension Testing of Metallic Materials	4f	Discontinued in 2009.
T 70-08	Brinell Hardness of Metallic Materials	4f	Deleted in 2009.
T 72-10	Saybolt Viscosity	2a	Revised extensively.
T 78-10	Distillation of Cutback Asphaltic (Bituminous) Products	2a	Revised extensively.
T 80-08	Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials	4f	Deleted in 2009.
T 84-10	Specific Gravity and Absorption of Fine Aggregate	1c	Revised Section 13.1.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
T 85-10	Specific Gravity and Absorption of Coarse Aggregate	1c	Revised Section 10.1.
T 88-10	Particle Size Analysis of Soils	1a	Revised reference to dispersing agent in Section 8.3.
T 89-10	Determining the Liquid Limit of Soils	1a	Revised to specify at what stage the samples should be taken.
T 92-97 (2009)	Determining the Shrinkage Factors of Soils	1a	Reconfirmed in 2009.
T 97-10	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)	3c	Revised to maintain equivalency with ASTM C 78-08.
T 99-10	Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop	1b	Revised to include information on what to do with discarded coarse material.
T 111-10	Mineral Matter or Ash in Asphalt Materials	2b	Revised to clarify procedure discussed in Section 6.3.
T 119M/T 119-10	Slump of Hydraulic Cement Concrete	3b	Revised to maintain equivalency with ASTM C 143/C 143M-08.
T 131-10	Time of Setting of Hydraulic Cement by Vicat Needle	3a	Revised to maintain equivalency with ASTM C 191-08.
T 132-87 (2009)	Tensile Strength of Hydraulic Cement Mortars	3a	Reconfirmed in 2009.
T 134-05 (2009)	Moisture-Density Relations of Soil-Cement Mixtures	1b	Reconfirmed in 2009.
T 135-97 (2009)	Wetting-and-Drying Test of Compacted Soil-Cement Mixtures	1b	Reconfirmed in 2009.
T 136-97 (2009)	Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures	1b	Reconfirmed in 2009.
T 140-97 (2009)	Compressive Strength of Concrete Using Portions of Beams Broken in Flexure	3c	Reconfirmed in 2009.
T 141-05 (2009)	Sampling Freshly Mixed Concrete	3b	Reconfirmed in 2009.
T 152-10	Air Content of Freshly Mixed Concrete by the Pressure Method	3b	Revised to maintain equivalency with ASTM C 231-08c.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
T 154-10	Time of Setting of Hydraulic Cement Paste by Gillmore Needles	3a	Revised to maintain equivalency with ASTM C 266-08.
T 164-10	Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)	2c	Revised the requirements for drying the test specimen and added definition of term.
T 165-02 (2006)	Effect of Water on Compressive Strength of Compacted Bituminous Mixtures	2d	Discontinued in 2009.
T 166-10	Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens	2c	Revised the precision and bias statement.
T 167-10	Compressive Strength of Hot Mix Asphalt	2d	Revised.
T 170-00 (2009)	Recovery of Asphalt Binder from Solution by Abson Method	2c	Reconfirmed in 2009.
T 177-10	Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)	3c	Revised to maintain equivalency with ASTM C 293-08.
T 178-10	Portland-Cement Content of Hardened Hydraulic-Cement Concrete	3c	Revised.
T 179-05 (2009)	Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)	2b	Reconfirmed in 2009.
T 180-10	Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop	1b	Revised to harmonize with T 99.
T 188-05 (2009)	Evaluation by Freezing and Thawing of Air-Entraining Additions to Hydraulic Cement	3b	Reconfirmed in 2009.
T 193-10	The California Bearing Ratio	1a	Revised to clarify procedure discussed in Section 8.5.
T 199-00 (2009)	Air Content of Freshly Mixed Concrete by the Chace Indicator	3b	Reconfirmed in 2009.
T 201-10	Kinematic Viscosity of Asphalts (Bitumens)	2b	Revised so that the temperature tolerances for the bath are less restrictive.
T 202-10	Viscosity of Asphalts by Vacuum Capillary Viscometer	2b	Revised so that the temperature tolerances for the bath are less restrictive.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
T 208-10	Unconfined Compressive Strength of Cohesive Soil	1a	Revised to clarify the procedure for extruding the sample.
T 209-10	Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)	2c	Revised extensively.
T 210-10	Aggregate Durability Index	1c	Revised to remove reference to the Tyler sieve shaker that is no longer available.
T 224-10	Correction for Coarse Particles in the Soil Compaction Test	1b	Revised to include information on dealing with discarded coarse material.
T 231-05 (2009)	Capping Cylindrical Concrete Specimens	3c	Reconfirmed in 2009.
T 235-96 (2004)	Bearing Capacity of Soil for Static Load on Spread Footings	1b	Deleted in 2009.
T 237-05 (2009)	Testing Epoxy Resin Adhesive	4c	Reconfirmed in 2009.
T 244-10	Mechanical Testing of Steel Products	4f	Revised to maintain equivalency with ASTM A 370-09a.
T 246-10	Resistance to Deformation and Cohesion of Hot Mix Asphalt (HMA) by Means of Hveem Apparatus	2d	Revised.
T 247-10	Preparation of Test Specimens of Hot Mix Asphalt (HMA) by Means of California Kneading Compactor	2d	Revised.
T 250-05 (2009)	Thermoplastic Traffic Line Material	4c	Reconfirmed in 2009.
T 260-97 (2009)	Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials	3c	Reconfirmed in 2009.
T 271-83 (2009)	Density of Plastic and Hardened Portland Cement Concrete In-Place by Nuclear Methods	3c	Reconfirmed in 2009.
T 272-10	Family of Curves—One-Point Method	1b	Revised to include information on dealing with discarded coarse material.
T 276-10	Measuring Early-Age Compression Strength and Projecting Later-Age Strength	3c	Revised.
T 296-10	Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression	1a	Revised to clarify the procedure for extruding the sample.

Designation Number	Title	Technical Section Number	2009 Ballot Revision
T 299-93 (2009)	Rapid Identification of Alkali-Silica Reaction Products in Concrete	3c	Reconfirmed in 2009.
T 302-05 (2009)	Polymer Content of Polymer-Modified Emulsified Asphalt Residue and Asphalt Binders	2a	Reconfirmed in 2009.
T 308-10	Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method	2c	Revised to expand methods to determine correction factors.
T 309M/T 309-10	Temperature of Freshly Mixed Hydraulic Cement Concrete	3b	Revised to include additional types of thermometers.
T 310-10	In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)	1b	Revised the Annex.
T 311-00 (2010)	Grain-Size Analysis of Granular Soil Materials	1a	Reconfirmed in 2010.
T 313-10	Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)	2b	Revised to change the composition of the Glycerol-Talc Mixture.
T 315-10	Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)	2b	Revised to provide guidance on Section 13.
T 316-10	Viscosity Determination of Asphalt Binder Using Rotational Viscometer	2b	Revised Section 9.1.
T 326-05 (2009)	Uncompacted Void Content of Coarse Aggregate (As Influenced by Particle Shape, Surface Texture, and Grading)	1c	Reconfirmed in 2009.
T 331-10	Bulk Specific Gravity and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method	2c	Revised extensively.
T 336-10	Coefficient of Thermal Expansion of Hydraulic Cement Concrete	3c	Revised.
T 339-10	Analysis of Structural Steel Coatings for Isocyanate Content	4c	Revised.
T 340-10	Determining Rutting Susceptibility of Hot Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA)	2d	Adopted TP 63 as full standard T 340-10.
T 341-10	Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading	4b	Adopted new test method based upon recommendation in NCHRP Report 631.

Standard Specification for

Reclaimed Concrete Aggregate for Use as Coarse Aggregate in Hydraulic Cement Concrete

AASHTO Designation: MP 16-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Specification for

Reclaimed Concrete Aggregate for Use as Coarse Aggregate in Hydraulic Cement Concrete

AASHTO Designation: MP 16-10

1. SCOPE

1.1. This specification covers coarse aggregate derived from reclaimed concrete for use in hydraulic cement concrete. The specification is not intended for use when lightweight, high-density, or other specialty concrete applications are required. When aggregate materials are properly processed and manufactured to the requirements of this specification, combined and mixed in accordance with the appropriate requirements, and placed, consolidated, and cured properly, a concrete structure of acceptable strength and durability can be produced. Introducing reclaimed concrete aggregate into concrete, however, requires the use of quality control and quality assurance procedures to ensure that deleterious materials that might be present in the reclaimed concrete aggregate will not adversely impact the quality of the concrete product.

1.2. Best practice applications for using reclaimed concrete aggregate in concrete shall consist of concrete pavements, cement-treated base courses, sidewalks, median barriers, curbings, and other non-structural applications.

Note 1—Caution should be exercised if reclaimed concrete aggregate is considered for use in structural applications. The presence of deleterious materials and the variability in the source concrete may produce inconstant volumetric properties and affect the properties of the concrete produced. Two properties of concern include dimensional stability and creep.

1.3. Since reclaimed concrete aggregate is a recycled material, various state and local jurisdiction laws and regulations may be applicable. The user of this specification is cautioned to contact state and local environmental and other local regulators to determine what requirements are appropriate.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 43, Sizes of Aggregate for Road and Bridge Construction
- M 80, Coarse Aggregate for Hydraulic Cement Concrete
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 19M/T 19, Bulk Density (“Unit Weight”) and Voids in Aggregate
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

- T 103, Soundness of Aggregates by Freezing and Thawing
- T 104, Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
- T 112, Clay Lumps and Friable Particles in Aggregate
- T 113, Lightweight Pieces in Aggregate
- T 161, Resistance of Concrete to Rapid Freezing and Thawing
- T 260, Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials
- T 299, Rapid Identification of Alkali-Silica Reaction Products in Concrete
- T 303, Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction
- T 327, Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 227, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
- C 289, Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- C 342, Standard Test Method for Potential Volume Change of Cement Aggregate Combinations
- C 586, Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock-Cylinder Method)
- C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- C 1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
- D 6928, Standard Test Method for Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus

3. TERMINOLOGY

3.1. The definitions of concrete and concrete aggregate terms used in this specification are provided in ASTM C 125. The term “reclaimed concrete aggregate,” as used in this specification, shall mean coarse aggregate material derived from the crushing, processing, and classification of hydraulic cement concrete construction debris recovered from roadways, sidewalks, buildings, bridges, and other sources.

4. ORDERING INFORMATION

4.1. The purchaser or specifier shall include the following information in the purchase order or contract documents:

4.1.1. Reference to this specification and year of issue,

4.1.2. Grading to be furnished (AASHTO Size No.) (Section 6.1),

4.1.3. Soundness testing requirement (Section 7.2), 4.1.4. Class designation of aggregate (Table 1),

4.1.5. Whether the restriction on reactive materials applies (Section 7.3),

4.1.6. Additional testing requirements, and

4.1.7. Any exceptions or additions to this specification.

5. SAMPLING

5.1. Sample reclaimed concrete aggregate in accordance with T 2.

6. GRADING AND PROPORTIONS

6.1. Coarse reclaimed concrete aggregate tested in accordance with T 27 shall conform to the coarse aggregate gradation requirements prescribed in M 43 for the size number specified in the contract documents.

Note 2—Generally, there is no reason that reclaimed concrete aggregate should have gradation requirements that differ from natural or conventional aggregate materials.

Note 3—The ranges shown in M 43 are, by necessity, very wide in order to accommodate nationwide conditions. For quality control of any specific operation, a producer should develop an average gradation for the particular source and production facilities, and control the gradation within reasonable tolerances from this average. Where coarse aggregate sizes numbers 357 or 467 are used, the aggregate should be furnished in at least two separate sizes.

7. PHYSICAL PROPERTIES

7.1. Reclaimed concrete aggregate shall have a maximum Los Angeles abrasion loss of 50 percent, measured in accordance with T 96.

Note 4—T 327, Micro-Deval, may be required in lieu of T 96 if the specifying agency has experience with the procedure and has established limits.

7.2. Reclaimed concrete aggregate soundness testing shall be conducted in accordance with T 104 at 5 cycles. The maximum limit for soundness shall be 12 percent if sodium sulfate is used and 18 percent if magnesium sulfate is used.

Note 5—Reclaimed concrete aggregate can be susceptible to sulfate attack when tested for soundness using sodium sulfate or magnesium sulfate solutions, resulting in higher than expected soundness loss values (particularly when sodium sulfate solution is used in the test procedure). Sulfate solution test methods (T 104) should be applied if local experience has shown these methods to be acceptable; however, alternative approaches may be used.

7.3. Reclaimed concrete aggregate for use in concrete that will be subjected to in-service wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are reactive with alkali components in the cement in an amount sufficient to cause excessive expansion of mortar or concrete. Except, if such materials are present in injurious amounts, the coarse aggregate may be used with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. Alkali reactivity shall be tested in accordance with T 303 when alkali-silica reaction is suspected, in accordance with ASTM C 586 when alkali-carbonate reaction is suspected.

Note 6—If the source and history of the reclaimed concrete aggregate are known and no reactive failures were present in the source concrete, testing for reactive expansion may not be necessary. However, unless a precise history is known, the source concrete may have not been exposed to all elements required to cause reactive expansion, and the reclaimed concrete aggregate may be reactive. See Appendix X2 for a discussion of alternative test methods. Mitigation methods found to work with natural reactive aggregates may not be effective with potentially expansive RCA. Aggregate that gave satisfactory performance in the original concrete may not continue to do so when used as RCA in new concrete. Consider the contribution of alkali from the RCA in addition to the alkali from the new hydraulic cement.

7.4. Reclaimed concrete aggregate for use in concrete that will be subjected to freeze-thaw action shall not contain aggregate components that expand and result in D-cracking of the concrete. When potential D-cracking is suspected, the reclaimed concrete aggregate shall be tested in accordance with T 161.

Note 7—In areas where D-cracking is a significant problem and agencies have developed equivalent test methods, local methods of testing may be used. Acceptance criteria for T 161 and equivalent methods should be based on local criteria that have been developed to address the issue of D-cracking.

7.5. Reclaimed concrete aggregate shall meet the flat and elongated particle requirements of the specifying jurisdiction.

7.6. Reclaimed concrete aggregate shall be tested in accordance with T 85 to establish the specific gravity and absorption. For specific gravity, the total variability of tests from minimum value to maximum value shall not exceed 0.100; and for absorption, the total variability of tests from minimum value to maximum value shall not exceed 0.8 percent.

Aggregates that have specific gravity and absorption values that fall outside of these limits shall be stockpiled separately, and the limits stated above shall apply to the new stockpile.

Note 8—Testing of specific gravity and absorption may not be necessary during production of aggregate if the reclaimed concrete is from one source with known aggregate properties.

Note 9—Coarse reclaimed concrete aggregate may contain air-entrained concrete mortar and, therefore, may be highly absorptive and can exhibit low and highly variable specific gravity values. Utilizing highly absorptive aggregates (coarse and fine) that do not exhibit consistent specific gravity values in hydraulic cement concrete can adversely affect the weighing and batching process in the concrete production operation. Further discussions of this issue are presented in Appendix X1.

8. DELETERIOUS SUBSTANCES

8.1. Reclaimed concrete aggregate shall not contain clay lumps and friable particles, chert, coal and lignite, or other deleterious substances that exceed the maximum allowable amounts listed in Table 1 when tested in accordance with T 112, T 113, and ASTM C 295.

Table 1—Limits for Deleterious Substances and Physical Property Requirements of Reclaimed Coarse Aggregate for Concrete

	Maximum Allowable Percent[a]				
Class Designation[b]	Clay Lumps and Friable Particles	Chert (Less Than 2.40 sp gr SSD)[c]	Sum of Clay Lumps, Friable Particles, and Chert (Less Than 2.40 sp gr SSD)[c]	Other Deleterious Substances[d]	Coal and Lignite
A	2.0	3.0	2.0	0.3	0.2
B	3.0	5.0	3.0	0.3	0.2
C	3.0	8.0	5.0	0.3	0.2

[a] The engineer may supplement the requirements of Table 1 by placing limits on the amount of deleterious substances or physical properties in accordance with local experience and practice.

[b] Aggregate conforming to the requirements for the various classes designated in Table 1 should generally be suitable for the following uses:

Typical Uses (Suggested)	Weathering Exposure	Class of Aggregate
Concrete pavements, cement-treated base courses, sidewalks, median barriers, curbings, and other non-structural applications	Severe	A
	Moderate	B
	Negligible	C

The purchaser or specifier must indicate the class of aggregate to be furnished as the degree of weathering exposure is not precisely defined.

[c] These limitations apply only to aggregate in which chert appears as an impurity. They are not applicable to gravels that are predominantly chert. Limitations on the soundness of such aggregate must be based on service records in the environment in which it is used.

[d] Other deleterious substances include adherent fines, vegetable matter, plastics, plaster, paper, gypsum board, metals, fabrics, wood, brick, tile, glass, and bituminous materials. The percentage of these materials shall be determined in accordance with ASTM C 295 or other equivalent method approved by the specifying jurisdiction.

Note 10—The presence of deleterious materials in aggregates used in the production of hydraulic cement concrete could adversely affect concrete setting time, strength, or both, and could also induce expansive reactions that could result in premature deterioration of the concrete structure. As a result, strict quality control and quality assurance procedures are required to ensure that reclaimed concrete aggregate material used as coarse aggregate in the production of concrete will not adversely affect the quality of the concrete product.

8.2. Reclaimed concrete aggregate shall not contain more than 1.5 percent by mass of material finer than the 75-µm (No. 200) sieve in accordance with T 11.

8.3. Reclaimed concrete aggregate, when sampled and tested according to T 260, shall not contain chloride ion in excess of 0.6 lb per cubic yard of concrete.

9. QUALITY CONTROL

9.1. If the contractor/supplier wishes to use reclaimed concrete aggregate, or combinations of reclaimed concrete aggregate and other approved aggregate materials, a request shall be made to the engineer for approval. The percentage of combined materials shall be established as part of a pre-submitted blended aggregate combination. At the engineer’s discretion, revised hydraulic cement concrete mix designs shall be required when percentages of materials change.

Note 11—A revised concrete mix design is recommended when percentages of materials change. The reclaimed concrete aggregate will likely have a different specific gravity and absorption than the virgin aggregate.

9.2. The contractor/supplier of recycled concrete aggregate shall develop and implement a quality control plan for aggregate production.

9.2.1. The quality control plan shall detail the production procedures, testing methods, and testing frequencies that will be used to ensure that recycled concrete aggregate meets the requirements of this specification.

9.2.2. The quality control plan will detail the production procedures and methods to ensure consistent production of aggregate from reclaimed concrete.

9.2.3. Detail methods to ensure that reclaimed concrete source materials are not contaminated with extraneous solid waste or hazardous materials. Methods and criteria for examining reclaimed concrete materials prior to use should be established.

9.3. Stockpiling will be required to assist in qualitatively and quantitatively identifying the presence of deleterious materials. Stockpiling can also be used as a means to qualitatively assess the uniformity of the material. The stockpile may represent all or part of the material to be used on a project and should be constructed in a manner that will minimize segregation and permit visual examination and representative sampling of the material.

9.4. If reclaimed concrete aggregate is blended with other approved aggregates, this shall be accomplished by mechanical interlock blending or belt blending to ensure uniform proportioning.

Note 12—Other methods of blending shall be permissible if it can be demonstrated through sampling and testing that the alternate blending method will prevent segregation.

9.5. Reclaimed concrete aggregate shall be saturated with water for a time period that is sufficient to saturate all particles, prior to introducing the reclaimed concrete aggregate into a concrete mix, by means of a water sprinkling system or another approved method. At the time of batching, the reclaimed concrete aggregate shall contain water in excess of the saturated surface dry condition. Provision shall also be made for the free drainage of excess water.

APPENDIXES

(Nonmandatory Information)

X1. SPECIFIC GRAVITY AND WATER ABSORPTION

X1.1. The specific gravity of reclaimed concrete aggregate from different sources can be expected to vary. Such fluctuations in specific gravity properties are undesirable in a concrete aggregate material. Since concrete is batched on the principle of weighing the components, the effect on the volume of material measured when the specific gravity varies may be significant. These potential variations can affect the yield of the mix, the cement factor, and the engineering properties of the concrete mixture.

X1.1.1. A technique to control the variability of specific gravity properties of reclaimed concrete aggregate is to use the source approval method. In this approach, the state or other jurisdiction specifies what materials within the limits of the project are suitable for recycling into reclaimed concrete aggregate. The concrete to be recycled generally contains aggregate from one source, where little variation in specific gravity can be expected.

X1.1.2. An alternative to the source approval approach is for the engineer to monitor the physical properties of the fresh concrete, including yield, to determine if specific gravity variations result in property changes. Standard practices of adjusting batch weights to correct yield should be followed. A ±3.0 percent variation in yield should require batch weight adjustments.

X1.2. Reclaimed concrete aggregate can be expected to exhibit higher and more variable water absorption properties than conventional aggregates. This is due to the presence of a highly absorptive mortar component of the original concrete material adhering to the aggregate particles.

X1.2.1. The primary effect on the quality of the concrete manufactured using aggregate with high water absorptive properties is to draw the free water that is present in the mortar of the fresh concrete into the pore structure of the aggregate. The net effect of this process is to reduce the water in the mortar, thus resulting in an early setting of the concrete and an early loss in workability.

X1.2.2. Since the fine portion (material passing the 2.36-mm (No. 8) sieve) of reclaimed concrete aggregate will contain the predominant fraction of high-absorption material in the recycled concrete aggregate, eliminating the fine portion from the source material can be utilized as a means to mitigate this problem.

X1.2.3. High-absorption problems can be further mitigated by requiring that coarse reclaimed concrete aggregate contains water in excess of the saturated surface dry condition prior to mixing it with cement and water. During this process, steps must also be taken to ensure that excess water readily drains from the reclaimed concrete aggregate material. This process ensures that the internal voids in the aggregate particles are filled with water at the time of batching of the concrete, eliminating any additional water demand.

X2. METHODS FOR EVALUATING POTENTIAL REACTIVITY OF AN AGGREGATE

X2.1. A number of methods for detecting potential reactivity have been proposed. However, they do not provide quantitative information on the degree of reactivity to be expected or tolerated in service. Therefore, the evaluation of the potential reactivity of an aggregate must be based upon judgment and on the interpretation of test data and examination of concrete structures containing a combination of fine and coarse aggregates and cements for use in the new work. For the test methods listed in this appendix, note that the required aggregate gradation shall be obtained by crushing the coarse RCA intended for use in the concrete. Fine aggregate produced from initial processing of the reclaimed concrete has been found to inaccurately represent the reactivity of the coarse RCA. A listing of suggested test methods follows:

X2.1.1. *T 299*—This rapid test method is intended to be used in conjunction with other tests to determine the presence of alkali-silica reaction (ASR) products in hardened concrete. A solution of uranyl acetate is applied to the fractured surface of hardened concrete. The reagent reacts with the sodium- and potassium-rich ASR gel present on the fractured surface of the concrete in such a manner that the uranium ions are absorbed by these gels. If sodium- and potassium-rich ASR gels are present on the fractured surface of the uranyl-acetate treated concrete, the areas in which the gel is concentrated will effloresce a bright yellow-green. However, both expansive and non-expansive sodium- and potassium-rich ASR gels will effloresce after exposure to a uranyl-acetate solution. This test, therefore, can only be used as an indicator that ASR may be present. A positive test then indicates that further evaluation is required. If sodium silicates are present, the light will effloresce. The use of this test method may be restricted by local environmental requirements because of the use of a uranyl-acetate solution.

X2.1.2. *T 303*—In this 16-day test, hardened mortar bars consisting of portland cement and the crushed suspect aggregate are subjected to submersion in a standard sodium hydroxide solution. The specimens are measured both before and after the 16-day submersion in the solution. If the specimens expand more than 0.10 percent, there is a strong probability that reactive aggregates are present.

X2.1.3. *ASTM C 295*—Certain materials are known to be reactive with the alkalis in cements. These include the following forms of silica: opal, chalcedony, tridymite, and cristobalite; intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite; and certain constituents of some phyllites. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. Some of these materials render an aggregate deleteriously reactive when present in quantities as small as 1.0 percent.

X2.1.4. *ASTM C 289*—This test method covers chemical determination of the potential reactivity of an aggregate with alkalis in concrete as indicated by the amount of reaction during 24 h at 80°C between 1N sodium hydroxide solution and aggregate that has been crushed and sieved to pass a 300-µm (No. 50) sieve and be retained on a 150-µm (No. 100) sieve. Test results from ASTM C 289, which indicate that the aggregate is non-reactive, should not be used as a final determination that the aggregate is indeed non-reactive. Many aggregates which react very slowly to cause deleterious expansion from alkali-silica reactivity have tested as non-reactive in ASTM C 289. In addition to ASTM C 289, the aggregate should be subjected to at least one of the following additional tests: T 303, ASTM C 295, or ASTM C 1293.

X2.1.5. *ASTM C 342*—This test method is intended primarily for research concerning the potential expansion of cement-aggregate combinations subjected to variations of temperature and water saturation during storage under prescribed conditions of test.

X2.1.6. *ASTM C 586*—The reaction of the dolomite in certain carbonate rocks with alkalis in hydraulic cement paste has been found to be associated with the deleterious expansion of concrete containing such rocks as coarse aggregate. Carbonate rock capable of such reactions possess a characteristic texture and composition. The characteristic texture is that in which large crystals of dolomite are scattered in a finer grained matrix of calcite and clay. The characteristic composition is that in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. This method has been successfully used in (1) research and (2) preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

X2.1.7. *T 161*—This test method applies freeze-thaw cycling to hardened concrete samples. The object of the test is to determine the potential of the aggregate used in the concrete to expand as a result of freeze-thaw action.

X2.1.8. *ASTM C 856*—An effective method of determining the nature of aggregate materials to react with alkali components of hydraulic cement to form alkali-silica reaction products is to perform a petrographic analysis of hardened concrete. The suspect concrete material is cut with a diamond saw into slices that are called thin sections. The thin sections are then studied with a petrographic microscope to determine if a reaction has taken place.

X2.1.9. *ASTM C 227*—A relatively long test in which mortar bars containing the test aggregate and cement are stored in sealed containers at 100°F for periods up to six months, or more. Test is relatively slow and allows potentially deleterious aggregate or cement-aggregate combinations to pass.

Standard Practice for

Determining Aggregate Source Shape Values from Digital Image Analysis Shape Properties

AASHTO Designation: PP 64-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Determining Aggregate Source Shape Values from Digital Image Analysis Shape Properties

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1. SCOPE

1.1. This standard covers the determination of aggregate source and source blend shape characteristics using gradation analysis and shape properties determined by means of digital image analysis.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- TP 81, Determining Aggregate Shape Properties by Means of Digital Image Analysis

3. TERMINOLOGY

3.1. *aggregate size*—material retained on a given sieve size after passing the next larger sieve.

3.1.1. *fine aggregate*—aggregate material passing 4.75-mm (No. 4) sieve. Sieve sizes are 2.36 mm (No. 8), 1.18 mm (No. 16), 0.60 mm (No. 30), 0.30 mm (No. 50), 0.15 mm (No. 100), and 0.075 mm (No. 200).

3.1.2. *coarse aggregate*—aggregate material retained on 4.75-mm (No. 4) sieve. Sieve sizes are 25.0 mm (1 in.), 19.0 mm ($^3/_4$ in.), 12.5 mm ($^1/_2$ in.), 9.5 mm ($^3/_8$ in.), and 4.75 mm (No. 4).

3.2. *Shape Properties for Each Retained Sieve (x)*:

3.2.1. *gradient angularity* (*GA*)—applies to both fine and coarse aggregate sizes and is related to the sharpness of the corners of two-dimensional images of aggregate particles. The gradient angularity quantifies changes along a particle boundary with higher gradient values indicating a more angular shape. Gradient angularity has a relative range of zero to 10000 with a perfect circle having a value of zero.

Gradient Angularity:

$$GA = \frac{1}{\frac{n}{3} - 1} \sum_{i=1}^{n-3} \left| \theta_i - \theta_{i+3} \right| \quad (1)$$

where:

θ = angle of orientation of the edge points

n = the total number of points

i = denoting the *i*th point on the edge of the particle

3.2.2. *texture (or micro-texture) (TX)*—applies to coarse aggregate sizes only and describes the relative smoothness or roughness of surface features less than approximately 0.5 mm in size that are too small to affect the overall shape. Texture has a relative scale of zero to 1000 with a smooth polished surface approaching a value of zero.

$$TX = \frac{1}{3N} \sum_{i=1}^{3} \sum_{j=1}^{N} \left(D_{i,j}(x, y) \right)^2 \quad (2)$$

where:

D = decomposition function

n = decomposition level

N = total number of coefficients in an image

i = 1, 2, or 3 for detailed images

j = wavelet index

x, y = location of the coefficients in transformed domain

3.2.3. *sphericity (SP)*—applies to coarse aggregate sizes only and describes the overall three-dimensional shape of a particle. Sphericity has a relative scale of zero to one. A sphericity value of one indicates a particle has equal dimensions (cubical).

$$SP = \sqrt[3]{\frac{d_S \times d_I}{d_L^2}} \quad (3)$$

where:

d_S = particle shortest dimension

d_I = particle intermediate dimension

d_L = particle longest dimension

3.2.4. *Form 2D*—Applies to fine aggregate sizes only and is used to quantify the relative form from 2-dimensional images of aggregate particles. Form 2D has a relative scale of 0 to 20. A perfect circle has a Form 2D value of zero.

$$\text{Form 2D} = \sum_{\theta=0}^{\theta=360-\Delta\theta} \left[\frac{R_{\theta+\Delta\theta} - R_\theta}{R_\theta} \right] \quad (4)$$

where:

R_θ = the radius of the particle at an angle of θ

$\Delta\theta$ = the incremental difference in the angle

3.2.5. *flat* ***and*** *elongated*—those particles having a ratio of longest dimension to shortest dimension greater than a specified value.

Aggregate particle dimensions in an *x, y, z* coordinate system:

d_S = particle shortest dimension

d_I = particle intermediate

d_L = particle longest dimension

Flatness Ratio (*S/L*): $Flatness = \frac{d_S}{d_I}$ (5)

Elongation Ratio (*I/L*): $Elongation = \frac{d_I}{d_L}$ (6)

Flat and Elongated Value (*F&E*): $L / S = \frac{d_L}{d_S}$ (7)

3.2.6. *flat* ***or*** *elongated*—those particles having a ratio of intermediate dimension to shortest dimension or longest dimension to intermediate dimension greater than a specified value.

Flat ***or*** Elongated (*F* or *E*): $\frac{d_I}{d_S}$ or $\frac{d_L}{d_I} >$ Ratio (i.e., 1, 2, 3…) (8)

3.2.7. $\%Pass_x$ = Percent passing sieve *x*.

3.2.8. $\%R_x$ = Percent retained on sieve *x* (passing sieve *x* + 1).

4. SIGNIFICANCE AND USE

4.1. Shape, angularity, and surface texture of aggregates have been shown to directly affect the engineering properties of highway construction materials such as hot mix asphalt concrete, portland cement concrete, and unbound aggregate layers. This standard is used to characterize the combined shape values for an aggregate source from the individual particle shape properties determined by digital image analysis from TP 81. The aggregate shape characterization includes Gradient Angularity, Form 2D, Sphericity, Texture, and Flat and Elongated value.

Note 1—The National Cooperative Highway Research Program Report 555 provides background information relevant to characterizing aggregate shape, texture, and angularity.

4.2. This practice may be used to characterize the shape characteristics of single source aggregate materials and multiple source aggregate material blends.

5. PROCEDURE

5.1. Determine the aggregate sample grading according to T 27 and the amount finer than 75 µm according to T 11.

5.2. Determine the aggregate sample specific gravities according to T 84 and T 85.

5.3. Determine the material sample shape values for Form 2D, Gradient Angularity, Sphericity, Form Ratios (*F&E*, *F* or *E*), and Texture according to TP 81.

6. CALCULATIONS—SINGLE SOURCE

6.1. The material sample is typically characterized by individual evaluation of material retained on each sieve size, passing the next larger sieve. For the purpose of calculating the combined shape values, consider any sizes that contain inadequate percent retained mass to achieve minimum particle count to have the same shape value as the average of the next larger or the next smaller size, whichever is present.

6.2. Calculate the Percent Retained for the aggregate sample on each sieve using the T 27 results:

Sieve Sizes (*x*):

Coarse: 25.0 mm (1 in.), 19.0 mm ($^3/_4$ in.), 12.5 mm ($^1/_2$ in.), 9.5 mm ($^3/_8$ in.), 4.75 mm (No. 4)

Fine: 2.36 mm (No. 8), 1.18 mm (No. 16), 0.60 mm (No. 30), 0.30 mm (No. 50), 0.15 mm (No. 100), 0.075 mm (No. 200)

Percent Passing:

$\%\text{Pass}_x$ = Percent passing sieve *x*

Percent Retained:

$\%R_x$ = Percent retained on sieve *x*

$$\%R_x = \%\text{Pass}_{x+1} - \%\text{Pass}_x$$

6.3. Calculate average particle size, volume, and surface area for each sieve size *x* for unit mass.

For the purposes of shape characterization, volume and surface area of an average particle is estimated by using a cubical shape with side dimensions estimated by the average of the retained sieve and next larger sieve dimension.

Average Particle Size: $D_x = \frac{(\text{Sieve}_x + \text{Sieve}_{x+1})}{2}$ (mm)

Average Particle Surface Area (cubical): $PSA_x = 6 \times D_x{}^2$ (mm^2)

Average Particle Volume (cubical): $V_x = D_x{}^3$ (mm^3)

6.4. Calculate number of particles per sample unit mass for each sieve size from the size distribution of T 27 and the respective specific gravities from T 84 and T 85.

Number of particles per sieve size: $\# P_x = \frac{\%R_x \times 1000}{G_{sb} \times V_x}$

Note 2—A mass of one is assumed in Eq 13. This calculation determines the weighting factor applied to each sieve size for a material sample; therefore, actual mass is not required.

6.5. Calculate total particle surface area for each sieve size per sample unit mass:

Particle Surface Area (each sieve *x*) (mm^2): $SSA_x = PSA_x \times \# P_x$

6.6. Calculate Sample Surface Area (per unit mass):

Total Surface Area (mm^2): $TSA = \sum_{x=0.075}^{25.0} SSA_x$

Coarse Surface Area (mm^2): $CSA = \sum_{x=4.75}^{25.0} SSA_x$

Fine Surface Area (mm^2): $FSA = \sum_{x=0.075}^{2.36} SSA_x$

6.7. Calculate Sample Particles Count (per unit mass):

Total Particles: $\#TP = \sum_{x=0.075}^{25.0} \#P_x$

\# Coarse Particles: $\#CP = \sum_{x=4.75}^{25.0} \#P_x$

\# Fine Particles: $\#FP = \sum_{x=0.075}^{2.36} \#P_x$

6.8. Calculate Sample Gradient Angularity (weighted by surface area):

Fine Gradient Angularity: $FGA = \frac{1}{FSA} \sum_{x=0.075}^{2.36} \left[SSA_x \times GA_x \right]$

Coarse Gradient Angularity: $CGA = \frac{1}{CSA} \sum_{x=4.75}^{25.0} \left[SSA_x \times GA_x \right]$

Overall Gradient Angularity: $GA = \frac{1}{TSA} \sum_{x=0.075}^{25.0} \left[SSA_x \times GA_x \right]$

6.9. Calculate Sample Fine Aggregate Form 2D (weighted by surface area):

$$\text{Form 2D} = \frac{1}{FSA} \sum_{x=0.075}^{2.36} \left[SSA_x \times 2D_x \right]$$

6.10. Calculate Sample Coarse Aggregate Texture (weighted by surface area):

$$TX = \frac{1}{CSA} \sum_{x=4.75}^{25.0} \left[SSA_x \times TX_x \right]$$

6.11. Calculate Sample Coarse Aggregate Sphericity (weighted by particle count):

$$SP = \frac{1}{\#CP} \sum_{x=4.75}^{25.0} \left[\#P_x \times SP_x \right]$$

6.12. Calculate Sample Sphericity Range Distribution (weighted by particle count):

Percent of Particles with Sphericity ≤ 0.3:

$$SP(0.3) = \frac{1}{\#CP}\sum_{x=4.75}^{25.0}\left[\#P_x \times SP(0.3)_x\right]$$

Percent of Particles with Sphericity $0.3 < SP \leq 0.7$:

$$SP(0.7) = \frac{1}{\#CP}\sum_{x=4.75}^{25.0}\left[\#P_x \times SP(0.7)_x\right]$$

Percent of Particles with Sphericity $0.7 < SP \leq 1.0$:

$$SP(1.0) = \frac{1}{\#CP}\sum_{x=4.75}^{25.0}\left[\#P_x \times SP(1.0)_x\right]$$

6.13. Calculate sample weighted percentages of coarse aggregate Flat ***and*** Elongated Values (weighted by mass fraction) at the following ratios: ≥1:1, >2:1, >3:1, >4:1, >5:1

% $d_L/d_S \geq 1$: $\%L/S(\geq 1) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%L/S(\geq 1)_x}{100}\right]$

% $d_L/d_S > 2$: $\%L/S(> 2) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%L/S(> 2)_x}{100}\right]$

% $d_L/d_S > 3$: $\%L/S(> 3) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \cdots \%L/S(> 3)_x}{100}\right]$

% $d_L/d_S > 4$: $\%L/S(> 4) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%L/S(> 4)_x}{100}\right]$

% $d_L/d_S > 5$: $\%L/S(> 5) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%L/S(> 5)_x}{100}\right]$

6.13.1. Calculate the sample weighted percentages of Coarse Aggregate Flat ***or*** Elongated (weighted by mass fraction) at the following ratios: ≥1:1, >2:1, >3:1, >4:1, >5:1

% d_I/d_S or $d_L/d_I \geq 1$: $\%\left(F \text{ or } E\right)(\geq 1) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%\left(F \text{ or } E\right)(\geq 1)_x}{100}\right]$

% d_I/d_S or $d_L/d_I > 2$: $\%\left(F \text{ or } E\right)(> 2) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%\left(F \text{ or } E\right)(> 2)_x}{100}\right]$

% d_I/d_S or $d_L/d_I > 3$: $\%\left(F \text{ or } E\right) > 3) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%\left(F \text{ or } E\right)(> 3)_x}{100}\right]$

% d_I/d_S or $d_L/d_I > 4$: $\%\left(F \text{ or } E\right)(> 4) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%\left(F \text{ or } E\right)(> 4)_x}{100}\right]$

% d_I/d_S *or* d_L/d_I > 5: $$\%\left(F \text{ or } E\right)(>5) = \sum_{x=4.75}^{25.0}\left[\frac{\%R_x \times \%\left(F \text{ or } E\right)(>5)_x}{100}\right]$$

7. CALCULATIONS—MULTIPLE SOURCE BLEND

7.1. Use the calculations in this section to estimate the shape characteristics of multiple material source blends. Each source must be sampled and characterized according to Section 6 calculations.

7.2. Determine Blend Composition Percentages:

$\%AS_n$ = Percent Aggregate Source n

$$\sum_{i=1}^{n}\%AS_i = 100$$

where:

n = number of aggregate sources

7.3. Calculate Blend Surface Area:

Blend Total Surface Area (each sieve):

$$SSA_{\text{Blend}\_x} = \sum_{i=1}^{n}\sum_{x=0.075}^{37.5}\left[\frac{\%AS_i \times SSA_{ix}}{100}\right]$$

where:

x = 0.075 to 25.0 mm

n = number of aggregate sources

Total Surface Area Blend (all sieves x = 0.075 to 25.0 mm)

$$TSA_{\text{Blend}} = \sum_{x=0.075}^{25.0} SSA_{\text{Blend}\_x}$$

Coarse Surface Area Blend (sieve x = 4.75 to 25.0):

$$CSA_{\text{Blend}} = \sum_{x=4.75}^{25.0} SSA_{\text{Blend}\_x}$$

Fine Surface Area Blend (sieve x =0.075 to 2.36):

$$FSA_{\text{Blend}} = \sum_{x=0.075}^{2.36} SSA_{\text{Blend}\_x}$$

7.4. Calculate number of particles per blend unit mass for each sieve size:

$$\#P_{\text{Blend}\_x} = \sum_{i=1}^{n}\sum_{x=0.075}^{25.0}\left[\frac{\%AS_i \times \#P_{ix}}{100}\right]$$

7.5. Calculate number of particles per blend unit mass:

Total Particle Count Blend:

$$\#TP_{\text{Blend}} = \sum_{x=0.075}^{25.0} \#P_{\text{Blend}\_x}$$

Coarse Particles Blend:

$$\#CP_{\text{Blend}} = \sum_{x=4.75}^{25.0} \#P_{\text{Blend}\_x}$$

Fine Particles Blend:

$$\#FP_{\text{Blend}} = \sum_{x=0.075}^{2.36} \#P_{\text{Blend}\_x}$$

7.6. Calculate Blend Gradient Angularity for each size x = 0.075 to 25.0 mm and combined (weighted by surface area):

$$GA_{\text{Blend}\_x} = \frac{1}{SSA_{\text{Blend}\_x}}\left[\sum_{i=1}^{i}\left[\frac{\%AS_i \times SSA_{ix} \times GA_{ix}}{100}\right]\right]$$

Blend Fine Gradient Angularity:

$$FGA_{\text{Blend}} = \frac{1}{FSA_{\text{Blend}}}\left[\sum_{x=0.075}^{2.36}\left[SSA_{\text{Blend}\_x} \times GA_{\text{Blend}\_x}\right]\right]$$

Blend Coarse Gradient Angularity:

$$CGA_{\text{Blend}} = \frac{1}{CSA_{\text{Blend}}}\left[\sum_{x=4.75}^{25.0}\left[SSA_{\text{Blend}\_x} \times GA_{\text{Blend}\_x}\right]\right]$$

Blend Overall Gradient Angularity:

$$GA_{\text{Blend}} = \frac{1}{TSA_{\text{Blend}}}\left[\sum_{x=0.075}^{25.0}\left[SSA_{\text{Blend}\_x} \times GA_{\text{Blend}\_x}\right]\right]$$

7.7. Calculate Blend Fine Aggregate Form 2D for each sieve size x = 0.075 to 2.36 mm and combined (weighted by surface area):

$$\text{Form 2D}_{\text{Blend}\_x} = \frac{1}{SSA_{\text{Blend}\_x}}\left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times SSA_{ix} \times 2D_{ix}}{100}\right]\right]$$

Blend Form 2D:

$$\text{Form 2D}_{\text{Blend}} = \frac{1}{FSA_{\text{Blend}}}\left[\sum_{x=0.075}^{2.36}\left[SSA_{\text{Blend}\_x} \times 2D_{\text{Blend}\_x}\right]\right]$$

7.8. Calculate Blend Texture for each sieve size x = 4.75 to 25.0 mm and combined (weighted by coarse aggregate surface area):

$$TX_{\text{Blend}\_x} = \frac{1}{SSA_{\text{Blend}\_x}}\left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times SSA_{ix} \times TX_{ix}}{100}\right]\right]$$

Blend Texture:

$$TX_{\text{Blend}} = \frac{1}{CSA_{\text{Blend}}}\left[\sum_{x=4.75}^{25.0}\left[SSA_{\text{Blend}\_x} \times TX_{\text{Blend}\_x}\right]\right]$$

7.9. Calculate Average Blend Sphericity for each sieve size x = 4.75 to 25.0 mm and blend (weighted by coarse particle count):

$$SP_{\text{Blend}\_x} = \frac{1}{\#P_{\text{Blend}\_x}}\left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \#P_{ix} \times SP_{ix}}{100}\right]\right]$$

Blend Sphericity:

$$SP_{\text{Blend}} = \frac{1}{\#CP_{\text{Blend}}}\left[\sum_{x=4.75}^{25.0}\left[\#P_{\text{Blend}\_x} \times SP_{\text{Blend}\_x}\right]\right]$$

7.10. Calculate Blend Sphericity Distribution for each sieve size x = 4.75 to 25.0 mm and blend (weighted by coarse particle count):

Percent of Particles with Sphericity ≤ 0.3 (Blend):

$$SP(0.3)_{\text{Blend}\_x} = \frac{1}{\#P_{\text{Blend}\_x}}\left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \#P_{ix} \times SP(0.3)_{ix}}{100}\right]\right]$$

$$SP(0.3)_{\text{Blend}} = \frac{1}{\#CP_{\text{Blend}}}\left[\sum_{x=4.75}^{25.0}\left[\#P_{\text{Blend}\_x} \times SP(0.3)_{\text{Blend}\_x}\right]\right]$$

Percent of Particles with Sphericity 0.3 < SP ≤ 0.7 (Blend):

$$SP(0.7)_{\text{Blend}\_x} = \frac{1}{\#P_{\text{Blend}\_x}}\left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \#P_{ix} \times SP(0.7)_{ix}}{100}\right]\right]$$

$$SP(0.7)_{\text{Blend}} = \frac{1}{\#CP_{\text{Blend}}}\left[\sum_{x=4.75}^{25.0}\left[\#P_{\text{Blend}\_x} \times SP(0.7)_{\text{Blend}\_x}\right]\right]$$

Percent of Particles with Sphericity 0.7 < SP ≤ 1.0 (Blend):

$$SP(1.0)_{\text{Blend}\_x} = \frac{1}{\#P_{\text{Blend}\_x}}\left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \#P_{ix} \times SP(1.0)_{ix}}{100}\right]\right]$$

$$SP(1.0)_{\text{Blend}} = \frac{1}{\#CP_{\text{Blend}}}\left[\sum_{x=4.75}^{25.0}\left[\#P_{\text{Blend}\_x} \times SP(1.0)_{\text{Blend}\_x}\right]\right]$$

7.11. Calculate combined Flat *and* Elongated Values for each sieve size x = 4.75 to 25.0 mm and blend (weighted by mass fraction):

% $d_L/d_S \geq 1$ (Blend):

$$\%L/S(\geq 1)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \%L/S(\geq 1)_{ix}}{100^2}\right]\right]$$

$$\%L/S(\geq 1)_{\text{Blend}} = \left[\sum_{x=4.75}^{25.0}\left[\%L/S(\geq 1)_{\text{Blend}\_x}\right]\right]$$

% $d_L/d_S > 2$ (Blend):

$$\%L/S(>2)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \%L/S(>2)_{ix}}{100^2}\right]\right]$$

$$\%L/S(>2)_{\text{Blend}} = \left[\sum_{x=4.75}^{25.0}\left[\%L/S(>2)_{\text{Blend}\_x}\right]\right]$$

% $d_L/d_S > 3$ (Blend):

$$\%L/S(>3)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \%L/S(>3)_{ix}}{100^2}\right]\right]$$

$$\%L/S(>3)_{\text{Blend}} = \left[\sum_{x=4.75}^{25.0}\left[\%L/S(>3)_{\text{Blend}\_x}\right]\right]$$

% $d_L/d_S > 4$ (Blend):

$$\%L/S(>4)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \%L/S(>4)_{ix}}{100^2}\right]\right]$$

$$\%L/S(>4)_{\text{Blend}} = \left[\sum_{x=4.75}^{25.0}\left[\%L/S(>4)_{\text{Blend}\_x}\right]\right]$$

% $d_L/d_S \leq 5$ (Blend):

$$\%L/S(>5)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \%L/S(>5)_{ix}}{100^2}\right]\right]$$

$$\%L/S(>5)_{\text{Blend}} = \left[\sum_{x=4.75}^{37.5}\left[\%L/S(>5)_{\text{Blend}\_x}\right]\right]$$

7.12. Calculate Flat *or* Elongated Values for each sieve size *x* = 4.75 to 25.0 mm and blend (weighted by mass fraction):

% d_I/d_S *or* $d_L/d_I \geq 1$ (Blend):

$$\%\left(F \text{ or } E\right)(\geq 1)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \%\left(F \text{ or } E\right)(\geq 1)_{ix}}{100^2}\right]\right]$$

$$\%\left(F \text{ or } E\right)(\geq 1)_{\text{Blend}} = \left[\sum_{x=4.75}^{25.0}\left[\%\left(F \text{ or } E\right)(\geq 1)_{\text{Blend}\_x}\right]\right]$$

% d_I/d_S *or* $d_L/d_I > 2$ (Blend):

$$\%\left(F \text{ or } E\right)(>2)_{\text{Blend}\_x} = \left[\sum_{i=1}^{n}\left[\frac{\%AS_i \times \%R_{ix} \times \left(F \text{ or } E\right)(>2)_{ix}}{100^2}\right]\right]$$

$$\%\left(F\ \text{or}\ E\right)(>2)_{\text{Blend}}=\left[\sum_{x=4.75}^{25.0}\left[\%\left(F\ \text{or}\ E\right)(>2)_{\text{Blend}\_x}\right]\right]$$

% d_I/d_S *or* $d_L/d_I > 3$ (Blend):

$$\%\left(F\ \text{or}\ E\right)(>3)_{\text{Blend}\_x}=\left[\sum_{i=1}^{n}\left[\frac{\%AS_i\times\%R_{ix}\times\%\left(F\ \text{or}\ E\right)(>3)_{ix}}{100^2}\right]\right]$$

$$\%\left(F\ \text{or}\ E\right)(>3)_{\text{Blend}}=\left[\sum_{x=4.75}^{25.0}\left[\%\left(F\ \text{or}\ E\right)(>3)_{\text{Blend}\_x}\right]\right]$$

% d_I/d_S *or* $d_L/d_I > 4$ (Blend):

$$\%\left(F\ \text{or}\ E\right)(>4)_{\text{Blend}\_x}=\left[\sum_{i=1}^{i}\left[\frac{\%AS_i\times\%R_{ix}\times\%\left(F\ \text{or}\ E\right)(>4)_{ix}}{100^2}\right]\right]$$

$$\%\left(F\ \text{or}\ E\right)(>4)_{\text{Blend}}=\left[\sum_{x=4.75}^{25.0}\left[\%\left(F\ \text{or}\ E\right)(>4)_{\text{Blend}\_x}\right]\right]$$

% d_I/d_S or $d_L/d_I > 5$ (Blend):

$$\%\left(F\ \text{or}\ E\right)(>5)_{\text{Blend}\_x}=\left[\sum_{i=1}^{n}\left[\frac{\%AS_i\times\%R_{ix}\times\%\left(F\ \text{or}\ E\right)(>5)_{ix}}{100^2}\right]\right]$$

$$\%\left(F\ \text{or}\ E\right)(>5)_{\text{Blend}}=\left[\sum_{x=4.75}^{25.0}\left[\%\left(F\ \text{or}\ E\right)(>5)_{\text{Blend}\_x}\right]\right]$$

8. REPORT

8.1. *Report the following information*:

8.1.1. Project name.

8.1.2. Date of the analysis.

8.1.3. Material sample identifications: type, source, size, gradation.

8.1.4. Number of particles analyzed for each size.

8.1.5. Material shape property mean and standard deviation. Graphical representations of the property distributions may be included.

8.2. A sample report format is presented in Appendix X1.

9. PRECISION AND BIAS

9.1. *Precision*—This practice uses data generated from other testing methods to generate cumulative information, therefore the precision of the values generated in this practice are established by the precision of the standards used to collect the raw data.

9.2. *Bias*—The research required to determine the bias of this procedure has not been conducted.

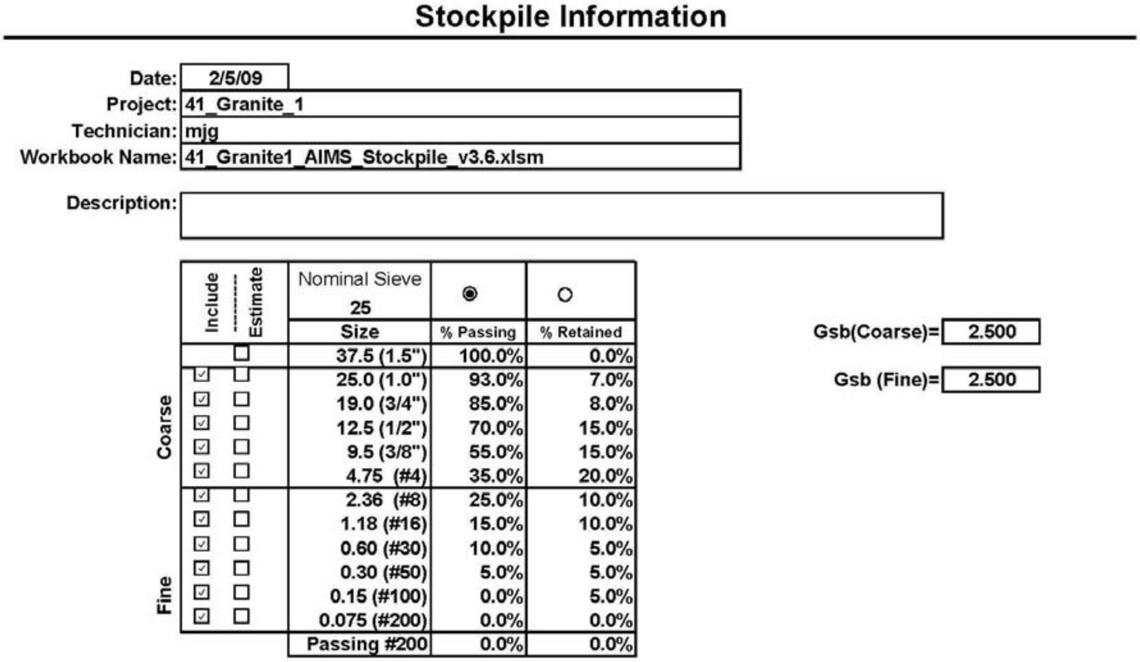
10. KEYWORDS

10.1. Aggregate; angularity; consensus property; elongation; form; shape; texture.

APPENDIX

(Nonmandatory Information)

X1. SAMPLE REPORT



Stockpile Information

Date: 2/5/09
Project: 41_Granite_1
Technician: mjg
Workbook Name: 41_Granite1_AIMS_Stockpile_v3.6.xlsm

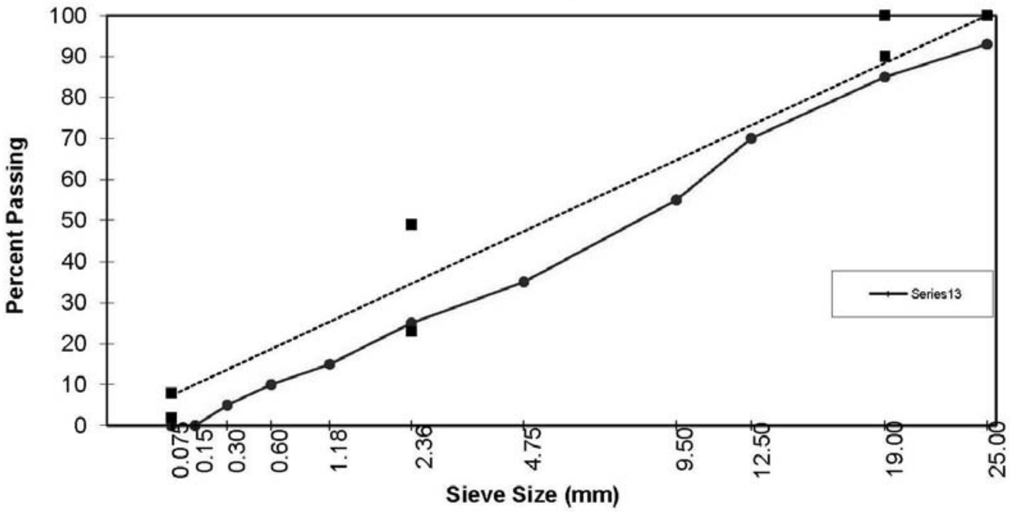
Description:

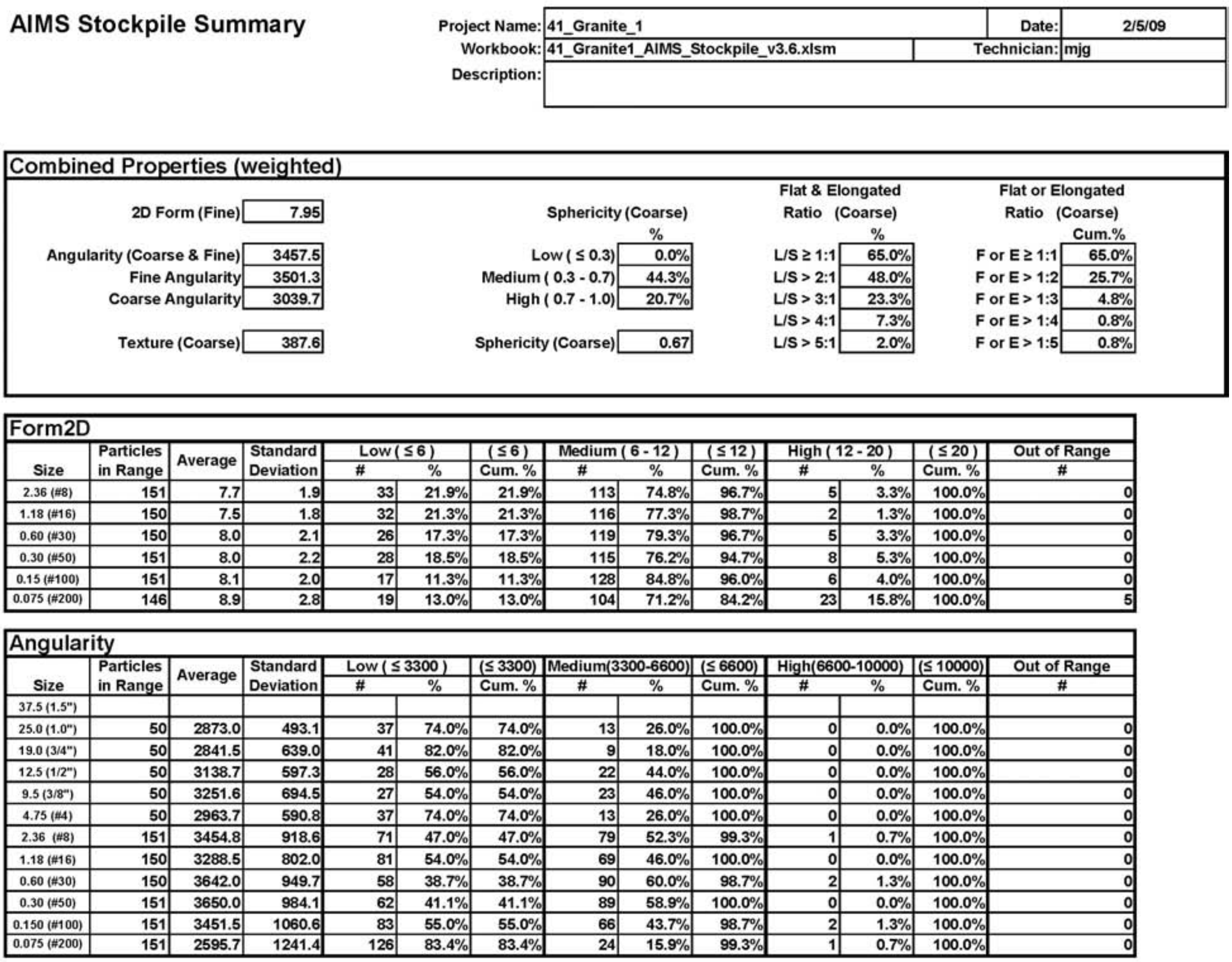
	Include	Estimate	Nominal Sieve 25	●	○
			Size	% Passing	% Retained
		☐	**37.5 (1.5")**	**100.0%**	**0.0%**
Coarse	☑	☐	**25.0 (1.0")**	**93.0%**	**7.0%**
	☑	☐	**19.0 (3/4")**	**85.0%**	**8.0%**
	☑	☐	**12.5 (1/2")**	**70.0%**	**15.0%**
	☑	☐	**9.5 (3/8")**	**55.0%**	**15.0%**
	☑	☐	**4.75 (#4)**	**35.0%**	**20.0%**
Fine	☑	☐	**2.36 (#8)**	**25.0%**	**10.0%**
	☑	☐	**1.18 (#16)**	**15.0%**	**10.0%**
	☑	☐	**0.60 (#30)**	**10.0%**	**5.0%**
	☑	☐	**0.30 (#50)**	**5.0%**	**5.0%**
	☑	☐	**0.15 (#100)**	**0.0%**	**5.0%**
	☑	☐	**0.075 (#200)**	**0.0%**	**0.0%**
			Passing #200	**0.0%**	**0.0%**

Gsb(Coarse)= 2.500

Gsb (Fine)= 2.500

19.0 mm Nominal Sieve Size





AIMS Stockpile Summary

Project Name:	41_Granite_1	Date:	2/5/09
Workbook:	41_Granite1_AIMS_Stockpile_v3.6.xlsm	Technician:	mjg
Description:			

Combined Properties (weighted)

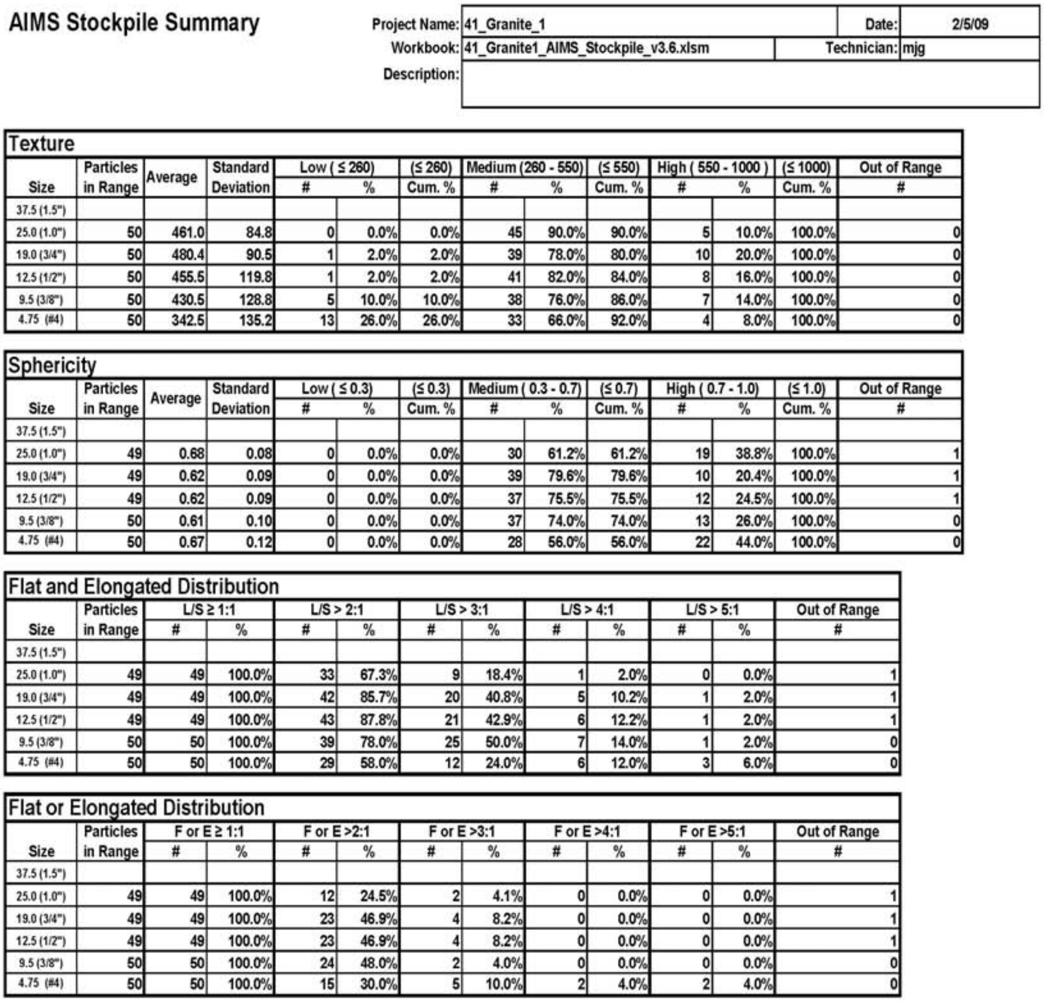
		Sphericity (Coarse)	%	Flat & Elongated Ratio (Coarse)	%	Flat or Elongated Ratio (Coarse)	Cum.%
2D Form (Fine)	7.95						
Angularity (Coarse & Fine)	3457.5	Low (≤ 0.3)	0.0%	L/S ≥ 1:1	65.0%	F or E ≥ 1:1	65.0%
Fine Angularity	3501.3	Medium (0.3 - 0.7)	44.3%	L/S > 2:1	48.0%	F or E > 1:2	25.7%
Coarse Angularity	3039.7	High (0.7 - 1.0)	20.7%	L/S > 3:1	23.3%	F or E > 1:3	4.8%
				L/S > 4:1	7.3%	F or E > 1:4	0.8%
Texture (Coarse)	387.6	Sphericity (Coarse)	0.67	L/S > 5:1	2.0%	F or E > 1:5	0.8%

Form2D

Size	Particles in Range	Average	Standard Deviation	Low (≤ 6)		(≤ 6)	Medium (6 - 12)		(≤ 12)	High (12 - 20)		(≤ 20)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
2.36 (#8)	151	7.7	1.9	33	21.9%	21.9%	113	74.8%	96.7%	5	3.3%	100.0%	0
1.18 (#16)	150	7.5	1.8	32	21.3%	21.3%	116	77.3%	98.7%	2	1.3%	100.0%	0
0.60 (#30)	150	8.0	2.1	26	17.3%	17.3%	119	79.3%	96.7%	5	3.3%	100.0%	0
0.30 (#50)	151	8.0	2.2	28	18.5%	18.5%	115	76.2%	94.7%	8	5.3%	100.0%	0
0.15 (#100)	151	8.1	2.0	17	11.3%	11.3%	128	84.8%	96.0%	6	4.0%	100.0%	0
0.075 (#200)	146	8.9	2.8	19	13.0%	13.0%	104	71.2%	84.2%	23	15.8%	100.0%	5

Angularity

Size	Particles in Range	Average	Standard Deviation	Low (≤ 3300)		(≤ 3300)	Medium(3300-6600)		(≤ 6600)	High(6600-10000)		(≤ 10000)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")													
25.0 (1.0")	50	2873.0	493.1	37	74.0%	74.0%	13	26.0%	100.0%	0	0.0%	100.0%	0
19.0 (3/4")	50	2841.5	639.0	41	82.0%	82.0%	9	18.0%	100.0%	0	0.0%	100.0%	0
12.5 (1/2")	50	3138.7	597.3	28	56.0%	56.0%	22	44.0%	100.0%	0	0.0%	100.0%	0
9.5 (3/8")	50	3251.6	694.5	27	54.0%	54.0%	23	46.0%	100.0%	0	0.0%	100.0%	0
4.75 (#4)	50	2963.7	590.8	37	74.0%	74.0%	13	26.0%	100.0%	0	0.0%	100.0%	0
2.36 (#8)	151	3454.8	918.6	71	47.0%	47.0%	79	52.3%	99.3%	1	0.7%	100.0%	0
1.18 (#16)	150	3288.5	802.0	81	54.0%	54.0%	69	46.0%	100.0%	0	0.0%	100.0%	0
0.60 (#30)	150	3642.0	949.7	58	38.7%	38.7%	90	60.0%	98.7%	2	1.3%	100.0%	0
0.30 (#50)	151	3650.0	984.1	62	41.1%	41.1%	89	58.9%	100.0%	0	0.0%	100.0%	0
0.150 (#100)	151	3451.5	1060.6	83	55.0%	55.0%	66	43.7%	98.7%	2	1.3%	100.0%	0
0.075 (#200)	151	2595.7	1241.4	126	83.4%	83.4%	24	15.9%	99.3%	1	0.7%	100.0%	0



AIMS Stockpile Summary

Project Name:	41_Granite_1	Date:	2/5/09
Workbook:	41_Granite1_AIMS_Stockpile_v3.6.xlsm	Technician:	mjg
Description:			

Texture

Size	Particles in Range	Average	Standard Deviation	Low (≤ 260)		(≤ 260)	Medium (260 - 550)		(≤ 550)	High (550 - 1000)		(≤ 1000)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")													
25.0 (1.0")	50	461.0	84.8	0	0.0%	0.0%	45	90.0%	90.0%	5	10.0%	100.0%	0
19.0 (3/4")	50	480.4	90.5	1	2.0%	2.0%	39	78.0%	80.0%	10	20.0%	100.0%	0
12.5 (1/2")	50	455.5	119.8	1	2.0%	2.0%	41	82.0%	84.0%	8	16.0%	100.0%	0
9.5 (3/8")	50	430.5	128.8	5	10.0%	10.0%	38	76.0%	86.0%	7	14.0%	100.0%	0
4.75 (#4)	50	342.5	135.2	13	26.0%	26.0%	33	66.0%	92.0%	4	8.0%	100.0%	0

Sphericity

Size	Particles in Range	Average	Standard Deviation	Low (≤ 0.3)		(≤ 0.3)	Medium (0.3 - 0.7)		(≤ 0.7)	High (0.7 - 1.0)		(≤ 1.0)	Out of Range
				#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
37.5 (1.5")													
25.0 (1.0")	49	0.68	0.08	0	0.0%	0.0%	30	61.2%	61.2%	19	38.8%	100.0%	1
19.0 (3/4")	49	0.62	0.09	0	0.0%	0.0%	39	79.6%	79.6%	10	20.4%	100.0%	1
12.5 (1/2")	49	0.62	0.09	0	0.0%	0.0%	37	75.5%	75.5%	12	24.5%	100.0%	1
9.5 (3/8")	50	0.61	0.10	0	0.0%	0.0%	37	74.0%	74.0%	13	26.0%	100.0%	0
4.75 (#4)	50	0.67	0.12	0	0.0%	0.0%	28	56.0%	56.0%	22	44.0%	100.0%	0

Flat and Elongated Distribution

Size	Particles in Range	L/S ≥ 1:1		L/S > 2:1		L/S > 3:1		L/S > 4:1		L/S > 5:1		Out of Range
		#	%	#	%	#	%	#	%	#	%	#
37.5 (1.5")												
25.0 (1.0")	49	49	100.0%	33	67.3%	9	18.4%	1	2.0%	0	0.0%	1
19.0 (3/4")	49	49	100.0%	42	85.7%	20	40.8%	5	10.2%	1	2.0%	1
12.5 (1/2")	49	49	100.0%	43	87.8%	21	42.9%	6	12.2%	1	2.0%	1
9.5 (3/8")	50	50	100.0%	39	78.0%	25	50.0%	7	14.0%	1	2.0%	0
4.75 (#4)	50	50	100.0%	29	58.0%	12	24.0%	6	12.0%	3	6.0%	0

Flat or Elongated Distribution

Size	Particles in Range	F or E ≥ 1:1		F or E >2:1		F or E >3:1		F or E >4:1		F or E >5:1		Out of Range
		#	%	#	%	#	%	#	%	#	%	#
37.5 (1.5")												
25.0 (1.0")	49	49	100.0%	12	24.5%	2	4.1%	0	0.0%	0	0.0%	1
19.0 (3/4")	49	49	100.0%	23	46.9%	4	8.2%	0	0.0%	0	0.0%	1
12.5 (1/2")	49	49	100.0%	23	46.9%	4	8.2%	0	0.0%	0	0.0%	1
9.5 (3/8")	50	50	100.0%	24	48.0%	2	4.0%	0	0.0%	0	0.0%	0
4.75 (#4)	50	50	100.0%	15	30.0%	5	10.0%	2	4.0%	2	4.0%	0

AIMS Angularity

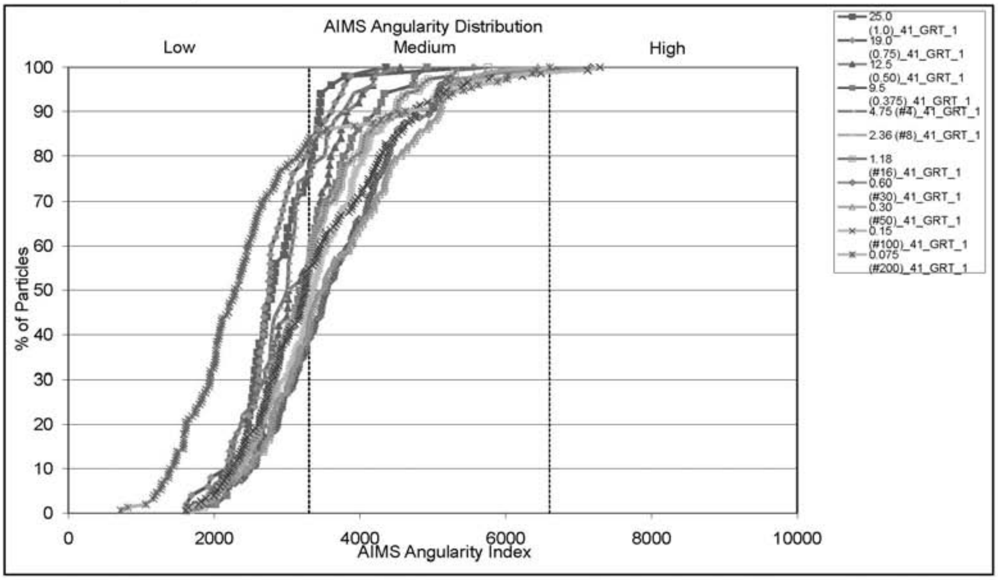
Project Name:	41_Granite_1	Date:	2/5/09
Workbook:	41_Granite1_AIMS_Stockpile_v3.6.xlsm	Technician:	mjg
Description:			

Particles in Range	1154
Average	3274.7
Std. Deviation	995.6
Median	3170.6
Mode	3330.1

	#	%
Low (≤ 3300)	651	56.4%
Medium (3300 - 6600)	497	43.1%
High (6600 - 10000)	6	0.5%
Out of Range	0	

	Cum. %
(≤ 3300)	56.4%
(≤ 6600)	99.5%
(≤ 10000)	100.0%

	#	%
$-\sigma < n < \sigma$	814	70.5%
$-2\sigma < n < 2\sigma$	1105	95.8%
$-3\sigma < n < 3\sigma$	1144	99.1%
$n<-3\sigma$ or $n>3\sigma$	10	0.9%



Standard Practice for

Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

AASHTO Designation: PP 65-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

AASHTO Designation: PP 65-10

1. SCOPE

1.1 This practice describes approaches for identifying potentially deleteriously reactive aggregates and selecting appropriate preventive measures to minimize the risk of expansion when such aggregates are used in concrete. Both alkali-silica reactive and alkali-carbonate reactive aggregates are covered. Preventive measures for alkali-silica reactive aggregates include avoiding the reactive aggregate, limiting the alkali content of the concrete, using blended cement, using supplementary cementitious materials, using lithium nitrate as an admixture, or a combination of these measures. Preventive measures for alkali-carbonate reactive rocks are limited to avoiding the reactive aggregate.

1.2 The values stated in SI units are the preferred standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 240, Blended Hydraulic Cement
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- M 302, Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
- M 307, Silica Fume Used in Cementitious Mixtures
- T 303, Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction

2.2 *ASTM Standards*:

- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- C 856, Standard Practice for Petrographic Examination of Hardened Concrete
- C 1105, Standard Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction
- C 1157/C 1157M, Standard Performance Specification for Hydraulic Cement

- C 1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
- C 1567, Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

2.3 *Canadian Standards*:

- CSA A23.2-26A, Determination of Potential Alkali-Carbonate Reactivity of Quarried Carbonate Rocks by Chemical Composition

2.4 *RILEM Recommendations*:

- RILEM TC 191-ARP, Alkali-Reactivity and Prevention—Assessment, Specification, and Diagnosis of Alkali-Reactivity

3. TERMINOLOGY

3.1 *accelerated mortar bar test (AMBT)*—test method used to determine aggregate reactivity (T 303) or to evaluate the effectiveness of measures to prevent deleterious expansion when reactive aggregates are used (ASTM C 1567).

3.2 *alkali-aggregate reaction (AAR)*—chemical reaction in either mortar or concrete between alkalis (sodium and potassium) present in the concrete pore solution and certain constituents of some aggregates; under certain conditions, deleterious expansion of concrete or mortar may result. Two types of AAR are considered in this standard practice; these are alkali-carbonate reaction (ACR) and alkali-silica reaction (ASR).

3.3 *alkali-carbonate reaction (ACR)*—the reaction between the alkalis (sodium and potassium) present in the concrete pore solution and certain carbonate rocks, particularly argillaceous calcitic dolomite and argillaceous dolomitic limestone, present in some aggregates; the products of the reaction may cause deleterious expansion and cracking of concrete.

3.4 *alkali-silica reaction (ASR*)—the reaction between the alkalis (sodium and potassium) present in the concrete pore solution and certain siliceous rocks or minerals, such as opaline chert, strained quartz, and acidic volcanic glass, present in significant quantities in some aggregates; the products of the reaction may cause deleterious expansion and cracking of concrete.

3.5 *class of structure*—in this guideline structures are classified on the basis of the severity of the consequences should ASR occur.

3.6 *concrete prism test (CPT)*—test method (ASTM C 1293) used to determine aggregate reactivity or to evaluate the effectiveness of measures to prevent deleterious expansion when reactive aggregates are used. Another version of this test, ASTM C 1105, can be used with a limited alkali content to determine the potential for alkali-carbonate reactivity.

3.7 *deleterious expansion*—term used to describe an increase in volume that is sufficient to cause cracking of the concrete or result in other problems (e.g., misalignment of adjacent components, closing of joints, etc.).

3.8 *deleteriously reactive*—term used to define aggregates that undergo chemical reactions in concrete that subsequently result in deleterious expansion of the concrete.

3.9 *equivalent alkali,* Na_2Oe—calculated from the sodium (Na_2O) and potassium oxide (K_2O) as follows: $Na_2Oe = Na_2O + 0.658 \times K_2O$.

3.10 *non-deleteriously reactive*—term used to define aggregates with no reactive constituents or minor amounts of reactive constituents that may exhibit some small amount of reaction without producing significant damage to the concrete.

3.11 *preventive measures*—termed used to describe strategies for suppressing damaging expansion due to alkali-aggregate reaction (AAR).

3.12 *supplementary cementitious material (SCM)*—term used to describe cementitious materials other than portland cement (i.e., pozzolans and slag).

4. SIGNIFICANCE AND USE

4.1 This practice describes a procedure for evaluating aggregate reactivity and determining measures to prevent deleterious expansion due to alkali-aggregate reaction (AAR).

4.2 Following this practice will not completely eliminate the possibility of deleterious expansion occurring in new construction; rather the practice provides various approaches for minimizing the risk of AAR to a level acceptable to the owner.

4.3 Aggregate reactivity is determined on the basis of one or more of the following: field performance, petrographic examination, or the expansion testing of mortars or concrete, or both.

4.4 If the aggregate is deemed to be non-deleteriously reactive, it can be accepted for use in concrete with no further consideration of preventive measures (assuming that the physical properties of the aggregate render it suitable for use).

4.5 If the aggregate is found to be deleteriously reactive, it must then be determined whether the reaction is of the alkali-carbonate or alkali-silica type.

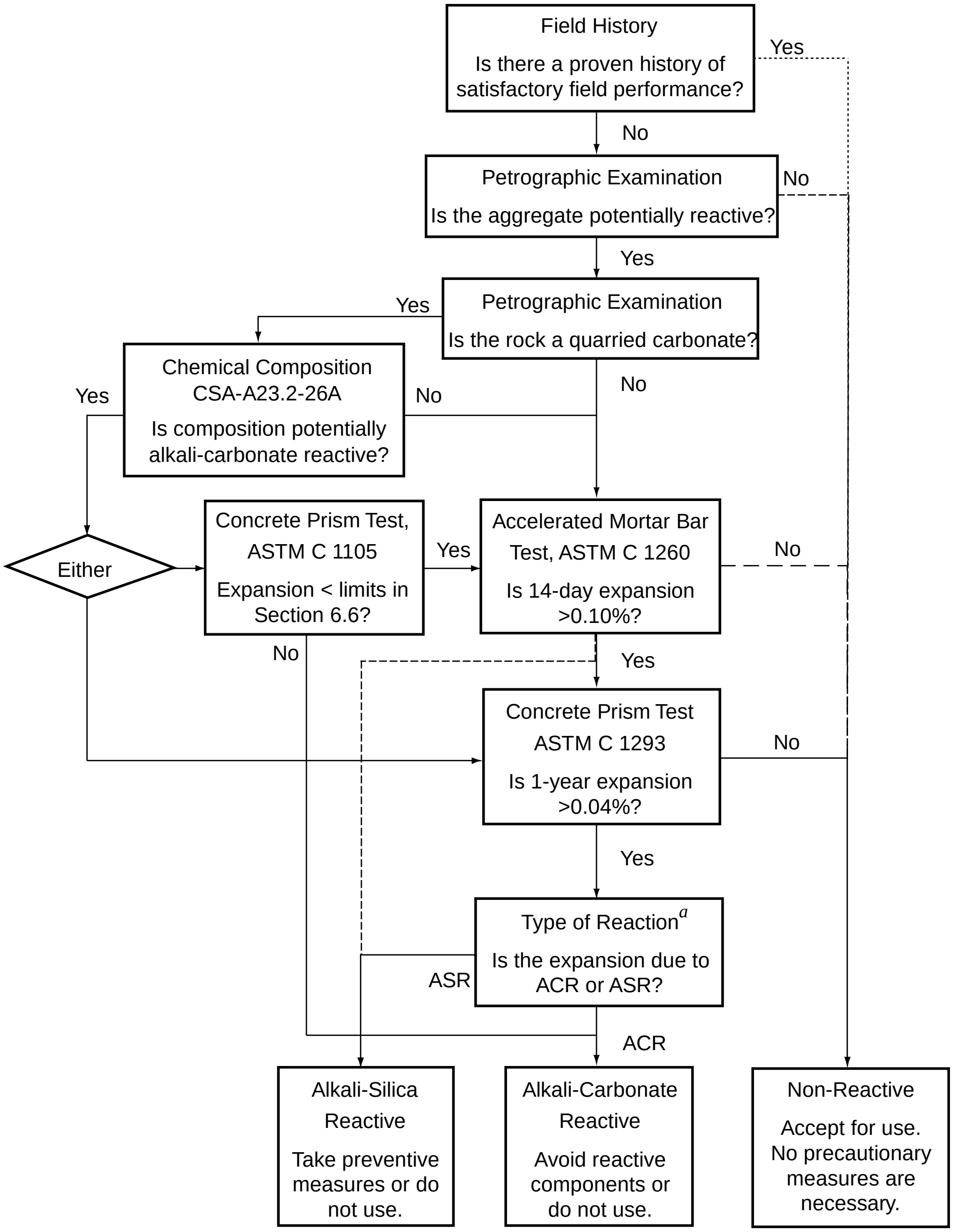
4.6 If the aggregate is alkali-silica reactive, the aggregate may be either rejected for use or accepted with an appropriate preventive measure. There are a number of options for minimizing the risk of expansion with alkali-silica reactive rocks. This practice allows for preventive measures to be evaluated on the basis of performance testing or to be selected prescriptively from a list of options based on previous experience. The level of prevention required is a function of the reactivity of the aggregate, the class of structure, the nature of the exposure conditions, the availability of alkali in the system, the type of material used for prevention, and the level of risk the owner is willing to accept.

4.7 If the aggregate is alkali-carbonate reactive, the aggregate must be rejected for use. There are no proven measures for effectively preventing damaging expansion with alkali-carbonate reactive rocks, and such materials should not be used in concrete without selective quarrying or processing to limit the reactive components to acceptable levels.

4.8 In the approach outlined here, the level of testing varies depending on the level of risk that is acceptable to the owner. For example, in regions where occurrences of AAR are rare or where the aggregate sources in use have a long history of good field performance, it may be reasonable to continue to rely on the previous field history without subjecting the aggregates to laboratory tests. However, in regions where AAR problems are known and where the reactivity of aggregates is known to vary from source to source, it may be necessary to implement a rigorous testing regime to establish the potential aggregate reactivity and evaluate preventive measures.

5. GENERAL APPROACH

5.1 The flow chart in Figure 1 shows the sequence of testing and decisions that has to be made when evaluating a source of aggregate for potential AAR. It is recommended that the following sequence of testing is followed to determine aggregate reactivity: consideration of field performance history, petrographic examination, accelerated mortar bar testing, and concrete prism testing. If the rock is a quarried carbonate, additional tests are required to determine the potential for alkali-carbonate reaction (as shown in Figure 1). Some agencies may adopt one or more of these test procedures depending on prior experience with AAR and the acceptable level of risk of AAR in new construction.



[a] The type of reaction only needs to be determined after the concrete prism test if the aggregate being tested is a quarried carbonate that has been identified as being potentially alkali-carbonate reactive by chemical composition in accordance with test method CSA A23.2-26A.

The solid lines show the preferred approach. However, some agencies may want to reduce the amount of testing and accept a higher level of risk, and this can be achieved by following the direction of the hashed lines.

Figure 1—Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

5.2 Appropriate preventive measures can be selected either by performance testing using the accelerated mortar bar test or concrete prism test, or by using prescribed measures that have been developed based on previous experience and published research data. The level of prevention prescribed is a function of the class of the structure, the reactivity of the aggregate, the alkali content of the portland cement, the composition of the material used for prevention, the exposure conditions, and the level of risk the owner is willing to accept.

Note 1—If desired, performance testing can be conducted on the aggregate with preventive measures, without first establishing aggregate reactivity.

6. DETERMINING AGGREGATE REACTIVITY

6.1 *Field Performance History*:

6.1.1 The long-term field performance history of an aggregate can be established by consulting the available documentation (e.g., specifications and construction files) and conducting a survey of existing structures that were constructed using the same or similar (i.e., from the same geological environment) aggregate source. As many structures as practical should be included in the survey, and these structures should, where possible, represent different types of construction (pavements, sidewalks, curb and gutter, elements of bridges, barrier walls, and even non-transportation structures). The following information should be collected for each structure: (1) *age*—structures should be at least 10 years old and preferably more than 15 years old as deleterious expansion due to AAR can take more than 10 years to develop; (2) *cement content and alkali content* of the cement used during construction; (3) use and type of *supplementary cementitious materials* during construction; (4) *exposure condition*—availability of moisture, use of deicing chemicals; and (5) presence and type of *symptoms of distress* due to AAR or other causes.

6.1.2 Cores should be taken from a representative number of these structures and petrographic examinations conducted in accordance with ASTM C 856 to establish the following: (1) the presence or not of evidence of deleterious expansion due to AAR, (2) the aggregate used in the structures surveyed is close in mineralogical composition to that of the aggregate currently being produced, and (3) the presence and an estimate of the quantity of supplementary cementitious materials.

6.1.3 If the results of the field survey indicate that the aggregate is non-deleteriously reactive, the aggregate may be used in new construction provided that the new concrete is not produced with a higher alkali loading, a lower amount of or different supplementary cementitious materials, or more aggressive exposure condition than the structures included in the survey.

6.1.4 If field performance indicates that an aggregate source is deleteriously reactive, laboratory expansion testing is required to determine the level of aggregate reactivity and to evaluate prevention measures.

Note 2—There is a certain level of risk associated with accepting aggregates solely on the basis of field performance due to difficulties in establishing unequivocally that the materials and proportions used are similar to those to be used in new construction. For example, petrographic examination can only estimate the quantity of pozzolans and slag to the nearest 10 percent or so and is not able to determine the composition of the material (e.g., Class F versus Class C fly ash). The presence of very finely divided pozzolans (silica fume) cannot be detected using a petrographic examination.

6.2 *Petrographic Examination*:

6.2.1 Petrographic examination of aggregates should be conducted in accordance with ASTM C 295. Petrography can reveal useful information about the composition of an aggregate, including the identification and approximate quantification of reactive minerals.

6.2.2 Petrography may be used to classify an aggregate as potentially reactive, but expansion testing is required to determine the extent of potential reactivity and appropriate levels of prevention.

6.2.3 Quarried carbonate rocks should be tested to determine the chemical composition and the potential for alkali-carbonate reaction in accordance with Section 6.3.

Note 3—Aggregates may be accepted as non-deleteriously-reactive solely on the basis of petrography, but there is certain level of risk associated with such a decision as some reactive phases may not be routinely detected by optical microscopy (e.g., finely dispersed cryptocrystalline silica found in some siliceous limestone).

6.3 *Determination of Potential Alkali-Carbonate Reactive Rocks by Chemical Composition*:

6.3.1 If the aggregate being assessed is a quarried carbonate rock, the potential for alkali-carbonate reaction may be assessed on the basis of its chemical composition using the test method CSA A23.2-26A. This test involves the determination of the lime (CaO), magnesia (MgO), and alumina (Al_2O_3) content of the rock, and determining where the composition of the rock falls on a plot of CaO/MgO ratio versus the Al_2O_3 content, as shown in Figure 2.

6.3.2 If the composition falls in one of the two ranges identified as “Aggregates considered non-expansive” in Figure 2, the aggregate is not potentially alkali-carbonate reactive, and it should be tested to determine the potential for alkali-silica reaction using the accelerated mortar bar test (Section 6.4) or the concrete prism test (Section 6.5), or both.

6.3.3 If the composition falls in the range of “aggregates considered to be potentially expansive,” the aggregate is potentially alkali-carbonate reactive and must be evaluated further. There are two options for further testing. One option is to test the aggregate in the concrete prism test, ASTM C 1293 (see Section 6.5), to simultaneously determine the potential for alkali-carbonate and alkali-silica reactivity. After the test, the prisms are examined by petrography to determine the role played by the alkali-carbonate reaction (see Section 6.5.5). The second option is to test using the concrete prism test, ASTM C 1105, with a reduced alkali loading to determine the potential for alkali-carbonate reaction only (see Section 6.6). If the aggregate passes the expansion criteria in Section 6.6, it is considered not to be alkali-carbonate reactive and can be tested in the same manner as aggregates with a composition that falls in the two ranges identified as “Aggregate considered non-expansive” in Figure 2 (see Section 6.3.2).

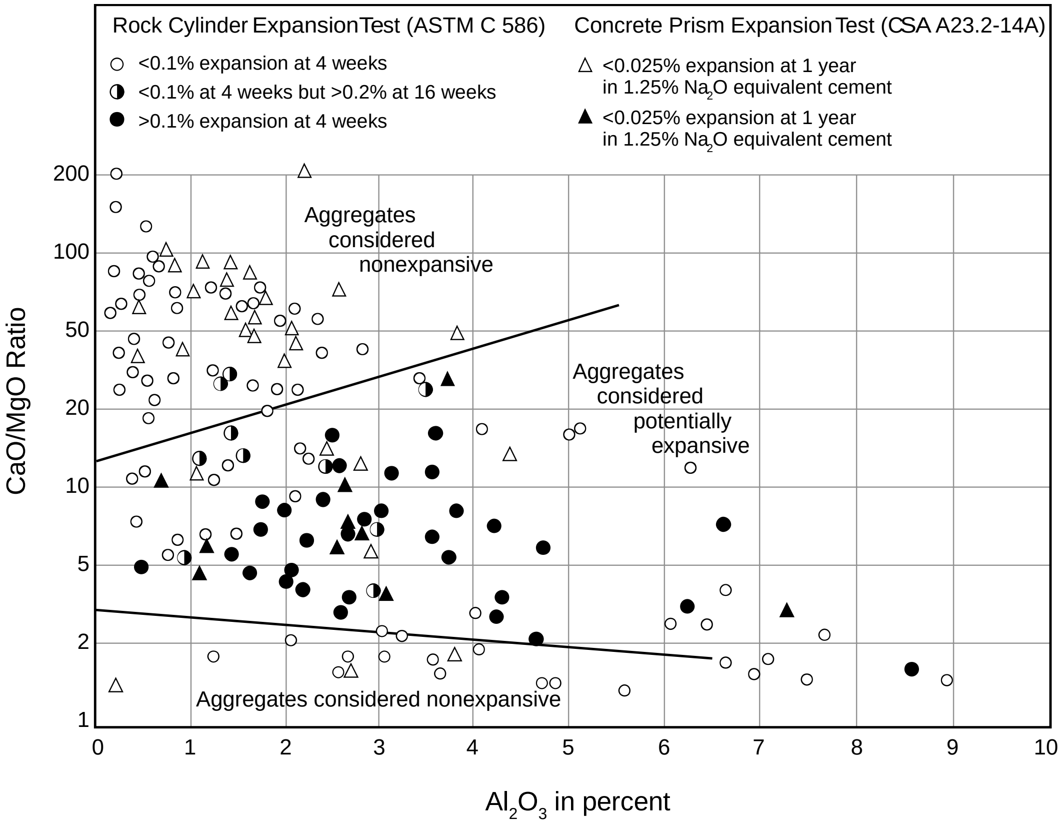


Figure 2—Using Chemical Composition as a Basis for Determining Potential Alkali-Carbonate Reactivity of Quarried Carbonates (from CSA A23.2-26A)

6.4 *Accelerated Mortar Bar Test (T 303)*:

6.4.1 The aggregate may be tested in accordance with T 303 if it meets one of the following three criteria: (1) the aggregate is not a quarried carbonate, (2) the aggregate is a quarried carbonate with a composition that falls outside of the region of “aggregates considered to be potentially expansive” in Figure 2 when tested in accordance with CSA A23.2-26A, or (3) the aggregate is a quarried carbonate that does not cause excessive expansion when tested in ASTM C 1105 in accordance with Section 6.6.

6.4.2 This test is intended to evaluate coarse and fine aggregates separately and should not be used to evaluate job combinations of coarse and fine aggregates.

6.4.3 If the expansion of mortar bars following 14 days immersion in sodium hydroxide solution is not greater than 0.10 percent, the aggregate is considered non-deleteriously reactive and can be accepted for use (see Note 4).

6.4.4 If the mortar bar expansion is greater than 0.10 percent at 14 days, the aggregate is considered to be potentially deleteriously reactive and its reactivity should be confirmed by testing in ASTM C 1293 (Section 6.5). If there is insufficient time or resources to run ASTM C 1293, the aggregate should be treated as potentially reactive and appropriate preventive measures must be selected.

Note 4—Many aggregates fail the accelerated mortar bar test (14-day expansion > 0.10 percent) but do not cause deleterious expansion in concrete. An aggregate should not be rejected solely on the basis of this test.

Note 5—A number of aggregates (e.g., some siliceous sandstones and granite/gneiss) that pass this test (14-day expansion ≤ 0.10 percent) have been found to cause deleterious expansion when used in concrete. There is a level of risk associated with relying solely on this test to identify reactive aggregates.

Note 6—Some agencies have used a lower expansion limit or an extended test duration, or both, (e.g., 0.08 percent and 28 days) or a higher expansion limit (e.g., 0.15 percent at 14 days).

6.5 *Concrete Prism Test (ASTM C 1293)*:

6.5.1 The concrete prism test is suitable for evaluating all aggregate types and is considered to be the most reliable laboratory test for predicting the field performance of aggregates. The test should be conducted in accordance with ASTM C 1293.

6.5.2 If the aggregate being tested is a coarse aggregate, it is blended with a non-deleteriously-reactive fine aggregate for testing. Similarly if the aggregate being tested is a fine aggregate, it is blended with a non-deleteriously-reactive coarse aggregate for testing. The coarse-fine aggregate combination is used to produce concrete prisms that have a specified high alkali loading.

6.5.3 If the expansion of concrete prisms is not greater than 0.04 percent after 1 year, the aggregate is considered non-deleteriously reactive and may be used in concrete with no further testing (for ASR or ACR).

6.5.4 If the expansion of concrete prisms is greater than 0.040 percent after 1 year, the aggregate is considered to be alkali-silica reactive provided it meets one of the following three criteria: (1) the aggregate is not a quarried carbonate, (2) the aggregate is a quarried carbonate with a composition that falls outside of the region of “aggregates considered to be potentially expansive” in Figure 2 when tested in accordance with CSA A23.2-26A, or (3) the aggregate is a quarried carbonate that does not cause excessive expansion when tested in ASTM C 1105 in accordance with Section 6.6. Preventive measures are required if the aggregate is to be used in concrete construction (see Sections 7 and 8).

6.5.5 If the expansion of concrete prisms is greater than 0.04 percent after 1 year and the aggregate tested was a quarried carbonate rock with a chemical composition that fell within the region of “aggregates considered to be potentially reactive,” the concrete prisms must be examined by an experienced petrographer to determine whether alkali-carbonate reaction contributed to the expansion. If damaging ACR is detected, either in isolation or in combination with ASR, the aggregate should not be used in concrete without selective quarrying or processing to limit the reactive components to acceptable levels. If ASR is determined to be the only cause of expansion of the concrete, preventive measures are required if the aggregate is to be used in concrete construction (see Sections 7 and 8). The use of ASTM C 1105 may be used as an option to ASTM C 1293 for determining the potential for alkali-carbonate reaction (see Section 6.6).

6.6 *Concrete Prism Test for Alkali-Carbonate Reaction (ASTM C 1105)*:

6.6.1 The aggregate shall be tested using ASTM C 1105, but the alkali content of the concrete shall be kept below 1.8 kg/m^3 (3.0 lb/yd^3) Na_2Oe to ensure that ASR does not occur. It is preferred that the test be run for a duration of 12 months, but expansion values at earlier ages may be used if necessary.

6.6.2 If the expansion of the cement-aggregate combination is equal to or greater than 0.025 percent at 6 months or 0.030 percent at 1 year, the aggregate shall be considered to be alkali-carbonate reactive and shall not be used in concrete.

6.6.3 If the expansion of the concrete prisms does not exceed the values set forth in Section 6.6.2, the aggregate shall be considered not to be alkali-carbonate reactive and should be tested to determine the potential for alkali-silica reactivity using the accelerated mortar bar test (T 303) or the concrete prism test (ASTM C 1293), or both, in accordance with Sections 6.4 and 6.5.

7. SELECTING PREVENTIVE MEASURES FOR ALKALI-SILICA REACTION (ASR)—PERFORMANCE APPROACH

7.1 *Using the Concrete Prism Test (ASTM C 1293) to Evaluate Preventive Measures*:

7.1.1 The concrete prism test may be used to evaluate the efficacy of supplementary cementitious materials (SCM), such as pozzolans and slag, blended cements (containing SCM), and lithium nitrate admixtures for preventing damaging alkali-silica reaction. It is prudent to conduct a number of tests using varying levels of SCM or lithium nitrate to determine the amount required to prevent deleterious expansion.

7.1.2 When testing blended cement or supplementary cementitious materials (SCM), the test should be conducted in accordance with ASTM C 1293 (see Note 7).

7.1.3 When testing lithium nitrate admixtures, the admixture should be added to the mix water and necessary corrections should be made to account for the water in the admixture. The test should otherwise be conducted in accordance with ASTM C 1293 (see Note 7). See Annex A2 on calculation of lithium nitrate additions.

7.1.4 If the expansion of concrete prisms is not greater than 0.04 percent after 2 years, the combination of SCM or lithium nitrate admixture and reactive aggregate is considered acceptable for use in concrete construction provided that the (equivalent) alkali content of the portland cement used in the job mixture does not exceed 1.00 percent Na_2Oe.

Note 7—If a reactive aggregate is to be used in a job mixture that contains a cement with an alkali content in excess of 1.00 percent Na_2Oe, the test procedure of ASTM C 1293 should be used with the following modifications. The job cement should be used in the test and the cement alkalis should be raised by 0.25 percent Na_2Oe above the alkali content of the job cement by the addition of NaOH to the mix water.

7.1.5 If the expansion of concrete prisms is greater than 0.04 percent after 2 years, the preventive measure is not deemed to be effective with the reactive aggregate. Consideration should be given to retesting the aggregate with an increased level of SCM or lithium nitrate.

7.2 *Using the Accelerated Mortar-Bar Test (T 303) to Evaluate Preventive Measures*:

7.2.1 Before the accelerated mortar bar test (AMBT) is used to determine the performance of a specific blended cement-aggregate, SCM-aggregate, or lithium nitrate-aggregate combinations, it is recommended that it first be demonstrated that the aggregate being evaluated responds well to the accelerated test. This requires a comparison of the results from the accelerated mortar bar test and the concrete prism test for the aggregate being used (without preventive measures). After subjecting the aggregate to both tests, the results are plotted on Figure 3. Provided the data fall within the region indicated in Figure 3, the accelerated mortar bar test (ASTM C 1567) is generally considered to be suitable for determining the efficacy of blended cements, SCMs, and lithium nitrate. The results from the accelerated mortar bar test and the concrete prism test should be compared every 2 years unless the results of petrography or other tests indicate a significant change in the composition of the material in the quarry, in which case new tests should be commenced immediately. If there is insufficient time to conduct a comparison between the two tests, then the accelerated mortar bar test can be used; however, there is an increased level of risk associated with making decisions based on this test alone.

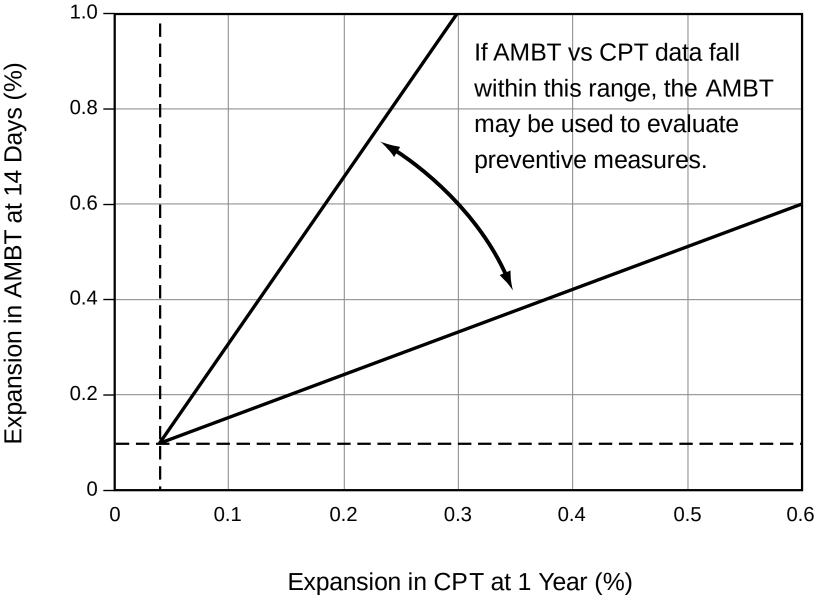


Figure 3—Comparison of AMBT and CPT Data for the Purpose of Determining Whether the AMBT is Suitable for Evaluating Preventive Measures with a Specific Aggregate

7.2.2 The effectiveness of blended cements or supplementary cementitious materials in controlling damaging expansion shall be determined in accordance with ASTM C 1567.

7.2.3 If the expansion of mortar bars containing blended cement or supplementary cementitious materials is not greater than 0.10 percent after 14 days in sodium hydroxide solution, the combination of blended cement or SCM and reactive aggregate shall be considered acceptable for use in concrete construction provided the alkali content of the portland cement used in the job does not exceed 1.0 percent Na_2Oe.

Note 8—If a reactive aggregate is to be used in a job mixture that contains a cement with an alkali content in excess of 1.00 percent Na_2Oe, the job cement should be used in the test.

7.2.4 If the expansion of mortar bars containing blended cement or supplementary cementitious materials is greater than 0.10 percent after 14 days in sodium hydroxide solution, the blended cement or level of SCM tested is not deemed to be effective with the reactive aggregate. Consideration should be given to retesting the aggregate with an increased level of SCM, a different blended cement, or a combination thereof.

7.2.5 When using the accelerated mortar bar test to determine the lithium nitrate dose required with a specific aggregate, the approach proposed by Tremblay et al. (2008) is recommended; the procedure is as follows:

7.2.5.1 Test the aggregate using the standard accelerated mortar bar test (T 303). Extend the duration of the test such that the mortar bars are exposed to sodium hydroxide for a period of 28 days. Let E_1 = expansion of bars without lithium nitrate at 28 days.

7.2.5.2 Test the aggregate in a modified version of the accelerated mortar bar test. In this test add sufficient lithium nitrate to the mortar bar mixture and the soak solution to achieve lithium-to-alkali molar ratios of [Li]/[Na + K] = 0.74 in the mortar and [Li]/[Na + K] = 0.148 in the soak solution. (See Annex A2 on calculation of lithium nitrate additions.) Conduct the rest of the test in accordance with T 303, extending the period in sodium hydroxide to 28 days. Let E_2 = expansion of bars with lithium nitrate at 28 days.

Note 9—To achieve [Li]/[Na+K] = 0.74 in the mortar add 4.6 L of 30 percent-$LiNO_3$ solution for every 1 kg of alkali (as Na_2Oe) in the mix (70.4 fl oz of 30 percent-$LiNO_3$ solution for every 1 lb of alkali).

7.2.5.3 If $(E_2 - E_1)/E_1 < 0.1$, then use the following lithium-to-alkali molar ratio in the job mix:

$$[Li]/[Na + K] = 1.0 + 0.7[(E_2 - E_1)/E_1]$$

7.2.5.4 If $(E_2 - E_1)/E_1 \geq 0.1$, then use the concrete prism test to determine the lithium nitrate content required (see Section 7.1).

8. SELECTING PREVENTIVE MEASURES FOR ALKALI-SILICA REACTION (ASR)—PRESCRIPTIVE APPROACH

8.1 The level of prevention is determined by considering the class, size, and exposure condition of the structure; the degree of aggregate reactivity and the level of alkalis from the portland cement (when SCMs are used as preventive measures). Worked examples using the prescriptive approach are given in Annex A3.

8.2 *Aggregate Reactivity*:

8.2.1 The degree of alkali-silica reactivity of an aggregate is determined by testing the aggregate in the concrete prism test (Section 6.5) and using the expansion value at 1 year. If data from the concrete prism test are not available, the degree of reactivity may be determined by testing the aggregate in the accelerated mortar bar test (Section 6.4). If data are not available from either test, the aggregate may be considered as very highly reactive (R3). Aggregate-reactivity classes are given in Table 1. Where the coarse and fine aggregates are of different reactivity, the level of prevention should be selected for the most reactive aggregate.

Table 1—Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in CPT (percent)	14-Day Expansion in AMBT (percent)
R0	Non-reactive	≤ 0.04	≤ 0.10
R1	Moderately reactive	$> 0.04, \leq 0.12$	$> 0.10, \leq 0.30$
R2	Highly reactive	$> 0.12, \leq 0.24$	$> 0.30, \leq 0.45$
R3	Very highly reactive	> 0.24	> 0.45

8.3 *Risk of ASR*:

8.3.1 The risk of ASR occurring in a structure is determined by considering the aggregate reactivity and the exposure conditions using Table 2.

Table 2—Determining the Level of ASR Risk

Size and Exposure Conditions	Aggregate-Reactivity Class			
	R0	R1	R2	R3
Non-massive concrete[a] in a dry environment[b]	Level 1	Level 1	Level 2	Level 3
Massive elements[a] in a dry environment[b]	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service[c]	Level 1	Level 4	Level 5	Level 6

[a] A massive element has a least dimension > 0.9 m (3 ft).

[b] A dry environment corresponds to an average ambient relative humidity lower than 60 percent, normally found only in buildings.

[c] Examples of structures exposed to alkalis (sodium and potassium) in service include marine structures exposed to seawater and highway structures exposed to deicing salts (e.g., NaCl) or anti-icing salts (e.g., potassium acetate, potassium formate, sodium acetate, sodium formate, etc.).

8.4 *Level of Prevention*:

8.4.1 The level of prevention required is determined from Table 3 by considering the risk of ASR from Table 2 together with the class of structure from Table 4.

Table 3—Determining the Level of Prevention

Level of ASR Risk (Table 4)	Classification of Structure (Table 4)			
	S1	S2	S3	S4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	[a]

[a] It is not permitted to construct a Class S4 structure (see Table 4) when the risk of ASR is Level 6. Measures must be taken to reduce the level of risk in these circumstances.

The level of prevention V, W, X, Y, Z, and ZZ are used in Tables 5 to 8.

Table 4—Structures Classified on the Basis of the Severity of the Consequences Should ASR Occur[a] (Modified for Highway Structures from RILEM TC 191-ARP)

Class	Consequences of ASR	Acceptability of ASR	Examples[b]
S1	Safety, economic, or environmental consequences small or negligible	Some deterioration from ASR may be tolerated.	• Non-load-bearing elements inside buildings • Temporary structures (e.g., < 5 years)
S2	Some safety, economic, or environmental consequences if major deterioration	Moderate risk of ASR is acceptable.	• Sidewalks, curbs, and gutters • Service-life < 40 years
S3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR acceptable.	• Pavements • Culverts • Highway barriers • Rural, low-volume bridges • Large numbers of precast elements where economic costs of replacement are severe • Service life normally 40 to 75 years
S4	Serious safety, economic, or environmental consequences if minor damage	ASR cannot be tolerated.	• Major bridges • Tunnels • Critical elements that are very difficult to inspect or repair • Service life normally > 75 years

[a] This table does not consider the consequences of damage due to ACR. This practice does not permit the use of alkali-carbonate aggregates.

[b] The types of structures listed under each class are meant to serve as examples. Some owners may decide to use their own classification system. For example, sidewalks or curbs and gutters may be placed in the Class S3.

Note 10—Structures are classified on the basis of the severity of the consequences should ASR occur. For example, the consequences of ASR are far more severe for a reinforced concrete bridge element than they are for a sidewalk. As such, more onerous measures are required to prevent damaging ASR in a bridge.

8.5 *Requirements for Prevention Level V*:

8.5.1 No special measures need to be taken for Prevention Level V.

8.6 *Requirements for Prevention Level W, X, or Y*:

8.6.1 If it is determined that Prevention Level W, X, or Y is required, there are two options for prevention as follows:

8.6.1.1 *Option 1—Limiting the Alkali Content of the Concrete*:

Table 5 prescribes maximum permissible concrete alkali contents. The alkali content of concrete is calculated on the basis of the alkali contributed by the portland cement alone. For blended cement, the alkali available from the portland cement component of the blend should be used.

Table 5—Maximum Alkali Contents in Portland Cement Concrete to Provide Various Levels of Prevention

Prevention Level	Maximum Alkali Content of Concrete (Na_2Oe)	
	kg/m^3	lb/yd^3
V	No limit	No limit
W	3.0	5.0
X	2.4	4.0
Y	1.8	3.0
Z[a]	Table 8	Table 8
ZZ[a]	Table 8	Table 8

[a] SCMs must be used in Prevention Levels Z and ZZ.

Note 11—The alkali content of the concrete is calculated by multiplying the portland cement content of the concrete by the alkali content of the portland cement. For example, for concrete containing 300 kg/m^3 of portland cement, which has an alkali content of 0.91 percent Na_2Oe, the alkali content of the concrete is 300 × 0.91/100 = 2.73 kg/m^3 Na_2Oe. The alkali content in pounds per cubic yard (lb/yd^3) is calculated by multiplying the cement content of the concrete in lb/yd^3 by the alkali content of the cement divided by 100. For example, for a concrete containing 550 lb/yd^3 of portland cement, which has an alkali content of 0.82 percent Na_2Oe, the alkali content of the concrete is 550 × 0.82/100 = 4.51 lb/yd^3 Na_2Oe.

Note 12—Other components of the mix, such as aggregates, wash water, and chemical admixtures, may contribute alkalis to the concrete and such alkalis should be considered when calculating the alkali content of the concrete. Supplementary cementing materials also contain alkalis; however, the use of SCM usually increases the amount of alkalis bound by the hydrates and thus reduces the available alkali content in the concrete. Thus, the alkalis present in SCMs need not be considered when calculating the alkali content of the concrete. However, the alkali content of the SCM should not exceed the limits given in Table 6.

Table 6—Minimum Levels of SCM to Provide Various Levels of Prevention

Type of SCM[a]	Alkali Level of SCM (% Na_2Oe)	Minimum Replacement Level[b] (% by Mass of Cementitious Material)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤ 18 percent)	≤ 3.0	15	20	25	35	Table 7
	> 3.0, ≤ 4.5	20	25	30	40	Table 7
Slag	≤ 1.0	25	35	50	65	Table 7
Silica Fume[c] (SiO_2 ≥ 85 percent)	≤ 1.0	2.0 × KGA or 1.2 × LBA	2.5 × KGA or 1.5 × LBA	3.0 × KGA or 1.8 × LBA	4.0 × KGA or 2.4 × LBA	Table 7

[a] The SCM may be added directly to the concrete mixer or it may be a component of a blended cement. SCMs should meet the requirements of M 295, M 302, or M 307. Blended cements should meet the requirements of M 240 or ASTM C 1157.

[b] The use of high levels of SCM in concrete may increase the risk of problems due to deicer salt scaling if the concrete is not properly proportioned, finished, and cured.

[c] The minimum level of silica fume (as a percentage of cementitious material) is calculated on the basis of the alkali (Na_2Oe) content of the concrete contributed by the portland cement and expressed in either units of kg/m^3 (KGA in Table 6) or lb/yd^3 (LBA in Table 6). KGA is calculated by multiplying the cement content of the concrete in kg/m^3 by the alkali content of the cement divided by 100. For example, for a concrete containing 300 kg/m^3 of cement with an alkali content of 0.91 percent Na_2Oe, the value of KGA = 300 × 0.91/100 = 2.73 kg/m^3. For this concrete, the minimum replacement level of silica fume for Level X is 2.5 × 2.73 = 6.8 percent. LBA is calculated by multiplying the cement content of the concrete in lb/yd^3 by the alkali content of the cement divided by 100. For example, for a concrete containing 500 lb/yd^3 of cement with an alkali content of 0.81 percent Na_2Oe the value of LBA = 500 × 0.81/100 = 4.05 lb/yd^3. For this concrete, the minimum replacement level of silica fume for Level Y is 1.8 × 4.05 = 8.1 percent. Regardless of the calculated value, the minimum level of silica fume shall not be less than 7 percent when it is the only method of prevention.

8.6.1.2 *Option 2—Using Supplementary Cementitious Materials or Blended Cements*:

Table 6 prescribes minimum replacement levels for fly ash with calcium content not greater than 18 percent CaO and alkali content not greater than 4.5 percent Na_2Oe, and for slag and silica fume with alkali content not greater than 1.0 percent Na_2Oe.

Fly ashes with greater than 18 percent CaO or greater than 4.5 percent Na_2Oe and slag and silica fume with greater than 1.0 percent Na_2Oe are not covered by these prescriptive measures; the ability of these materials to control ASR with a particular reactive aggregate should be determined by performance testing (see Section 7).

When natural pozzolans are to be used to control ASR, the efficacy of a particular aggregate-pozzolan combination should be determined by performance testing (see Section 7).

When two or more SCMs (including SCMs in blended cements) are used together to control ASR, the minimum replacement levels given in Table 6 for the individual SCMs may be reduced provided the sum of the parts of each SCM is greater than or equal to one.

Note 13—For example, when silica fume and slag are used together, the silica fume level may be reduced to one-third of the minimum silica fume level given in the table provided the slag level is at least two-thirds of the minimum slag level.

The minimum replacement levels in Table 6 are appropriate for use with portland cements of moderate to high alkali contents (0.7 to 1.0 percent Na_2Oe). Table 7 provides recommendations for adjusting the level of SCM when the alkali content of the portland cement is above or below this range. The replacement levels should not be below those given in Table 6 for prevention level W, regardless of the alkali content of the portland cement.

Table 7—Adjusting the Minimum Level of SCM Based on the Alkali Content of the Portland Cement

Cement Alkalis (% Na_2Oe)	Level of SCM
≤ 0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level.[a]
> 0.70, ≤ 1.00	Use the minimum levels of SCM given in Table 6.
> 1.00, ≤1.25	Increase the minimum amount of SCM given in Table 6 by one prevention level.
> 1.25	No guidance is given.

[a] The replacement levels should not be below those given in Table 6 for prevention level W, regardless of the alkali content of the portland cement.

No guidance is given for using preventive measures with reactive aggregates when the alkali content of the portland cement exceeds 1.25 percent Na_2Oe.

Note 14—If this approach is used for portland cements with alkali contents in excess of 1.25 percent Na_2Oe, there will be an increased risk of damaging ASR.

8.7 *Requirements for Prevention Level Z*:

8.7.1 If it is determined that Prevention Level Z is required, there are two options: (1) use the minimum level of supplementary cementitious material shown in Table 6, or (2) use the minimum level of supplementary cementitious material and the maximum concrete alkali content shown in Table 8.

Table 8—Using SCM and Limiting the Alkali Content of the Concrete to Provide Exceptional Levels of Prevention

Prevention Level	SCM as Sole Prevention	Limiting Concrete Alkali Content Plus SCM	
	Minimum SCM Level	Maximum Alkali Content, kg/m^3 (lb/yd^3)	Minimum SCM Level
Z	SCM level shown for Level Z in Table 6	1.8 (3.0)	SCM level shown for Level Y in Table 6
ZZ	Not permitted	1.8 (3.0)	SCM level shown for Level Z in Table 6

8.8 *Requirements for Prevention Level ZZ*:

8.8.1 If it is determined that Prevention Level ZZ is required, use the minimum level of supplementary cementitious material and the maximum concrete alkali content shown in Table 8.

9. REPORTING

9.1 The report shall list the tests conducted and the results of the tests.

9.2 If a study was conducted to determine the field performance history of the aggregate, details should be provided of the structures examined including type, age, visual and photographic observations, and details of laboratory testing of cores removed from the structure.

9.3 If a petrographic examination was conducted on the aggregate, the report should be produced in accordance with ASTM C 295.

9.4 If testing in accordance with CSA A23.2-26A was performed, the lime (CaO), magnesia (MgO) and alumina (Al_2O_3) content of the rock shall be reported.

9.5 If accelerated mortar bar or concrete prism tests were conducted, the results shall be reported in accordance with the relevant test method (T 303, ASTM C 1293, or ASTM C 1567).

9.6 The chemical composition of the cement, SCM, and lithium nitrate admixture used in expansion tests shall be reported.

10. KEYWORDS

10.1 Alkali-aggregate reaction; alkali-carbonate reaction; alkali-silica reaction; concrete; expansion; fly ash; lithium nitrate; pozzolan; preventive measures; reaction; reactive aggregate; silica fume; slag.

11. REFERENCED DOCUMENTS

11.1 *The following references were used or referred to in the preparation of this text*:

11.1.1 Canadian Standards Association. “Determination of potential alkali-carbonate reactivity of quarried carbonate rocks by chemical composition.” CSA A23.2-26A, Canadian Standards Association, Mississauga, ON.

11.1.2 Canadian Standards Association. “Standard practice to identify degree of alkali-reactivity of aggregates and to identify measures to avoid deleterious expansion in concrete.” CSA A23.2-27A, Canadian Standards Association, Mississauga, ON.

11.1.3 FHWA. *Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction*. FHWA-HIF-09-001, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2008.

11.1.4 Folliard, K. J., R. Barborak, T. Drimalas, L. Du, S. Garber, J. Ideker, T. Ley, S. Williams, M. Juenger, M. D. A. Thomas, and B. Fournier. *Preventing ASR/DEF in New Concrete: Final Report*. The University of Texas at Austin, Center for Transportation Research (CTR), CTR 4085-5, 2006.

11.1.5 Ozol, M. A. Alkali-Carbonate Rock Reaction. In *Significance of Tests and Properties of Concrete*, STP 169D, Chapter 23. American Society of Testing and Materials, West Conshohocken, PA, 2006, pp. 410–424.

11.1.6 Rogers, C. A. Evaluation for the potential for expansion and cracking of concrete caused by the alkali-carbonate reaction. In *Journal of Cement, Concrete and Aggregates,* Vol. 8, No. 1. American Society of Testing and Materials, West Conshohocken, PA, 1986, pp. 13–23.

11.1.7 Thomas, M. D. A., B. Fournier, K. Folliard, J. Ideker, and M. Shehata. Test Methods for Evaluating Preventive Measures for Controlling Expansion due to Alkali-silica Reaction in Concrete. *Cement and Concrete Research,* Vol. 36 (10), Pergamon Press, Elsevier, Inc., Burlington, MA, 2006, pp. 1842–1856.

11.1.8 Thomas, M. D. A., B. Fournier, K. J. Folliard, M. Shehata, J. Ideker, and C. A. Rogers. Performance limits for evaluating supplementary cementing materials using the accelerated mortar bar test. *ACI Materials Journal,* Vol. 104 (2), American Concrete Institute, Farmington Hills, MI, 2007, pp. 115–122.

11.1.9 Tremblay, C., M. A. Berube, B. Fournier, M. D. A. Thomas, and K. J. Folliard. Use of the Accelerated Mortar Test to Evaluate the Effectiveness of $LiNO_3$ against Alkali-Silica Reaction. Part 2: Comparison with Results from the Concrete Prism Test. *Journal of ASTM International,* Vol. 5 (8), American Society of Testing and Materials, West Conshohocken, PA, 2008.

ANNEXES

(Mandatory Information)

A1. CALCULATING LITHIUM NITRATE ADDITIONS

A1.1. These calculations assume that the admixture being used is a 30 percent $LiNO_3$ solution. This is the only solution commercially available at this time.

A1.2. Published research indicates that a lithium nitrate dose that results in a lithium-to-sodium-plus-potassium molar ratio of [Li]/[Na + K] = 0.74 will be effective with many, but not all, aggregates. It is recommended that concrete prism tests be conducted at this lithium nitrate dose and at lower and higher doses.

A1.3. To achieve a dose of [Li]/[Na + K] = 0.74 using a 30 percent $LiNO_3$ solution requires 4.6 liters of solution for every kilogram of alkali (as Na_2Oe) in the concrete (from the portland cement) or 0.55 gallons for every pound of alkali.

A1.4. A solution of 30 percent $LiNO_3$ contains 70 percent water by mass, and this amount should be included in the calculation of the batch water. One liter of 30 percent $LiNO_3$ solution weighs 1.2 kg and contains 0.84 kg of water. One gallon of 30 percent $LiNO_3$ solution weighs 10.02 lb and contains 7.01 lb of water.

A1.5. *Metric Example*—For a 16-liter batch of concrete (typical quantity for CPT) with 420 kg/m^3 of cement raised to 1.25 percent Na_2Oe, the quantity of alkali present is $16/1000 \times 420 \times 1.25/100 = 0.084$ kg Na_2Oe. To achieve [Li]/[Na + K] = 0.74 in the mix, $4.6 \times 0.084 = 0.3864$ liters of 30 percent $LiNO_3$ solution needs to be added to the mix. This quantity of solution contains $0.3864 \times 0.84 = 0.3246$ kg of water that should be subtracted from the mix water.

A1.6. *English Example*—For a 0.6 ft^3 batch of concrete (typical quantity for CPT) with 708 lb/yd^3 of cement raised to 1.25 percent Na_2Oe, the quantity of alkali present is $0.6/27 \times 708 \times 1.25/100 = 0.197$ lb Na_2Oe. To achieve [Li]/[Na + K] = 0.74 in the mix, $0.55 \times 0.197 = 0.1084$ gallons of 30 percent $LiNO_3$ solution needs to be added. This quantity of solution contains $0.1084 \times 7.01 = 0.7600$ lb of water that should be subtracted from the mix water.

A2. CALCULATING LITHIUM NITRATE ADDITIONS FOR THE MODIFIED ACCELERATED MORTAR BAR METHOD (FOR LITHIUM NITRATE SOLUTIONS)

A2.1. The calculations below assume that the admixture being used is a 30 percent $LiNO_3$ solution. This is the only solution commercially available at this time.

A2.2. In this modified version of the accelerated mortar bar test, sufficient lithium nitrate shall be added to the mortar bar mixture and to the soak solution to achieve: (1) lithium-to-alkali molar ratios of

[Li]/[Na + K] = 0.74 in the mortar, and (2) [Li]/[Na + K] = 0.148 in the soak solution (i.e., 20 percent of the «standard dosage» of 0.74).

A2.3. *Example of calculation of the lithium nitrate dose in the mortar*—The cement content in the modified AMBT is 440 g. For a cement with 1 percent Na_2Oe, the alkali content for $LiNO_3$ calculation is: 440 g × 1/100 = 4.4 g of Na_2Oe. To achieve a dose of [Li]/[Na + K] = 0.74 using a 30 percent $LiNO_3$ solution requires 4.6 liters of solution for every kilogram (or 4.6 mL for every gram) of alkali (as Na_2Oe) in the mortar (provided by the portland cement). So, 4.4 g of Na_2Oe × 4.6 mL (of $LiNO_3$ solution) = 20.2 mL of $LiNO_3$ solution (= [Li] / [Na + K] of 0.74).

A2.4. The water content in the $LiNO_3$ solution needs to be accounted for in the calculation of the mortar mix water. Since 1 mL of 30 percent $LiNO_3$ solution weighs 1.2 g and there is 70 percent water (by mass in the 30 percent $LiNO_3$ solution), the mass of water in 20.2 mL of $LiNO_3$ solution is: 20.2 × 1.2 × 0.7 = 17 g. Since the water-to-cement ratio to use in the AMBT is 0.47 and the cement content is 440 g, then the mixing water content is: 0.47 × 440 g = 206.8 g – 17 g (water provided by the $LiNO_3$ solution) = 189.8 g.

A3. WORKED EXAMPLES FOR SELECTING PREVENTIVE MEASURES FOR ALKALI-SILICA REACTION (ASR)—PRESCRIPTIVE APPROACH

A3.1. *Example 1—Major Bridge Crossing*:

A3.1.1. Preventive measures are required for a major bridge that is not exposed to deicing salts. When tested, according to ASTM C 1293, the coarse and fine aggregates intended for use produced 1-year expansion values of 0.093 percent and 0.032 percent, respectively. Portland cement with an alkali content of 0.86 percent Na_2Oe and fly ash with a calcium content of 14.1 percent CaO and an alkali content of 3.51 percent Na_2Oe are available.

A3.1.2. *Aggregate Reactivity*—Table 1 indicates the coarse aggregate reactivity to be R1 (moderately reactive) and the fine aggregate to be R0 (non-reactive). Design for worse case: R1.

A3.1.3. *Level of ASR Risk*—Table 2 indicates the risk of ASR to be Level 3 for a moderately reactive (R1) aggregate exposed to humid air, buried or immersed (no deicing salts).

A3.1.4. *Level of Prevention*—Table 3 indicates the level of prevention required to be Level Y for an S4 class of structure (Table 4) with an ASR risk of Level 3.

A3.1.5. *Prevention Required*—Either control alkali content of concrete or use SCM.

A3.1.5.1. *Option to Limit Alkali Content of Concrete*—Table 5 indicates that the maximum alkali content is 3.0 lb/yd^3 Na_2Oe for Prevention Level Y. This translates to a maximum cement content of 3/(0.86/100) = 349 lb/yd^3 for a cement with an alkali content of 0.86 percent Na_2Oe (this option is unlikely to be feasible).

A3.1.5.2. *Option to use SCM*—Table 6 indicates a minimum fly ash replacement of 30 percent for fly ash with 14.1 percent CaO and 3.51 percent Na_2Oe for Prevention Level Y.

A3.2. *Example 2—Sidewalk Exposed to Deicing Salts*:

A3.2.1. Preventive measures are required for a city sidewalk exposed to deicing salts. When tested in T 303, the coarse and fine aggregates produce 14-day expansions of 0.35 percent and 0.55 percent, respectively. Portland cement with an alkali content of 0.38 percent Na_2Oe and slag with an alkali content of 0.71 percent Na_2Oe are available.

A3.2.2. *Aggregate Reactivity*—Table 1 indicates the coarse aggregate reactivity to be R2 (highly reactive) and the fine aggregate to be R3 (very highly reactive). Design for worse case: R3.

A3.2.3. *Level of ASR Risk*—Table 3 indicates the risk of ASR to be Level 6 for a very highly reactive (R3) aggregate exposed to alkalis in service (deicing salts).

A3.2.4. *Level of Prevention*—Table 3 indicates the level of prevention to be Level Z for an S2 class of structure (Table 4) with an ASR risk of Level 6.

A3.2.5. *Prevention Required*—Use SCM. (Table 5 does not permit the control of the concrete alkali content as the only prevention measure for Prevention Level Z.)

A3.2.5.1. *Option to Use SCM*—Table 6 indicates a minimum slag replacement of 65 percent for slag for Prevention Level Z. Table 7 allows the minimum amount of SCM in Table 6 to be reduced by one prevention level if the cement alkalis are below 0.70 percent Na_2Oe. Therefore, the minimum slag replacement level is 50 percent (Prevention Level Y).

Standard Method of Test for

Specific Gravity and Absorption of Aggregate by Volumetric Immersion Method

AASHTO Designation: TP 77-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Specific Gravity and Absorption of Aggregate by Volumetric Immersion Method

AASHTO Designation: TP 77-09[1]

1. SCOPE

1.1 This method covers the determination of bulk and apparent specific gravity and absorption of fine and coarse aggregate at 20 ± 1°C (70 ± 2°F) for dry and saturated aggregates.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size
- T 255, Total Evaporable Moisture Content of Aggregate by Drying

3. SIGNIFICANCE AND USE

3.1 Bulk specific gravity is the characteristic generally used for calculations of the volume occupied by the aggregate in various mixtures containing aggregate including portland cement concrete (PCC), bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity is also used in the computation of voids in aggregate in T 19M/T 19. Bulk specific gravity determined on the saturated surface-dry basis is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity determined on the oven-dry basis is used for computations when the aggregate is dry or assumed to be dry.

3.2 Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles that is accessible to water. This value is not widely used in construction aggregate technology.

3.3 When it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential, the absorption values are used to represent the change in the mass of an aggregate due to water absorbed into the pore spaces within the constituent particles, compared to the dry condition. The laboratory standard for absorption is that obtained after submerging dry aggregate for approximately 15 hours in water. Aggregates mined from below the water table may have a higher absorption when used, if not allowed to dry. Conversely, some aggregates when used may contain an amount of absorbed moisture less than the 15-hour soaked condition. For an aggregate that has been in contact with water and that has free moisture on the particle surfaces, the percentage of free moisture can be determined by deducting the absorption from the total moisture content determined by T 255 drying.

3.4 Users of this method are encouraged to be cautious in applying the results. Values achieved for specific gravity and absorption are significantly different from those achieved from T 84 and T 85. Results from this method will affect the calculated results for volumetrics in hot mix asphalt (HMA) and absorption in PCC. The user is cautioned to thoroughly evaluate these effects before implementing this test method. Correlation methods discussed in Appendix X2.1 or X2.2 should be utilized when the values from this method are to be directly substituted for those from T 84 or T 85.

4. APPARATUS

4.1 *Flask with Plug for Coarse Aggregate*—A glass flask with a bulb volume of 3000 to 4000 mL and a separate plug. The neck of the flask shall be marked with 5 mL graduated increments which correspond to a precision of at least 0.1 percent of the sample volume. Overall length of the flask is approximately 760 mm (30 in.). (See Note 1 and Figure 1.)

4.2 *Flask for Fine Aggregate*—A glass flask with a bulb volume of 2000 mL. The neck of the flask shall be marked with 1 mL graduated increments which correspond to a precision of at least 0.1 percent of the sample volume. Overall length of the flask is approximately 760 mm (30 in.). (See Note 1 and Figure 1.)

Note 1—The flask to be used for fine aggregate will have a neck approximately 25 mm (1 in.) in diameter. The flask used for coarse aggregate will have a neck approximately 51 mm (2 in.) in diameter. These flasks are available from Humboldt Manufacturing Company, 7300 W. Agatite Avenue, Norridge, IL 60706.

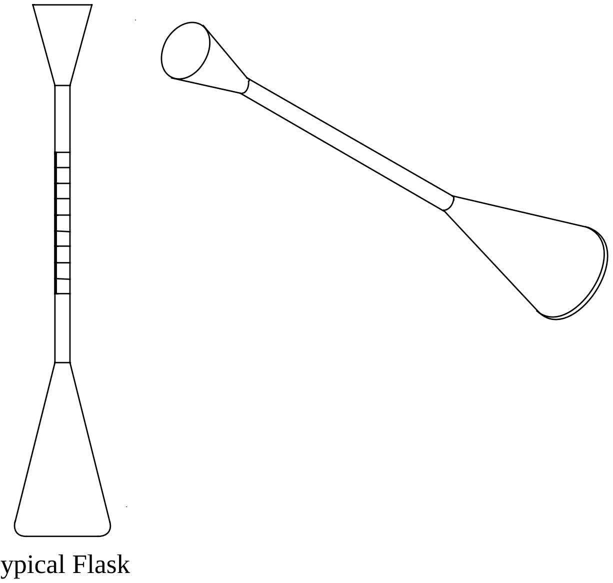


Figure 1—Typical Flask

4.3 *Scale with a capacity of at least 10,000 g*—The scale shall comply with the requirements in M 231.

4.4 Minimum 450-mm (18-in.) long rod with dry, absorbent swab.

4.5 Timer that can be read to the nearest second, and that can measure elapsed time up to 24 hours.

5. CALIBRATION OF FLASK

5.1 Determine and record the empty weight of the flask, to the nearest gram.

5.2 Fill flask with distilled water at 20 ± 1°C (70.0 ± 2°F) such that the bottom of the meniscus is exactly even with the zero mark.

Note 2—If a flask does not have a zero mark, add water to the first major graduation (10 mL mark on a fine aggregate flask); then subtract that amount from the calibrated flask volume in Equation 1.

5.3 Determine and record the weight of the filled flask to the nearest gram.

5.4 Determine the calibrated volume of the flask as follows:

$$V_{cal} = B - A \tag{1}$$

where:

V_{cal} = calibrated volume of the flask, mL;

A = weight of empty flask, g; and

B = weight of flask filled with water, g.

Note 3—Due to the definition of a milliliter and a gram (1 milliliter of water weighs 1 gram), these values can be interchanged without conversions.

6. SAMPLING

6.1 Sampling of aggregate shall be accomplished in accordance with T 2.

7. PREPARATION OF TEST SPECIMEN

7.1 Obtain approximately 2 kg of fine aggregate or 3 kg of coarse aggregate using the applicable procedures described in T 248.

7.2 Dry the sample in an oven or a suitable pan or vessel to constant mass at a temperature of 110 ± 5ºC (230 ± 9ºF). Allow it to cool to comfortable handling temperature, without allowing it to re-absorb any water from the surrounding environment. This can be accomplished by covering the container with a plate or cover that blocks direct access of the ambient humid air to the cooling sample.

8. TEST PROCEDURE

8.1 Weigh out 1200 ± 10 g of oven-dry fine aggregate or 2500 ± 50 g of oven-dry coarse aggregate to be tested. If testing lightweight aggregate, reduce the amount of material to 600 ± 10 g for fine aggregate, or 900 g ± 10 g for coarse aggregate.

8.2 The actual weight, W_d, of oven dry aggregate should be recorded to the nearest 0.01 grams.

8.3 Fill the bottom portion of the flask approximately one half full, by height, with 20 ± 1°C (70 ± 2°F) distilled water. (See Note 4.)

8.4 Measure out, but do not add, approximately 250 g of 20 ± 1°C (70 ± 2°F) distilled water.

Note 4—The volume of water in Sections 8.2 and 8.3 may need to be adjusted for the individual flask being used. It is important that during the filling process, the combined initial volume of water and the dry aggregate not plug the neck of the flask. Therefore, the following procedure is intended to allow sufficient water for the aggregate to become completely submerged, but to not rise into the narrow neck of the flask.

8.5 Dry the inside of the neck of the flask with a dry absorbent swab.

Note 5—If the inside of the neck is not completely dry, finer portions of the sample may adhere to the moisture, plugging the neck of the flask as the sample is added.

8.6 Pour the aggregate sample into the flask as quickly as possible, without plugging the neck.

Note 6—It is recommended that an outside funnel not be used. The sand has a tendency to plug the smaller hole of the funnel, where it typically pours through the built-in funnel without plugging.

8.7 Start the timer immediately when the aggregate first hits the water in the flask.

8.8 After all of the sample has been poured into the flask, immediately add enough of the holdback water measured out in Section 8.3 to raise the water level sufficiently up into the graduated portion of the neck of the flask, so that the water level does not drop below the graduated portion during the duration of the test.

8.9 Do not shake, agitate, or otherwise disturb the flask at this time.

8.10 Take the reading of the initial water level, R_i, in the neck of the flask 30 seconds after the first particle has entered the water.

8.11 Determine and record the weight of the flask filled with aggregate and water, W_T to 0.01 grams.

8.12 Aggressively shake, roll, and otherwise agitate the flask in order to remove all of the released air. Place a plug into the neck of the coarse aggregate flask to prevent loss of water during the shaking and agitation of the flask. Stop shaking and agitating the flask when the timer shows three minutes.

8.13 Allow the flask to remain undisturbed for two minutes.

8.14 Obtain and record the reading of the water level in the neck of the flask at five minutes elapsed time (from when the aggregate first hits the water).

8.15 It is recommended that water level readings be taken at 10 minutes, 30 minutes, 60 minutes, 2 hours, and 4 hours elapsed time (see Note 7). Make sure to agitate all of the air out of the sample, and allow the flask to settle for at least two minutes before taking each reading. See Appendix X1.

Note 7—It is not critical that the readings are taken at the exact times shown. Record the time the water level reading is actually made.

8.16 Take the final water level reading, R_{final}, at 25 ± 1 hour. It is extremely important that all air released during the soak period be completely eliminated from the flask before taking the final reading. Make sure that the flask has been thoroughly and completely shaken and agitated, and then left undisturbed to allow all of the air to escape from the flask until there is no air left in the system. Make sure that the air removal process is started early enough to completely eliminate all of the air within the designated time.

9. ABSORPTION

9.1 Calculate the absorption as follows:

$$\text{Absorption, (\%)} = [W_{abs}/W_d] \times 100 \qquad (2)$$

where:

W_{abs} = water absorbed into the sample, $(R_i - R_{\text{final}})$, mL, where
  R_i = initial water level reading, mL; and
  R_{final} = final water level reading, mL; and
W_d = original dry weight of sample, g

10. SATURATED BULK SPECIFIC GRAVITY (S_S)

10.1 Calculate the saturated bulk specific gravity as follows:

$$S_s = (W_d + W_{abs})/[V_i - V_w] \qquad (3)$$

where:

W_d = original dry weight of sample, g;
W_{abs} = water absorbed into the sample, mL;
V_i = initial volume, $(R_i + V_{cal})$, mL, where
  V_{cal} = calibrated flask volume, mL;
V_w = volume of test water $[W_T - (W_d + W_f)]$, mL, where
  W_T = total weight of flask, water and sample, g; and
  W_f = weight of flask, g.

11. DRY BULK SPECIFIC GRAVITY (S_d)

11.1 Calculate the dry bulk specific gravity as follows:

$$S_d = W_d/(V_i - V_w) \qquad (4)$$

12. APPARENT DRY SPECIFIC GRAVITY (S_a)

12.1 Calculate the apparent dry specific gravity as follows:

$$S_a = W_d/[(W_d + W_f + V_{cal}) - (WT - R_{final})] \qquad (5)$$

13. CONVENTIONAL ABSORPTION

13.1 Use the correlation equation shown in Appendix X2.3 to calculate the conventional absorption for fine aggregate (T 84) as follows:

$$\text{Conventional Absorption, (\%)} = [(\text{Absorption \{from Section 9.1\}} \times 1.8243) + 0.0038] \qquad (6)$$

13.2 Use the correlation procedure in Appendix X2.2 to determine the conventional absorption and specific gravities for fine or coarse aggregates, according to T 84 or T 85, respectively.

Note 8—The use of either of these methods is at the discretion of the user. The user is encouraged to use the method of preference.

14. REPORT

14.1 Report the specific gravity results to the nearest 0.001, and indicate the type of specific gravity, whether bulk, bulk (saturated-surface-dry), or apparent.

14.2 Report the absorption result to the nearest 0.1 percent. Unless otherwise specified, the end user shall use the absorption value that is appropriate to the specific application.

APPENDIXES

(Nonmandatory Information)

X1. INTERMEDIATE WATER LEVEL READINGS

X1.1. This test provides an internal quality process check. By plotting the intermediate readings against time on a logarithmic scale, an approximately straight line should be determined. If the line is not essentially straight, then something happened during the performance of the test.

X1.2. It also provides the ability to determine the time-rate of absorption relationship for a particular material. Once the time-rate of absorption plot has been established, it can then be used in the field. If intermediate levels of absorption are to be acknowledged during the delivery and construction procedures using this aggregate, the starting and anticipated ending points and their relative degree of saturation can be taken directly from the resulting plot.

X1.3. A typical plot is shown in Figure X1.1:

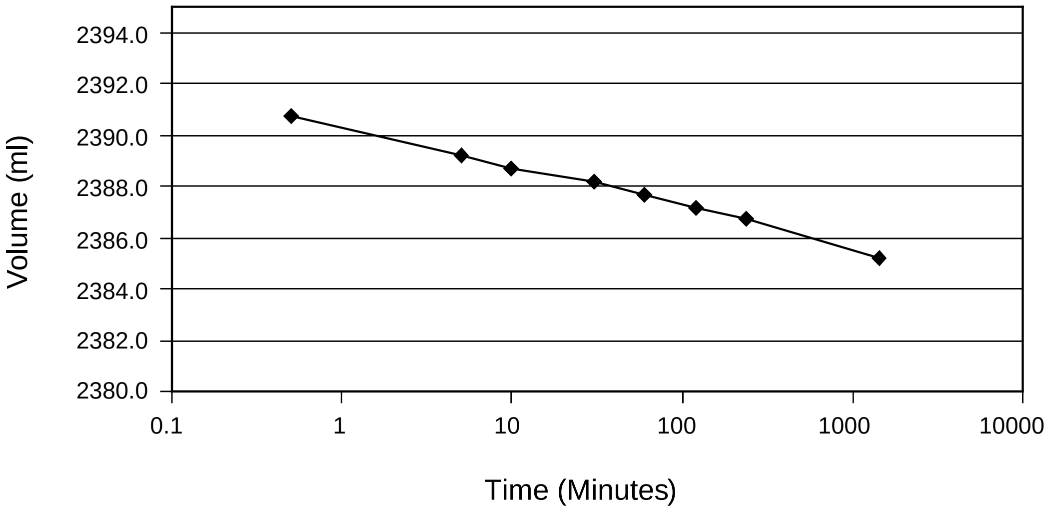


Figure X1.1—Phunque Absorption Test

X1.4. Plot the readings on semi-log paper with the *x*-axis being time on the logarithmic scale.

X1.5. *Example Data*:

X1.6. A typical datasheet that has been found to work well with this procedure is shown in Figure X1.2.

Source of Sample:	ABC Contractor—Concrete Sand		
Tare Weight of Flask, g:	887.90		
Calibrated Volume of the Flask, g:	2312.20		
Conventional Absorption (T 84/T 85):	0.8%		
Conventional Bulk Specific Gravity (SSD) (T 84/T 85):	2.623		
Dry Weight of Sample:	1200.00		
Total Initial Volume of Water Added:	1937.2		
Total Weight of Flask, Sample and Water, g:	4025.10		
Elapsed Time (in minutes):	Readings		Total Volume (mL)
R_i 0.5		78.5	2390.7
5		77.0	2389.2
10		76.5	2388.7
30		76.0	2388.2
60		75.5	2387.7
120	2 Hrs	75.0	2387.2
240	4 Hrs	74.5	2386.7
R_{final} 1440	24.0 Hrs	73.0	2385.2
Technician:	[Name of ABC Technician]		
Date of Test:	[February 14, 2008]		
Initial Volume:	2390.7	mL	T 84 or T 85
Absorption:	0.5	%	0.8
Bulk Specific Gravity (dry)	2.646		2.601
Bulk Specific Gravity (SSD)	2.658		2.623
Bulk Specific Gravity (apparent)	2.679		2.656

Figure X1.2—Sample of Phunque Absorption Test Datasheet

X2. STATISTICAL CORRELATION WITH T 84

X2.1. The absorption values for fine aggregates determined from this method vary significantly from those determined by T 84. In many applications the magnitude of effect from using Phunque values in lieu of the conventional values makes it extremely difficult to proceed with the intended application. At this time, it is not known which is more accurate. However, the Phunque method is much more consistent, repeatable, and easier to perform. Therefore, a statistical study was performed by comparing representative samples of fine aggregate sources throughout the country and determining the specific gravities and absorptions using both methods concurrently. The relationship for fine aggregate absorption shown in Figure X2.1 is the result of this effort.

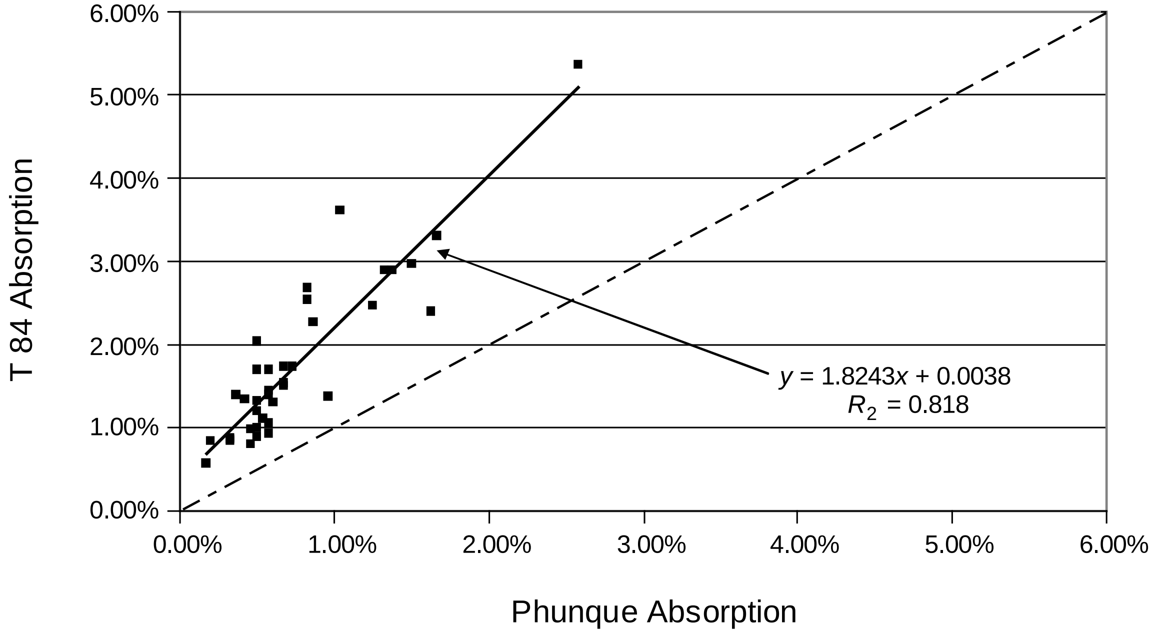


Figure X2.1—Absportion Comparison (Fine Aggregate Only)

X2.2. *Direct Correlation with T 84 or T 85*:

X2.3. In situations where these numbers will be used in significant applications, and where a preliminary evaluation has not been performed to assess the nature and magnitude of the differences using the Phunque values in lieu of T 84 or T 85 values, the user is encouraged to perform a source specific correlation for each material type from each source or stockpile. This correlation effort should be performed by using the Phunque method to determine the specific gravities and absorption on at least three samples split from a single master sample. The process should be repeated using T 84 or T 85 procedures on at least five samples split from the same master sample. Once completed, the correlation factor, *CF*, can be calculated as follows:

CF = (Average Conventional Measurements)/(Average Phunque Measurements)

Example: Determine the *CF* to use in the conventional applications:

(Values taken from Figure X1.2)

Average Phunque Absorption = 0.5	Average T 84 Absorption = 0.8
Average Phunque Dry Bulk Specific Gravity, S_d = 2.646	Average T 84 Dry Bulk Specific Gravity, S_d = 2.601
Average Phunque Saturated Bulk Specific Gravity, S_s = 2.658 Average	T 84 Saturated Bulk Specific Gravity, S_s = 2.623
Average Phunque Apparent Dry Specific Gravity, S_a =2.679	Average T 84 Apparent Dry Specific Gravity, S_a =2.656

Calculating the *CF* for each property:

$CF_{\text{absorption}}$ = 0.8/0.5 = 1.6

CF_{S_d} = 2.601/2.646 = 0.983

CF_{S_s} = 2.623/2.658 = 0.987

CF_{S_a} = 2.656/2.679 = 0.991

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[1] This provisional method of test was adopted and first published in 2009.

Standard Method of Test for

Determining Aggregate Shape Properties by Means of Digital Image Analysis

AASHTO Designation: TP 81-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Aggregate Shape Properties by Means of Digital Image Analysis

AASHTO Designation: TP 81-10

1. SCOPE

1.1. This standard covers the measurement of aggregate shape properties using the Digital Image Analysis techniques.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 248, Reducing Samples of Aggregate to Testing Size

3. TERMINOLOGY

3.1. *aggregate size*—sieve size in which material is retained after passing the next larger sieve.

3.1.1. *fine aggregate*—aggregate material passing 4.75-mm (No. 4) sieve. Sieve sizes are 2.36 mm (No. 8), 1.18 mm (No. 16), 0.60 mm (No. 30), 0.30 mm (No. 50), 0.15 mm (No. 100), and 0.075 mm (No. 200).

3.1.2. *coarse aggregate*—aggregate material retained on 4.75-mm (No. 4) sieve. Sieve sizes are 25.0 mm (1 in.), 19.0 mm ($^3/_4$ in.), 12.5 mm ($^1/_2$ in.), 9.5 mm ($^3/_8$ in.), and 4.75 mm (No. 4).

3.2. *Shape Properties for Each Retained sieve (x)*:

3.2.1. *gradient angularity (GA)*—applies to both fine and coarse aggregate sizes and is related to the sharpness of the corners of 2-dimensional images of aggregate particles. The gradient angularity quantifies changes along a particle boundary with higher gradient values indicating a more angular shape. Gradient angularity has a relative scale of 0 to 10000 with a perfect circle having a value of 0.

Gradient Angularity:

$$GA = \frac{1}{\frac{n}{3} - 1} \sum_{i=1}^{n-3} \left| \theta_i - \theta_{i+3} \right| \qquad (1)$$

where:

θ = angle of orientation of the edge points

n = the total number of points

i = denoting the *i*th point on the edge of the particle

3.2.2. *texture or micro-texture (TX)*—applies to coarse aggregate sizes only describing relative smoothness or roughness of surface features less than approximately 0.5 mm in size that are too small to affect the overall shape. Texture has a relative scale of 0 to 1000 with a smooth polished surface approaching a value of 0.

$$TX = \frac{1}{3N} \sum_{i=1}^{3} \sum_{j=1}^{N} \left(D_{i,j} \left(x, y \right) \right)^2 \qquad (2)$$

where:

D = decomposition function

n = decomposition level

N = total number of coefficients in an image

i = 1, 2, or 3 for detailed images

j = wavelet index

x, y = location of the coefficients in transformed domain

3.2.3. *sphericity (SP)*—applies to coarse aggregate sizes only and describes the overall three-dimensional shape of a particle. Sphericity has a relative scale of 0 to 1. A sphericity value of one indicates a particle has equal dimensions (cubical).

$$SP = \sqrt[3]{\frac{d_S * d_I}{d_L^2}} \qquad (3)$$

where:

d_S = particle shortest dimension

d_I = particle intermediate dimension

d_L = particle longest dimension

3.2.4. *Form 2D*—Applies to fine aggregate sizes only and is used to quantify the relative form from 2-dimensional images of aggregate particles. Form 2D has a relative scale of 0 to 20. A perfect circle has a Form 2D value of zero.

$$\text{Form 2D} = \sum_{\theta=0}^{\theta=360-\Delta\theta} \left[\frac{R_{\theta+\Delta\theta} - R_\theta}{R_\theta} \right] \qquad (4)$$

where:

R_θ = the radius of the particle at an angle of θ

$\Delta\theta$ = the incremental difference in the angle

3.2.5. *flat **and** elongated*—those particles having a ratio of longest dimension to shortest dimension greater than a specified value.

Aggregate particle dimensions in an *x, y, z* coordinate system:

d_S = particle shortest dimension
d_I = particle intermediate
d_L = particle longest dimension

Flatness Ratio (*S/L*): $Flatness = \frac{d_S}{d_I}$ (5)

Elongation Ratio (*I/L*): $Elongation = \frac{d_I}{d_L}$ (6)

Flat and Elongated Value (*F&E*): $L/S = \frac{d_L}{d_S}$ (7)

3.2.6. *flat **or** elongated*—those particles having a ratio of intermediate dimension to shortest dimension or longest dimension to intermediate dimension greater than a specified value.

Flat or Elongated Value (*F* or *E*): $\frac{d_I}{d_S}$ or $\frac{d_L}{d_I} >$ Ratio (i.e., 1, 2, 3…) (8)

4. SIGNIFICANCE AND USE

4.1. Shape, angularity, and surface texture of aggregates have been shown to directly affect the engineering properties of highway construction materials such as hot mix asphalt concrete, Portland cement concrete, and unbound aggregate layers. This standard provides direct measurement of aggregate shape, angularity, and texture. For coarse aggregates, the shape properties include: Gradient Angularity, Sphericity, Texture, and Flat and Elongated value. For fine aggregates the shape properties include: Gradient Angularity and Form 2D.

Note 1—The National Cooperative Highway Research Program Report 555 provides background information relevant to characterizing aggregate shape, texture, and angularity.

4.2. This test method may be used to characterize and monitor the shape properties of aggregate material sizes 0.075 mm (No. 200) through 25.0 mm (1 in.). This method may be used to characterize a single size within a material source or all sizes within the source.

5. APPARATUS

5.1. *Digital Image Acquisition and Analysis System*—A computer controlled electro-mechanical instrument for capturing digital images at variable magnification and software for image analysis. Instrumentation and analysis software shall include algorithms for Gradient Angularity, Form 2D, Flat and Elongated, Sphericity, and Texture.

5.1.1. A camera and optic system capable of providing the required resolutions over the range of particles being analyzed.

5.1.2. A system for positioning the particle for imaging. This can be a movable camera, a movable support tray, or a combination thereof.

5.1.3. A system for auto-focusing the image.

5.1.4. A system for determining particle three-dimensional measurements *x, y, z* in millimeters.

5.1.5. A system for detecting and removing touching particles from the analysis.

5.1.6. A system for presenting the particles for imaging consisting of trays or other support surface for aggregate sizes from 0.075 mm (No. 200) through 25.0 mm (1 in.). The particles shall be presented for imaging on a flat surface. A small recess for aligning particles is acceptable.

5.1.7. A variable lighting system for backlighting or top lighting, or both, the material sample.

Note 2—The Aggregate Image Measurement System and the associated AIMS Software algorithms for image analysis computations have proven to be an acceptable system for a Digital Image Acquisition and Analysis System.

5.2. *Balance*—A balance meeting the requirements of M 231, Class G 5, for determining the mass of aggregates.

5.3. *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of 110 ± 5°C (290 ± 9°F).

5.4. *Miscellaneous*—Equipment to perform sample preparation methods according to one or more of the following: T 2, T 11, T 27, or T 248.

6. HAZARDS

6.1. Use standard safety precautions and protective clothing when handling materials and preparing material samples.

7. STANDARDIZATION

7.1. Confirm the digital image acquisition system has been standardized. Frequency and method of standardization shall follow manufacturer's instructions.

8. PREPARATION OF APPARATUS

8.1. Confirm the system has been standardized by verifying the standardization date.

8.2. Confirm the machine operation settings are correct for the analysis to be performed.

9. SAMPLE PREPARATION

9.1. Obtain sample of the aggregate according to procedures in T 2.

Note 3—Material samples obtained for T 84 and T 85 specific gravity determinations have proven to be acceptable.

9.2. Thoroughly mix the sample and reduce it to the approximate quantity needed using the applicable procedures in T 248.

9.3. Determine the amount of material finer than 0.075 mm (No. 200) by T 11.

9.4. Dry the sample to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F).

9.5. Determine the sample grading on the washed, dry sample in accordance with T 27. Calculate the percentage of material in each size fraction. Maintain sample material as separate retained sieve sizes.

9.6. Obtain the required aggregate of each size from the sample using the procedures described in T 248.

9.7. Maintain the necessary size fractions obtained in a dry condition in separate containers for each size.

9.7.1. The following list provides approximate sample mass to achieve the required minimum particle count for each size fraction:

Size	Approx. Mass	Minimum Number of Particles
0.075 mm (No. 200)	200 g	150
0.15 mm (No. 100)	200 g	150
0.3 mm (No. 50)	200 g	150
0.6 mm (No. 30)	200 g	150
1.18 mm (No. 16)	200 g	150
2.36 mm (No. 8)	200 g	150
4.75 mm (No. 4)	2 kg	50
9.5 mm ($^3/_8$-in.)	2 kg	50
12.5 mm ($^1/_2$-in.)	2 kg	50
19.0 mm ($^3/_{©}$-in.)	2 kg	50
25.0 mm (1-in.)	5 kg	50

10. PROCEDURE FOR COARSE AGGREGATE

10.1. Position the coarse aggregate sample for digital image acquisition by size fraction. Each size fraction of retained material may be run separately.

10.2. Distribute the coarse aggregate sample over the support surface in a manner which provides separation of at least 1.0 mm between particles. Particle orientation shall be determined by permitting them to come to rest randomly.

10.3. Initiate the digital image acquisition sequence and analysis algorithms. This process is typically automated. The operator inputs the material size and the system automatically captures the required images and calculates the shape properties for each particle.

10.4. Each characterization requires the minimum number of particles for each size fraction listed in Section 9.7 to be analyzed. If the required particle count is not achieved in one sequence, repeat the sequence with additional particles until the required number of images is acquired.

10.4.1. For sizes that contain inadequate percent retained mass to achieve minimum particle count, use the shape value obtained from the next larger or the next smaller size, whichever is present.

11. PROCEDURE FOR FINE AGGREGATE

11.1. Position the fine aggregate sample for digital image acquisition by size fraction. Each size fraction of retained material may be run separately.

Note 4—Most fine aggregate materials are analyzed using backlighting. However, some translucent materials may require a dark background and top lighting to achieve the appropriate image contrast. If the system fails to capture usable images with backlighting, use a dark background and top lighting. A dark background is typically required for 0.30 mm (No. 50) and smaller sizes.

11.2. Distribute the fine aggregate sample over the support surface in a manner which provides separation between particles. Typically, only a very light coating is needed. Particles' orientation shall be determined by permitting them to come to rest randomly.

11.3. Initiate the digital image acquisition sequence and run the analysis routines. This process is typically automated. The operator selects the material size and the system automatically captures the required images and calculates the shape properties for each particle.

11.4. Each characterization requires the minimum number of particles for each size fraction listed in Section 9.7 to be analyzed. If the required particle count is not achieved in one sequence, repeat the sequence until the required number of images is acquired.

11.4.1. For sizes that contain inadequate percent retained mass to achieve minimum particle count, use the shape value obtained from the next larger or the next smaller size, whichever is present.

12. CALCULATIONS

12.1. Calculate gradient angularity value for each fine and coarse aggregate particle.

12.1.1. Calculate the gradient angularity mean and standard deviation for each size fraction.

12.2. Calculate the texture (TX) value for each coarse particle.

12.2.1. Calculate the texture mean and standard deviation for each coarse size fraction.

12.3. Calculate the sphericity (SP) for each coarse aggregate particle.

12.3.1. Calculate the sphericity mean and standard deviation for each coarse size fraction.

12.4. Calculate the Form 2D value for each fine particle.

12.4.1. Calculate the Form 2D mean and standard deviation for each fine size fraction.

12.5. Calculate the percent distribution of Flat ***and*** Elongated at the following ratios:
≥1:1, >2:1, >3:1, >4:1, >5:1

$\%L/S(\geq 1)_x$ = % of Particles with $d_L/d_S \geq 1$

$\%L/S(>2)_x$ = % of Particles with $d_L/d_S > 2$

$\%L/S(>3)_x$ = % of Particles with $d_L/d_S > 3$

$\%L/S(>4)_x$ = % of Particles with $d_L/d_S > 4$

$\%L/S(>5)_x$ = % of Particles with $d_L/d_S > 5$

where:

x designates the retained sieve size

12.6. Calculate the percent distribution of Flat ***or*** Elongated at the following ratios: ≥1:1, >2:1, >3:1, >4:1, >5:1

$\%F \text{ or } E(\geq 1)_x$ = % of Particles with d_I/d_S or $d_L/d_I \geq 1$

$\% F \text{ or } E\ (>2)_x$ = % of Particles with d_I/d_S or $d_L/d_I > 2$

$\% F \text{ or } E\ (>3)_x$ = % of Particles with d_I/d_S or $d_L/d_I \leq 3$

$\% F \text{ or } E\ (>4)_x$ = % of Particles with d_I/d_S or $d_L/d_I > 4$

$\% F \text{ or } E\ (>5)_x$ = % of Particles with d_I/d_S or $d_L/d_I > 5$

where:

x designates the retained sieve size

13. REPORT

13.1. *Report the following information*:

13.1.1. Procedure used;

13.1.2. Date of the analysis;

13.1.3. *Material Sample Identification*—type, source, and size;

13.1.4. Number of particles analyzed; and

13.1.5. Material shape property mean and standard deviation. Graphical representations of the property distributions may be included.

13.2. A sample report format is presented in Appendix X1.

14. PRECISION AND BIAS

14.1. *Precision*—The research required to determine the precision of this procedure has not been completed.

14.2. *Bias*—The research required to determine the bias of this procedure has not been conducted.

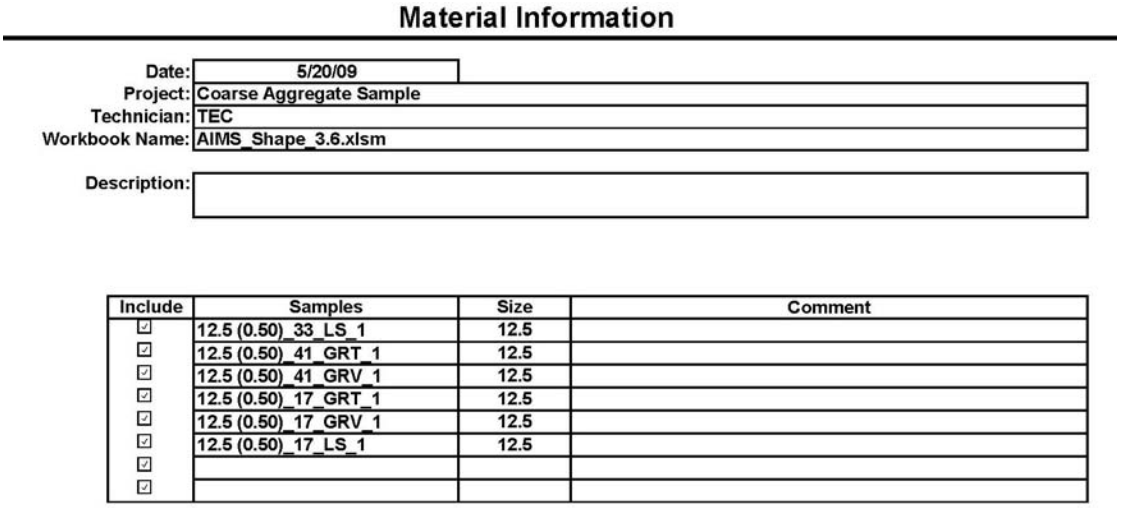
15. KEYWORDS

15.1. Aggregate; angularity; consensus property; elongated; form; shape; texture.

APPENDIX

(Nonmandatory Information)

X1. SAMPLE REPORT

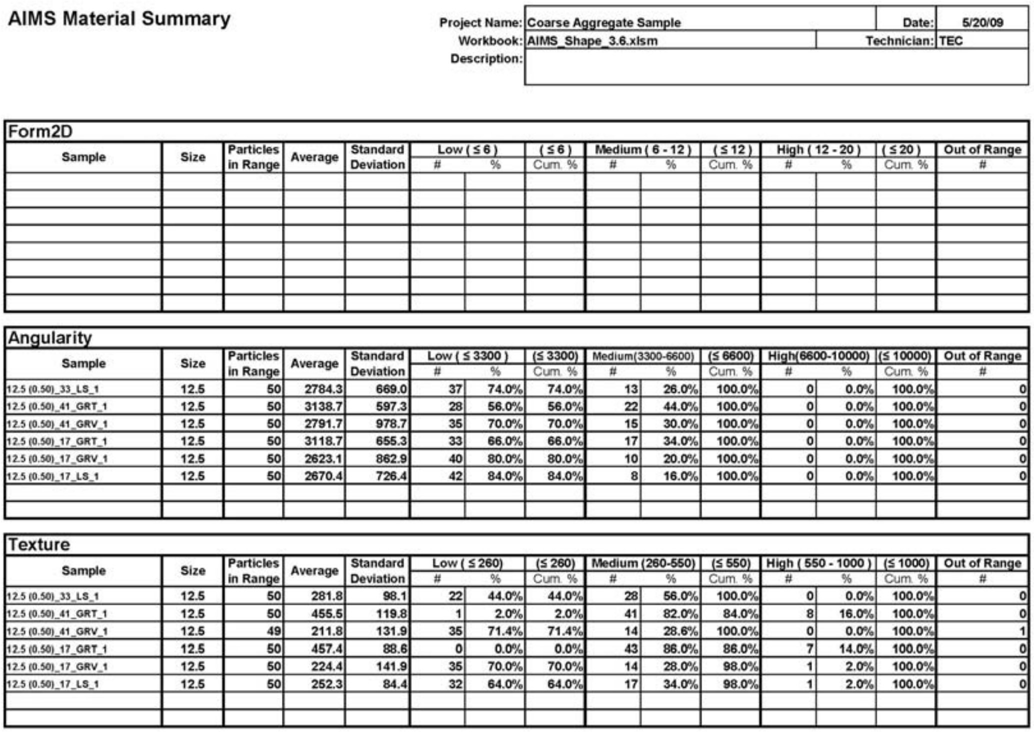


Material Information

Date: 5/20/09
Project: Coarse Aggregate Sample
Technician: TEC
Workbook Name: AIMS_Shape_3.6.xlsm

Description:

Include	Samples	Size	Comment
☑	12.5 (0.50)_33_LS_1	12.5	
☑	12.5 (0.50)_41_GRT_1	12.5	
☑	12.5 (0.50)_41_GRV_1	12.5	
☑	12.5 (0.50)_17_GRT_1	12.5	
☑	12.5 (0.50)_17_GRV_1	12.5	
☑	12.5 (0.50)_17_LS_1	12.5	
☑			
☑			



AIMS Material Summary

Project Name: Coarse Aggregate Sample **Date:** 5/20/09
Workbook: AIMS_Shape_3.6.xlsm **Technician:** TEC
Description:

Form2D

Sample	Size	Particles in Range	Average	Standard Deviation	Low (≤ 6)		(≤ 6)	Medium (6 - 12)		(≤ 12)	High (12 - 20)		(≤ 20)	Out of Range
					#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#

Angularity

Sample	Size	Particles in Range	Average	Standard Deviation	Low (≤ 3300)		(≤ 3300)	Medium(3300-6600)		(≤ 6600)	High(6600-10000)		(≤ 10000)	Out of Range
					#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
12.5 (0.50)_33_LS_1	12.5	50	2784.3	669.0	37	74.0%	74.0%	13	26.0%	100.0%	0	0.0%	100.0%	0
12.5 (0.50)_41_GRT_1	12.5	50	3138.7	597.3	28	56.0%	56.0%	22	44.0%	100.0%	0	0.0%	100.0%	0
12.5 (0.50)_41_GRV_1	12.5	50	2791.7	978.7	35	70.0%	70.0%	15	30.0%	100.0%	0	0.0%	100.0%	0
12.5 (0.50)_17_GRT_1	12.5	50	3118.7	655.3	33	66.0%	66.0%	17	34.0%	100.0%	0	0.0%	100.0%	0
12.5 (0.50)_17_GRV_1	12.5	50	2623.1	862.9	40	80.0%	80.0%	10	20.0%	100.0%	0	0.0%	100.0%	0
12.5 (0.50)_17_LS_1	12.5	50	2670.4	726.4	42	84.0%	84.0%	8	16.0%	100.0%	0	0.0%	100.0%	0

Texture

Sample	Size	Particles in Range	Average	Standard Deviation	Low (≤ 260)		(≤ 260)	Medium (260-550)		(≤ 550)	High (550 - 1000)		(≤ 1000)	Out of Range
					#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
12.5 (0.50)_33_LS_1	12.5	50	281.8	98.1	22	44.0%	44.0%	28	56.0%	100.0%	0	0.0%	100.0%	0
12.5 (0.50)_41_GRT_1	12.5	50	455.5	119.8	1	2.0%	2.0%	41	82.0%	84.0%	8	16.0%	100.0%	0
12.5 (0.50)_41_GRV_1	12.5	49	211.8	131.9	35	71.4%	71.4%	14	28.6%	100.0%	0	0.0%	100.0%	1
12.5 (0.50)_17_GRT_1	12.5	50	457.4	88.6	0	0.0%	0.0%	43	86.0%	86.0%	7	14.0%	100.0%	0
12.5 (0.50)_17_GRV_1	12.5	50	224.4	141.9	35	70.0%	70.0%	14	28.0%	98.0%	1	2.0%	100.0%	0
12.5 (0.50)_17_LS_1	12.5	50	252.3	84.4	32	64.0%	64.0%	17	34.0%	98.0%	1	2.0%	100.0%	0

AIMS Material Summary

Project Name:	Coarse Aggregate Sample	Date:	5/20/09
Workbook:	AIMS_Shape_3.6.xlsm	Technician:	TEC
Description:			

Sphericity

Sample	Size	Particles in Range	Average	Standard Deviation	Low (≤ 0.3)		(≤ 0.3)	Medium (0.3-0.7)		(≤ 0.7)	High (0.7 - 1.0)		(≤ 1.0)	Out of Range
					#	%	Cum. %	#	%	Cum. %	#	%	Cum. %	#
12.5 (0.50)_33_LS_1	12.5	50	0.69	0.10	0	0.0%	0.0%	28	56.0%	56.0%	22	44.0%	100.0%	0
12.5 (0.50)_41_GRT_1	12.5	49	0.62	0.09	0	0.0%	0.0%	37	75.5%	75.5%	12	24.5%	100.0%	1
12.5 (0.50)_41_GRV_1	12.5	49	0.69	0.08	0	0.0%	0.0%	24	49.0%	49.0%	25	51.0%	100.0%	1
12.5 (0.50)_17_GRT_1	12.5	50	0.63	0.11	0	0.0%	0.0%	37	74.0%	74.0%	13	26.0%	100.0%	0
12.5 (0.50)_17_GRV_1	12.5	50	0.69	0.08	0	0.0%	0.0%	27	54.0%	54.0%	23	46.0%	100.0%	0
12.5 (0.50)_17_LS_1	12.5	50	0.69	0.09	0	0.0%	0.0%	27	54.0%	54.0%	23	46.0%	100.0%	0

Flat and Elongated Distribution

Sample	Size	Particles in Range	L/S ≥ 1:1		L/S > 2:1		L/S > 3:1		L/S > 4:1		L/S > 5:1		Out of Range
			#	%	#	%	#	%	#	%	#	%	#
12.5 (0.50)_33_LS_1	12.5	50	50	100.0%	28	56.0%	6	12.0%	1	2.0%	0	0.0%	0
12.5 (0.50)_41_GRT_1	12.5	49	49	100.0%	43	87.8%	21	42.9%	6	12.2%	1	2.0%	1
12.5 (0.50)_41_GRV_1	12.5	49	49	100.0%	29	59.2%	5	10.2%	1	2.0%	0	0.0%	1
12.5 (0.50)_17_GRT_1	12.5	50	50	100.0%	40	80.0%	22	44.0%	9	18.0%	1	2.0%	0
12.5 (0.50)_17_GRV_1	12.5	50	50	100.0%	26	52.0%	4	8.0%	2	4.0%	0	0.0%	0
12.5 (0.50)_17_LS_1	12.5	50	50	100.0%	33	66.0%	7	14.0%	1	2.0%	0	0.0%	0

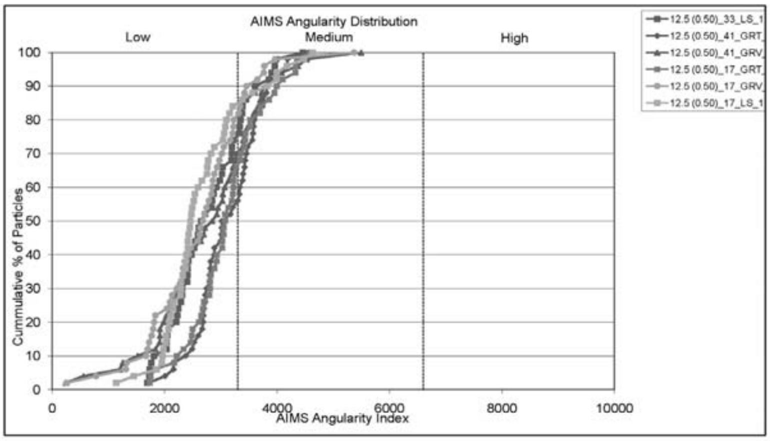
Flat or Elongated Distribution

Sample	Size	Particles in Range	F or E ≥ 1:1		F or E >2:1		F or E >3:1		F or E >4:1		F or E >5:1		Out of Range
			#	%	#	%	#	%	#	%	#	%	#
12.5 (0.50)_33_LS_1	12.5	50	50	100.0%	10	20.0%	0	0.0%	0	0.0%	0	0.0%	0
12.5 (0.50)_41_GRT_1	12.5	49	49	100.0%	23	46.9%	4	8.2%	0	0.0%	0	0.0%	1
12.5 (0.50)_41_GRV_1	12.5	49	49	100.0%	8	16.3%	0	0.0%	0	0.0%	0	0.0%	1
12.5 (0.50)_17_GRT_1	12.5	50	50	100.0%	24	48.0%	5	10.0%	0	0.0%	0	0.0%	0
12.5 (0.50)_17_GRV_1	12.5	50	50	100.0%	6	12.0%	1	2.0%	0	0.0%	0	0.0%	0
12.5 (0.50)_17_LS_1	12.5	50	50	100.0%	13	26.0%	1	2.0%	0	0.0%	0	0.0%	0

AIMS Angularity

Project Name:	Coarse Aggregate Sample	Date:	5/20/09
Workbook:	AIMS_Shape_3.6.xlsm	Technician:	TEC
Description:			

				#	%		Cum. %		#	%
Particles in Range	300	Low (≤ 3300)		215	71.7%	(≤ 3300)	71.7%	-σ < n < σ	210	70.0%
Average	2854.5	Medium (3300 - 6600)		85	28.3%	(≤ 6600)	100.0%	-2σ < n < 2σ	285	95.0%
Std. Deviation	786.4	High (6600 - 10000)		0	0.0%	(≤ 10000)	100.0%	-3σ < n < 3σ	296	98.7%
Median	2837.8	Out of Range		0				n<-3σ or n>3σ	4	1.3%
Mode	#N/A									



AIMS Texture

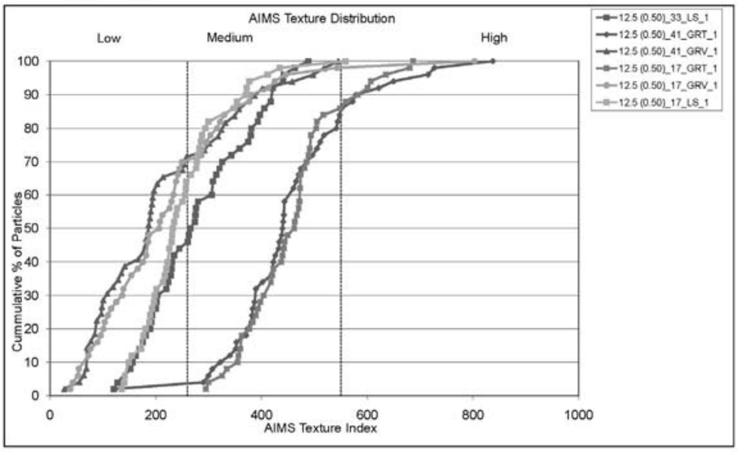
Project Name: Coarse Aggregate Sample **Date:** 5/20/09
Workbook: AIMS_Shape_3.6.xlsm **Technician:** TEC
Description:

Particles in Range	299
Average	314.2
Std. Deviation	152.9
Median	300.9
Mode	175.6

	#	%
Low (≤ 260)	125	41.8%
Medium (260 - 550)	157	52.5%
High (550 - 1000)	17	5.7%
Out of Range	1	

	Cum. %
(≤ 260)	41.8%
(≤ 550)	94.3%
(≤ 1000)	100.0%

	#	%
-σ < n < σ	202	67.6%
-2σ < n < 2σ	290	97.0%
-3σ < n < 3σ	297	99.3%
n<-3σ or n>3σ	2	0.7%



AIMS Sphericity

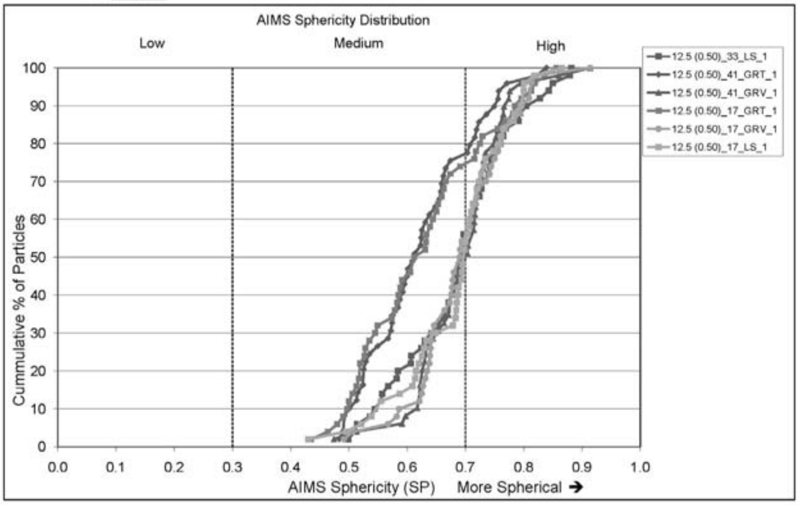
Project Name: Coarse Aggregate Sample **Date:** 5/20/09
Workbook: AIMS_Shape_3.6.xlsm **Technician:** TEC
Description:

Particles in Range	298
Average	0.669
Std. Deviation	0.096
Median	0.678
Mode	0.694

	#	%
Low (≤ 0.3)	0	0.0%
Medium (0.3 - 0.7)	180	60.4%
High (0.7 - 1.0)	118	39.6%
Out of Range	2	

	Cum. %
(≤ 0.3)	0.0%
(≤ 0.7)	60.4%
(≤ 1.0)	100.0%

	#	%
-σ < n < σ	202	67.8%
-2σ < n < 2σ	288	96.6%
-3σ < n < 3σ	298	100.0%
n<-3σ or n>3σ	0	0.0%



AIMS Flat and Elongated

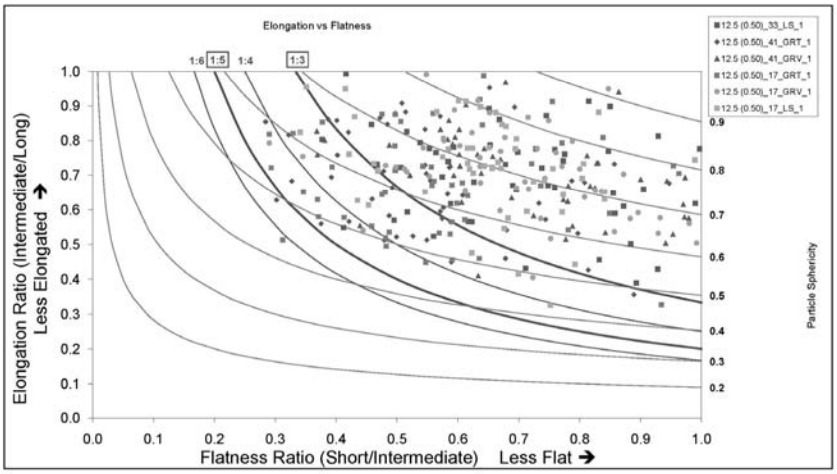
Project Name: Coarse Aggregate Sample Date: 5/20/09
Workbook: AIMS_Shape_3.6.xlsm Technician: TEC
Description:

	F & E	Sphericity
Particles in Range	298	298
Average	2.481	0.669
Std. Deviation	0.818	0.096
Median	2.273	0.678
Mode	2.316	0.694

	F & E	
	#	%
L/S ≥ 1:1	298	100.0%
L/S > 2:1	199	66.8%
L/S > 3:1	65	21.8%
L/S > 4:1	20	6.7%
L/S > 5:1	2	0.7%

	Sphericity	
	#	%
Low(≤ 0.3)	0	0.0%
Medium(0.3 - 0.7)	180	60.4%
High(0.7 - 1.0)	118	39.6%
Out of Range	2	

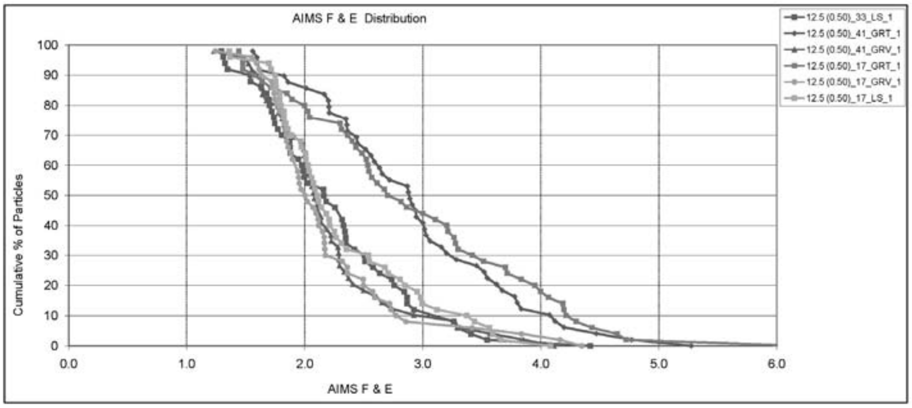
	F & E		Sphericity	
	#	%	#	%
$-\sigma < n < \sigma$	219	73.5%	202	67.8%
$-2\sigma < n < 2\sigma$	282	94.6%	288	96.6%
$-3\sigma < n < 3\sigma$	296	99.3%	298	100.0%
$n < -3\sigma$ or $n > 3\sigma$	2	0.7%	0	0.0%



AIMS Flat and Elongated Distribution

Project Name: Coarse Aggregate Sample Date: 5/20/09
Workbook: AIMS_Shape_3.6.xlsm Technician: TEC
Description:

F and E		
Ratio	#	Cum. %
L/S ≥ 1:1	298	100.0%
L/S > 2:1	199	66.8%
L/S > 3:1	65	21.8%
L/S > 4:1	20	6.7%
L/S > 5:1	2	0.7%



Standard Specification for

Use of Reclaimed Asphalt Shingles as an Additive in Hot Mix Asphalt (HMA)

AASHTO Designation: MP 15-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Use of Reclaimed Asphalt Shingles as an Additive in Hot Mix Asphalt (HMA)

AASHTO Designation: MP 15-09[1]

1. SCOPE

1.1. This specification covers reclaimed asphalt shingle material used as an additive in hot mix asphalt (HMA). The use of reclaimed asphalt shingles in hot-in-place pavements, cold-in-place pavements, and cold recycled pavements is not included in this specification.

1.2. The values stated in SI units are to be regarded as the standard.

Note 1—Refer to PP 53 for information on mix design, determining shingle aggregate gradation, and binder considerations when designing HMA mixtures which incorporate reclaimed asphalt shingles as an additive.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 29, Fine Aggregate for Bituminous Paving Mixtures
- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- PP 53, Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in New Hot Mix Asphalt (HMA)
- T 2, Sampling of Aggregates
- T 30, Mechanical Analysis of Extracted Aggregate
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 170, Recovery of Asphalt Binder from Solution by Abson Method
- T 319, Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- D 692, Standard Specification for Coarse Aggregate for Bituminous Paving Mixtures

2.3. *Other Standard*:

- Code of Federal Regulations Title 40 Chapter 1 Subchapter C Part 61 Subpart M (40 CFR 61 Subpart M), National Emission Standard for Asbestos

3. TERMINOLOGY

3.1. The definition of coarse and fine aggregate in terms of bituminous paving mixtures is provided in M 29 and ASTM C 125 and D 692.

3.2. *manufactured shingle waste*—for the purpose of this specification, shall mean rejected asphalt shingles or shingle tabs that are discarded in the manufacturing process of new asphalt shingles.

3.3. *post-consumer asphalt shingles*—for the purpose of this specification, shall mean asphalt shingles that are removed from the roofs of residential dwellings, as defined by the U.S. Environmental Protection Agency's National Emission Standards for Hazardous Air Pollution (NESHAP), 40 CFR 61 Subpart M, when new roofs are being installed. Post-consumer asphalt shingles are often called "tear-off" shingles.

3.4. *reclaimed asphalt shingles*—for the purpose of this specification, shall mean either manufactured shingle waste or post-consumer asphalt shingles that have been processed into a product that meets the requirements of this standard.

3.5. *shingle asphalt binder*—for the purpose of this specification, shall mean the asphalt binder that is present in the reclaimed asphalt shingles.

3.6. *shingle aggregate*—for the purpose of this specification, shall mean mineral granules, sand, or other mineral matter present in the reclaimed asphalt shingles, excluding the shingle fiber content.

3.7. *shingle fiber*—for the purpose of this specification, shall mean glass felt, paper felt, foil, and fabrics or films used as the structural basis of asphalt shingles and other asphalt roofing products.

3.8. *virgin asphalt binder*—for the purpose of this specification, shall mean new performance-graded asphalt binder to be used in the new HMA.

3.9. *final blended binder*—for the purpose of this specification, shall mean the mixture of virgin asphalt binder and shingle asphalt binder.

3.10. *virgin aggregate*—for the purpose of this specification, shall mean coarse and fine aggregate introduced into new HMA that is exclusive of the shingle aggregate.

3.11. *new HMA*—for the purpose of this specification, shall mean HMA manufactured using aggregates, recycled asphalt pavement (if used), virgin asphalt binder, and reclaimed asphalt shingles.

4. ORDERING INFORMATION

4.1. The purchaser or specifier shall include the following information in the purchase order or contract documents:

4.1.1. Reference to this specification and year of issue;

4.1.2. Additional testing requirements; and

4.1.3. Any exceptions to this specification.

5. SOURCES AND SAMPLING

5.1. Reclaimed asphalt shingles may be derived from either manufactured shingle waste or from post-consumer asphalt shingles (see Note 2).

Note 2—Asphalt shingle material is construction debris, and various state and local regulations may be applicable to its use. The user of this specification is advised to contact state and local transportation departments and environmental agencies to determine what additional requirements may be necessary.

5.2. Post-consumer asphalt shingles shall be processed prior to use to meet the requirements of Section 8 of this specification and shall consist of asphalt roll roofing, cap sheets, and shingles, including underlayment, only. Roofing debris, including coal tar epoxy, rubber materials, or other undesirable components, shall not be used. Post-consumer asphalt shingles shall be certified as conforming to EPA's NESHAP and any other local requirements concerning asbestos.

5.3. Manufactured shingle waste and post-consumer asphalt shingles shall not be blended for the production of new HMA.

5.4. Reclaimed asphalt shingle samples collected and analyzed, for the purpose of identifying the properties of reclaimed asphalt shingles as defined in this specification, shall be representative of the reclaimed asphalt shingle material that will be used in the full production run of new HMA.

6. GRADATION OF RECLAIMED ASPHALT SHINGLES

6.1. Reclaimed asphalt shingles shall be processed so that 100 percent passes the 12.5-mm (0.5-in.) sieve, or as required by the specifying jurisdiction.

Note 3—The HMA supplier may wish to uniformly blend fine aggregate or reclaimed asphalt pavement (RAP) with the reclaimed asphalt shingles as a method of preventing the agglomeration of reclaimed asphalt shingle particles. The fine aggregate or RAP so added must be considered in the final gradation of the new HMA.

7. ADDITION RATES OF RECLAIMED ASPHALT SHINGLES

7.1. The addition rate of reclaimed asphalt shingles shall be such that the gradation of the new HMA shall comply with the gradation requirements of M 323 (see Note 4).

Note 4—The gradation of the new HMA shall account for the shingle aggregate as well as the virgin aggregate. The shingle aggregate gradation shall be determined in accordance with the procedures outlined in PP 53.

7.2. The addition rate of reclaimed asphalt shingles shall be such that the new HMA shall comply with the volumetric mix design requirements of M 323.

7.3. If the virgin asphalt binder content expressed as a percentage of the total binder content of the new HMA is less than 70 percent (see Note 5), the virgin asphalt binder and shingle binder combination shall be further evaluated to ensure that the performance grade of the final blended binder complies with the performance grade requirements of M 320 (see Note 6).

Note 5—The virgin asphalt binder content, expressed as a percentage of the total binder content of the new HMA, is the percentage of virgin asphalt binder introduced into the new HMA (P_{bv}) divided by the sum of the percentage of available shingle asphalt binder present in the reclaimed shingles (P_{br}) and the percentage of virgin asphalt introduced into the new HMA (P_{bv}).

Note 6—The performance grade and percentage of virgin asphalt binder introduced into the new HMA (P_{bv}) shall be determined in accordance with the procedures outlined in PP 53.

8. DELETERIOUS SUBSTANCES

8.1. Reclaimed asphalt shingles shall not contain extraneous waste materials and shall be essentially nail-free. Extraneous materials such as metals, glass, rubber, soil, brick, tars, paper, wood, and plastic shall not exceed 3.0 percent by mass as determined on material retained on the 4.57-mm (No. 4) sieve. Lightweight material such as paper, wood, and plastic shall not exceed 1.5 percent by mass as determined on material retained on the 4.75-mm (No. 4) sieve.

8.2. Reclaimed asphalt shingles shall contain less than the maximum percentage of asbestos fibers based on testing procedures and frequencies established in conjunction with the specifying jurisdiction and state or federal environmental regulatory agencies.

9. METHODS OF SAMPLING AND TESTING

9.1. Sample and test the reclaimed asphalt shingles using the following AASHTO standards, except as otherwise provided in this specification:

9.1.1. Sampling according to T 2;

9.1.2. Extraction and recovery of asphalt binder according to T 164, T 170, or T 319;

9.1.3. Mechanical analysis of extracted aggregate according to T 30. Additional guidance for handling fibers may be found in PP 53.

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[1] Approved in December 2005, this standard was first published in July 2006. Revised in 2009.

Standard Specification for

Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test

AASHTO Designation: MP 19-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test

AASHTO Designation: MP 19-10

1. SCOPE

1.1 This specification covers asphalt binders graded by performance using the multiple stress creep recovery (MSCR) test. Grading designations are related to the average seven-day maximum pavement design temperature, minimum pavement design temperature, and traffic loading.

1.2 This specification incorporates TP 70 for determining non-recoverable creep compliance, J_{nr}. “S”, “H”, “V”, or “E” grades must be specified for standard, high, very high, or extremely high traffic loading, respectively.

Note 1—For asphalt cements graded by viscosity at 60ºC, see M 226.

Note 2—For Performance-Graded Asphalt Binder, see M 320.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 226, Viscosity-Graded Asphalt Cement
- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- R 35, Superpave Volumetric Design for Hot-Mix Asphalt (HMA)
- T 40, Sampling Bituminous Materials
- T 44, Solubility of Bituminous Materials
- T 48, Flash and Fire Points by Cleveland Open Cup
- T 55, Water in Petroleum Products and Bituminous Materials by Distillation
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer
- TP 70, Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

2.2 *ASTM Standards*:

- D 8, Standard Terminology Relating to Materials for Roads and Pavements
- D 5546, Standard Test Method for Solubility of Asphalt Binders in Toluene by Centrifuge

3. TERMINOLOGY

3.1 *Definitions*:

3.1.1 Definitions for many terms common to asphalt binder are found in ASTM D 8.

3.1.2 *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

4. ORDERING INFORMATION

4.1 When ordering under this specification, include in the purchase order the performance grade (PG) of asphalt binder required and the grade (e.g., MP 19, PG 64-22, Grade S).

4.2 The required environmental asphalt binder grades may be selected by following the procedures described in M 323 and R 35, except do not use the “grade bumping” procedure in M 323. Select the environmentally appropriate high and low temperature grades and the appropriate “S”, “H”, “V”, or “E” grade for the expected traffic level and traffic load rate.

4.2.1 Standard Grade “S” in most typical situations will be for traffic levels fewer than 10 million Equivalent Single Axle Loads (ESALs) and less than the standard traffic load rate (>70 km/h).

4.2.2 High Grade “H” in most situations will be for traffic levels of 10 to 30 million ESALs or slow-moving traffic (20 to 70 km/h).

4.2.3 Very High Grade “V” in most situations will be for traffic levels of greater than 30 million ESALs or standing traffic (< 20 km/h).

4.2.4 Extremely High Grade “E” in most situations will be for traffic levels of greater than 30 million ESALs and standing traffic (< 20 km/h) such as toll plazas or port facilities.

Note 3—“Grade bumping” is accomplished by using “H”, “V”, or “E” grades and not by increasing the PG high temperature grade as recommended in M 323.

5. MATERIALS AND MANUFACTURE

5.1 Asphalt binder shall be prepared by the refining of crude petroleum by suitable methods, with or without the addition of modifiers.

5.2 Modifiers may be any organic material of suitable manufacture that is used in virgin or recycled condition and that is dissolved, dispersed, or reacted in asphalt binder to enhance its performance.

5.3 The asphalt binder shall be homogeneous, free from water and deleterious materials, and shall not foam when heated to 175°C.

5.4 The asphalt binder shall be at least 99.0 percent soluble as determined by T 44 or ASTM D 5546.

5.5 This specification is not applicable for asphalt binders in which fibers or other discrete particles are larger than 250 μm in size.

5.6 The grades of asphalt binder shall conform to the requirements given in Table 1.

6. SAMPLING

6.1 The material shall be sampled in accordance with T 40.

7. TEST METHODS

7.1 The properties outlined in Sections 5.3, 5.4, and 5.6 shall be determined in accordance with R 28, T 44 or ASTM D 5546, T 48, T 55, T 240, T 313, T 314, T 315, T 316, and TP 70.

8. INSPECTION AND CERTIFICATION

8.1 Inspection and certification of the material shall be agreed upon between the purchaser and the seller. Specific requirements shall be part of the purchase contract. The seller shall provide material handling and storage procedures to the purchaser for each asphalt binder grade certified.

9. REJECTION AND RETESTING

9.1 If the results of any test do not conform to the requirements of this specification, retesting to determine conformity is performed as indicated in the purchase order or as otherwise agreed upon between the purchaser and the seller.

10. KEYWORDS

10.1 Asphalt binder; asphalt cement; direct tension; flash point; modifier; multiple stress creep recovery (MSCR), performance specifications; pressure aging; rheology.

Table 1—Performance-Graded Asphalt Binder Specification[a]

Performance Grade	PG 46			PG 52							PG 58				
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40
Average 7-day max pavement design temp, °C[b]	<46			<52							<58				
Min pavement design temp, °C[b]	>–34	>–40	>–6	>–10	>–6	>–22	>–28	>–34	>–40	>–46	>–16	>–22	>–28	>–34	>–40
Original Binder															
Flash point temp, T 48, min °C	230														
Viscosity, T 316:[c] max 3 Pa·s, test temp, °C	135														
Dynamic shear, T 315:[d] G*/sinδ, min 1.00 kPa[e] test temp @ 10 rad/s, °C	46			52							58				
Rolling Thin-Film Oven Residue (T 240)															
Mass change, max, percent[f]	1.00														
MSCR, TP 70: Standard Traffic "S" Grade $J_{nr3.2}$, max 4.0 kPa^{-1} $J_{nr\mathrm{diff}}$, max 75% test temp, °C	46			52							58				
MSCR, TP 70: Heavy Traffic "H" Grade $J_{nr3.2}$, max 2.0 kPa^{-1} $J_{nr\mathrm{diff}}$, max 75% test temp, °C	46			52							58				
MSCR, TP 70: Very Heavy Traffic "V" Grade $J_{nr3.2}$, max 1.0 kPa^{-1} $J_{nr\mathrm{diff}}$, max 75% test temp, °C	46			52							58				
MSCR, TP 70: Extremely Heavy Traffic "E" Grade $J_{nr3.2}$, max 0.5 kPa^{-1} $J_{nr\mathrm{diff}}$, max 75% test temp, °C	46			52							58				
Pressurized Aging Vessel Residue (R 28)															
PAV aging temp, °C[g]	90			90							100				
Dynamic shear, T 315: "S" Grade G* sinδ, max 5000 kPa[e] test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13
Dynamic shear, T 315: "H", "V", "E" Grades G* sinδ, max 6000 kPa[e] test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13
Creep stiffness, T 313:[h] *S*, max 300 MPa *m*-value, min 0.300 test temp @ 60 s, °C	–24	–30	–36	0	–6	–12	–18	–24	–30	–36	–6	–12	–18	–24	–30
Direct tension, T 314:[h] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	–24	–30	–36	0	–6	–12	–18	–24	–30	–36	–6	–12	–18	–24	–30

[a] MSCR testing on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

[b] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for "grade bumping".

[c] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[d] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[e] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[f] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[g] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[h] If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The *m*-value requirement must be satisfied in both cases.

Table 1—Performance-Graded Asphalt Binder Specification[a] *(continued)*

Performance Grade	PG 64						PG 70					
	10	16	22	28	34	40	10	16	22	28	34	40
Average 7-day max pavement design temp, °C[b]							<70					
Min pavement design temp, °C[b]	>–10	>–16	>–22	>–28	>–34	>–40	>–10	>–16	>–22	>–28	>–34	>–40
	Original Binder											
Flash point temp, T 48, min °C	230											
Viscosity, T 316:[c] max 3 Pa·s, test temp, °C	135											
Dynamic shear, T 315:[d] G*/sinδ, min 1.00 kPa[e] test temp @ 10 rad/s, °C	64						70					
	Rolling Thin-Film Oven Residue (T 240)											
Mass change, max, percent[f]	1.00											
MSCR, TP 70: Standard Traffic "S" Grade $J_{nr3.2}$, max 4.0 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	64						70					
MSCR, TP 70: Heavy Traffic "H" Grade $J_{nr3.2}$, max 2.0 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	64						70					
MSCR, TP 70: Very Heavy Traffic "V" Grade $J_{nr3.2}$, max 1.0 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	64						70					
MSCR, TP 70: Extremely Heavy Traffic "E" Grade $J_{nr3.2}$, max 0.5 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	64						70					
	Pressurized Aging Vessel Residue (R 28)											
PAV aging temp, °C[g]	100						100 (110)					
Dynamic shear, T 315: "S" Grade G* sinδ, max 5000 kPa[e] test temp @ 10 rad/s, °C	31	28	25	22	19	16	34	31	28	25	22	19
Dynamic shear, T 315: "H, "V", "E" Grades G* sinδ, max 6000 kPa[e] test temp @ 10 rad/s, °C	31	28	25	22	19	16	34	31	28	25	22	19
Creep stiffness, T 313:[h] *S*, max 300 MPa *m*-value, min 0.300 test temp @ 60 s, °C	0	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	–30
Direct tension, T 314:[h] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	–6	–12	–18	–24	–30	0	–6	–12	–18	–24	–30

[a] MSCR test on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

[b] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for "grade bumping".

[c] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[d] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[e] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[f] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[g] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[h] If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The *m*-value requirement must be satisfied in both cases.

Table 1—Performance-Graded Asphalt Binder Specification[a] *(continued)*

Performance Grade	PG 76					PG 82				
	10	16	22	28	34	10	16	22	28	34
Average 7-day max pavement design temp, °C[b]	<76					<82				
Min pavement design temp, °C[b]	>–10	>–16	>–22	>–28	>–34	>–10	>–16	>–22	>–28	>–34
Original Binder										
Flash point temp, T 48, min°C	230									
Viscosity, T 316:[c] max 3 Pa·s, test temp, °C	135									
Dynamic shear, T 315:[d] G*/sin δ, min 1.00 kPa[e] test temp @ 10 rad/s, °C	76					82				
Rolling Thin-Film Oven Residue (T 240)										
Mass change, max, percent[f]	1.00									
MSCR, TP 70: Standard Traffic “S” Grade $J_{nr3.2}$, max 4.0 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	76					82				
MSCR, TP 70: Heavy Traffic “H” Grade $J_{nr3.2}$, max 2.0 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	76					82				
MSCR, TP 70: Very Heavy Traffic “V” Grade $J_{nr3.2}$, max 1.0 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	76					82				
MSCR, TP 70: Extremely Heavy Traffic “E” Grade $J_{nr3.2}$, max 0.5 kPa^{-1} J_{nrdiff}, max 75% test temp, °C	76					82				
Pressurized Aging Vessel Residue (R 28)										
PAV aging temp, °C[g]	100 (110)					100 (110)				
Dynamic shear, T 315: “S” Grade G* sinδ, max 5000 kPa[e] test temp @ 10 rad/s, °C	37	34	31	28	25	40	37	34	31	28
Dynamic shear, T 315: “H”, “V”, “E” Grades G* sinδ, max 6000 kPa[e] test temp @ 10 rad/s, °C	37	34	31	28	25	40	37	34	31	28
Creep stiffness, T 313:[h] *S*, max 300 MPa *m*-value, min 0.300 test temp @ 60 s, °C	0	–6	–12	–18	–24	0	–6	–12	–18	–24
Direct tension, T 314:[h] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	0	–6	–12	–18	–24	0	–6	–12	–18	–24

[a] MSCR test on RTFO residue should be performed at the PG grade based on the environmental high pavement temperature. Grade bumping is accomplished by requiring a lower J_{nr} value while testing at the environmental temperature.

[b] Pavement temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, may be provided by the specifying agency, or by following the procedures as outlined in M 323 and R 35, excluding the provisions for “grade bumping”.

[c] This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

[d] For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be used to supplement dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid.

[e] G*/sinδ = high temperature stiffness and G* sinδ = intermediate temperature stiffness.

[f] The mass change shall be less than 1.00 percent for either a positive (mass gain) or a negative (mass loss) change.

[g] The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures, 90°C, 100°C, or 110°C. Normally the PAV aging temperature is 100°C for PG 58-xx and above. However, in desert climates, the PAV aging temperature for PG 70-xx and above may be specified as 110°C.

[h] If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The *m*-value requirement must be satisfied in both cases.

Standard Practice for

Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in New Hot Mix Asphalt (HMA)

AASHTO Designation: PP 53-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Design Considerations When Using Reclaimed Asphalt Shingles (RAS) in New Hot Mix Asphalt (HMA)

AASHTO Designation: PP 53-09[1]

1. SCOPE

1.1. This recommended practice provides guidance for designing new hot mix asphalt (HMA) that incorporates reclaimed asphalt shingles (RAS). Specific guidance includes design considerations, how to determine the shingle aggregate gradation, how to determine the performance grade (PG) and percentage of the virgin asphalt binder, and how to estimate the contribution of the shingle asphalt binder to the final blended binder.

Note 1—Refer to MP 15 for information specifying the use of RAS in HMA. Additionally, refer to the *White Paper for Recycled Asphalt Shingle as an Additive in Hot-Mix Asphalt* for more details concerning the origins and development of this recommended practice.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- MP 15, Use of Reclaimed Asphalt Shingles as an Additive in Hot Mix Asphalt (HMA)
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- T 30, Mechanical Analysis of Extracted Aggregate
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 170, Recovery of Asphalt Binder from Solution by Abson Method
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
- T 319, Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

2.2. *ASTM Standard*:

- D 228, Standard Test Methods for Sampling, Testing, and Analysis of Asphalt Roll Roofing, Cap Sheets, and Shingles Used in Roofing and Waterproofing

2.3. *Other Reference*:

- *White Paper for Recycled Asphalt Shingle as an Additive in Hot-Mix Asphalt*. University of New Hampshire, Recycled Materials Resource Center, Project 13: Development and Preparation of Specifications for Recycled Materials in Transportation Applications, 123 Nesmith Hall, Durham, NH, 2003.

3. INTRODUCTION

3.1. Although RAS has been used as an additive in HMA in the United States for more than 15 years, it remains a relatively new application. As a result, there are design considerations that are not generally known to the specification user. Four separate areas are addressed by this recommended practice, with each elaborating on and providing recommendations relative to the following:

- Design Considerations When Using RAS in HMA
- Determining the Shingle Aggregate Gradation and Specific Gravity
- Estimating the Contribution of the Shingle Asphalt Binder to the Final Blended Binder in New HMA (Values of *F*)
- Determining the Performance Grade (PG) and Percentage of the Virgin Asphalt Binder in New HMA

4. DESIGN CONSIDERATIONS WHEN USING RAS IN NEW HMA

4.1. The introduction of shingle aggregate from RAS will affect the gradation properties of the new HMA. The designer must determine the particle size and percentage of shingle aggregate present and adjust the virgin aggregate composition, if necessary, to ensure that the new HMA meets the appropriate gradation requirements.

4.2. The introduction of RAS will affect virgin asphalt binder content requirements. The designer must determine the virgin asphalt binder content of the new HMA as part of the volumetric design procedure.

4.3. During the production of the new HMA, shingle asphalt binder present in the RAS will mix with the virgin asphalt binder to produce a final blended binder. The properties of the shingle asphalt binder can be considerably different from those of virgin asphalt binder. If the quantity of virgin asphalt binder is less than 70 percent by mass of the total binder, the properties (PG) of the final blended binder may be measurably different from the design PG of the binder as specified by the local jurisdiction. In addition, the size of the RAS can be expected to affect the percentage of shingle asphalt binder that contributes to the final blended binder. For example, material that is ground to a size passing a 12.5-mm (0.5-in.) sieve can be expected to release lower levels of available shingle asphalt binder (20 to 40 percent) than RAS ground to a size passing a 4.75-mm (No. 4) sieve (as much as 95 percent available). The designer must be prepared to adjust the PG of the virgin asphalt binder to compensate for this effect.

4.4. The release of shingle asphalt binder into the virgin asphalt binder can result in reduced virgin asphalt binder requirements. It is unlikely, however, that all of the shingle asphalt binder will dissolve and blend with the virgin asphalt binder. Particles of undissolved shingle asphalt binder may act like aggregate particles that require more virgin asphalt binder to accomplish coating. Additionally, particles of shingle asphalt binder may absorb bituminous oils from the virgin asphalt binder. The location in an HMA plant where RAS is introduced into new HMA can also affect the binder blending process. This point of introduction must minimize damage to the RAS from excess heat and maximize the softening of shingle asphalt binder to facilitate the blending of the shingle asphalt binder with virgin asphalt binder.

5. DETERMINING THE SHINGLE AGGREGATE GRADATION AND SPECIFIC GRAVITY

5.1. Collect a representative sample of RAS and proceed in accordance with T 164, T 170, or T 319 to extract the shingle asphalt binder. The size of the sample should be such that the amount of aggregate material recovered will meet the size requirements of the gradation procedure. Alternate extraction methods, when it is not necessary to retain the shingle asphalt binder, are provided in T 308 and ASTM D 228.

5.2. To determine the shingle aggregate gradation, it is suggested that the shingle fiber present in the RAS be removed prior to testing the recovered aggregate in accordance with T 30. Since the major portion of the shingle fiber will be retained on a 4.75-mm (No. 4) sieve, the fiber fabric can be removed by tweezers or other appropriate method prior to grading the shingle aggregate during the T 30 test procedure.

Note 2—Sieving the aggregate may liberate fiberglass or other fibers present in the RAS. The amount of aggregate contributed by the RAS produces an almost negligible effect in the overall mixture gradation. The following gradation, which approximates the composition of most types of shingles, may be used as a standard gradation in lieu of determining the shingle aggregate gradation:

Shingle Aggregate Gradation	
Sieve Size	Percent Passing by Mass
9.5 mm ($^3/_8$ in.)	100
4.75 mm (No. 4)	95
2.36 mm (No. 8)	85
1.18 mm (No. 16)	70
600 µm (No. 30)	50
300 µm (No. 50)	45
150 µm (No. 100)	35
75 µm (No. 200)	25

5.3. Determine the shingle aggregate specific gravity by determining the theoretical maximum specific gravity (G_{mm}) of the RAS according to T 209 and calculating the effective specific gravity (G_{se}) of the aggregate according to Equation 1. A fine spray of alcohol may help reduce surface tension to allow fine particles to sink.

$$G_{se} = \frac{100 - P_{br}}{\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_{br}}{1.03}\right)} \quad (1)$$

where:

G_{se} = the effective specific gravity of the shingle aggregate;

G_{mm} = the theoretical maximum specific gravity of the RAS; and

P_{br} = the percentage of shingle asphalt binder in the RAS by mass, percent.

Note 3—The absorption of most shingle aggregate is so low that little difference exists between the bulk and apparent specific gravities. Therefore, the effective specific gravity of the shingle aggregate may be substituted for the bulk specific gravity in subsequent calculations.

6. ESTIMATING THE CONTRIBUTION OF THE SHINGLE ASPHALT BINDER TO THE FINAL BLENDED BINDER IN NEW HMA (VALUES OF *F*)

6.1. When RAS is added to new HMA, there is uncertainty as to the exact amount of asphalt binder that is released from the shingle asphalt binder to blend with the virgin asphalt binder. There are many factors that control the blending of these two binders. Perhaps the most significant factor is the size to which the RAS is ground. The finer the grind, the greater the amount of the contribution of binder from the RAS is to the final blended binder. Other factors include the location in the manufacturing process where the RAS is added to the new HMA, the temperature of the aggregates, the temperature of the virgin asphalt binder, and the length of mixing time.

6.2. A calculated initial estimate of the percentage of asphalt binder (F_c) that is released from the RAS and blends with the virgin asphalt binder may be made by determining the difference between the design binder content of a mix without RAS (P_{bv}) and the design binder content of the new HMA with RAS (P_{vbr}), and dividing this value by the total available shingle asphalt binder in the new HMA. Expressed mathematically:

$$F_c = \frac{P_{bv} - P_{bvr}}{(P_{sr})(P_{br})} \tag{2}$$

where:

F_c = the estimated shingle asphalt binder availability factor, percent;

P_{bv} = the design asphalt binder content of a mix without RAS, percent;

P_{bvr} = the design asphalt binder content of the same mix (new HMA) with RAS, percent;

P_{sr} = the percentage of RAS in the new HMA expressed as a decimal; and

P_{br} = the percentage of shingle asphalt binder in the RAS expressed as a decimal.

Define the value of Δ as follows:

$$\Delta = P_{bv} - P_{bvr} \tag{3}$$

then:

$$F_c = \frac{\Delta}{(P_{sr})(P_{br})} \tag{4}$$

For example, assuming the following values for the variables involved, F_c is calculated as follows:

- P_{bv} = 5.3 percent;
- P_{bvr} = 5.0 percent;
- P_{sr} = 5.0 percent, or 0.05; and
- P_{br} = 40 percent, or 0.40.

$$F_c = \frac{5.3 - 5.0}{(0.05)(0.40)} = \frac{0.3}{0.02} = 15 \text{ percent}$$

This calculation will underestimate the value of F_c. A corrected value of F, used in Section 7.3, is defined as follows:

$$F = 100\left(\frac{1+F_c}{2}\right) \qquad (5)$$

where:

F = the shingle asphalt binder availability factor (determined using the procedure outlined in Section 6.2.6), percent; and

F_c = the estimated shingle asphalt binder availability factor (determined from Equation 4) expressed as a decimal.

For example, using the value for F_c determined above (expressed as a decimal), F is calculated as follows:

$$F = 100\left(\frac{1+0.15}{2}\right) = 100\left(\frac{1.15}{2}\right) = 57.5 \text{ percent}$$

A discussion of the corrected value of F is presented in Section 6.2.6. More detailed instructions, which outline the steps in this procedure, are as follows:

6.2.1 Perform a volumetric mix design on the new HMA that includes all of the components of the mixture except for the RAS in accordance with R 35. Select the design aggregate structure and prepare replicate mixtures in accordance with R 35. Condition the mixtures according to R 30. Determine the design binder content (P_{bv}).

6.2.2 Perform a second volumetric mix design procedure according to R 35 with the same combination of materials but including the RAS in the percentage desired for the new HMA. The RAS should be added at ambient temperature to the heated aggregates just prior to the addition of the heated virgin asphalt binder. Condition the mixtures according to R 30. Determine the design binder content (P_{br}).

6.2.3 If the value of Δ as calculated in Equation 3 is positive, then the shingle asphalt binder is contributing to the final blended binder. If the value of Δ as calculated in Equation 3 is negative, then coating undissolved shingle asphalt binder particles and absorption of virgin asphalt binder by RAS particles resulting from the introduction of the RAS is exceeding the amount of shingle asphalt binder contributing to the final blended binder. Additional virgin binder will then be required.

6.2.4 Multiply the percentage of shingle asphalt binder in the RAS (P_{br}) by the percentage of RAS added to the mixture (P_{sr}). This value represents the total available shingle asphalt binder expressed as a percentage of the new HMA.

6.2.5 Divide the value for Δ determined in Section 6.2.3 by the product of $(P_{sr})(P_{br})$ determined in Section 6.2.4. The quotient from this calculation is the initial estimate of the percentage of asphalt binder that is released from the RAS and blends with the virgin asphalt binder (F_c).

6.2.6 There are practical limitations, however, to this approach for estimating the value of F. These limitations are inherent in the assumption that Δ is the quantity of shingle asphalt binder that is contributing to the final blended binder. The value of Δ is dependent on at least three factors:

- The amount of shingle asphalt binder released into the mix,
- Minus the additional absorption due to the RAS present in the mix,
- Minus the additional coating requirements due to the RAS present in the mix.

As a result, the calculated value of F [$\Delta/(P_{sr})(P_{br})$] will always be less than the true value of F, and the critical design temperature of the virgin asphalt will always be overestimated. This relationship is illustrated more clearly in Figure 1.

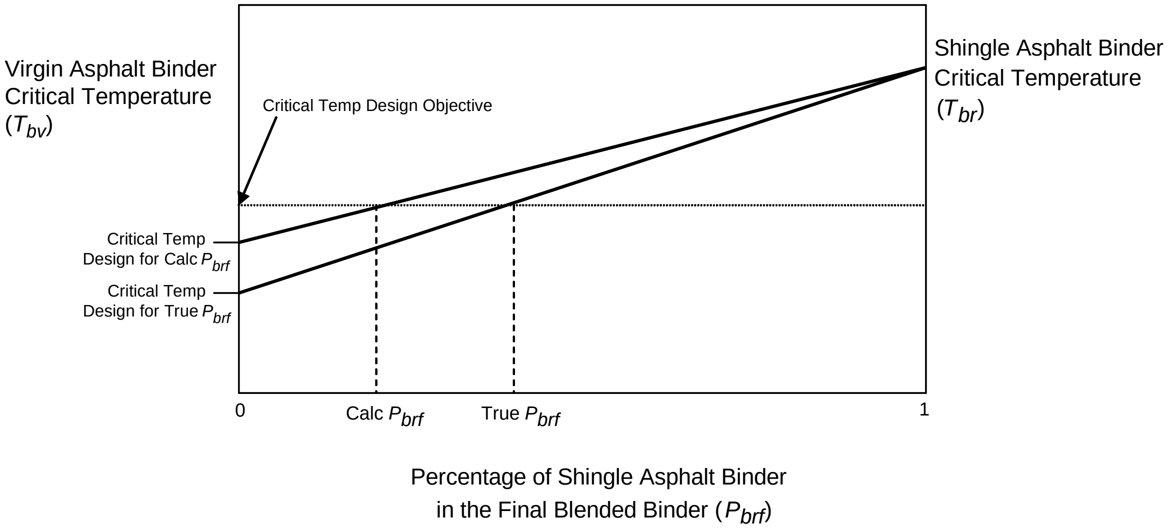

Figure 1—RAS Hypothetical Blending Chart

In the blending, it can be observed that since the calculated value of P_{brf} will always be less than the true value, the calculated critical temperature will always be higher than the true critical temperature. In the design (selection of critical temperature/PG of the virgin binder), this relationship must be considered in order to avoid selecting a harder asphalt binder.

Since the maximum value of F is theoretically equal to 1, the true value of F can be expected to lie between the value of F_c and 1, or expressed mathematically, $F_c < F < 1$. As a result, the best approximation of F can be expressed by Equation 5.

This value of F is used to calculate P_{brf} in Section 7.3.

7. DETERMINING THE PG AND PERCENTAGE OF THE VIRGIN ASPHALT BINDER IN NEW HMA

7.1. Select the percentage of RAS (P_{sr}) to be introduced into the new HMA.

7.2. Determine the percentage of shingle asphalt binder (P_{br}) present in the RAS in accordance with T 164, T 170, or T 319.

7.3. Determine the expected percentage of shingle asphalt binder present in the final blended binder (P_{brf}) using the following equation:

$$P_{brf} = \frac{F(P_{sr})(P_{br})}{P_{bbf}} \qquad (6)$$

where:

P_{brf} = the percentage of shingle asphalt binder in the final blended binder;

F = the shingle asphalt binder availability factor (determined using the procedure outlined in Section 6.2.6), percent;

P_{sr} = the percentage of RAS in the new HMA expressed as a decimal;

P_{br} = the percentage of shingle asphalt binder in the RAS (determined in Section 7.2) expressed as a decimal; and

P_{bbf} = the percentage of final blended binder in the new HMA expressed as a decimal.

For example, assuming the following values for the variables involved, P_{brf} is calculated as follows:

- F = 57.5 percent (as determined in the example for Equation 5);
- P_{sr} = 5.0 percent, or 0.05;
- P_{br} = 40 percent, or 0.40; and
- P_{bbf} = 5.0 percent, or 0.05.

$$P_{brf} = \frac{(57.5)(0.05)(0.40)}{0.05} = \frac{1.15}{0.05} = 23 \text{ percent of the final blended binder is contributed by RAS.}$$

7.4. Establish the required PG (or critical temperatures for the high, intermediate, and low properties) for the virgin asphalt binder in accordance with M 323. This procedure can be accomplished by constructing a blending chart and plotting the critical temperature of the shingle asphalt binder for 100 percent shingle asphalt binder and the value of P_{brf} on the chart abscissa to determine the critical temperatures of virgin asphalt binder that must be used in the new HMA. The blending chart approach in M 323 considers the effect of reclaimed asphalt pavement (RAP) on the virgin asphalt binder PG; in this practice, the effect of RAS is evaluated instead. Figure 1 of this practice provides a conceptual representation of this procedure. As an alternative to this procedure, utilize the following equation, which is a mathematical representation of the blending chart:

$$T_{bv} = T_{br} - \frac{\left(T_{br} - T_{bbf}\right)}{\left(1 - P_{brf}\right)} \qquad (7)$$

where:

T_{bv} = the critical temperature of the virgin asphalt binder (°C);

T_{br} = the critical temperature of the shingle asphalt binder (°C);

T_{bbf} = the critical temperature of the final blended binder (°C); and

P_{brf} = the percentage of shingle asphalt binder in the final blended binder expressed as a decimal.

For example, assuming the following values for the variables involved, T_{bv} is calculated as follows:

- T_{br} = 88°C (determined by laboratory analysis conforming to M 320);
- T_{bbf} = 64°C (the high-temperature PG specified for the project in question); and
- P_{brf} = 23 percent, or 0.23, as determined in the example for Equation 6.

$$T_{bv} = 88 - \frac{\left(88 - 64\right)}{\left(1 - 0.23\right)} = 88 - \frac{24}{0.77} = 56.8 \text{ degrees Celsius}$$

In this case (the high critical temperature analysis), the next highest available PG (T_{bv} = 58ºC) would be selected.

7.5. To make use of Equation 7, T_{br} values for high, intermediate, and low critical temperatures for each of the defined properties in M 320 must be determined by testing the extracted shingle asphalt binder from Section 7.2. The value for T_{bbf} is based on the climatic conditions where the new HMA will be used, while the value for P_{brf} is determined in Section 7.3. The equation may then be solved for T_{bv} (for the high, intermediate, and low critical temperatures).

7.6. If the PG for the virgin asphalt binder as determined in Sections 7.4 and 7.5 is different from the grade used in Section 6.2.2, then an additional volumetric design for the new HMA must be performed in accordance with R 35 and a revised design binder content (P_{bvr}) in the HMA determined.

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[1] Approved in December 2005, this standard was first published in July 2006. Revised in 2009.

Standard Practice for

Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)

AASHTO Designation: PP 60-09[1,2]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)

AASHTO Designation: PP 60-09[1,2]

1. SCOPE

1.1 This practice covers the use of a Superpave gyratory compactor (SGC) to prepare 100-mm diameter by 150-mm tall cylindrical test specimens for use in a variety of axial compression and tension performance tests. This practice is intended for dense-, gap-, and open-graded hot mix asphalt (HMA) with nominal maximum aggregate sizes up to 37.5 mm.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- TP 62, Determining Dynamic Modulus of Hot Mix Asphalt (HMA)
- TP 79, Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)

2.2 *ASTM Standard*:

- D 3549, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens

3. TERMINOLOGY

3.1 *SGC specimen*—a 150-mm diameter by 170-mm tall (minimum) cylindrical specimen prepared in an SGC meeting the requirements of T 312.

3.2 *test specimen*—a 100-mm diameter by 150-mm tall cylindrical specimen that is sawed and cored from the SGC specimen.

3.3 *end perpendicularity*—the degree to which an end surface departs from being perpendicular to the axis of the cylindrical test specimen. This configuration is measured using a combination square with the blade touching the cylinder parallel to its axis, and the head touching the highest point on the end of the cylinder. The distance between the head of the square and the lowest point on the end of the cylinder is measured with feeler gauges.

3.4 *end planeness*—maximum departure of the specimen end from a plane. This dimension is measured using a straightedge and feeler gauges.

4. SUMMARY OF PRACTICE

4.1 This practice presents methods for preparing 100-mm diameter by 150-mm tall cylindrical test specimens for use in a variety of axial compression and tension performance tests.

5. SIGNIFICANCE AND USE

5.1 This practice should be used to prepare specimens for TP 62 and TP 79.

5.2 This practice may also be used to prepare specimens for other tests requiring 100-mm diameter by 150-mm tall cylindrical test specimens.

6. APPARATUS

6.1 *Superpave Gyratory Compactor*—Meeting the requirements of T 312 and capable of preparing 150-mm diameter specimens that are a minimum of 170 mm tall.

6.2 *Mixture Preparation Equipment*—Balances, ovens, thermometers, mixer, pans, and other miscellaneous equipment needed to prepare SGC specimens in accordance with T 312 and perform bulk specific gravity (G_{mb}) measurements in accordance with T 166 and T 209.

6.3 *Core Drill*—An air- or water-cooled, diamond-bit core drill capable of cutting cores to a nominal diameter of 100 mm and meeting the dimensional requirements of Section 9.6.3. The core drill shall be equipped with a fixture for holding 150-mm diameter SGC specimens.

Note 1—Core drills with fixed and adjustable rotational speed have been used successfully to prepare specimens meeting the dimensional tolerances given in Section 9.6.3. Rotational speeds from 450 to 750 rpm have been used.

Note 2—Core drills with automatic and manual feed-rate control have been used successfully to prepare specimens meeting the dimensional tolerances given in Section 9.6.3.

6.4 *Masonry Saw*—An air- or water-cooled, diamond-bladed masonry saw capable of cutting specimens to a nominal length of 150 mm and meeting the tolerances for end perpendicularity and end flatness given in Section 9.6.3.

Note 3—Single- and double-bladed saws have been used successfully to prepare specimens meeting the dimensional tolerances given in Section 9.6.3. Both types of saws require a fixture to securely hold the specimen during sawing and to control the feed rate.

Note 4—In NCHRP Project 9-29, a machine that performs both the sawing and coring operation within the tolerances specified in Section 9.6.3 was developed. To obtain one of these devices, contact Shedworks, Inc., 2151 Harvey Mitchell Parkway S., Suite 320, College Station, TX 77840-5244, Phone (979) 695-8416, Fax 695-9629, e-mail wwc@shedworks.com.

6.5 *Square*—Combination square with a 300-mm blade and 100-mm head.

6.6 *Feeler Gauges*—Tapered-leaf feeler gauges in 0.05-mm increments.

6.7 *Metal Ruler*—Capable of measuring nominal 150-mm long (nominal) specimens to the nearest 1 mm.

6.8 *Calipers*—Capable of measuring nominal 100-mm diameter (nominal) specimens to the nearest 0.1 mm.

7. HAZARDS

7.1 This practice and associated standards involve handling of hot asphalt binder, aggregates, and asphalt mixtures, and the use of sawing and coring machinery. Use standard safety precautions, equipment, and clothing when handling hot materials and operating machinery.

8. STANDARDIZATION

8.1 Items associated with this practice that require calibration or verification are included in the AASHTO standards referenced in Section 2. Refer to the pertinent section of the referenced standards for information concerning calibration or verification.

9. PROCEDURE

9.1 *Select SGC Specimen Target Height*:

9.1.1 SGC specimens shall be prepared to a minimum height of 170 mm.

9.1.2 SGC specimen height shall be chosen based on the air void gradient produced by the specific SGC and effect of the sawing equipment.

Note 5—Test specimens with acceptable properties have been prepared from SGC specimens ranging in height from 165 mm to greater than 180 mm. Coarse-graded mixtures may require a taller height in order to ensure smooth, uniform ends with minimal or no surface irregularities after the sawing process. For tension performance testing, a taller height is required for all mixtures.

Note 6—Each laboratory should determine a target SGC specimen height based on the procedure for evaluating test specimen uniformity given in Appendix X2, and an evaluation of the ability of the sawing equipment to maintain the dimensional tolerances given in Table 1.

9.2 *HMA Preparation*:

9.2.1 Prepare HMA for each test specimen and a companion maximum specific gravity (G_{mm}) test in accordance with T 312.

9.2.2 The mass of HMA needed for each specimen will depend on the SGC specimen height, the G_{mm} of the aggregate, nominal maximum aggregate size, gradation (coarse or fine), and target air void content for the test specimens.

Note 7—Appendix X1 describes a trial-and-error procedure developed in NCHRP 9-19 for determining the mass of HMA required to reach a specified test specimen target air void content for SGC specimens prepared to a height of 170 mm.

9.2.3 Perform conditioning for the test specimens and companion G_{mm} sample test in accordance with R 30.

9.3 *SGC Specimen Compaction*:

9.3.1 Compact the SGC specimens to the target specimen height determined in Section 9.1 in accordance with T 312.

9.4 *Long-Term Conditioning (Optional)*:

9.4.1 If it is desired to simulate long-term aging, condition the SGC specimen in accordance with R 30.

9.4.2 To obtain accurate volumetric measurements on the long-term-conditioned specimens, also condition a companion sample of short-term-conditioned loose HMA meeting the sample size requirements of T 209 in accordance with R 30.

9.5 *SGC Specimen Density and Air Voids (Optional)*:

9.5.1 Determine the G_{mm} of the HMA in accordance with T 209. If long-term conditioning has been used, determine the G_{mm} on the long-term-conditioned loose HMA. Record the G_{mm} of the mixture.

9.5.2 For dense- and gap-graded mixtures, determine the G_{mb} of the SGC specimen in accordance with T 166. Record the G_{mb} of the SGC specimen.

9.5.3 For open-graded mixtures, determine the G_{mb} of the SGC specimen in accordance with T 269. Record the G_{mb} of the SGC specimen.

9.5.4 Compute the air void content of the SGC specimen in accordance with T 269. Record the air void content of the SGC specimen.

Note 8—Section 9.5 is optional because acceptance of the test specimen for mechanical property testing is based on the air void content of the test specimen, not the SGC specimen. However, monitoring SGC specimen density can identify improperly prepared specimens early in the specimen fabrication process. Information on SGC specimen air voids and test specimen air voids will also assist the laboratory in establishing potentially more precise methods than Appendix X1 for preparing test specimens to a target air void content.

9.6 *Test Specimen Preparation*:

9.6.1 Drill a core of nominal diameter of 100 mm from the center of the SGC specimen. Both the SGC specimen and the drill shall be adequately supported to ensure that the resulting core is cylindrical with sides that are smooth, parallel, and meet the tolerances on specimen diameter given in Table 1.

9.6.2 Saw the ends of the core to obtain a test specimen of a nominal height of 150 mm. Both the core and the saw shall be adequately supported to ensure that the resulting test specimen meets the tolerances given in Table 1 for height, end flatness, and end perpendicularity.

Note 9—With most equipment, it is better to perform the coring before the sawing. However, these operations may be performed in either order as long as the dimensional tolerances in Table 1 are satisfied.

9.6.3 Test specimens shall meet the dimensional tolerances given in Table 1.

Table 1—Test Specimen Dimensional Tolerances

Item	Specification	Method Reference
Average diameter	100 to 104 mm	9.6.3.1
Standard deviation of diameter	≤0.5 mm	9.6.3.1
Height	147.5 to 152.5 mm	9.6.3.2
End flatness	≤0.5 mm	9.6.3.3
End perpendicularity	≤1.0 mm	9.6.3.4

9.6.3.1 Using calipers, measure the diameter at the center and third points of the test specimen along axes that are 90 degrees apart. Record each of the six measurements to the nearest 0.1 mm. Calculate the average and the standard deviation of the six measurements. The standard deviation shall be less than 0.5 mm. Reject specimens not meeting the average and standard deviation requirements listed in Table 1. The average diameter, reported to the nearest 0.1 mm, shall be used in all material property calculations.

9.6.3.2 Measure the height of the test specimen in accordance with ASTM D 3549. Reject specimens with an average height outside the height tolerance listed in Table 1. Record the average height.

9.6.3.3 Using a straightedge and feeler gauges, measure the flatness of each end. Place a straightedge across the diameter at three locations approximately 120 degrees apart, and measure the maximum departure of the specimen end from the straightedge using tapered-end feeler gauges. For each end, record the maximum departure along the three locations as the end flatness. Reject specimens with end flatness exceeding 0.5 mm.

9.6.3.4 Using a combination square and feeler gauges, measure the perpendicularity of each end. At two locations approximately 90 degrees apart, place the blade of the combination square in contact with the specimen along the axis of the cylinder and the head in contact with the highest point on the end of the cylinder. Measure the distance between the head of the square and the lowest point on the end of the cylinder using tapered-end feeler gauges. For each end, record the maximum measurement from the two locations as the end perpendicularity. Reject specimens with end perpendicularity exceeding 1.0 mm.

9.7 *Test Specimen Density and Air Voids*:

9.7.1 Determine the G_{mm} of the HMA in accordance with T 209. If long-term conditioning has been used, determine the G_{mm} on the long-term-conditioned loose HMA. Record the G_{mm} of the HMA.

9.7.2 For dense- and gap-graded mixtures, determine the G_{mb} of the test specimen in accordance with T 166. Record the G_{mb} of the test specimen.

Note 10—When wet-coring and sawing methods are used, measure the immersed mass, followed by the surface-dry mass followed by the dry mass, to minimize drying time and expedite the specimen fabrication process.

9.7.3 For open-graded mixtures, determine the G_{mb} of the test specimen in accordance with T 269. Record the G_{mb} of the test specimen.

9.7.4 Compute the air void content of the test specimen in accordance with T 269. Record the air void content of the test specimen. Reject test specimens exceeding the air void tolerances specified in the applicable test.

9.8 *Test Specimen Storage*:

9.8.1 Mark the test specimen with a unique identification number.

9.8.2 Store the test specimen, until tested, on its end on a flat shelf in a room with the temperature controlled between 15 and 27°C.

Note 11—Definitive research concerning the effects of test specimen aging on various mechanical property tests has not been completed. Some users enclose specimens in plastic wrap and minimize specimen storage time to 2 weeks.

10. REPORTING

10.1 *Report the following information*:

10.1.1 Unique test specimen identification number.

10.1.2 Mixture design data including design compaction level and air void content, asphalt binder type and grade, binder content, binder specific gravities, aggregate types and bulk specific gravities, aggregate consensus properties, and G_{mm}.

10.1.3 Type of conditioning used.

10.1.4 G_{mm} for the conditioned specimens.

10.1.5 SGC specimen target height (optional).

10.1.6 SGC specimen G_{mb} (optional).

10.1.7 SGC specimen air void content (optional).

10.1.8 Test specimen average height.

10.1.9 Test specimen average diameter.

10.1.10 Test specimen G_{mb}.

10.1.11 Test specimen air void content.

10.1.12 Test specimen end flatness for each end.

10.1.13 Test specimen end perpendicularity for each end.

10.1.14 Remarks concerning deviations from this standard practice.

11. KEYWORDS

11.1 Gyratory compaction; performance test specimens.

APPENDIXES

(Nonmandatory Information)

X1. METHOD FOR ACHIEVING A TARGET AIR VOID CONTENT

X1.1. *Purpose*:

X1.1.1. This appendix presents a procedure for estimating the mass of HMA required to produce test specimens at a target air void content. It was developed to reduce the number of trial specimens needed to obtain a target air void content for a specific mixture.

X1.1.2. This procedure can be used with either plant-produced or laboratory-prepared HMA.

X1.2. *Summary*:

X1.2.1. Trial test specimens are prepared as described in this standard practice from SGC specimens produced with a standard mass of 6650 g and compacted to a standard height of 170 mm.

X1.2.2. Based on the air void content of the trial specimens, the mass of HMA required to produce test specimens at a target air void content is estimated using a regression equation. Background information regarding the regression equation is presented in Section X1.4.

X1.2.3. To use this method, it is critical that all SGC specimens are prepared to a standard height of 170 mm. The approach described in Section X1.4 can be used to develop a similar equation for other SGC specimen heights.

X1.3. *Procedure*:

X1.3.1. Prepare the first and second trial test specimens following this standard practice from SGC specimens produced with a standard mass of 6650 g and compacted to a standard height of 170 mm.

X1.3.2. Determine the air void content of the first and second trial test specimens.

X1.3.3. Calculate the average air void content of the two specimens, and designate this value as Va_s.

X1.3.4. Estimate the mass of HMA, W_t, required to produce test specimens with a target air void content of Va_t using Equation X1.1.

$$W_t = 7175 - (525)\frac{Va_t}{Va_s} \quad (X1.1)$$

where:

W_t = the estimated mass of HMA required to produce a SGC specimen for a test specimen with a target air void content of Va_t, g;

Va_t = the target air void content for the test specimen, % by volume; and

Va_s = the test specimen air void content produced with a gyratory mass of 6650 g, % by volume.

X1.3.5. Prepare the third trial test specimen following this standard practice from a SGC specimen produced with the target mass estimated in Section X1.3.4 and compacted to the standard height of 170 mm.

X1.3.6. Determine the air void content of the third trial test specimen.

X1.3.7. If the air void content of the third trial test specimen is within 0.5 percent of the target air void content, use the mass determined in Section X1.3.4 as the target mass for test specimen production.

X1.3.8. If the air void content of the third trial test specimen is not within 0.5 percent of the target air void content, prepare the fourth trial specimen using 50 g less than the mass calculated in Section X1.3.4 and the fifth trial test specimen using 50 g more than the mass calculated in Section X1.3.4.

X1.3.9. Determine the air void content of the fourth and fifth trial test specimens.

X1.3.10. Plot the air void content of the third, fourth, and fifth trial test specimens on the *y* axis versus the mass of HMA used to prepare the SGC specimen on the *x* axis, and draw the best-fit line through the three data points.

X1.3.11. From the best-fit line, determine the mass of HMA needed to produce a test specimen with the target air void content.

X1.3.12. Use the mass determined in Section X1.3.11 as the target mass for test specimen production.

X1.4. *Background*:

X1.4.1. The method described in this appendix was developed by the Arizona State University during NCHRP 9-19. It is based on analysis of 38 different mixtures, where test specimens were prepared to varying target air void contents representative of *in situ* conditions.

X1.4.2. For a given mixture, when SGC specimens are prepared to a specific height, the relationship between the HMA mass used to prepare the SGC specimen and the air void content of the test specimens was found to be linear as provided in Equation X1.2 as follows:

$$Va = I + S(W) \quad (X1.2)$$

where:

Va = the test specimen air void content, % by volume;

W = the mass of HMA used to produce the SGC specimen;

I = the intercept of the regression line; and

S = the slope of the regression line.

X1.5. When a wide range of mixtures is considered, the intercepts and slopes for individual mixtures were also found to be linearly related as provided in Equation X1.3 as follows:

$$I = -C(S) \tag{X1.3}$$

where:

I = the intercept of the individual mixture regression lines;

S = the slope of the individual mixture regression lines; and

C = a constant.

X1.6. In the NCHRP 9-19 research, the constant, *C*, was found to be 7175 for SGC specimens prepared to a standard height of 170 mm. Substituting this constant into Equation X1.3, then substituting Equation X1.3 into Equation X1.2 and simplifying, yields an equation relating the air void content of the test specimen to the mass of HMA used to prepare the SGC specimen to the standard height of 170 mm as provided in Equation X1.4 as follows:

$$Va = S(W - 7175) \tag{X1.4}$$

X1.7. If SGC specimens are compacted using a standard mass, W_s, and the air void contents for the resulting test specimens are determined to be Va_s, then Equation X1.4 can be solved for the slope as provided in Equation X1.5 as follows:

$$S = \frac{Va_s}{W_s - 7175} \tag{X1.5}$$

where:

Va_s = the test specimen air void content produced with an SGC mass of W_s, % by volume;

W_s = the mass of HMA used to produce the SGC specimen, g; and

S = the slope of the regression line.

X1.8. Using the slope from Equation X1.5, the target SGC specimen mass, W_t, required to produce a test specimen with a specific air void content, Va_t, can be estimated by substituting Equation X1.5 into Equation X1.4 and simplifying as provided in Equation X1.6 as follows:

$$W_t = 7175 + \frac{Va_t}{Va_s}(W_s - 7175) \tag{X1.6}$$

where:

W_t = the estimated mass of HMA required to produce an SGC specimen for a test specimen with a target air void content of Va_t, g;

Va_t = the target air void content for the test specimen;

Va_s = the test specimen air void content produced with an SGC mass of W_s, % by volume; and

W_s = the mass of HMA used to produce the SGC specimen.

X1.9. For a standard HMA mass of 6650 g, which was the average mass used in the NCHRP 9-19 study, Equation X1.6 reduces to the following:

$$W_t = 7175 - (525)\frac{Va_t}{Va_s} \qquad (X1.7)$$

where:

W_t = the estimated mass of HMA required to produce an SGC specimen for a test specimen with a target air void content of Va_t, g;

Va_t = the target air void content for the test specimen;

Va_s = the test specimen air void content produced with an SGC mass of W_s, % by volume; and

W_s = the mass of HMA used to produce the SGC specimen.

X2. METHOD FOR ASSESSING TEST SPECIMEN UNIFORMITY

X2.1. *Purpose*:

X2.1.1. This appendix presents a procedure for assessing the uniformity of the air void content in test specimens produced using this standard practice.

X2.1.2. The approach tests the significance of the difference in mean G_{mb} between the top and bottom third of the specimen relative to the middle third.

X2.1.3. The procedure can be used to determine the height for preparing SGC specimens with a specific SGC to minimize within-sample variations in air voids.

X2.2. *Summary*:

X2.2.1. Three test specimens are prepared as described in this standard practice from SGC specimens produced with the same mass and compacted to the same height.

X2.2.2. The test specimens are cut into three slices of equal thickness and the G_{mb} of each slice is determined.

X2.2.3. A statistical hypothesis test is conducted to determine the significance of the difference in the mean G_{mb} of the top and bottom slices relative to the middle third.

X2.3. *Procedure*:

X2.3.1. Prepare three test specimens following this standard practice to a target air void content of 5.5 percent. All three specimens shall have air void contents between 5.0 and 6.0 percent.

X2.3.2. Label the top, middle, and bottom third of each specimen; then saw the specimens into three slices of equal thickness.

X2.3.3. Determine the G_{mb} of each of the nine test section slices in accordance with T 166 for dense- and gap-graded HMA or T 269 for open-graded HMA.

X2.3.4. Assemble a summary table of the G_{mb} data where each column contains data for a specific slice and each row contains the data from a specific core.

X2.3.5. For each column, compute the mean and variance of the G_{mb} measurements using Equations X2.1 and X2.2 as follows:

$$\bar{y} = \frac{\sum_{i=1}^{3} y_i}{3} \qquad (X2.1)$$

$$s^2 = \frac{\sum_{i=1}^{3} \left(y_i - \bar{y}\right)^2}{2} \qquad (X2.2)$$

where:

$\bar{y}$ = the mean of the G_{mb} of the three slices;

s^2 = the variance of the G_{mb} of the slices; and

y_i = the measured G_{mb} of each slice.

X2.3.6. *Statistical Comparison of Means*—Compare the mean G_{mb} of the top and bottom slices to the middle slice using the hypothesis tests described below. In the descriptions below, the subscripts *t*, *m*, and *b* refer to the top, middle, and bottom slices, respectively.

X2.3.6.1. Check the top slice relative to the middle slice.

Null Hypothesis:

The mean G_{mb} of the top slice equals the mean G_{mb} of the middle slice, $\mu_t^2 = \mu_m^2$.

Alternative Hypothesis:

The mean G_{mb} of the top slice is not equal to the mean G_{mb} of the middle slice, $\mu_t^2 \neq \mu_m^2$.

Test Statistic:

$$t = \frac{\left(\bar{y}_t - \bar{y}_m\right)}{0.8165\left(s\right)} \qquad (X2.3)$$

where:

$$s = \sqrt{\frac{s_t^2 + s_m^2}{2}}$$

where:

$\bar{y}_t$ = the computed mean for the top slices;

$\bar{y}_m$ = the computed mean for the middle slices;

s_t^2 = the computed variance for the top slices; and

s_m^2 = the computed variance for the middle slices.

Region of Rejection:

For the sample sizes specified, the absolute value of the test statistic must be less than 2.78 to conclude that G_{mb} of the top and middle slices are equal.

X2.3.6.2. Check the bottom slice relative to the middle slice.

Null Hypothesis:

The mean G_{mb} of the bottom slice equals the mean G_{mb} of the middle slice, $\mu_b{}^2 = \mu_m{}^2$.

Alternative Hypothesis:

The mean G_{mb} of the bottom slice is not equal to the mean G_{mb} of the middle slice, $\mu_b{}^2 \neq \mu_m{}^2$.

Test Statistic:

$$t = \frac{\left(\bar{y}_b - \bar{y}_m\right)}{0.8165\left(s\right)} \qquad (X2.4)$$

where:

$$s = \sqrt{\frac{s_b{}^2 + s_m{}^2}{2}}$$

where:

$\bar{y}_b$ = the computed mean for the bottom slices;

$\bar{y}_m$ = the computed mean for the middle slices;

$s_b{}^2$ = the computed variance for the bottom slices; and

$s_m{}^2$ = the computed variance for the middle slices.

Region of Rejection:

For the sample sizes specified, the absolute value of the test statistic must be less than 2.78 to conclude that G_{mb} of the bottom and middle third slices are equal.

X2.4. *Analysis*:

X2.4.1. Significant differences in the G_{mb} of the top and bottom slices relative to the middle third indicate a systematic variation in density within the specimen.

X2.4.2. Specimens with differences for the top or bottom slices relative to the middle slices on the order of 0.025 have performed satisfactorily in the dynamic modulus, flow number, flow time, and continuum damage fatigue tests.

X2.4.3. Changing the height of the SGC specimen can improve the uniformity of the density in the test specimen.

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[1] This provisional practice was adopted and first published in 2009.

[2] This provisional practice was developed from NCHRP Project 9-29, Simple Performance Tester for Superpave Mix Design. The name of the device has been changed to the “Asphalt Mixture Performance Tester.” To obtain research documents, refer to the Simple Performance Tester.

Standard Practice for

Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)

AASHTO Designation: PP 61-10[1,2]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)

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1. SCOPE

1.1 This practice describes testing and analysis for developing a dynamic modulus master curve for hot mix asphalt (HMA) using the Asphalt Mixture Performance Tester (AMPT). This practice is intended for dense- and gap-graded mixtures with nominal-maximum aggregate sizes up to 37.5 mm. This practice accounts for the temperature limitations of the AMPT and provides guidance to the user for the selection of appropriate test temperatures.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- PP 60, Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)
- *Mechanistic-Empirical Pavement Design Guide* (MEPDG)

2.2 *Other Publication*:

- Equipment Specification for the Simple Performance Test System, Version 3.0, Prepared for National Cooperative Highway Research Program (NCHRP), October 16, 2007.

3. TERMINOLOGY

3.1 *dynamic modulus master curve*—a composite curve constructed at a reference temperature by shifting dynamic modulus data from various temperatures along the “log frequency” axis.

3.2 *reduced frequency*—the computed frequency at the reference temperature, equivalent to the actual loading frequency at the test temperature.

3.3 *reference temperature*—the temperature at which the master curve is constructed.

3.4 *shift factor*—shift in frequency associated with a shift from a test temperature to the reference temperature.

4. SUMMARY OF PRACTICE

4.1 This practice describes the testing required using the AMPT and the analysis needed to develop a dynamic modulus master curve for HMA. It involves collecting dynamic modulus test data at specified temperatures and loading rates, then manipulating the test data to obtain a continuous function describing the dynamic modulus as a function of frequency and temperature.

5. SIGNIFICANCE AND USE

5.1 Dynamic modulus master curves can be used for mixture evaluation and for characterizing the modulus of HMA for mechanistic-empirical pavement design.

6. APPARATUS

6.1 *Specimen Fabrication Equipment*—For fabricating dynamic modulus test specimens as described in PP 60.

6.2 *Dynamic Modulus Test System*—Meeting the requirements of the equipment specification for the Simple Performance Test (SPT) System, Version 3.0.

6.3 *Analysis Software*—Capable of performing numerical optimization of non-linear equations.

Note 1—The “Solver” tool included in Microsoft Excel® is capable of performing the numerical optimization required by this practice.

7. HAZARDS

7.1 This practice and associated standards involve handling of hot asphalt binder, aggregates, and HMA. It also includes the use of sawing and coring machinery and servo-hydraulic testing equipment. Use standard safety precautions, equipment, and clothing when handling hot materials and operating machinery.

8. STANDARDIZATION

8.1 Items associated with this practice that require calibration or verification are included in the documents referenced in Section 2. Refer to the pertinent section of the referenced documents for information concerning calibration or verification.

9. DYNAMIC MODULUS TEST DATA

9.1 *Test Specimen Fabrication*:

9.1.1 Prepare at least two test specimens at the target air void content ±0.5 percent and with the aging condition in accordance with PP 60. Use Table 1 to select an appropriate number of specimens based on the uncertainty that can be tolerated in the analysis.

Note 2—The coefficient of variation for properly conducted dynamic modulus tests is approximately 13 percent. The coefficient of variation of the mean dynamic modulus for tests on multiple specimens is given in Table 1.

Table 1—Coefficient of Variation for the Mean of Dynamic Modulus Test on Replicate Specimens

Number of Specimens	Coefficient of Variation for Mean
2	9.2
3	7.5
4	6.5
5	5.8
6	5.3
7	4.9
8	4.6
9	4.3
10	4.1

9.1.2 Record the following volumetric properties for each test specimen:

- Voids in the mineral aggregate (VMA)
- Voids filled with asphalt (VFA)

9.2 *Testing Conditions*:

9.2.1 Measure the dynamic modulus and phase angle of each specimen using the dynamic modulus test system at each of the temperatures and loading frequencies given in Table 2. Begin testing at the lowest temperature and highest frequency. Test all frequencies in descending order before moving to the next highest temperature.

Table 2—Recommended Testing Temperatures and Loading Frequencies

PG 58-XX and softer		PG 64-XX and PG 70-XX		PG 76-XX and stiffer	
Temperature, °C	Loading Frequencies, Hz	Temperature, °C	Loading Frequencies, Hz	Temperature, °C	Loading Frequencies, Hz
4	10, 1, 0.1	4	10, 1, 0.1	4	10, 1, 0.1
20	10, 1, 0.1	20	10, 1, 0.1	20	10, 1, 0.1
35	10, 1, 0.1, and 0.01	40	10, 1, 0.1, and 0.01	45	10, 1, 0.1, and 0.01

Note 3—The dynamic modulus testing may be performed with or without confinement. The same confining stress conditions must be used at all temperatures and loading rates. An unconfined dynamic modulus master curve is typically used in mechanistic-empirical pavement analysis methods.

9.2.2 Accept only test data meeting the data quality statistics given in Table 3. Repeat tests as necessary to obtain test data meeting the data quality statistics requirements.

Table 3—Data Quality Statistics Requirements

Data Quality Statistic	Limit
Load standard error	10%
Deformation standard error	10%
Deformation uniformity	30%
Phase uniformity	3 degrees

Note 4—The data quality statistics in Table 3 are reported by the AMPT software. If a dynamic modulus test system other than the AMPT is used, refer to the equipment specification for the SPT

System, Version 3.0, for algorithms for the computation of dynamic modulus, phase angle, and data quality statistics.

9.3 *Dynamic Modulus Data Summary*:

9.3.1 Prepare a summary table of the dynamic modulus data. At each temperature and frequency, compute the following:

1. Average dynamic modulus;
2. Average phase angle;
3. Coefficient of variation of the dynamic modulus; and
4. Standard deviation of the phase angle.

Figure 1 presents an example summary data sheet.

Conditions		Specimen 1		Specimen 2		Specimen 3					
Temperature, °C	Frequency, Hz	Modulus, ksi	Phase Angle, degree	Modulus, ksi	Phase Angle, degree	Modulus, ksi	Phase Angle, degree	Average Modulus, ksi	Modulus CV, %	Average Phase Angle, degree	Std Dev Phase Angle, degree
4	0.1	1170.9	18.8	1214.8	19.6	1443.2	18.5	1276.3	11.5	19.0	0.5
4	1	1660.8	12.0	1743.5	12.5	2027.0	11.6	1810.5	10.6	12.0	0.4
4	10	2107.3	8.1	2245.6	8.4	2596.1	8.2	2316.3	10.9	8.2	0.2
20	0.1	259.1	33.9	289.9	33.5	315.2	34.6	288.1	9.8	34.0	0.6
20	1	604.1	27.4	657.3	26.8	711.2	27.0	657.5	8.1	27.1	0.3
20	10	1065.1	21.0	1181.5	18.8	1231.4	19.8	1159.3	7.4	19,9	1.1
40	0.01	17.2	18.6	16.5	18.8	18.8	19.2	17.5	6.7	18.9	0.3
40	0.1	26.5	24.8	26.4	26.1	30.6	26.0	27.8	8.6	25.6	0.7
40	1	62.9	31.5	63.9	32.1	74.5	32.7	67.1	9.6	32.1	0.6
40	10	180.1	35.2	197.6	35.1	220.6	35.2	199.4	10.2	35.2	0.1

Figure 1—Example Dynamic Modulus Summary Sheet

10. DATA ANALYSIS

10.1 *Dynamic Modulus Master Curve Equation*:

10.1.1 *General Form*—The general form of the dynamic modulus master curve is a modified version of the dynamic modulus master curve equation included in the *Mechanistic-Empirical Pavement Design Guide* (MEPDG).

$$\log\left|E^*\right| = \delta + \frac{\left(\text{Max} - \delta\right)}{1 + e^{\beta + \gamma \log f_r}} \qquad (1)$$

where:

$\left|E^*\right|$ = the dynamic modulus, psi;

δ, β, and γ = the fitting parameters;

Max = the limiting maximum modulus, psi; and

f_r = the reduced frequency, Hz.

10.1.2 *Reduced Frequency*—The reduced frequency in Equation 1 is computed using the Arrhenius equation.

$$\log f_r = \log f + \frac{\Delta E_a}{19.14714}\left(\frac{1}{T} - \frac{1}{T_r}\right) \qquad (2)$$

where:

f_r = the reduced frequency at the reference temperature, Hz;

f = the loading frequency at the test temperature, Hz;

ΔE_a = the activation energy (treated as a fitting parameter);

T = the test temperature, °K; and

T_r = the reference temperature, °K.

10.1.3 *Final Form*—The final form of the dynamic modulus master curve equation is obtained by substituting Equation 2 into Equation 1.

$$\log\left|E^*\right| = \delta + \frac{(\text{Max} - \delta)}{1 + e^{\beta + \gamma\left\{\log f + \frac{\Delta E_a}{19.14714}\left[\left(\frac{1}{T}\right) - \left(\frac{1}{T_r}\right)\right]\right\}}} \qquad (3)$$

10.2 *Shift Factors*—The shift factors at each temperature are given in Equation 4 as follows:

$$\log\left[a(T)\right] = \frac{\Delta E_a}{19.14714}\left(\frac{1}{T} - \frac{1}{T_r}\right) \qquad (4)$$

where:

$a(T)$ = the shift factor at temperature *T*;

ΔE_a = the activation energy (treated as a fitting parameter);

T = the test temperature, °K; and

T_r = the reference temperature, °K.

10.3 *Limiting Maximum Modulus*—The maximum limiting modulus is estimated from HMA volumetric properties using the Hirsch model (Christensen et al., 2003) and a limiting binder modulus of 1 GPa as provided in Equations 5 and 6.

$$\left|E^*\right|_{\max} = P_c\left[4,200,000\left(1 - \frac{VMA}{100}\right) + 435,000\left(\frac{VFA \times VMA}{10,000}\right) + \frac{1 - P_c}{\frac{\left(1 - \frac{VMA}{100}\right)}{4,200,000} + \frac{VMA}{435,000(VFA)}}\right] \qquad (5)$$

where:

$$P_c = \frac{\left(20 + \frac{435,000(VFA)}{VMA}\right)^{0.58}}{650 + \left(\frac{435,000(VFA)}{VMA}\right)^{0.58}} \qquad (6)$$

$\left|E^*\right|_{\max}$ = the limiting maximum HMA dynamic modulus, psi;

VMA = the voids in the mineral aggregate, %; and

VFA = the voids filled with asphalt, %.

10.4 *Fitting the Dynamic Modulus Master Curve*:

10.4.1 Estimate Limiting Maximum Modulus:

10.4.1.1 Using the average VMA and VFA of the specimens tested, compute the limiting maximum modulus using Equations 5 and 6.

10.4.1.2 Compute the logarithm of the limiting maximum modulus, and designate this value as “max.”

10.4.2 Select the Reference Temperature:

10.4.2.1 Select the reference temperature for the dynamic modulus master curve, and designate this value as T_r. Usually 20°C (293.15°K) is used as the reference temperature.

10.4.3 Perform Numerical Optimization:

10.4.3.1 Substitute “max,” computed in Section 10.4.1.2, and T_r, selected in Section 10.4.2.1, into Equation 3.

10.4.3.2 Determine the four fitting parameters of Equation 3 (δ, β, γ, and ΔE_a) using numerical optimization. The optimization can be performed using the “Solver” function in Microsoft Excel®. This calculation is performed by a spreadsheet to compute the sum of the squared errors between the logarithm of the average measured dynamic moduli at each temperature/frequency combination and the values predicted by Equation 3. The “Solver” function is used to minimize the sum of the squared errors by varying the fitting parameters in Equation 3. The following initial estimates are recommended: $\delta = 0.5$, $\beta = -1.0$, $\gamma = -0.5$, and $\Delta E_a = 200\,000$.

10.4.4 Compute “Goodness of Fit” Statistics:

10.4.4.1 Compute the standard deviation of the logarithm of the average measured dynamic modulus values for each temperature/frequency combination. Designate this value as S_y.

10.4.4.2 Compute the standard error of estimate using Equation 7.

$$S_e = \left[\frac{1}{6} \sum_{1}^{10} \left(\log \left| \hat{E}^* \right|_i - \log \left| E^* \right|_i \right)^2 \right]^{0.5} \qquad (7)$$

where:

S_e = the standard error of estimate;

$\log \left| \hat{E}^* \right|_i$ = the value predicted by Equation 3 after optimization for each temperature/frequency combination; and

$\log \left| E^* \right|_i$ = the logarithm of the average measured dynamic modulus for each temperature/frequency combination.

10.4.4.3 Compute the explained variance, R^2, using Equation 8.

$$R^2 = 1 - \frac{8{S_e}^2}{9{S_y}^2} \qquad (8)$$

where:

R^2 = the explained variance;

S_e = the standard error of estimate from Equation 7; and

S_y = the standard deviation of the logarithm of the average dynamic modulus values.

10.5 *Evaluate Fitted Master Curve*:

10.5.1 The ratio of S_e to S_y should be less than 0.05.

10.5.2 The explained variance should exceed 0.99.

10.6 *Determine AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) Inputs*:

10.6.1 Substitute the logarithm of the limiting maximum modulus (max) determined in Section 10.4.1.2 and the fitting parameters (δ, β, γ, and ΔE_a) determined in Section 10.4.3.2 into Equation 3, and compute the dynamic modulus at the following temperatures and loading frequencies. A total of 30 dynamic modulus values will be calculated.

Temperatures, °C	Frequencies, Hz
–10, 4.4, 21.1, 37.8, and 54.4 (14, 40, 70, 100, and 130)	25, 10, 5, 1, 0.5, and 0.1

11. REPORT

11.1 *Report the following*:

11.1.1 Mixture identification.

11.1.2 Measured dynamic modulus and phase angle data for each specimen at each temperature/frequency combination.

11.1.3 Average measured dynamic modulus and phase angle at each temperature/frequency combination.

11.1.4 Coefficient of variation of the measured dynamic modulus data at each temperature/frequency combination.

11.1.5 Standard deviation of the measured phase angle data at each temperature/frequency combination.

11.1.6 VMA and VFA of each specimen tested.

11.1.7 Average VMA and VFA for the specimens tested.

11.1.8 Reference temperature.

11.1.9 Parameters of the fitted master curve (Max, δ, β, γ, and ΔE_a).

11.1.10 “Goodness of fit” statistics for the fitted master curve (S_e, S_y, S_e/S_y, R^2).

11.1.11 Plot of the fitted dynamic modulus master curve as a function of reduced frequency showing average measured dynamic modulus data.

11.1.12 Plot of shift factors as a function of temperature.

11.1.13 Plot of average phase angle as a function of reduced frequency.

11.1.14 Tabulated temperature, frequency, and dynamic modulus for input into MEPDG.

12. KEYWORDS

12.1 Dynamic modulus; master curve; phase angle.

13. REFERENCES

13.1 Applied Research Associates, Inc., ERES Consultants Division. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*. Final Report prepared for the National Cooperative Highway Research Program, March 2004.

13.2 Christensen, D. W., T. K. Pellinen, and R. F. Bonaquist. Hirsch Model for Estimating the Modulus of Asphalt Concrete. *Journal of the Association of Asphalt Paving Technologists*, Vol. 72, 2003.

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[1] This provisional practice was adopted and first published in 2009. Revised in 2010.

[2] This provisional practice was developed from NCHRP Project 9-29, Simple Performance Tester for Superpave Mix Design. The name of the device has been changed to the “Asphalt Mixture Performance Tester.” To obtain research documents, refer to the Simple Performance Tester.

Standard Practice for

Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA)

AASHTO Designation: PP 62-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA)

AASHTO Designation: PP 62-10[1]

1. SCOPE

1.1 This practice describes testing and analysis for developing a dynamic modulus master curve for hot mix asphalt (HMA). This practice is intended for dense- and gap-graded mixtures with nominal-maximum aggregate sizes up to 37.5 mm. This practice is intended for use with TP 62 and addresses the wide range of test temperatures and frequencies specified therein.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- PP 60, Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)
- R 35, Superpave Volumetric Design for Hot Mix Asphalt (HMA)
- TP 62, Determining Dynamic Modulus of Hot Mix Asphalt (HMA)
- *Mechanistic-Empirical Pavement Design Guide* (MEPDG)

3. TERMINOLOGY

3.1 *dynamic modulus master curve*—a composite curve constructed at a reference temperature by shifting dynamic modulus data from various temperatures along the “log frequency” axis.

3.2 *reduced frequency*—the computed frequency at the reference temperature, equivalent to the actual loading frequency at the test temperature.

3.3 *reference temperature*—the temperature at which the master curve is constructed.

3.4 *shift factor*—the shift in frequency associated with a shift from a test temperature to the reference temperature.

4. SUMMARY OF PRACTICE

4.1 This practice describes the testing and analysis needed to develop a dynamic modulus master curve for HMA. It involves collecting dynamic modulus test data at specified temperatures and loading rates, then manipulating the test data to obtain a continuous function describing the dynamic modulus as a function of frequency and temperature.

5. SIGNIFICANCE AND USE

5.1 Dynamic modulus master curves can be used for mixture evaluation and for characterizing the modulus of HMA for mechanistic-empirical pavement design.

6. APPARATUS

6.1 *Specimen Fabrication Equipment*—For fabricating dynamic modulus test specimens as described in PP 60.

6.2 *Dynamic Modulus Test System*—Meeting the requirements of TP 62.

6.3 *Analysis Software*—Capable of performing numerical optimization of non-linear equations.

Note 1—The “Solver” tool included in Microsoft Excel® is capable of performing the numerical optimization required by this practice.

7. HAZARDS

7.1 This practice and associated standards involve handling of hot asphalt binder, aggregates, and HMA. It also includes the use of sawing and coring machinery and servo-hydraulic testing equipment. Use standard safety precautions, equipment, and clothing when handling hot materials and operating machinery.

8. STANDARDIZATION

8.1 Items associated with this practice that require calibration or verification are included in the documents referenced in Section 2. Refer to the pertinent section of the referenced documents for information concerning calibration or verification.

9. DYNAMIC MODULUS TEST DATA

9.1 *Test Specimen Fabrication*:

9.1.1 Prepare at least two test specimens at the target air void content ±0.5 percent and with the aging condition in accordance with PP 60. Use Table 1 to select an appropriate number of specimens based on the uncertainty that can be tolerated in the analysis.

Note 2—The coefficient of variation for properly conducted dynamic modulus tests is approximately 13 percent. The coefficient of variation of the mean dynamic modulus for tests on multiple specimens is given in Table 1.

Table 1—Coefficient of Variation for the Mean of Dynamic Modulus Test on Replicate Specimens

Number of Specimens	Coefficient of Variation for Mean
2	9.2
3	7.5
4	6.5
5	5.8
6	5.3
7	4.9
8	4.6
9	4.3
10	4.1

9.1.2 Record the following volumetric properties for each test specimen:

- Air void content
- Binder content
- Voids in the mineral aggregate (VMA)
- Voids filled with asphalt (VFA)

9.1.2.1 Refer to R 35 for methods for computing volumetric properties.

9.2 *Testing Conditions*:

9.2.1 Determine the dynamic modulus and phase angle for each specimen as specified in TP 62.

9.2.2 Accept only test data meeting the data quality statistics given in Table 2. Repeat tests as necessary to obtain test data meeting the data quality statistics requirements.

Table 2—Data Quality Statistics Requirements

Data Quality Statistic	Limit
Load standard error	10%
Deformation standard error	10%
Deformation uniformity	30%
Phase uniformity	3 degrees

Note 3—Algorithms for computation of the data quality statistics are given in TP 62.

9.3 *Dynamic Modulus Data Summary*:

9.3.1 Prepare a summary table of the dynamic modulus data. At each temperature and frequency, compute the following:

1. Average dynamic modulus;
2. Average phase angle;
3. Coefficient of variation of the dynamic modulus; and
4. Standard deviation of the phase angle.

Figure 1 presents an example of a summary data sheet.

Conditions		Specimen 1		Specimen 2		Modulus		Phase Angle	
Temperature, °F	Frequency, Hz	Modulus, ksi	Phase Angle, degree	Modulus, ksi	Phase Angle, degree	Average, ksi	CV, %	Average, degree	Std Dev, degree
14	25	3100.0	6.1	3320.0	9.1	3210.0	4.8	7.6	2.1
14	10	3080.0	5.6	2990.0	4.2	3035.0	2.1	4.9	0.9
14	5	2970.0	6.8	2930.0	7.9	2950.0	1.0	7.4	0.8
14	1	2700.0	7.1	2670.0	8.6	2685.0	0.8	7.9	1.1
14	0.5	2580.0	6.7	2540.0	8.9	2560.0	1.1	7.8	1.5
14	0.1	2080.0	9.6	2250.0	11.9	2165.0	5.6	10.8	1.6
40	25	2650.0	18.0	2410.0	19.3	2530.0	6.7	18.7	0.9
40	10	2430.0	13.2	2170.0	10.0	2300.0	8.0	11.6	2.3
40	5	2290.0	10.1	2070.0	9.6	2180.0	7.1	9.8	0.3
40	1	1890.0	12.4	1730.0	10.5	1810.0	6.3	11.4	1.3
40	0.5	1690.0	15.2	1630.0	12.9	1660.0	2.6	14.0	1.6
40	0.1	1360.0	17.6	1330.0	15.1	1345.0	1.6	16.4	1.8
70	25	1060.0	26.6	1220.0	29.4	1140.0	9.9	28.0	2.0
70	10	890.0	24.8	1010.0	27.0	950.0	8.9	25.9	1.5
70	5	763.0	26.3	856.0	27.6	809.0	8.1	27.0	0.9
70	1	514.0	28.3	573.0	28.8	543.5	7.7	28.5	0.4
70	0.5	420.0	25.2	492.0	26.4	456.0	11.2	25.8	0.8
70	0.1	270.0	36.1	317.0	36.6	293.5	11.3	36.4	0.4
100	25	308.0	36.4	416.0	39.6	362.0	21.1	38.0	2.2
100	10	240.0	34.8	308.0	36.7	274.0	17.5	35.8	1.4
100	5	192.0	34.5	232.0	35.7	212.0	13.3	35.1	0.8
100	1	111.0	34.6	132.0	35.0	121.5	12.2	34.8	0.3
100	0.5	87.5	32.9	104.0	34.2	95.8	12.2	33.5	0.9
100	0.1	55.3	34.6	64.0	35.7	59.7	10.3	35.2	0.8
130	25	90.7	40.1	109.0	41.1	99.9	13.0	40.6	0.7
130	10	64.0	35.0	78.0	34.6	71.0	13.9	34.8	0.3
130	5	50.9	32.3	59.0	32.5	55.0	10.4	32.4	0.2
130	1	31.4	27.9	36.1	28.8	33.8	9.8	28.4	0.7
130	0.5	25.7	26.0	30.1	26.9	27.9	11.2	26.4	0.6
130	0.1	18.7	26.8	20.2	27.6	19.5	5.5	27.2	0.5

Figure 1—Example Dynamic Modulus Summary Sheet

10. DATA ANALYSIS

10.1 *Dynamic Modulus Master Curve Equation*:

10.1.1 *General Form*—The general form of the dynamic modulus master curve is the sigmoid function included in the *Mechanistic-Empirical Pavement Design Guide* (MEPDG).

$$\log\left|E^*\right| = \delta + \frac{(\alpha)}{1+e^{\beta+\gamma\log f_r}} \qquad (1)$$

where:

$\left|E^*\right|$ = the dynamic modulus, psi;

α, β, δ, and γ = the fitting parameters; and

f_r = the reduced frequency, Hz.

10.1.2 *Reduced Frequency*—The reduced frequency in Equation 1 is computed using time-temperature shift factors. Several time temperature shift functions are available in the literature. This practice presents two shift factor equations: shift factors from the MEPDG and second-order polynomial.

10.1.2.1 MEPDG Shift Factors:

$$\log f_r = \log f + c\left(\log \eta - \log \eta_{T_R}\right) \qquad (2)$$

where:

f_r = the reduced frequency at the reference temperature;
f = the loading frequency at the test temperature;
c = a fitting coefficient;
η = the viscosity of the binder at the test temperature, cP;
T_R = the reference temperature, °R; and
η_{T_R} = the viscosity of the binder at the reference temperature, cP.

Viscosities in Equation 2 are determined using Equation 3 as follows:

$$\log \eta = 10^{\left[A + VTS \log(T)\right]} \qquad (3)$$

where:

η = the viscosity, cP;
A and *VTS* = the parameters of the binder viscosity-temperature susceptibility relationship; and
T = the test temperature, °R (°F + 459.67).

10.1.2.2 Second-Order Polynomial:

$$\log f_r = \log f + a_1\left(T_R - T\right) + a_2\left(T_R - T\right)^2 \qquad (4)$$

where:

f_r = the reduced frequency at the reference temperature;
f = the loading frequency at the test temperature;
a_1, a_2 = the fitting coefficients;
T_R = the reference temperature, °F; and
T = the test temperature, °F.

10.1.3 *Final Form*—The final form of the dynamic modulus master curve equation is obtained by substituting the selected shift factor relationship into Equation 1.

10.1.3.1 MEPDG Shift Factors:

$$\log\left|\hat{E}*\right| = \delta + \frac{(\alpha)}{1 + e^{\beta + \gamma\left\{\log f + c\left[10^{\left(A + VTS \log T\right)} - 10^{\left(A + VTS \log T_R\right)}\right]\right\}}} \qquad (5)$$

10.1.3.2 Second-Order Polynomial Shift Factors:

$$\log\left|\hat{E}^*\right| = \delta + \frac{(\alpha)}{1+e^{\beta+\gamma\left[\log f + a_1(T_R - T) + a_2(T_R - T)^2\right]}} \qquad (6)$$

10.1.4 Fitting the Dynamic Modulus Master Curve:

10.1.4.1 Select Reference Temperature:

Select the reference temperature for the dynamic modulus master curve, and designate this value as T_R. Usually 70°F is used as the reference temperature.

10.1.4.2 Perform Numerical Optimization:

Determine the fitting parameters of Equation 5 or 6 using numerical optimization. The optimization can be performed using the "Solver" function in Microsoft Excel®. This calculation is performed by a spreadsheet to compute the sum of the squared errors between the logarithm of the average measured dynamic moduli at each temperature/frequency combination and the values predicted by Equation 5 or 6. See Equation 7.

$$\sum \text{error}^2 = \sum_{1}^{n}\left(\log\left|\hat{E}^*\right|_i - \log\left|E^*\right|_i\right)^2 \qquad (7)$$

where:

$\sum \text{error}^2$ = the sum of squared errors;

n = the number of temperature/frequency combinations used in the testing;

$\log\left|\hat{E}^*\right|_i$ = the value predicted by Equation 5 or 6 for each temperature/frequency combination; and

$\log\left|E^*\right|_i$ = the logarithm of the average measured dynamic modulus for each temperature/frequency combination.

The "Solver" function is used to minimize the sum of the squared errors by varying the fitting parameters. Recommended initial estimates are listed in Table 3. Note that these estimates depend on the units used as shown in Table 3.

Table 3—Recommended Initial Estimates

MEPDG Shift Factors T_R = 529.67°R $\left\|E^*\right\|$ = ksi f = Hz		Polynomial Shift Factors T_R = 70°F $\left\|E^*\right\|$ = ksi f = Hz	
Fitting Parameter	Initial Estimate	Fitting Parameter	Initial Estimate
α	3.0	α	3.0
β	–1.0	β	–1.0
δ	0.5	δ	0.5
γ	–0.5	γ	–0.5
c	1.0	a_1	0.1
		a_2	0.0001

10.1.4.3 Compute “Goodness of Fit” Statistics:

Compute the standard deviation of the logarithm of the average measured dynamic modulus values for all temperature/frequency combinations. Designate this value as S_y.

$$S_y = \sqrt{\frac{\sum_{1}^{n}\left(\log\left|E^*\right|_i - \overline{\log\left|E^*\right|}\right)^2}{n-1}} \qquad (8)$$

where:

S_y = the standard deviation of the logarithm of the average measured data;

$\log\left|E^*\right|_i$ = the logarithm of the average measured dynamic modulus for each temperature/frequency combination;

$\log\left|E^*\right|_i$ = the logarithm of the average measured dynamic modulus for each temperature/frequency combination;

$\overline{\log\left|E^*\right|}$ = the average of the logarithm of the average measured dynamic moduli

= $\sum_{1}^{n}\frac{\log\left|E^*\right|_i}{n}$; and

n = the number of temperature/frequency combinations used in the testing.

Compute the standard error of estimate using Equation 7 as follows:

$$S_e = \left[\frac{1}{(n-p-1)}\sum_{1}^{n}\left(\log\left|\hat{E}^*\right|_i - \log\left|E^*\right|_i\right)^2\right]^{0.5} \qquad (9)$$

where:

S_e = the standard error of estimate;

n = the number of temperature/frequency combinations used in the testing;

p = the number of fitting parameters;

$\log\left|\hat{E}^*\right|_i$ = the value predicted by Equation 5 or 6 after optimization for each temperature/frequency combination; and

$\log\left|E^*\right|_i$ = the logarithm of the average measured dynamic modulus for each temperature/frequency combination.

Compute the explained variance, R^2, using Equation 10 as follows:

$$R^2 = 1 - \frac{(n-p-1)\,{S_e}^2}{(n-1)\,{S_y}^2} \qquad (10)$$

where:

R^2 = the explained variance;

n = the number of temperature/frequency combinations used in the testing;

p = the number of fitting parameters;

S_e = the standard error of estimate from Equation 9; and

S_y = the standard deviation of the logarithm of the average measured dynamic modulus values from Equation 8.

10.1.5 Evaluate Fitted Master Curve:

10.1.5.1 The ratio of S_e to S_y should be less than 0.05.

10.1.5.2 The explained variance should exceed 0.99.

11. REPORT

11.1 *Report the following*:

11.1.1 Mixture identification.

11.1.2 Measured dynamic modulus and phase angle data for each specimen at each temperature/frequency combination.

11.1.3 Average measured dynamic modulus and phase angle at each temperature/frequency combination.

11.1.4 Coefficient of variation of the measured dynamic modulus data at each temperature/frequency combination.

11.1.5 Standard deviation of the measured phase angle data at each temperature/frequency combination.

11.1.6 Air voids, binder content, VMA, and VFA of each specimen tested.

11.1.7 Average air voids, average binder content, average VMA, and average VFA for the specimens tested.

11.1.8 Reference temperature.

11.1.9 Parameters of the fitted master curve.

11.1.10 "Goodness of fit" statistics for the fitted master curve (S_e, S_y, S_e/S_y, R^2).

11.1.11 Plot of the fitted dynamic modulus master curve as a function of reduced frequency showing average measured dynamic modulus data.

11.1.12 Plot of shift factors as a function of temperature.

11.1.13 Plot of average phase angle as a function of reduced frequency.

12. KEYWORDS

12.1 Dynamic modulus; master curve; phase angle.

13. REFERENCES

13.1 Applied Research Associates, Inc., ERES Consultants Division. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*. Final Report prepared for the National Cooperative Highway Research Program, March 2004.

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[1] This provisional standard was adopted and first published in 2009. Revised in 2010.

Standard Practice for

Determination of Long-Term Strength for Geosynthetic Reinforcement

AASHTO Designation: PP 66-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Determination of Long-Term Strength for Geosynthetic Reinforcement

AASHTO Designation: PP 66-10

INTRODUCTION

Through this protocol, the long-term strength and stiffness of geosynthetic reinforcements can be determined. This protocol contains test and evaluation procedures to determine reduction factors for installation damage, creep, and chemical/biological durability, as well as the method to combine these factors to determine the long-term strength. The long-term strength and stiffness values determined from this protocol can be used as input values for geosynthetic structure designs conducted in accordance with the *AASHTO LRFD Bridge Design Specifications* and related FHWA design guidelines. The long-term strength and stiffness values determined from this protocol can also be compared to the required design strength and stiffness values provided in the contract for the geosynthetic structure(s) in question to determine whether the selected product meets the contract requirements. This protocol can be used for initial product qualification or acceptance (e.g., for inclusion in a Qualified Products List), or for quality assurance (QA) to facilitate periodic review of products for which the long-term strength has been previously determined using this standard practice.

1. SCOPE

1.1 This protocol has been developed to address polypropylene (PP), polyethylene (PE or HDPE), and polyester (PET) geosynthetics (i.e., geotextiles and geogrids). For other geosynthetic polymers [(e.g., polyamide (PA) or polyvinyl alcohol (PVA)], the installation damage and creep protocols provided herein are directly applicable. While the chemical and biological durability procedures and criteria provided herein may also be applicable to other polymers (for example, hydrolysis testing as described in Annex C is likely applicable to PA and PVA geosynthetics), additional investigation will be required to establish a detailed protocol and acceptance criteria for these other polymers. These other polymers may be considered for evaluation using this protocol once modifications to the chemical/biological durability aspects of this protocol have been developed and are agreed upon by the approval authority.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not propose to address all safety problems associated with its usage. It is the duty and responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Note 1—The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards and Specifications*:

- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

- *AASHTO LRFD Bridge Design Specifications*
- *Standard Specifications for Highway Bridges*, 17th Edition

2.2 *ASTM Standards*:

- D 1248, Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable
- D 1557, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft (2,700 kN-m/m))
- D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D 2837, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
- D 3045, Standard Practice for Heat Aging of Plastics Without Load
- D 3083-89, Standard Specification for Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining (Withdrawn 1998)
- D 3418, Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry
- D 3895, Standard Test Method for Oxidative-Induction Time of Polyolefins by Differential Scanning Calorimetry
- D 4101, Standard Specification for Polypropylene Injection and Extrusion Materials
- D 4354, Standard Practice for Sampling of Geosynthetics for Testing
- D 4355, Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus
- D 4595, Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method
- D 4603, Standard Test Method for Determining Inherent Viscosity of Poly(Ethylene Terephthalate) (PET) by Glass Capillary Viscometer
- D 4873, Standard Guide for Identification, Storage, and Handling of Geosynthetic Rolls and Samples
- D 5261, Standard Test Method for Measuring Mass per Unit Area of Geotextiles
- D 5262, Standard Test Method for Evaluating the Unconfined Tension Creep and Creep Rupture Behavior of Geosynthetics
- D 5322, Standard Practice for Laboratory Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids
- D 5818, Standard Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics
- D 5885, Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry
- D 6637, Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method
- D 6992, Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method

2.3 *Other Standards*:

- ENV ISO 13438:1999, Geotextiles and geotextile-related products—screening test method for determining the resistance to oxidation
- GRI-GG1, Single-Rib Test
- GRI-GG7, Carboxyl End Group Content of PET Yarns

- GRI-GG8, Determination of the Number Average Molecular Weight of PET Yarns Based on a Relative Viscosity Value
- ISO 10319:1993, Geotextiles—Wide-Width Tensile Test
- ISO/DIS 10722:2007, Procedure for simulating damage during installation. Part 1: Installation in granular materials
- ISO/FDIS 9080:2003, Plastic piping and ducting systems—Determination of long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation
- WSDOT Test Method T 925, Geogrid Transverse Flexibility Test

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3. TERMINOLOGY

3.1 *apertures*—the open spaces formed between the interconnected network of longitudinal and transverse ribs of a geogrid.

3.2 d_{50}—the grain size at 50 percent passing by weight for the backfill.

3.3 *effective design temperature*—the temperature that is halfway between the average yearly air temperature and the normal daily air temperature for the warmest month at the geosynthetic structure site.

3.4 *HDPE*—high-density polyethylene.

3.5 *hydrolysis*—the reaction of water molecules with the polymer material, resulting in polymer chain scission, reduced molecular weight, and strength loss.

3.6 *in-isolation testing*—geosynthetic testing in which the specimen is surrounded by air or a fluid (not soil).

3.7 *installation damage*—damage to the geosynthetic, such as cuts, holes (geotextiles only), abrasion, fraying, etc., created during installation of the geosynthetic in the backfill soil.

3.8 *load level*—for creep or creep-rupture testing, the load applied to the test specimen divided by T_{lot}, the short-term ultimate strength of the lot or roll of material used form the creep testing.

3.9 *MARV*—the minimum average roll value for the geosynthetic, defined as two standard deviations below the mean for the product (i.e., 97.5 percent of all test results will meet or exceed the MARV). For practical purposes, from the user's viewpoint, the average for a sample taken from any roll in the lot shipped to the job site should meet or exceed the MARV.

3.10 *minimum value*—the lowest sample value from documented manufacturing quality control test results for a defined population from one test method associated with one specific property.

3.11 *MSE*—mechanically stabilized earth.

3.12 *nonaggressive environment*—for geosynthetic walls and slopes, soils that have a d_{50} of 4.75 mm or less, a maximum particle size of 31.5 mm or less, a pH of 4.5 to 9, and an effective design temperature of 30°C (85°F) or less.

3.13 *oxidation*—the reaction of oxygen with the polymer material, initiated by heat, UV radiation, and possibly other agents, resulting in chain scission and strength loss.

3.14 *PET*—polyester.

3.15 *post-consumer recycled material*—polymer products sold to consumers that have been returned by the consumer after use of the products for the purpose of recycling.

3.16 *PP*—polypropylene.

3.17 *product line*—a series of products manufactured using the same polymer (including stabilizers) in which the polymer for all products in the line comes from the same source, the manufacturing process is the same for all products in the line, and the only difference is in the product weight/unit area or number of fibers contained in each reinforcement element.

3.18 *QPL*—qualified products list.

3.19 *RF*—combined reduction factor to account for long-term degradation due to installation damage, creep, and chemical/biological aging.

3.20 RF_{CR}—strength reduction factor to prevent long-term creep rupture of the reinforcement.

3.21 RF_{D}—strength reduction factor to prevent rupture of the reinforcement due to long-term chemical and biological degradation.

3.22 RF_{ID}—strength reduction factor to account for installation damage to the reinforcement.

3.23 *sample*—a portion of material that is taken for testing or for record purposes, from which a group of specimens can be obtained to provide information that can be used for making statistical inferences about the population(s) from which the specimens are drawn.

3.24 *specimen*—a specific portion of a material or laboratory sample upon which a test is performed or that is taken for that purpose.

3.25 *survivability*—the ability of a geosynthetic to survive a given set of installation conditions with an acceptable level of damage.

3.26 T_{al}—the long-term tensile strength that will not result in rupture of the reinforcement during the required design life, calculated on a load per unit of reinforcement width basis.

3.27 T_{ult}—the ultimate tensile strength of the reinforcement determined from wide width tensile tests.

3.28 *UV*—Ultraviolet light.

4. SIGNIFICANCE AND USE

4.1 This recommended practice provides a protocol to assess the reduction in tensile strength and stiffness of geosynthetic (i.e., geotextiles and geogrids) reinforcement that occurs due to the installation of the material in or immediately beneath soil backfill and due to time exposure to the ambient environment (e.g., temperature, pH, oxygen, water, or other materials or chemicals in the surrounding environment) during the design life for the structure. This recommended practice is applicable to the assessment of these long-term properties for individual geosynthetic reinforcement products as well as for geosynthetic reinforcement products lines. This reduced strength can be used as a design value in the design of geosynthetic reinforced structures such as walls, reinforced slopes, or embankment base reinforcement, or at can be used for material acceptance and QA purposes for the construction of such structures.

4.2 Due to the length of time required to obtain the test data required by this recommended practice, this recommended practice is generally not practical to be carried out on a suite of products for a specific project. Its primary use is to establish values that can be used at a program level by an agency or the geosynthetic manufacturer, using data developed for a range of site conditions likely to be encountered that can be adapted to the site specific conditions encountered in specific construction projects as needed.

4.3 This practice has not been developed to establish strength and stiffness properties directly applicable to dynamic loading situations such as in pavement base course reinforcement. The strength and stiffness properties obtained using this practice have been shown to be applicable to seismic loading situations, though the values obtained are likely to be conservative in that case, at least with regard to creep.

5. EVALUATION OF SOIL ENVIRONMENT AGGRESSIVENESS EFFECTS ON LONG-TERM STRENGTH DETERMINATION

5.1 The aggressiveness of the environment with regards to geosynthetic long-term strength determination shall be based on soil gradation and particle characteristics of the backfill soil, chemical properties of the backfill soil and adjacent environment, and site temperature. The backfill pH should be considered the key chemical property that will affect the chemical aggressiveness of the geosynthetic environment. Soil gradation and particle characteristics primarily affect potential RF_{ID} values, chemical properties affect the potential for high RF_D values, and temperature affects potential for high RF_D and high RF_{CR} values. The aggressiveness of the soil gradation will depend on the distribution, the maximum size, the angularity, and the durability of the soil particles. In general, the more angular the soil, the more uniform its gradation, the greater the maximum particle size, and the more durable the particles, the more aggressive the soil is with regard to potential for installation damage. Installation damage for geosynthetic reinforcement has been approximately correlated to the d_{50} size of the soil, and the d_{50} size can be used as a basis to interpolate to a specific soil gradation using test results at other gradations (Elias, 2000). However, other gradation characteristics may need to be considered to more accurately interpolate to a specific soil gradation and angularity. While installation damage can be evaluated for the anticipated soil gradation and characteristics, it is generally undesirable to use soils and associated installation conditions that result in a RF_{ID} value that is greater than approximately 1.7 due to the likelihood of excessive variability in the results. The decision regarding what gradation characteristics are to be considered too aggressive shall be made by the approval authority.

5.2 Regarding chemical properties of the environment surrounding the geosynthetic in the wall or slope, the pH shall be between 4.5 and 9 to be considered nonaggressive. This applies both in the reinforced backfill and at the back of the face of walls or other surficial treatments.

5.3 Regarding temperature, the effective design temperature at the wall or slope site shall be less than 30°C (85°F) for the environment to be considered nonaggressive. In all but the most southerly tier of states in the United States, all geosynthetic structure sites are anticipated to have an effective design temperature that is below 30°C (85°F). Unless otherwise indicated in the contract specifications for a given project, the design temperature used to determine RF and T_{al} from product specific data shall be assumed to be 20°C (68°F).

5.4 The contract specifications for the geosynthetic structure should identify whether the environment is anticipated to be aggressive and the reason for the aggressive environment designation (i.e., backfill gradation, site chemistry, or site temperature). If aggressive conditions are not identified in the contract specifications, and the contract specifications provide soil chemical criteria that are consistent with nonaggressive conditions as described herein, the environment should be considered to be nonaggressive to determine the long-term strength. However, the backfill should be tested prior to use to verify that it is nonaggressive.

Note 2—For most soil conditions in the United States, the environment will likely be chemically nonaggressive. A possible exception to this is immediately behind a concrete wall face, where pH levels could possibly be elevated above a pH of 9. However, recent research has indicated that for well-drained backfills, the pH adjacent to a concrete face stays below 9 in the long-term (Koerner, et al., 2001, Koerner, et al., 2002). In any case, the long-term strength determination must account for the environment at the face. However, there are specific geological regions in the United States that are more likely to have chemically aggressive conditions, as described in Elias (2000). Examples include salt-affected soils in the arid western (especially southwest) regions of the United States, acid-sulphate soils that are commonly found in the Appalachian region of the United States, and calcareous soils commonly found in Florida, Texas, New Mexico, and many western states.

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6. PRODUCT QUALIFICATION TESTING AND EVALUATION

6.1 *Product Qualification Testing Approach*:

6.1.1 As a first step, it shall be verified which geosynthetic products should be included as a single product line, unless only a single product is to be evaluated. The focus of the product qualification testing program shall be to characterize the long-term strength and stiffness properties for the entire product line, selecting samples from specific products within the product line to represent the entire product line. If a single product is to be evaluated, the product shall be subjected to the full suite of product qualification tests as described herein.

Note 3—The product line concept provides the ability to conduct performance testing to assess strength reduction factors and stiffness values on selected representative products in the product line. The test results from these representative products are then used to interpolate the reduction factors and stiffness values for the products in the product line not performance tested. This interpolation or, in some cases extrapolation, is performed using a parameter for which a clear relationship with the value of the strength reduction factor or stiffness for the product line exists (e.g., unit weight or tensile strength). Alternatively, a lower bound value could be applied to the rest of the product line based on the test results from the weakest or lightest weight product in the product line, provided the lower bound value can be selected with confidence. The ability to test only representative products from the product line can significantly reduce testing costs. However, it must be recognized that there is some risk associated with the use of this product line concept with regard to the determination of the properties of the intermediate products not specifically tested. The product line concept relies on the ability of the testing/evaluating organization to verify that the polymer source and fibers used to make the products in the line not tested are, in fact, the same as those used in the products that are specifically tested. In addition, for coated geogrids, the consistency of the coating type, process, and thickness/weight across all the products in the product line must also be verified. To reduce this risk to an acceptable level, a manufacturing plant auditing process should be used, and a limited testing program focused on evaluating the consistency among all products in the product line should be conducted on products in the product line not selected and subjected to performance tests as product line representatives. See Section 6.3 for details.

6.2 *Sampling*:

6.2.1 All materials or products, or both, to be tested will be furnished by the manufacturer/supplier at no cost to the review/approval authority. Samples will be selected for testing by agency or owner personnel or designated parties.

6.2.2 Sampling shall be conducted in accordance with the requirements in the specific AASHTO, ASTM, GRI, or ISO test standard for the specific tests conducted as part of this standard practice. For products selected as representative of the product line, an entire roll should be taken, but no less than the sum of the sample sizes required for all tests to be conducted on each product. For the remaining products in the product line, a sample with the dimensions of the product roll width by 20 ft should be taken. As a minimum, the following shall be obtained:

- a geosynthetic product sample of sufficient size to accommodate all of the specified testing;
- information showing the manufacturer’s name and description of product (style, brand name, etc.);
- product roll and lot number; and
- a sample of the polymer component(s) used to manufacture the product or product line in sufficient quantity to conduct the specified polymer tests.

6.2.3 All samples for the specified product qualification testing shall be from the same roll of material for each product tested. Regarding the polymer components, they should be obtained from the production line used to produce the geosynthetic products being evaluated.

6.2.4 A sampling report should be developed and, as a minimum, should include the following information:

- date of sampling;
- a brief description of the manufacturing facility/production line;
- the facility location;
- any prearrangements made with the manufacturer to sample, especially considering any advance warning of the sampling event provided to the manufacturer;
- the information for each sample required in Section 6.2.2;
- where the sample was taken within the facility; and
- how the sample was prepared for shipping and supervised by the sampler.

6.3 *Evaluation of Product Lines*:

6.3.1 *Assessment to Define Product Line*—If determining the long-term strength or stiffness values for a product line, data must be obtained for each product to facilitate the determination of which products should be considered as included in the product line. A product line is defined as a series of products manufactured using the same polymer (including stabilizers) in which the polymer for all products in the line comes from the same source, the manufacturing process is the same for all products in the line, and the only difference is in the product weight/unit area or number of fibers contained in each reinforcement element. The assessment of whether or not all products identified as a product line by the geosynthetic manufacturer qualify as such should be based, as a minimum, on the following information for each product in the product line:

- geosynthetic type, structure, and weaving process used to construct yarns or ribs;
- spacing and dimensions of geogrid elements, including photographs or small samples for visual examination. The receiving laboratory should verify these dimensions upon receipt of the sample(s) using hand measurement techniques. This is especially critical for strength determination based on a single or limited number of ribs in the specimens tested.

- polymer(s) used for fibers, ribs, etc.;
- polymer(s) used for coating, if present;
- polymer source(s) used for product;
- for HDPE and PP, primary resin ASTM type, class, grade, category (for HDPE use ASTM D 1248, and for PP use ASTM D 4101), and any other specifications used as manufacturing targets;
- for PET, minimum production number average molecular weight (ASTM D 4603 and GRI-GG8) and maximum carboxyl end group content (GRI-GG7), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided, and any other specifications used as manufacturing targets;
- percent of post-consumer recycled material by weight;
- minimum weight per unit area for product (ASTM D 5261);
- Minimum average roll value (MARV) for ultimate wide width tensile strength (ASTM D 4595 or ASTM D 6637), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.

Additional guidance on assessing whether or not a product or series of products should be included within a product line is provided in Annex B, Section B1.7.

6.3.2 Once an initial assessment of the product line has been made based on the product description and index property data described above, performance and additional index property testing for installation damage, creep, and durability shall be conducted for the products identified as a product line. The full suite of performance tests for installation damage, creep, and durability shall be obtained for at least one product in the product line to qualify the product line. This product shall be designated as the “primary product” for product line characterization purposes. For certain tests, such as UV resistance and oven aging, it is permissible to only test the lightest weight product in the product line, provided it is obvious that doing so will be a conservative characterization of the entire product line for those specific properties. Additional product specific test results for installation damage, creep, and durability as described herein shall be obtained for other products in the product line to verify consistency of the other products in the line with the primary product and the ability to interpolate installation damage, creep, and durability behavior to estimate strength reduction factors for the entire product line. In addition, a limited manufacturing plant audit should be conducted at the time the samples for testing are obtained. See Sections 6.3.2.1 through 6.3.2.4 and Note 3 for additional guidance on the assessment of each product in the product line.

6.3.2.1 Product specific installation damage data obtained in accordance with Annex A should be obtained for each product in the line. However, it is permissible to obtain installation damage data for only some of the products in the product line if interpolation of the installation damage reduction factor between products is feasible, or if an upper bound value of RF_{ID} can be determined for the entire product line. Testing and interpretation requirements to determine RF_{ID} for each product in the product line provided in Annex A, Section A1.1.6.4 shall be followed. For the products in the product line not tested in accordance with Annex A as primary or secondary products for product line characterization, a limited testing program should be conducted that allows direct comparison to the installation damage test results obtained for the products (primary and secondary per Section 6.3.2) used to characterize the product line. One of the following two options should be used to accomplish this:

1. Conduct bench-scale installation damage tests (ISO 10722-1) on all products in the product line, or
2. Conduct a full-scale field installation damage test per Annex A and ASTM D5818, but only using the coarsest soil used in the testing for characterizing the product line with regard to installation damage.

This limited testing program should be used to verify that the installation damage test results for products not tested as primary or secondary products per Section 6.3.2 for product line characterization are consistent with the installation damage data for the primary and secondary products. Consistency between the primary and secondary product test results and the limited test results for the remaining products in the product line should be judged as follows:

- If there is no consistent trend or relationship between a product property such as strength or weight and strength retained after damage, and a lower bound approach must be used to estimate strength retained (and RF_{ID}) for all products in the product line, the measured retained strength after damage shall be greater than or equal to the retained strength measured for the primary and secondary products.
- If there is a consistent trend or relationship between a product property such as strength or weight and strength retained after damage, the installation damage test results for the remaining products in the product line shall be greater than or equal to the 95 percent prediction limit for the regression of the primary and secondary product installation damage data (see Section 7.5.3.2 for procedures to be used to conduct this analysis).

The comparison between the primary/secondary product installation damage test results and the test results for the remaining products shall be conducted for the same type of installation damage test (i.e., ISO tests for all products in the product line, or full-scale installation damage tests for the coarsest soil for all products in the product line).

6.3.2.2 For extension of the creep data obtained on the product identified as the primary product for the product line to the entire product line as defined herein, a limited creep testing program shall be conducted on at least two additional products (i.e., secondary products per Section 6.3.2) in the product line. If the results are not consistent with the primary product creep-rupture envelope in accordance with Section B1.7 in Annex B, all products in the product line shall be creep tested, or the product line should be divided into groups of products that are consistent and that meet the definition of a product line. The testing and analysis shall be conducted in accordance with Annex B, Section B1.7.

6.3.2.3 For determination of the durability reduction factor, RF_D, for the product line, the weakest or lightest product in the range of products in the product line should be tested. For molecular weight/viscosity and carboxyl end group testing of polyester geosynthetics, it is acceptable to perform the tests on the yarn sampled at the geosynthetic manufacturing facility provided that it can be demonstrated that the yarn sampled is used to manufacture the geosynthetic products that are included in the product line being evaluated, in accordance with Section 6.3.2.4. If this cannot be verified, then yarn/fibers obtained from each product in the product line shall be tested.

6.3.2.4 The focus of the geosynthetic reinforcement manufacturing plant limited audit is to verify traceability of materials used for each product in the product line, and to verify consistency in the manufacturing process used for all products in the product line. The audit of the geosynthetic reinforcement manufacturing facility, as a minimum, shall include the following:

- verification that the same base polymer and yarn is used in all products included in the product line;
- verification of polymer source(s) used and consistency of the polymer property standards for the sources used;
- verification in the consistency of the manufacturing process used with regard to the base polymeric yarn, filament, or rib, including heating/quenching history, weaving, rib junction construction, etc.; and
- for coated geogrids, verification of the coating material used and its consistency for all products in the line, including thickness and/or weight per unit area, temperature history, and other processing variables.

The audit should be conducted in conjunction with the sampling conducted. A report of the audit findings shall be developed by the auditor and included with the sampling report.

6.4 *Determination of Long-Term Geosynthetic Strength for Initial Product Qualification*:

The long-term geosynthetic strength shall be determined by applying strength reduction factors to the ultimate tensile strength of the geosynthetic, Tult. Tult shall be determined in accordance with ASTM D 4595 for geotextiles and ASTM D 6637 for geogrids.

$$T_{al} = \frac{T_{\mathrm{ult}}}{RF} \qquad (1)$$

where:

$$RF - RF_{ID} \times RF_{CR} \times RF_{D} \qquad (2)$$

where:

T_{al} = the long-term tensile strength that will not result in rupture of the reinforcement during the required design life, calculated on a load per unit of reinforcement width basis;

T_{ult} = the ultimate tensile strength (MARV) of the reinforcement determined from wide width tensile tests;

RF = a combined reduction factor to account for potential long-term degradation due to installation damage, creep, and chemical/biological aging;

RF_{ID} = a strength reduction factor to account for installation damage to the reinforcement;

RF_{CR} = a strength reduction factor to prevent long-term creep rupture of the reinforcement;

RF_{D} = a strength reduction factor to prevent rupture of the reinforcement due to chemical and biological degradation.

6.4.1 The value selected for T_{ult} is the MARV for the product to account for statistical variance in the material strength. For geogrids, a statistically based minimum value may be used in lieu of the MARV. Other sources of uncertainty and variability in the long-term strength include installation damage (Annex A), creep extrapolation (Annex B), and chemical degradation (Annex C). It is assumed that the observed variability in the creep-rupture envelope is 100 percent correlated with the short-term tensile strength, T_{ult}, as the creep strength is typically directly proportional to the short-term tensile strength within a product line (see Annex B and Note B7 in Annex B if this is not the case). Therefore, the MARV of T_{ult} adequately takes into account that source of variability. For additional discussion of this issue, see Note 4.

Note 4—The product strength variability is not taken into account by using the creep limited strength, T_l, directly or in normalizing T_l by T_{baseline} (see Annex B). T_l only accounts for extrapolation uncertainty. Furthermore, T_{lot} is specific to the lot of material used for the creep testing. Normalizing by T_{lot} makes the creep reduction factor RF_{CR} applicable to the rest of the product line, as creep strength is typically directly proportional to the ultimate tensile strength, within a product line. As shown below, it is not correct to normalize the creep strength T_l using T_{ult}, the MARV of the tensile strength for the product, nor is it correct to use T_l directly in the numerator to calculate T_{al}.

$$RF_{CR} = \frac{T_{\mathrm{baseline}}}{T_l} \neq \frac{T_{\mathrm{ult}}}{T_l} \qquad \text{and} \qquad T_{al} \neq \frac{T_l}{RF_{ID} \times RF_{D}}$$

In the former case, the creep strength is not indexed to the actual tensile strength of the material used in the creep testing, and since there is a 50 percent chance that T_{baseline} will be less than or equal to T_{baseline}, using T_{ult} in this case would result in an unconservative determination of RF_{CR}. In the latter case, where T_l is used directly as a creep-reduced strength, the product strength variability is not taken into account, since T_l is really a mean creep strength. Hence, RF_{CR} must be determined as shown in Equation B-9 (see Annex B), and the MARV or minimum value must be used for T_{ult} when determining T_{al}. Note that the use of the MARV for T_{ult} may not fully take into account the additional variability caused by installation damage. For the typical degree of installation damage observed in practice, this additional variability is minor and can be easily handled through the overall safety factor used in design of reinforced structures. For durability (RF_D), additional variability does not come into play if a default reduction factor is used. If a more refined durability analysis is performed, additional variability resulting from chemical degradation may need to be considered.

6.4.2 The RF_{ID} and RF_{CR} shall be determined from product specific data for all geosynthetic reinforcement products or product lines. The product specific data for these reduction factors shall be interpreted/extrapolated in accordance with Annexes A and B. RF_D shall be determined from long-term product specific data interpreted/extrapolated in accordance with Annex C, or a default value may be used as described below. A default reduction factor for RF_D may be used if the environment is nonaggressive and if the product meets the minimum polymer and physical property requirements provided in Table 1. In this case, a default value for RF_D of 1.3 may be used for PET, HDPE, and PP geosynthetics.

Note 5—The default value for RF_D of 1.3, which can be used for products that meet the minimum property requirements in Table 1, was determined for effective design temperatures that are less than or equal to 20°C (68°F). A higher default value of 1.5 for products that meet the property requirements in Table 1 may be desirable for more temperate climates that still meet the requirements for a nonaggressive environment, especially to address polyolefin oxidative degradation, as the potential for this type of degradation, even for products that meet the property requirements in Table 1, becomes more uncertain at higher temperatures due to the lack of protocols that can accurately identify the amount or effectiveness of end use antioxidants present.

6.4.3 If the environment is identified as aggressive due to the chemical regime or due to temperature, or if the geosynthetic product does not meet the requirements in Table 1, default reduction factors should **not** be used for RF_D. For chemically aggressive or elevated temperature environments, RF_D must be determined based on long-term product specific data for an environment that is as or more aggressive than the project specific environment in question. Aggressive environments need to be addressed in the product submittal only if specifically requested by the contracting agency or the geosynthetic supplier. Once the appropriate reduction factors are established, the long-term geosynthetic strength is determined using Equations 1 and 2, or as determined in Note B7 of Annex B.

6.4.4 If a default reduction factor for RF_D is to be used, geosynthetic products likely to have good resistance to installation stresses and to long-term chemical degradation are required to minimize the risk of significant long-term degradation. Polymer materials not meeting the requirements in Table 1 could be used if detailed product specific data are extrapolated to the design life intended for the geosynthetic structure (see Annex C) is provided.

6.4.5 Unless otherwise specified by the agency or owner, geosynthetic reinforcement elements in MSE walls and reinforced slopes should be designed to have a durability to ensure a minimum design life of 75 years for permanent structures in accordance with the *AASHTO LRFD Bridge Design Specifications*. This design life requirement should be reflected in the long-term strength test data and analysis.

Table 1—Minimum Requirements for Geosynthetic Products to Allow Use of Default Reduction Factor for Long-Term Degradation

Polymer Type	Property	Test Method	Criteria to Allow Use of Default *RF**
PP and HDPE	UV Oxidation Resistance	ASTM D 4355	Min. 70% strength retained after 500 hours in weatherometer
PET	UV Oxidation Resistance	ASTM D 4355	Min. 50% strength retained after 500 hours in weatherometer if geosynthetic will be buried within 1 week, 70% if left exposed for more than 1 week.
PP and HDPE	Thermo-Oxidation Resistance	ENV ISO 13438:1999, Method A (PP) or B (HDPE)	Min. 50% strength retained after 28 days (PP) or 56 days (HDPE)
PET	Hydrolysis Resistance	Inherent Viscosity Method (ASTM D 4603 and GRI-GG8), or Determine Directly Using Gel Permeation Chromatography	Min. Number Average Molecular Weight of 25 000
PET	Hydrolysis Resistance	GRI-GG7	Max. Carboxyl End Group Content of 30
All Polymers	% Post-Consumer Recycled Material by Weight	Certification of Materials Used	Maximum of 0%

Note 6—The requirements provided in Table 1 utilize currently available index tests and are consistent with current *AASHTO LRFD Bridge Design Specifications*, with the exception of the oven aging test (i.e., ENV ISO 13438:1999) to assess thermo-oxidation resistance for PP and HDPE, which is a new requirement. These index tests can provide an approximate measure of relative resistance to long-term chemical degradation of geosynthetics. Values selected as "minimum" criteria to allow use without additional long-term testing are based on values for such properties based on long-term research reported in the literature. These values are considered indicative of good long-term performance or represent a readily available current standard within the industry that signifies that a product has been enhanced for long-term environmental exposure. There is little long-term history or even laboratory data regarding the durability of geosynthetics containing a significant percentage of recycled material. Therefore, their potential long-term performance is unknown, and it is recommended that long-term data be obtained for products with significant recycled material to verify their performance before using them.

6.5 *Report—Initial Product Qualification Testing*:

For initial product qualification, the following information shall be included in the product or product line evaluation report:

6.5.1 Basis for Determination of Product Line Members:

6.5.1.1 Geosynthetic type, structure, and weaving process used to construct yarns or ribs.

6.5.1.2 Spacing and dimensions of geogrid elements, including photographs or small samples for visual examination. The receiving laboratory should verify these dimensions upon receipt of the sample(s) using hand measurement techniques. This is especially critical for strength determination based on a single or limited number of ribs in the specimens tested.

6.5.1.3 Polymer(s) used for fibers, ribs, etc.

6.5.1.4 Polymer(s) used for coating, if present.

6.5.1.5 Polymer source(s) used for product.

6.5.1.6 For HDPE and PP, primary resin ASTM type, class, grade, category (for HDPE use ASTM D 1248, and for PP use ASTM D 4101), and any other specification used as manufacturing targets.

6.5.1.7 For PET, minimum production number average molecular weight (ASTM D 4603 and GRI-GG8) and maximum carboxyl end group content (GRI-GG7), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided, and any other specifications used as manufacturing targets.

6.5.1.8 Percent of post-consumer recycled material by weight.

6.5.1.9 Minimum weight per unit area for product (ASTM D 5261).

6.5.1.10 MARV for ultimate wide width tensile strength (ASTM D 4595 or D 6637), with supporting test data. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.

6.5.2 Installation Damage Data Requirements (RF_{ID}):

Installation damage testing and interpretation shall be conducted in accordance with Annex A. As a minimum, for each product tested, the following information should be obtained:

6.5.2.1 Date tests were conducted.

6.5.2.2 Name(s), location(s), and telephone number(s) of laboratory(ies) conducting the testing and evaluation.

6.5.2.3 Identify whether installation damage testing was conducted as a site specific evaluation for an actual construction project or was conducted as a non-site specific evaluation.

6.5.2.4 Description of specific procedures used to conduct the installation damage testing, including installation procedures, sample size, method of specimen selection, sample removal procedures, etc. Identify any deviations in the installation procedures relative to typical installation practice in full-scale structures, if the testing was not site specific.

6.5.2.5 Photographs illustrating procedures used and the conditions at the time of the testing, if available.

6.5.2.6 Measured mass/unit area per ASTM D 5261 for the sample tested for installation damage and for the sample used to establish the undamaged strength. Also obtain product manufacturer Quality Control (QC) data on the uncoated product (i.e., “greige-good”) for the lot used for installation damage testing.

6.5.2.7 Tensile test results for the product before exposure to installation conditions (i.e., virgin material, T_{baseline}), and whether both virgin and damaged samples were taken from the same roll of material, or just from rolls within the same lot of material.

6.5.2.8 Tensile test results for specimens taken from the damaged material after installation.

6.5.2.9 Tensile test results for both virgin and damaged specimens should include individual test results for each specimen, typical individual load-strain curves that are representative of the specimens tested, including associated calibration data as necessary to interpret the curves (curves in which strain and load/unit width are already calculated are preferred), the average value for each sample, the coefficient of variation for each sample, and a description of any deviations from the standard tensile test procedures required by Annex A.

6.5.2.10 Gradation curves for backfill material located above and below the installation damage geosynthetic samples, including the d_{50} size, maximum particle size, and a description of the angularity of the soil particles per ASTM D 2488, including photographs illustrating the soil particle angularity, if available. Also include LA Abrasion (T 96) test results for the backfill material used.

6.5.2.11 Photographs or a description, or both, of the type and extent of damage visually evident in the exhumed samples and specimens.

6.5.2.12 The RF_{ID}, and a description of the data interpretation method used to determine RF_{ID} for each sample.

6.5.2.13 For geogrids, evaluation of geogrid flexibility per WSDOT Test Method T 925. Creep Data Requirements (RF_{CR} and Creep Stiffness J):

Creep testing and interpretation shall be conducted in accordance with Annex B. As a minimum, for each product tested, the following information should be obtained:

6.5.2.14 Date tests were conducted.

6.5.2.15 Name(s), location(s), and telephone number(s) of laboratory(ies) conducting the testing and evaluation.

6.5.2.16 Photographs illustrating the creep testing equipment and procedures used, as available.

6.5.2.17 Tensile test results for the product before creep testing (i.e., virgin material), and whether both virgin and creep tested samples were taken from the same roll of material or just from rolls within the same lot of material.

6.5.2.18 Tensile test results should include individual test results for each specimen, typical load-strain curves that are representative of the specimens tested, including associated calibration data as necessary to interpret the curves (curves in which strain and load/unit width are already calculated are preferred), the average value for each sample, the coefficient of variation for each sample, and a description of any deviations from the standard tensile test procedures required by Annex B.

6.5.2.19 Creep test procedures used, especially any deviations from the procedures required in Annex B.;

6.5.2.20 Iif RF_{CR} is determined using data obtained in accordance with Annex B, provide load and time to rupture for each specimen as a minimum; however, strain data as a function of time are desirable if available.

6.5.2.21 If elevated temperature testing is conducted, creep data before and after time/load shifting, including shift factors used and a description of how the shift factors were derived, shall be provided.

6.5.2.22 Data illustrating the variability of the creep test environment, including temperature and humidity, during the creep test time period, or some assurance that the creep test environment was maintained within the variation of temperature prescribed herein, shall be provided.

6.5.2.23 Description of statistical extrapolation procedures used in accordance with Annex B, if statistical extrapolation is performed.

6.5.2.24 RF_{CR}, and a description of how RF_{CR} was determined for each product.

6.5.2.25 In addition, regardless which approach is used to determine RF_{CR}, creep strain data at a load level that results in a strain of 2 percent at approximately 1000 hours shall be submitted to determine the low strain (i.e., 2 percent) creep stiffness at 1000 hours and at the specified design life (typically 75 years).

6.5.2.26 For both creep rupture and low strain creep stiffness testing, if single-rib, yarn, or narrow width specimens are used, 1000-hour creep data in accordance with Annex B that demonstrate the single-rib, yarn, or narrow width test results are consistent with the results from multi-rib/wide width testing.

6.5.3 Long-Term Durability Data Requirements to Establish Default Value of RF_D:

If a default value for RF_D is to be used, the following information and test results shall be provided in the report:

6.5.3.1 Ultraviolet resistance at 500 hours in weatherometer (ASTM D 4355). As a minimum, test data for the lightest weight product submitted in the product line should be included in the report. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.

6.5.3.2 Oven aging tests conducted in accordance with ENV ISO 13438:1999, Method A (PP) or B (HDPE), for polyolefin geosynthetics. As a minimum, test data for the lightest weight product in the product line should be included in the report. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.

6.5.3.3 Inherent viscosity/molecular weight (ASTM D 4603 and GRI-GG8) and carboxyl end group (CEG) content (GRI-GG7) for polyester geosynthetics conducted on the base yarn used for the manufacture of the geosynthetic. Information regarding the laboratory where the testing was conducted and date of testing shall also be provided.

6.5.4 Long-Term Durability Data Requirements if Default Value for RF_D is Not Used:

If it is desired to submit detailed durability performance test data to justify a lower RF_D, or to allow use in environments classified as chemically aggressive, durability testing and interpretation shall be conducted in accordance with Annex C and, as a minimum, for each product tested, the following information shall be obtained:

6.5.4.1 Date tests were conducted.

6.5.4.2 Name(s), location(s), and telephone number(s) of laboratory(ies) conducting the testing and evaluation.

6.5.4.3 Photographs and drawings illustrating the durability testing equipment and procedures used as well as a summary of the specific procedures used.

6.5.4.4 Tensile test results for the product before durability testing (i.e., virgin material), and whether both virgin and durability test samples were taken from the same roll of material, or just from rolls within the same lot of material.

6.5.4.5 Polymer characteristics for the lot or roll of material actually tested before long-term exposure in the laboratory, including, for example, molecular weight and carboxyl end group content for PET, melt flow index and OIT for polyolefins, percent crystallinity, SEM photographs of fiber surface, etc.

Note 7—Percent crystallinity can be determined using differential scanning calorimetry (DSC). An appropriate test method is ASTM D 3418. By definition, crystallinity (*X*) is calculated as follows:

$X = \Delta H / \Delta H^\circ$ (× 100 for %)

where:

ΔH = the latent heat under the DSC melt curve, and

ΔH° = the latent heat for a 100 percent crystalline polymer, °C.

Temperature scan should start 10°C below, continue through, and stop 10°C above the melt range. Recommended test parameters are as follows:

Homo-Polymer	Sample Size, (mg)	Melt Range, (°C)	Latent Heat, ΔH°, (cal/gm)	DSC Scan Speed, (°C/min)
HDPE	5	100–145	68.4	10
PP	7.5	100–165	45	10
PET	10	200–245	30	10

Other values of sample size, melt range, and DSC scan speed can be used with justification.

6.5.4.6 Tensile test results for specimens taken for each retrieval from the incubation chambers.

6.5.4.7 Tensile test results, including tensile strength, strain at peak load, and 5 percent secant or offset modulus, for both virgin material and degraded material, should include individual test results for each specimen, typical load-strain curves that are representative of the specimens tested, including associated calibration data as necessary to interpret the curves (curves in which strain and load/unit width are already calculated are preferred), the average value for each sample, the coefficient of variation for each sample, and a description of any deviations from the standard tensile test procedures required by Annex C.

6.5.4.8 A detailed description of the data characterization and extrapolation procedures used, including data plots illustrating these procedures and their theoretical basis.

6.5.4.9 Results of any chemical tests taken (e.g., OIT or HPOIT, molecular weight, product weight/unit area, etc.), and any scanning electron micrographs taken, to verify the significance of any degradation in strength observed.

6.5.4.10 Results of biological degradation testing, if performed.

6.5.4.11 The RF_D and a description of the method used to determine RF_D for the product.

7. QUALITY ASSURANCE REQUIREMENTS FOR GEOSYNTHETIC PRODUCTS THAT HAVE BEEN THROUGH INITIAL PRODUCT QUALIFICATION TESTING

7.1 *Quality Assurance (QA) Geosynthetic Product Verification and Testing Approach*:

As a first step, it shall be verified in accordance with the data verification requirements provided below that the current product or product line has not changed significantly relative to the product or product line that was tested and evaluated for initial product qualification. If the product or product line has not changed significantly based on this data verification step, results from index and performance tests on the product or product line shall be compared to baseline index or performance test results obtained for initial product qualification purposes. If the QA test results are within acceptable tolerances relative to the baseline results in accordance with Section 7.5, the baseline test data obtained for product qualification purposes shall be considered valid for the product line. Retesting shall be done if there is any change in the product. If it is determined that one or more products in the product line has changed since the last product qualification testing program was conducted, a complete assessment of the product or product line in accordance with this standard practice instead of just a QA evaluation may be required by the approval authority to maintain acceptance status, depending on the nature and magnitude of the change(s). Examples of changes that could necessitate a new product qualification testing program be conducted include changes in the processing technique or variables used for the product line, changes in the polymer properties or additives used that could affect the product's(s') mechanical/chemical durability or creep resistance, changes in the shape or surface area of the ribs or yarns, changes in the way ribs and cross-ribs are connected together, changes in the coating properties or thickness, changes in tensile strength, etc. The potential impact of such changes on the long-term strength of the reinforcement product(s) should be assessed by the approval authority. Some types of product changes may only affect certain aspects of the product's(s') long-term strength, necessitating that only a portion of the product qualification testing program be conducted (e.g., changes in yarn or rib geometry may only affect installation damage resistance). Therefore, the approval authority may need to make a determination of what portions of the product qualification testing program that should be conducted.

7.2 *Data Verification Requirements*:

The following information about each product shall be submitted for verification purposes:

7.2.1 Geosynthetic type and structure, and weaving process used to construct yarns or ribs.

7.2.2 Spacing and dimensions of geogrid elements. The receiving laboratory should verify these dimensions upon receipt of the sample(s) using hand measurement techniques. This is especially critical for strength determination based on a single or limited number of ribs in the specimens tested.

7.2.3 Polymer(s) used for fibers, ribs, etc.

7.2.4 Polymer(s) used for coating, if present.

7.2.5 Polymer source(s) used for product.

7.2.6 For HDPE and PP, primary resin ASTM type, class, grade, and category (for HDPE, use ASTM D 1248, and for PP use ASTM D 4101).

7.2.7 Percent post-consumer recycled material by weight.

7.2.8 Minimum weight per unit area for product (ASTM D 5261).

7.2.9 MARV for ultimate wide width tensile strength (ASTM D 4595 or D 6637).

7.3 *Quality Assurance (QA) Sampling*:

7.3.1 All materials and/or products to be tested will be furnished by the manufacturer/supplier at no cost to the review/approval authority. Samples will be selected for testing by agency or owner personnel or designated parties. Sampling shall be conducted in accordance with the requirements in the specific AASHTO, ASTM, GRI, or ISO test standard for the specific tests conducted as part of this standard practice. For products selected as representative of the product line, an entire roll should be taken, but no less than the sum of the sample sizes required for all tests to be conducted on each product. As a minimum, the following shall be obtained:

- a geosynthetic product sample of sufficient size to accommodate all of the specified testing;
- information showing the manufacturer's name and description of product (style, brand name, etc.);
- product roll and lot number; and
- a sample of the polymer component(s) used to manufacture the product or product line in sufficient quantity to conduct the specified polymer tests.

7.3.2 All samples for the specified QA testing shall be from the same roll of material for each product tested. Regarding the polymer components, they should be obtained from the production line used to product the geosynthetic products being evaluated.

7.4 *Quality Assurance (QA) Testing*:

Short-term ultimate tensile strength test results and other QA test results to verify that the values of RF_{ID}, RF_{CR}, and RF_D determined from initial product qualification testing are accurate for the product or product line, shall be obtained. Short-term tensile strength shall be determined in accordance with ASTM D 4595 for geotextiles and ASTM D 6637 for geogrids. Quality Assurance testing required to verify that the values of RF_{ID}, RF_{CR}, and RF_D determined from initial product qualification testing are applicable to the current product (i.e., the QA test results are statistically consistent with the initial product qualification test results) is as follows:

7.4.1 Installation Damage Testing:

For installation damage evaluation, a field-exposure trial conducted in accordance with Annex A shall be conducted for the product in the product line with the highest RF_{ID} from the initial product qualification testing using the soil with a d_{50} size that is equal to or larger than a d_{50} size of 4.75 mm, or other d_{50} size as determined by the approval authority, and the aggregate shall have a maximum LA Abrasion (T 96) percent loss of 35 percent. The d_{50} size, angularity, and durability of the selected backfill should be consistent with the d_{50} size used for initial product qualification testing (preferably, the same material should be used for both the product qualification testing and the QA testing, if possible). Alternatively, reduced scale laboratory installation damage tests conducted in accordance with ISO/DIS 10722-1 may be used. In this case, these laboratory installation damage tests must also be conducted during initial product qualification testing to establish a baseline value. The ultimate tensile strength of the lot or roll of material used in the installation damage testing obtained in accordance with ASTM D 4595 or ASTM D 6637 using the multi-rib procedure (or ISO 10319 if ISO/DIS 10722-1 is used) shall be obtained to normalize the installation damage test results in accordance with Annex A. If it was determined during the initial product qualification testing for coated geogrids that the installation damage factor was not a function of product weight or tensile strength, the coating weight shall also be evaluated. In this case, the mass/unit area of the sample tested shall be determined in accordance with ASTM

D 5261. The coating weight can then be established using the lot specific mass/unit area of the uncoated product from product manufacturer QC data.

7.4.2 Creep Testing:

7.4.2.1 For creep-rupture evaluation, a minimum of three creep-rupture points shall be obtained using the Stepped Isothermal Method (i.e., SIM) per ASTM D 6992 or conventional ASTM D 5262 tests (for which elevated test temperatures may be employed to accelerate creep—see Annex B) at a load level established at the time of initial product qualification testing that corresponds to a minimum rupture time of 100 000 hours at the reference temperature. If elevated temperature conventional creep testing using ASTM D 5262 is performed, the shift factors obtained from the conventional creep testing for the temperatures used in the QA testing conducted for initial product qualification testing shall be used to extrapolate the test data to the reference temperature. A fourth SIM test (or conventional ASTM D 5262 test conducted at the reference temperature) shall be performed at a load level established at the time of initial product qualification testing that corresponds to a minimum rupture time of 500 hours at the reference temperature.

7.4.2.2 For creep stiffness evaluation, if the product qualification testing conducted indicates that the creep is log linear at the low strain levels tested, short-term (1,000-second) ramp and hold (R+H) tests as described in ASTM D 6992 may be used and extrapolated to 1000 hours in lieu of 1000-hour creep tests. A minimum of two R+H tests shall be conducted for one product in the product line at the load level in which 2 percent strain at 1000 hours was achieved in the product qualification testing. If the product qualification testing indicates that the creep is not log linear at the low strain level tested, then a minimum of two full 1000-hour creep tests must be conducted at that load level. These tests shall be conducted on the same width specimens as used for the product qualification creep stiffness testing.

7.4.2.3 If SIM is used for this creep-rupture testing, it shall have been demonstrated for the initial qualification testing that the reduced specimen width typically used for SIM testing does not have a significant effect on the creep-rupture results, and have been provided that the validity of SIM for the product through comparison of SIM data with “conventional” creep-rupture data was established for the initial product qualification testing.

7.4.2.4 The ultimate tensile strength of the lot or roll of material used in the creep testing obtained in accordance with ASTM D 4595 or D 6637 shall be obtained to normalize the creep-rupture loads in accordance with Annex B.

Note 8—If “conventional” creep testing is performed for QA purposes, it is assumed that the product has not changed relative to what was tested for initial product qualification purposes, thereby allowing the assumption to be made that the shift factors obtained through the initial product qualification testing are valid to be applied to the QA testing. Requiring new “conventional” creep test shift factors to be re-established would result in the need to fully repeat the test program for the initial product qualification, which would not be practical for QA purposes. Regarding the fourth creep test data point, the requirement to use only data obtained at the reference temperature if “conventional” creep testing is performed provides a second check that eliminates the need for this shift factor assumption and any inaccuracies associated with that assumption.

7.4.3 Durability Testing:

7.4.3.1 If only index durability testing was conducted to allow use of a default value for RF_D for the initial product qualification testing, only index durability testing should be conducted for QA purposes. In this case, durability testing for QA purposes shall consist of the determination of molecular weight based on GRI-GG7 and carboxyl end group content based on GRI-GG8 for polyesters, UV resistance based on ASTM D 4355 for polyolefins and PETs), and an oven aging exposure test per ENV ISO 13438:1999 for polyolefin geosynthetics. Regarding the oven aging test, control and postexposure specimens shall be tested for tensile properties (ASTM D 4595 or D 6637). The results of this oven aging testing should be used only to compare a product with itself, and to meet the minimum requirements in Table 1.

7.4.3.2 If long-term performance durability testing was conducted to justify the use of a lower RF_D or to justify use in aggressive environments for initial product qualification, a minimum of five specimens shall be exposed to the most aggressive environment used in the initial product qualification testing, at the highest temperature tested, for a minimum of 2000 hours. These specimens, and unexposed specimens from the same roll of material, shall be tested for tensile properties (ASTM D 4595 or D 6637). In addition, for polyolefins, either oxidative induction time per ASTM D 3895 or high pressure oxidative induction time per ASTM D 5885 shall be conducted for each specimen tested (before and after exposure), and for PETs, molecular weight (ASTM D 4603 and GRI-GG8) and specimen weight per unit area (ASTM D 5261) shall be conducted for each specimen tested (before and after exposure).

7.5 *Quality Assurance (QA) Analysis and Reporting*:

The acceptability of the QA test results to allow a product or product line to maintain its prior qualification or acceptance status shall be established based on the statistical significance, or lack thereof, of the difference between the QA test results and the initial product qualification test results. The criteria and methods for determining the statistical significance between the QA and initial product qualification test results shall be as follows:

7.5.1 Short-Term Index Tensile Testing:

For wide width tensile strength, the mean of the test results for the sample for each product tested shall be greater than or equal to the MARV reported for the product. Report both the MARV, or minimum value, and the QA tensile test results.

7.5.2 Installation Damage Testing:

7.5.2.1 If the mean of the average strength of the sample after damage as a percent of the undamaged strength is less than the average value obtained for the same product and condition during the product qualification testing, the maximum difference between the two means shall be no greater that what is defined as statistically insignificant based on a one-sided Student's *t*-distribution at a level of significance of 0.05. In this case, *t* is determined as follows:

$$t_{\alpha/2,n_1+n_2-2} = \frac{\left(\bar{P}_1 - \bar{P}_2\right) - \delta}{\sqrt{\left(n_1 - 1\right)s_1^2 + \left(n_2 - 1\right)s_2^2}} \sqrt{\frac{n_1 n_2 \left(n_1 + n_2 - 2\right)}{\left(n_1 + n_2\right)}} \qquad (3)$$

where:

$t_{\alpha/2,n_1+n_2-2}$ = value of the *t*-distribution for the installation damage samples;

$\bar{P}_1$ = the mean of the strength retained after installation damage (i.e., T_{dam}/T_{lot}) obtained for initial product qualification;

$\bar{P}_2$ = the mean of the strength retained after installation damage (i.e., T_{dam}/T_{lot}) obtained for QA testing;

δ = the difference in the means for the populations corresponding to the sample means $\bar{P}_1$ and $\bar{P}_2$ (assumed equal to zero for this test);

s_1 = the standard deviation corresponding to $\bar{P}_1$;

s_2 = the standard deviation corresponding to $\bar{P}_2$;

n_1 = the number of data points corresponding to $\bar{P}_1$;

n_2 = the number of data points corresponding to $\bar{P}_2$.

7.5.2.2 The $t_{\alpha/2,n_1+n_2-2}$ calculated using Equation 3 shall be no greater than *t* determined from the applicable Student's *t*-table (or from the Microsoft EXCEL function TINV(α,*n*–2)) at $\alpha = 0.05$ and n_1+n_2-2 degrees of freedom. If this is not true, the difference between $\bar{P}_1$ and $\bar{P}_2$ is determined to be statistically significant and $\bar{P}_1 > \bar{P}_2$, two additional samples from the same installation condition shall be tested, and $\bar{P}_2$ recalculated and statistically compared to $\bar{P}_1$. If the QA test results are still too low, a full installation damage study for initial product qualification must be completed in accordance with Annex A, and new values of RF_{ID} established.

7.5.2.3 Report the results of the statistical analysis, as well as the mean values for the product qualification testing and the QA testing.

7.5.3 Creep-Rupture Testing for Prediction of Creep Limit:

7.5.3.1 For creep evaluation, the four creep-rupture points, one at a load level that results in an approximate rupture time, after time shifting, of 500 hours, and three at a load level that results in an approximate rupture time, after time shifting, of 100 000 hours on the rupture envelope obtained for initial product qualification purposes, shall be compared to the creep data obtained for initial product qualification purposes. The log of the rupture time for each of these four rupture points shall be equal to or greater than the 95 percent lower prediction limit of the variable, log time, established by Student's *t*-test of the original product qualification data set.

7.5.3.2 The prediction limit for the regression performed for initial product qualification is given by (Wadsworth, 1998):

$$\log t_L = \log t_{\mathrm{reg}} - \left[t_{\alpha/2,n-2} \sqrt{1 + \frac{1}{n} + \frac{\left(P - \bar{P}\right)^2}{\sum \left(P_i - \bar{P}\right)^2}} \right] \times \sigma \qquad (4)$$

and

$$\sigma = \sqrt{\frac{\sum \left[\log t_i - \log \bar{t}\,\right]^2 - \dfrac{\left\{\sum \left[\left(P_i - \bar{P}\right)\left(\log t_i - \log \bar{t}\,\right)\right]\right\}^2}{\sum \left(P_i - \bar{P}\right)^2}}{n-2}} \qquad (5)$$

where:

$\log t_L$ = lower bound prediction limit;

t_{reg} = time corresponding to the load level from the initial product qualification creep rupture envelope at which QA creep tests were performed (e.g., at 500 and 100 000 hours after time shifting);

$t_{\alpha/2,n-2}$ = value of the Student's *t*-distribution determined from applicable Student's *t*-table (or from the Microsoft EXCEL function TINV(α,*n*–2)) at $\alpha/2 = 0.05$ and *n*–2 degrees of freedom (this corresponds to the 95 percent one-sided prediction limit);

n = the number of rupture or allowable run-out points in the original test sample (i.e., for initial product qualification);

P = load level obtained at t_{reg} from the regression line developed from the initial product qualification testing;

$\bar{P}$ = the mean rupture load level for the original test sample (i.e., all rupture or run-out points used in the regression to establish the rupture envelope for initial product qualification);

P_i = the rupture load level of the *i*th point for the rupture points used in the regression for establishing the rupture envelope for initial product qualification;

$\log \bar{t}$ = the mean of the log of the rupture time for the original test sample (i.e., all rupture or run-out points used in the regression to establish the rupture envelope for initial product qualification);

t_i = the rupture time of the *i*th point for the rupture points used in the regression for establishing the rupture envelope for initial product qualification.

7.5.3.3 The comparison between the QA test results and the initial product qualification test results is illustrated conceptually in Figure 1. Once $\log t_L$ has been determined at each specified load level, compare this value to the log rupture time (i.e., $\log t_{\text{QA}}$) obtained for each QA creep-rupture test at the specified load level (e.g., 500 and 100 000 hours). If $\log t_{\text{QA}} < \log t_L$ for any of the QA creep-rupture test results, perform two additional tests at the load level P for the specified t_{reg} where this QA criterion was not met and compare those results to $\log t_L$. If, for these two additional tests, this criterion is not met, perform adequate additional creep-rupture testing to establish a new rupture envelope for the product in accordance with initial product qualification requirements (Annex B). This new rupture envelope will form the baseline for any future QA testing.

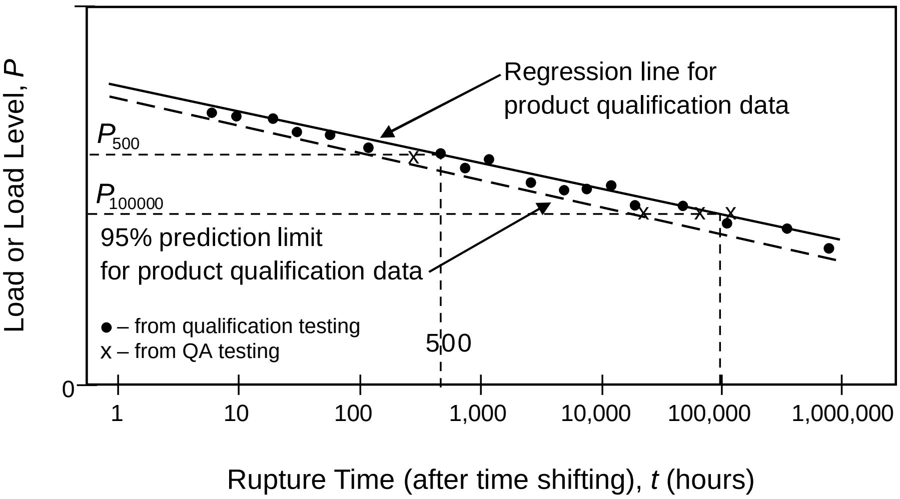

Figure 1—Conceptual Illustration of the Comparison of QA Creep-Rupture Test Results to Initial Product Qualification Creep-Rupture Test Results

7.5.3.4 Report a plot of the QA data in comparison to the product qualification test results as shown in Figure 1, and the QA creep-rupture load levels and time to rupture in comparison to the 95 percent prediction limit calculated at the load levels used to obtain the QA creep-rupture data.

7.5.4 Assessment of Creep Stiffness at Low Strain:

7.5.4.1 The comparison between the creep data obtained for the initial product qualification testing and the QA creep data shall be performed at a specified strain, in this case 2 percent unless otherwise specified by the agency or owner. Where the selected strain level intersects each creep curve, determine the time required to reach the specified strain. Plot the load level as a function of the logarithm of time to reach the specified strain for the initial product qualification data, and perform a regression for this data set. The log times to the specified strain level for the QA creep data shall be determined at a load level that corresponds to 1000 hours on the initial product qualification creep curve. The estimated time to reach the same specified strain for each of the two QA creep data points shall be equal to or greater than the 95 percent lower prediction limit of the variable, log time, established by the Student's *t*-test of the original product qualification data set, using Equations 4 and 5.

7.5.4.2 Once $\log t_L$ has been determined at the specified load level, compare this value to the log time to reach the specified strain (i.e., $\log t_{\mathrm{QA}}$) obtained for each QA creep test at the specified load level (e.g., 1000 hours). Report these values for the product qualification testing and the QA testing. If $\log t_{\mathrm{QA}} < \log t_L$ for any of the QA creep-rupture test results, perform two additional tests at the same load level P for the specified strain and compare those results to $\log t_L$. If, for these two additional tests, this criterion is not met, perform adequate additional creep testing to establish a new low strain creep stiffness value for the product in accordance with initial product qualification requirements (Annex B). This new low strain creep stiffness value will form the baseline for any future QA testing.

7.5.5 Durability Testing:

7.5.5.1 For UV resistance (all polymers), molecular weight and CEG (PET only), and oven aging (PP and HDPE), the QA test results shall meet the minimum requirements provided in Table 1. For the oven aging tests (polyolefins only), compare the tensile strength retained (i.e., strength after oven exposure divided by the strength of the control specimens to the strength observed during initial product qualification testing). The maximum difference between the values of the changes shall be no greater that what is defined as statistically insignificant based on a one-sided Student's *t*-distribution at a level of significance of 0.05, as determined using Equation 3. In this case, $\bar{P}_1$ and $\bar{P}_2$ are defined as the strength retained after oven aging.

7.5.5.2 The $t_{\alpha/2,n_1+n_2-2}$ calculated using Equation 3 shall be no greater than t determined from the applicable Student's *t*-table (or from the Microsoft EXCEL function TINV(α,n–2)) at $\alpha/2 = 0.05$ and n–2 and $n_1 + n_2$–2 degrees of freedom. If this is not true, and the difference between $\bar{P}_1$ and $\bar{P}_2$ is determined to be statistically significant and $\bar{P}_1 > \bar{P}_2$, two additional samples from the same roll of material shall be tested in accordance with ISO 13438:1999 and $\bar{P}_2$ recalculated and statistically compared to $\bar{P}_1$. If the QA test results are still unacceptable, or if the product loses more than 50 percent of its tensile strength during the QA test, a more complete investigation shall be performed in accordance with Annex C. Report $\bar{P}_1$ and $\bar{P}_2$ for the product qualification and QA testing.

7.5.5.3 If long-term performance durability testing was conducted to justify the use of a lower RF_D or to justify use in aggressive environments for initial product qualification, the statistical methodology and criteria provided above for index oven aging (i.e., that there is no statistically significant difference between the initial product qualification test results and the QA test results at a level of significance of 0.05) shall be applied to the oxidation or hydrolysis performance test results at the maximum exposure time and environmental conditions used for the QA testing. Report $\bar{P}_1$ and $\bar{P}_2$ for the product qualification and QA testing.

8. KEYWORDS

8.1 Creep; durability; geogrid; geosynthetic; quality assurance; stiffness; strength.

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ANNEX A

(Mandatory Information)

A1. PRODUCT SPECIFIC TESTING AND DATA INTERPRETATION REQUIREMENTS TO DETERMINE RF_{ID} FOR GEOSYNTHETIC REINFORCEMENTS

A1.1. *General*:
The effect of installation damage on geosynthetic reinforcement strength and deformation shall be determined from the results of full-scale installation damage tests in accordance with ASTM D 5818, except as modified herein:

A1.1.1. Place and compact 150 mm (6 in.) or more of soil (same soil as used to cover the geosynthetic) on a flat, level, relatively incompressible subgrade. The compacted layer shall simulate the roughness and compressibility of the backfill conditions in which the geosynthetic layer is likely to be placed in full-scale structures.

A1.1.2. Place the geosynthetic on top of the compacted soil pad. The geosynthetic shall be pulled taut with no wrinkles or folds. It may be necessary to pin the corners of the geosynthetic to maintain its position as soil is placed over the geosynthetic.

Note A1—In addition to the removal requirements described in ASTM D 5818, a lifting plate may be placed below the compacted soil pad below the geosynthetic layer as described in Sprague and Allen (2003) to facilitate easy removal of the soil above the geosynthetic.

A1.1.3. If the installation damage test is conducted for a specific project, the actual backfill material planned for use in the geosynthetic structure should be used for the test. If the purpose of the installation damage testing is to generate RF_{ID} values for general use for future projects (i.e., the testing is not intended to be project specific), a range of soil backfill gradations/types shall be used in the testing. The range of backfill materials selected should permit interpolation as needed to match to a project specific soil used as reinforced soil backfill. In general, the backfill materials tested should range from soil classified as a sand to coarse gravel (e.g., d_{50} sizes ranging from 0.5 to 25 mm). The backfill materials selected should be angular to subangular and shall be durable. The coarse sand and gravel portions of the backfill material should have a Los Angeles Wear (LA Abrasion) percent loss after 500 revolutions (T 96) of no more than 35 percent. Additional installation damage tests may be conducted with a less durable backfill material, at the discretion of the manufacturer and the approval authority. If tests are conducted using a backfill material that does not meet the LA Abrasion requirement stated above, the condition of the backfill shall be evaluated for changes in angularity and gradation after each use. If changes in these two parameters are observed, the aggregate shall be immediately replaced with fresh material. This gradation/angularity evaluation should be conducted periodically even for more durable backfill material. Note that if the backfill materials available in the region for which the approval authority has jurisdiction consistently cannot meet the maximum LA Abrasion requirement of 35 percent loss, a less durable aggregate may be used for all the backfill materials tested, at the discretion of the approval authority.

A1.1.4. The first nine prenumbered specimens identified on the exhumed sample shall be selected for testing. If any of these specimens were damaged due to the exhumation process, that specimen(s) shall be skipped, and the next consecutively numbered specimen(s) shall be selected for testing. If the coefficient of variation for the tensile test results of these first nine prenumbered specimens is greater than 5 percent, the required number of specimens shall be recomputed using the one-sided

Student's t-distribution as required by ASTM D 4595 or D 6637. The additional specimens shall be selected from the next consecutively numbered specimens.

Note A2—An alternative predetermined numbering scheme may be used to ensure that the sample locations are not biased within the sample with regard to damage patterns, provided that bias due to the visual appearance of specimen damage is eliminated.

A1.1.5. Geosynthetic Testing:

Samples subjected to installation damage shall be tested for tensile strength and deformation characteristics in accordance with ASTM D 4595 (geotextiles) or ASTM D 6637 (geogrids). The number of specimens tested should be in accordance with ASTM D 4595 or D 6637. Single-rib tests such as GRI-GG1 shall not be used for installation damage evaluation, as it is difficult to assess the effect of severed ribs on the strength and stiffness of damaged materials. Test results from damaged specimens shall be compared to tensile test results obtained from undamaged (i.e., not exposed to installation conditions) control specimens.

A1.1.6. Data Analysis and Report:

A1.1.6.1. The installation damage reduction factor RF_{ID} is determined as follows:

$$P = \frac{T_{\mathrm{dam}}}{T_{\mathrm{baseline}}} \qquad (A1\text{-}1)$$

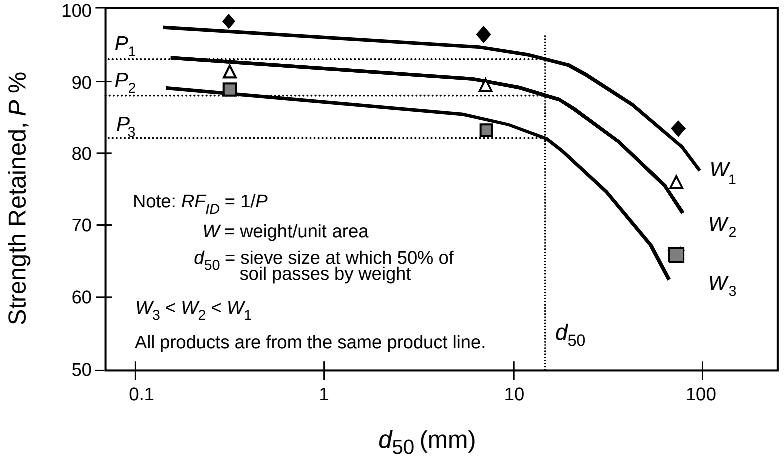
where:

T_{dam} = the average roll specific tensile strength after installation. In no case should RF_{ID} be less than 1.05; and

T_{baseline} = the average roll specific tensile strength before exposure to installation (baseline tensile strength for the installation damage test).

A1.1.6.2. To select an appropriate reduction factor for design, the project site installation conditions must be related to the installation test conditions. To relate the installation damage test conditions to the actual site conditions, primary consideration shall be given to the backfill characteristics (d_{50} particle size, potential for oversize material, particle angularity, and overall gradation) and, to a lesser degree, the method of spreading the backfill over the geosynthetic, the type of compaction equipment, and initial backfill lift thickness over the geosynthetic, provided that the initial lift thickness is 150 mm (6 in.) or more. The actual installation conditions used in the test must be clearly stated in the test report, specifically identifying any deviations from typical geosynthetic reinforcement installation practices in full-scale structures, and the impact those deviations have on the values of RF_{ID} determined.

A1.1.6.3. A repeatable interpolation procedure to estimate RF_{ID} for soils that fall between the soil gradations tested and for the products in the product line not tested (if not all the products in the product line are tested for installation damage resistance) shall be developed. Values of RF_{ID} may be estimated for a specified soil gradation using interpolation as illustrated in Figure A1-1. The d_{50} size of the soil has commonly been used for interpolating between soil backfills for determination of RF_{ID}. Other combinations of soil particle size and factors that account for soil angularity and durability may be considered for this correlation and interpolation procedure per mutual agreement between the geosynthetic manufacturer and the approval authority. The range of backfill gradations, angularity, and durability will affect the range of applicability of the RF_{ID} values obtained from the testing. RF_{ID} values should not be extrapolated beyond the coarsest backfill soil tested.



Note: $RF_{ID} = 1/P$

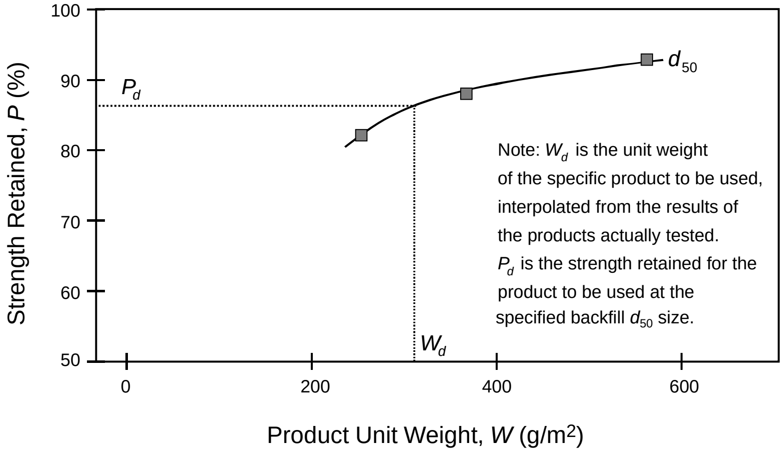
W = weight/unit area

d_{50} = sieve size at which 50% of soil passes by weight

$W_3 < W_2 < W_1$

All products are from the same product line.

Figure A1-1—Example of Installation Damage Data for Several Products That Represent a Product Line When a Strong Relationship between a Product Index Property (e.g., Weight/Unit Area, *W*) and Strength Retained Is Observed



Note: W_d is the unit weight of the specific product to be used, interpolated from the results of the products actually tested.

P_d is the strength retained for the product to be used at the specified backfill d_{50} size.

Figure A1-2—Example of Installation Damage Data Presentation That Can Be Used to Interpolate Values of Strength Retained for Products Not Installation Damage Tested When a Strong Relationship between a Product Index Property and Strength Retained Is Observed

A1.1.6.4. If not all the products within a product line are tested for installation damage, interpolation between products to estimate RF_{ID} is required. The interpolation procedures used depend on whether or not there is strong relationship between a product property (e.g., weight/unit area, tensile strength) and the product's ability to resist damage. As a minimum, the weakest (lightest) and strongest (heaviest) products within the product line, plus at least one additional intermediate strength (weight) product (i.e., the product selected as the primary product for product line characterization) should be used to characterize RF_{ID} for the product line. If the installation damage resistance of each product in the product line can be correlated to a product property, the interpolation procedure provided in Figure A1-2 may be used.

If the installation damage resistance of each product in the product line cannot be strongly correlated to a product property, the interpolation/RF_{ID} product line assessment procedures for backfill gradation and product characteristics in Figures A1-3 and A1-4 may be used.

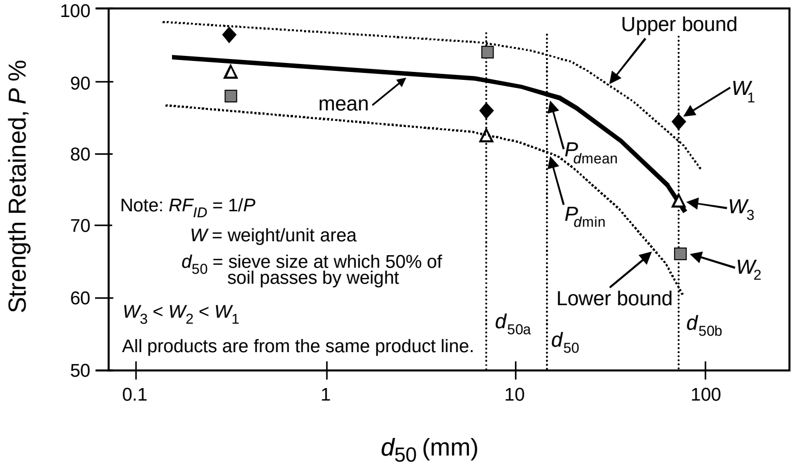


Figure A1-3—Example of Installation Damage Data for Several Products That Represent a Product Line When a Weak Relationship between a Product Index Property and Strength Retained Is Observed

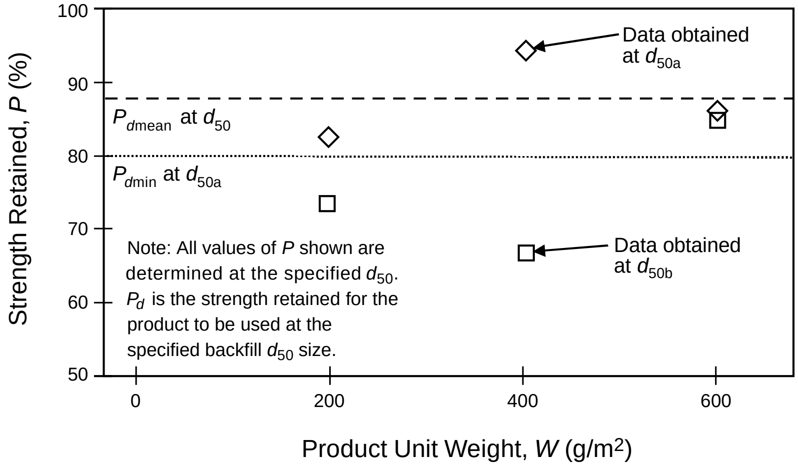


Figure A1-4—Example of Installation Damage Data Presentation That Can Be Used to Interpolate Values of Strength Retained for Products Not Installation Damage Tested When a Weak Relationship (or No Relationship) between a Product Index Property and Strength Retained Is Observed

If it is determined that the RF_{ID} values obtained for a product line are not correlated with product weight per unit area, undamaged tensile strength, coating weight, or some other product parameter, and the variance of RF_{ID} between any two products in the product line is 0.1 or more, then each product in the product line shall be tested. If, in this case (i.e., no correlation could be found), the variance of RF_{ID} between any two products in the product line is less than 0.1 and the upper bound value of RF_{ID} is selected for all products in the product line, not all products in the product line need to be tested.

For coated polyester geogrids, typical properties such as weight/unit area or tensile strength usually do not correlate well to installation damage and the magnitude of RF_{ID}. In that case, the coating thickness or coating mass per unit area relative to the mass per unit area of the product should be considered for the purpose of correlating RF_{ID} between products rather than product unit weight or tensile strength alone.

Note A3—For coated geogrids, the weight of coating placed on the fibers or yarns may influence the amount of installation damage obtained (Sprague, et al., 1999). It is acceptable to obtain the coating mass/unit area through the use of manufacturer QC data on the lot specific mass/unit area of the uncoated material (i.e., the weight of the “greige-good”), subtracting that mass/unit area from the total mass/unit area of the finished product. The total mass per unit area of the sample used in the installation damage testing should be obtained in accordance with ASTM D 5261.

A1.2. *References*:

A1.3. Sprague, C. J., and S. A. Allen. Testing Installation Damage of Geosynthetic Reinforcement. *Geotechnical Fabrics Report*, Vol. 21, No. 6. Industrial Fabrics Association International, St. Paul, MN, 2003, pp. 24–27.

ANNEX B

(Mandatory Information)

B1. CREEP TESTING AND EXTRAPOLATION PROCEDURES TO DETERMINE RF_{CR} FOR GEOSYNTHETIC REINFORCEMENTS

B1.1. *General*:

B1.1.1. The effect of long-term load/stress on geosynthetic reinforcement strength and deformation characteristics shall be determined from the results of product specific, controlled, long-term laboratory creep tests conducted for a range of load levels and durations, adequate for extrapolation purposes to the desired design life, carried out to rupture of the geosynthetic when possible.

B1.2. *Creep Testing Requirements*:
Creep testing, unless otherwise specified herein, shall be conducted in accordance with ASTM D 5262 or D 6992.

B1.2.1. Creep testing in accordance with ASTM D 5262, carried out to rupture when feasible, and at elevated temperatures for the purpose of creep extrapolation using time–temperature superposition principles, is identified herein as the “conventional method.” ASTM D 6992 (Stepped Isothermal Method, or SIM) is also identified herein as an alternative accelerated creep testing method.

B1.2.2. For both test methods, unless otherwise specified or mutually agreed upon by the geosynthetic supplier, the testing laboratory, and the owner, a baseline testing temperature of 68°F (20°C) shall be used for this testing. Higher test temperatures shall be considered as elevated temperatures to be used for the purpose of time extrapolation, unless a higher baseline temperature is needed to match the effective design temperature for a specific site.

B1.2.3. ASTM D 5262 requires that the testing temperature be maintained at +3.6°F (2°C). For some polymers, this degree of variance could significantly affect the accuracy of the shift factors and extrapolations determined in accordance with this annex. For polymers that are relatively sensitive to temperature variations, this issue should be considered when extrapolating creep data using time–temperature superposition techniques, or minimized by using a tighter temperature tolerance.

B1.2.4. Specimens shall be tested in the direction in which the load will be applied in use.

Single ribs for geogrids, or yarns or narrow width specimens for woven geotextiles, may be used for creep testing for the determination of RF_{CR} provided that it can be shown through a limited creep testing program conducted as described in Section B1.7 that the rupture behavior and envelope for the single-rib, yarns, or narrow width specimens are the same as that for the full width product as defined in ASTM D 5262. This comparison must demonstrate that there is no statistical difference between the full width product creep-rupture regression line and the single-rib, yarn, or narrow width specimen regression line at a time of 1000 hours using Student's *t*-distribution at a confidence level of 0.10 (see Equation B1-3).

B1.3. *Overview of Creep Extrapolation Approach*:

B1.3.1. Test results shall be extrapolated to the required structure design life. Based on the extrapolated test results, for ultimate limit state design, determine the highest load level, designated T_l, that precludes both ductile and brittle creep rupture within the required lifetime. T_l should be determined at the required design life and at the design site temperature. Creep test results shall also be extrapolated (not necessarily to the structure design life) to estimate the long-term stiffness of the geosynthetic as specified in Section B2.

B1.3.2. The details of the creep extrapolation approach depend on whether stress rupture or creep strain data are used. To determine T_l, the objective is to predict the rupture limit. Obviously, extrapolating stress rupture data is the most direct way to estimate T_l. However, it is possible to estimate T_l using creep strain data without detailed time to rupture data as discussed herein. Extrapolation of creep strain data is also necessary to estimate the long-term stiffness of the geosynthetic.

B1.3.3. If elevated temperature is used to obtain accelerated creep data, minimum increments of 10°C should be used to select temperatures for elevated temperature creep testing. The highest temperature tested, however, should be below any transitions for the polymer in question. If one uses test temperatures below 70 to 75°C for PP, HDPE, and PET geosynthetics, significant polymer transitions will be avoided. If higher temperatures must be used, the effect of any transitions on the creep behavior should be carefully evaluated.

Note B1—At high temperatures, significant chemical interactions with the surrounding environment are possible, necessitating that somewhat lower temperatures or appropriate environmental controls be used. These chemical interactions are likely to cause the creep test results to be conservative. Therefore, from the user's point of view, potential for chemical interactions is not detrimental to the validity of the data for predicting creep limits. However, exposure to temperatures near the upper end of these ranges could affect the stress-strain behavior of the material due to loss of molecular orientation, or possibly other effects that are not the result of chemical degradation. Therefore, care needs to be exercised when interpreting results from tests performed at temperatures near or above the maximum test temperatures indicated above. In general, if the stiffness of the material after exposure to the environment is significantly different from that of the virgin material, the stress-strain properties, and possibly the strength, of the material may have been affected by the exposure temperature in addition to the chemical environment. If the stiffness has been affected, the cause of the stiffness change should be thoroughly investigated to determine whether or not the change in stiffness is partially or fully due to the effect of temperature, or alternatively not use the data obtained at and above the temperature where the stiffness was affected. The SIM does use temperatures above 75°C, and, at least for PET geosynthetics, test temperatures above this level have not adversely affected the accuracy of the SIM extrapolations.

B1.3.4. This annex provides extrapolation procedures for both stress rupture test data and creep strain data. Two creep extrapolation techniques are provided herein for creep rupture and creep strain data evaluation: the conventional method, which utilizes a simplified visual/graphical approach, temperature acceleration of creep, regression techniques, and statistical extrapolation, and the SIM. This does not mean that the more complex mathematical modeling techniques cannot be used to extrapolate creep of geosynthetics, per agreement with the parties involved; however, they are simply not explained herein.

B1.4. *Extrapolation of Stress Rupture (Creep) Data*:

B1.4.1. Conventional Method:

B1.4.1.1. Plot the stress (creep) rupture data as log time to rupture versus log load level (i.e., log-log plot) or just load level (i.e., semi-log plot), as shown in Figure B1-1. Do this for each temperature in which creep-rupture data are available. The plotting method that provides the best and most consistent fit of the data should be used. A minimum 12 to 18 data points (i.e., combined from all temperature levels tested to produce the envelope for a given product, with a minimum of four data points at each temperature) are required to establish a rupture envelope. The data points should be evenly distributed through each log cycle of time. Rupture points with a time to rupture of less than 5 hours, in general, should not be used, unless it can be shown that these shorter duration points are consistent with the rest of the envelope (i.e., they do not contribute to nonlinearity of the envelope).

Note B2—As a guide, three of the test results should have rupture times (not shifted by temperature acceleration) of 10 to 100 hours, four of the test results should have rupture times between 100 and 1000 hours, and four of the test results should have rupture times of 1000 to 10 000 hours, with at least one additional test result having a rupture time of approximately 10 000 hours (1.14 years) or more. It is recommended that creep strain be measured as well as time to rupture, since the creep strain data may assist with conventional time–temperature shifting and in identifying any change in behavior that could invalidate extrapolation of the results.

B1.4.1.2. Extrapolate the creep-rupture data. Elevated temperature creep-rupture data can be used to extrapolate the rupture envelope at the design temperature through the use of a time shift factor, a_T. If the rupture envelope is approximately linear, the single time shift factor a_T should be adequate to perform the time–temperature superposition.

Note B3—This time–temperature superposition procedure assumes that the creep-rupture curves at all temperatures are linear on a semi-logarithmic or double logarithmic scale and parallel.

Use of a single time shift factor to shift all the creep-rupture data at a given temperature, termed "block shifting," assumes that the shift factor a_T is not highly stress level dependent and that the envelopes at all temperatures are parallel, allowing an average value of a_T to be used for all of the rupture points at a given temperature.

The time to rupture for the elevated temperature rupture data is shifted in accordance with the following equation:

$$t_{\text{amb}} = (t_{\text{elev}})(a_T) \qquad (B1\text{-}1)$$

where:

t_{amb} = the predicted time at the ambient or temperature to reach rupture under the specified load,

t_{elev} = the measured time at elevated temperature to reach a rupture under the specified load, and

a_T = the time shift factor.

The time shift factor, a_T, can be estimated approximately by using a visual/graphical approach as illustrated in Figures B1-1 and B1-2. The preferred approach, however, is to use a computer spreadsheet optimization program to select the best shift factors for each constant temperature block of data to produce the highest R^2 value for the combined creep-rupture envelope to produce the result in Figure B1-2.

Note B4—Incomplete tests may be included, with the test duration replacing the time to rupture, but should be listed as such in the reported results, provided that the test duration, after time shifting, is 10 000 hours or more. The rule for incomplete tests is as follows. The regression should be performed with and without the incomplete tests included. If the incomplete test results in an increase in the creep limit, keep the incomplete tests in the regression, but if not, do not include them in the regression, in both cases for incomplete tests that are 10 000 hours in duration after time shifting or more. Record the duration of the longest test that has ended in rupture, or the duration of the longest incomplete test the duration of which exceeds its predicted time to failure: this duration is denoted as $t_{\max}$.

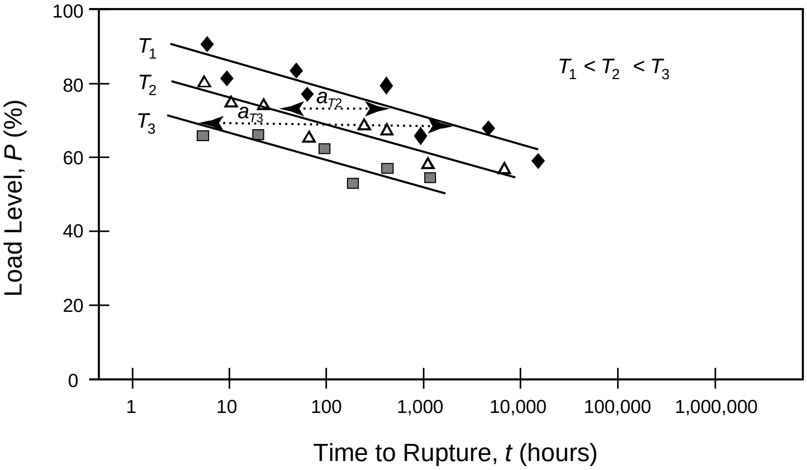


Figure B1-1—Typical Stress Rupture Data for Geosynthetics, and the Determination of Shift Factors for Time–Temperature Superposition

B1.4.1.3. It is preferred that creep-rupture data not be extrapolated statistically beyond the elevated temperature time shifted data. However, if statistical extrapolation is necessary, it shall be accomplished using regression analysis (i.e., curve fitting) up to a maximum of one log cycle of time for all geosynthetic polymers (greater extrapolation using only statistical methods is feasible, but uncertainty in the result increases substantially and must be taken into account). Therefore, adequate elevated temperature data should be obtained to limit the amount of statistical extrapolation required.

Note B5—There may be situations in which extrapolation to create a creep-rupture envelope at a lower temperature than was tested is necessary. Situations in which this may occur include the need to elevate the ambient temperature to have greater control regarding the temperature variations during the creep testing (i.e., ambient laboratory temperature may vary too much), or for sites where the effective design temperature is significantly lower than the "standard" reference temperature used for creep testing (e.g., northern or high-elevation climates). In such cases, it is feasible to use lower bound shift factors based on previous creep testing experience to allow the creep-rupture envelope to be shifted to the lower temperature, as shift factors for the materials typically used for geosynthetic reinforcement are reasonably consistent. Based on previous creep testing experience and data reported in the literature (Chow and Van Laeken, 1991; Thornton, et al. 1998; Thornton, et al., 1998a; Lothspeich and Thornton, 2000; Takemura, 1959; Bush, 1990; Popelar, et al., 1990; Wrigley, et al., 1999; Takaku, 1981; Thornton and Baker, 2002), shift factors for HDPE and PP geosynthetics are typically in the range of 0.05 to 0.18 decades (i.e., log cycles of time) per 1°C increase in temperature (i.e., a 10°C increase would result in a time shift factor of 12 to 15) and 0.05 to 0.12 decades per 1°C increase in temperature for PET geosynthetics. It is recommended that if shifting the creep-rupture envelope to temperatures below the available data is necessary, a shift factor of 0.05 decades per 1°C increase in temperature for PP, HDPE, and PET be used. This default shift factor should not be used to shift the creep-rupture data more than 10°C.

B1.4.1.4. Once the creep data have been extrapolated, determine the design, roll specific, creep limit load by taking the load level at the desired design life directly from the extrapolated stress rupture envelope as shown in Figure B1-2. If statistical extrapolation beyond the time shifted stress rupture envelopes (PP or HDPE), or beyond the actual data if temperature accelerated creep data are not available, is necessary to reach the specified design life, the calculated creep load T_l should be reduced by an extrapolation uncertainty factor as follows:

$$T_l = \frac{P_{cl}}{(1.2)^{x-1}} \qquad (B\text{-}2)$$

where:

P_{cl} = the creep limit load taken directly from the extrapolated stress rupture envelope, and

x = the number of log cycles of time the rupture envelope must be extrapolated beyond the actual or time shifted data and is equal to $\log t_d - \log t_{\max}$ as illustrated in Figure B1-2.

The factor $(1.2)^{x-1}$ is the extrapolation uncertainty factor. If extrapolating beyond the actual or time shifted data less than one log cycle, set "x–1" equal to "0". This extrapolation uncertainty factor only applies to statistical extrapolation beyond the actual or time shifted data using regression analysis and assumes that a "knee" in the rupture envelope beyond the actual or time shifted data does not occur.

Note B6—A condition on the extrapolation is that there is no evidence or reason to believe that the rupture behavior will change over the desired design life. It should be checked at long durations and at elevated temperatures, if used:

- There is no apparent change in the gradient of the creep-rupture curve.
- There is no evidence of disproportionately lower strains to failure.
- There is no significant change in the appearance of the fracture surface.

Any evidence of such changes, particularly in accelerated tests, should lead to the exclusion of any reading in which either the gradient, strain at failure, or appearance of the failure is different from those in the test with the longest failure duration. Particular attention is drawn to the behavior of unoriented thermoplastics under sustained load, where a transition in behavior is observed in long-term creep-rupture testing (i.e., the so called "ductile to brittle transition" – Popelar, et al., 1991). The effect of this transition is that the gradient of the creep-rupture curve becomes steeper at the so-called "knee" such that long-term failures occur at much shorter lifetimes than would otherwise be predicted. The strain at failure is greatly reduced and the appearance of the fracture surface changes from ductile to semi-brittle. If this is observed, any extrapolation should assume that the "knee" will occur. For the method of extrapolation, reference should be made to ISO/FDIS 9080:2001, ASTM D 2837, and Popelar, et al. (1991).

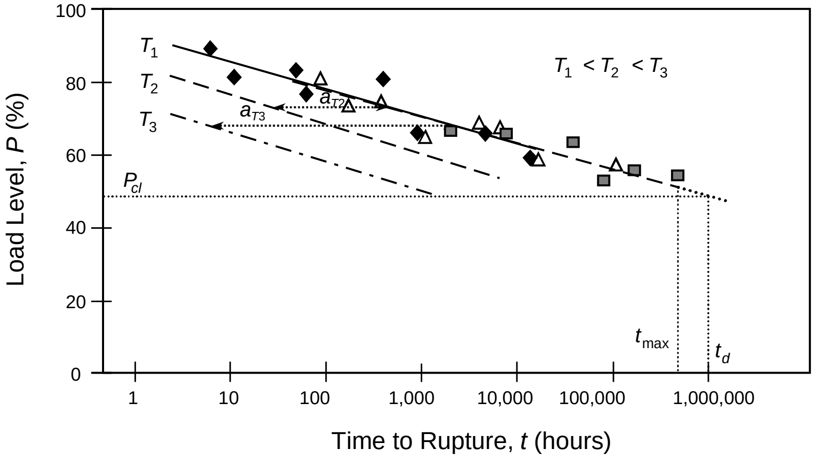


Figure B1-2—Extrapolation of Stress Rupture Data and the Determination of the Creep Limit Load

B1.4.1.5. The extrapolation uncertainty factor also assumes that the data quality is good, data scatter is reasonable, and that approximately 12 to 18 well distributed data points define the stress rupture envelope for the product. If these assumptions are not true for the data in question, this uncertainty factor should be increased. This extrapolation uncertainty factor should be increased to as much as (1.4)x if there is the potential for a “knee” in the stress rupture envelope to occur beyond the actual or time shifted data, or if the data quality, scatter, or amount is inadequate. Furthermore, if the data quantity or distribution over the time scale is inadequate, it may be necessary to begin applying the extrapolation uncertainty factor before the end of the time shifted data.

Note B7—Based on experience, the R^2 value for the composite (i.e., time shifted) creep-rupture envelope should be approximately 0.8 to 0.9 or higher to be confident that Equation B1-2 will adequately address the extrapolation uncertainty. If the R^2 value is less than approximately 0.6 to 0.7, extrapolation uncertainty is likely to be unacceptably high and additional testing and investigation should be performed. In general, such low R^2 values are typically the result of data that is too bunched up, unusually high specimen-to-specimen variability, or, possibly, poor testing technique.

B1.4.2. Stepped Isothermal Method (SIM):

B1.4.2.1. The testing and analysis shall be conducted in accordance with ASTM D 6992.

B1.4.2.2. The SIM may be used to generate and extrapolate geosynthetic creep and creep-rupture data provided this method is shown to produce results that are consistent with the “conventional” extrapolation techniques recommended in Section B1.4.1. To this end, creep-rupture testing shall be conducted using conventional tests (ASTM D 5262) and SIM tests (ASTM D 6992). At least six SIM rupture tests and six conventional rupture tests shall be conducted on one of the products in the product line being evaluated. Typically, the product tested is the one defined as the primary product in Section 6.3.2. Of the six SIM rupture tests, four shall have rupture times (shifted as appropriate) between 100 and 2000 hours and two shall have rupture times greater than 2000 hours. For the conventional (ASTM D 5262) creep tests, a distribution of rupture points similar to that described for the six SIM rupture points should be used. All of the conventional creep-rupture points shall be obtained at the reference temperature (i.e., not temperature shifted). For both the SIM and conventional creep-rupture tests, the test with the longest rupture time should have a rupture time that is approximately 10 000 hours. Creep-rupture plots shall be constructed, regression lines computed, and the log times to rupture determined at a load level that corresponds with 1000 hours and 50 000 hours on the conventional creep-rupture envelope, for the two data sets. The log time to rupture for the SIM regression at this load level shall be within the upper and lower 90 percent confidence limits of the mean conventional regressed rupture time at the same load level using Student’s *t*-test.

B1.4.2.3. The confidence limit for the regression performed for the conventional creep-rupture data is given by (Wadsworth, 1998):

$$\log t_L = \log t_{\mathrm{reg}} \pm \left[t_{\alpha,n-2} \sqrt{\frac{1}{n} + \frac{\left(P - \bar{P}\right)^2}{\sum\left(P_i - \bar{P}\right)^2}} \right] \times \sigma \qquad (B1\text{-}3)$$

and

$$\sigma = \sqrt{\frac{\sum\left[\log t_i - \log \bar{t}\right]^2 - \dfrac{\left\{\sum\left[\left(P_i - \bar{P}\right)\left(\log t_i - \log \bar{t}\right)\right]\right\}^2}{\sum\left(P_i - \bar{P}\right)^2}}{n-2}} \qquad (B1\text{-}4)$$

where:

$\log t_L$ = lower and upper bound confidence limit. The + or – term in Equation B1-3 results in the lower and upper bound confidence limits, respectively.

t_{reg} = time corresponding to the load level from the conventional creep-rupture envelope at which the comparison between the two envelopes will be made (e.g., at 1000 and 50 000 hours after time shifting).

$t_{\alpha,n-2}$ = value of the Student's *t*-distribution determined from applicable Student's *t*-table (or from the Microsoft EXCEL function TINV(α,n–2)) at $\alpha = 0.10$ and n–2 degrees of freedom (this corresponds to the 90 percent two-sided prediction limit).

n = the number of rupture or allowable run-out points in the original test sample (i.e., the conventional creep-rupture data).

P = load level obtained at t_{reg} from the regression line developed from the conventional creep-rupture testing.

$\overline{P}$ = the mean rupture load level for the original test sample (i.e., all rupture or run-out points used in the regression to establish the conventional creep rupture envelope).

P_i = the rupture load level of the *i*th point for the rupture points used in the regression for establishing the conventional creep-rupture envelope.

$\log \overline{t}$ = the mean of the log of rupture time for the original test sample (i.e., all rupture or run-out points used in the regression to establish the conventional creep-rupture envelope).

t_i = the rupture time of the *i*th point for the rupture points used in the regression for establishing the conventional creep-rupture envelope.

Once $\log t_L$, both upper and lower bound, has been determined at the specified load level, compare these values to the log rupture time (i.e., $\log t_{\mathrm{SIM}}$) obtained for the SIM creep-rupture envelope test at the specified load level (e.g., 1000 and 50 000 hours). The value of $\log t_{\mathrm{SIM}}$ at the two specified load levels must be between the upper and lower bound confidence limits ($\log t_L$). If this requirement is not met, perform two additional SIM tests at each load level P for the specified t_{reg} where this comparison was made, and develop a new SIM creep-rupture envelope using all of the SIM data. If, for the revised SIM regression envelope resulting from these additional tests, this criterion is still not met, perform adequate additional conventional creep-rupture testing to establish the complete rupture envelope for the product in accordance with this annex.

B1.4.2.4. If the criterion provided above is met, the SIM testing shall be considered to be consistent with the conventional data, and SIM may be used in combination with the conventional data to meet the requirements of Section B1.4 regarding the number of rupture points and their distribution in time and maximum duration. Therefore, the combined data can be used to create the creep-rupture envelope as shown in Figure B1-2. In that figure, the SIM data shall be considered to already be time shifted. Equation B1-2 is then used to determine T_l. If, for a given product or product line, SIM has been previously demonstrated to be consistent with the conventional creep data, and it is known that the product or product line has not changed significantly with regard to the polymer and the product processing, SIM data may continue to be used without performing a new comparison between the SIM and conventional data.

B1.5. *Extrapolation of Creep Strain Data*:
While it is possible to use creep strain data to estimate T_l, it generally provides no practical advantage over taking creep test specimens to rupture to develop a creep-rupture envelope. Therefore, detailed procedures to use creep strain data for this purpose are not provided in this standard practice. See WSDOT T 925 for additional information and discussion on use of creep strain data for this purpose, as well as other related information and guidance on handling creep strain data.

B1.6. *Determination of RF_{CR}*:

B1.6.1. The creep reduction factor, RF_{CR}, is determined by comparing the long-term creep strength, T_l , to the ultimate tensile strength (ASTM D 4595 or ASTM D 6637) of the sample tested for creep (T_{baseline}). The sample tested for ultimate tensile strength should be taken from the same roll of material used for the creep testing. The strength reduction factor to prevent long-term creep rupture is determined as follows:

$$RF_{CR} = \frac{T_{\text{baseline}}}{T_l} \qquad (B1\text{-}5)$$

where:

T_{baseline} = the average roll specific ultimate tensile strength (ASTM D 4595 or ASTM D 6637) for the roll of material used for the creep testing.

B1.6.2. This creep reduction factor takes extrapolation uncertainty into account, but does not take into account variability in the strength of the material. Material strength variability shall be taken into account when RF_{CR} is applied to T_{ult} to determine the long-term allowable tensile strength, using the minimum average roll value or minimum value for T_{ult}.

B1.7. *Evaluation of Product Lines with Regard to Creep Data*:

B1.7.1. For creep evaluation of a new product not part of the original product line, but, based on the definition of a product line in Sections 3.18 and 6.3.1, considered as part of the original product line, this limited testing program should include creep tests taken to at least 1000 to 2000 hours in duration before time shifting if using the “conventional” creep testing approach, with adequate elevated temperature data to permit extrapolation to 50 000 hours or more. If it has been verified that the use of SIM is acceptable for the product line in accordance with Section B1.4.2.2, durations after time shifting due to elevated temperature up to a minimum of 50 000 hours are required. A minimum of four data points per temperature level tested should be obtained to determine time shift factors and to establish the envelope for the new product. The data points, after time shifting, should be as evenly distributed along the time axis as possible. This comparison between the creep rupture data obtained for the original product line and the creep data for the new product shall demonstrate that there is no statistical difference between the regression lines for the existing product line and the new product at a time of 1000 hours (not temperature accelerated) and 50 000 hours (after time shifting) using Student’s *t*-distribution at a confidence level of 0.10 (see Section B1.4.2.3, specifically Equation B1-4). If no statistical difference is observed, the results from the full testing program for the original product line could be applied to the new product. If this is not the case, then a full testing and evaluation program for the new product should be conducted (i.e., treat it as a primary product as defined in Section 6.3.2).

B1.7.2. For extension of the creep data obtained on one product in the product line (i.e., the primary product tested, which is typically a product in the middle of the range of products in the product line) to the entire product line as defined herein, a limited creep testing program shall be conducted on at least two additional products in the product line. The combination of the three or more products should span the full range of the product line in terms of weight and/or strength. The limited test program described in Section B1.7.1 shall be applied to these additional products. The loads obtained for the data in each envelope should then be normalized by the roll specific ultimate tensile strength, T_{baseline}. All three envelopes should plot on top of one another, once normalized in this manner, and the two additional product envelopes should be located within the confidence limits for the product with the more fully developed creep-rupture envelope (i.e., the “primary” product) as described in Section B1.7.1. If this is the case, then the creep reduction factor for the product line shall be the lesser of (1) the reduction factor obtained for the product with the fully developed rupture envelope, and (2) the envelope of all three products combined. Normalization using the ultimate tensile strength shall be considered acceptably accurate if this is the case. If this is not the case, then the creep-rupture envelopes for the other two products, plus enough other products within the product line, to establish the trend in RF_{CR} as a function of product weight or ultimate tensile strength, so that the RF_{CR} for the other products within the product line can be accurately interpolated. Furthermore, T_{al} must be determined in accordance with Note B8.

Note B8—Note that normalization using the ultimate lot specific tensile strength may not be completely accurate for some geosynthetic products regarding characterization of creep-rupture behavior, and other normalization techniques may be needed (Wrigley, et al., 1999). In such cases, individual creep reduction factors for each product in the product line may need to be established through fully developed creep-rupture envelopes for representative products obtained at the low-, middle-, and high-strength end of the product series. Once the creep limited strength, P_{cl} and the creep reduction factors are established for each product, in this case, product variability must still be taken into account. In such cases, T_{al} must be the lesser of the determination from Equation 1 and the following determination:

$$T_{al} = \frac{P_{95}}{RF_{ID} \times RF_{D}}$$

where:

P_{95} = the tensile strength determined from the 95 percent lower bound prediction limit for the creep rupture envelope at the specified design life (see Equations 4 and 5 in Section 7.5.3.2.

B2. ESTIMATION OF CREEP STIFFNESS FOR WORKING STRESS DESIGN

B2.1. *General*:

Strains for working stress design, such as when using the K-Stiffness Method (Allen et al., 2003) are typically small (i.e., approximately 2 percent). Since reinforcement stiffness is generally a nonlinear function of strain, it is important to obtain the creep stiffness at the appropriate strain level. Therefore, unless otherwise specified per agreement of the parties involved, the creep stiffness should be determined at a strain level of 2 percent. The stiffness value to be used for geosynthetic structure design should be determined at the end of construction (J_{EOC}) or at the end of the structure design life (J_{DL}). Either "conventional" creep testing may be used, or SIM may be used to estimate the stiffness if SIM is determined to be consistent with the conventional creep strain, especially at low strain levels. If comparison between SIM creep strain data and "conventional" creep strain data at low strain levels has not been conducted, then comparison testing between the two approaches will be needed if it is desired to use SIM for the products tested at low strain levels. J_{EOC} should be determined at 1000 hours from creep data, unless another time period is specified by the parties involved to match the actual or anticipated time required to construct the geosynthetic structure for which the stiffness values are to be used.

Note B9—The primary purpose of this stiffness calculation is to provide input data for working stress methods such as the K-Stiffness method (Allen, et al., 2003; WSDOT, 2006), or for more sophisticated analyses such as finite element or finite difference numerical simulations. The time period upon which the stiffness value J_{EOC} is to be based is typically 1000 hours, or the time required to construct the geosynthetic structure. See Walters, et al. (2002) and Allen and Bathurst (2002) for a detailed explanation regarding the time period that should be used to determine J_{EOC}. For J_{DL}, the stiffness should be determined at a time equal to the structure design life (typically 75 years).

B2.2. *Creep Stiffness Testing and Analysis Requirements*:

B2.2.1. The load application rate during creep load ramp up should be consistent with the application rate used in the governing tensile test method (e.g., ASTM D 4595 or D 6637). If it is not possible to accurately apply the load at a specified rate (e.g., if dead weight is applied through the use of a jack), the actual application rate should be measured and recorded.

B2.2.2. The slack tension, T_o, applied to the specimen based on the governing tensile test (e.g., ASTM D 4595 or D 6337) will likely be too large for creep stiffness testing due to the very low loads that are likely for this type of testing. A maximum slack tension of approximately 10 percent of the anticipated load at 2 percent strain or 9 N (2 lbf), whichever is less, should be used for single-rib or narrow width specimens. For full width specimens (i.e., per ASTM D 5262), a maximum slack tension of approximately 10 percent of the anticipated load at 2 percent strain or 70 N (15 lbf), whichever is less, should be used. Since these maximum slack tension values differ from what is specified in ASTM D 4595 and ASTM D 6637, a special set of tensile tests may need to be conducted for use with the low strain creep stiffness testing program. ASTM D 4595 and D 6637 allow both the slack tension and the slack displacement, d_o, to be set to zero for calculation purposes. For low strain creep stiffness testing, the slack displacement should be set to zero, but the slack tension should be left at its full value for stiffness calculation purposes.

B2.2.3. If it has been shown that single-rib/narrow width specimens can be used in lieu of full width specimens for creep testing at high load levels (see Section B1.2.5), single-rib/narrow width specimens may also be used for low strain creep stiffness testing if respective short-term tensile tests also indicate no significant specimen width effects. The maximum difference between the mean values of the load at 2 percent strain in the single-rib/narrow width tensile tests and the full width tensile tests must be no greater than what is considered statistically insignificant based on a one-sided Student's *t*-distribution at a level of significance of 0.05, as determined using Equation 3 in Section 7.5.2.1.

B2.2.4. Obtain creep strain data for at least one load level low enough to produce a strain level at the end of structure construction (assume to be 1000 hours unless otherwise specified by the approval authority). Per agreement between the approval authority and the reinforcement manufacturer, load levels to produce additional 1000-hour strain levels may be tested. A minimum of two specimens per product at each load level shall be tested.

B2.2.5. To establish the load levels needed to produce the desired 1000-hour strains for each product, conduct a series of 1000 second R+H tests. An initial estimate of the load levels needed for the R+H tests may be obtained from the tensile tests used to establish T_{baseline} for each product tested. Test a load level that is likely to produce a strain of approximately 2 percent at 1000 hours, and then two other load levels to bracket the 2 percent load level (e.g., at load levels that would yield approximately 1 percent strain and 3 to 4 percent strain at 1000 hours). Do three replicate R+H tests at each of those load levels, plotting the load level as a function of the estimated strain at 1000 hours, assuming a log linear extrapolation is valid for the R+H test results. The creep data extrapolation and analysis process is illustrated in Figures B1-3 and B1-4. Perform a regression analysis of that data to obtain a more accurate estimation of the load level required to produce a strain of 2 percent at 1000 hours, and run three replicate R+H tests at that load level. If one of the load levels used for the R+H tests does not produce an estimated strain of 2 percent at 1000 hours, a fourth set of three replicate R+H tests may be needed, estimating the load level based on a regression of the R+H tests for the first three load levels. Then conduct two full 1000-hour creep tests at the R+H load level that results in the closest estimate to 2 percent strain at 1000 hours.

Note B10—It is desirable to conduct the full 1000-hour creep tests at the R+H load levels tested so that a direct comparison can be made between the 1000-hour creep tests and the R+H tests. If the creep observed in the 1000-hour creep tests is, in fact, log linear, the R+H tests can then be used for quality assurance testing in the future.

B2.2.6. If log linear extrapolation of the short-term creep data is not feasible, create creep stiffness curves at the desired constant strain level (typically 2 percent) as shown in Figures B2-1 and B2-2, but without using R+H tests to establish the creep stiffness as a function of strain at the desired time (i.e., all creep curves must instead be taken to at least 1000 hours without log linear extrapolation). Elevated temperature extrapolation should not be necessary if the "conventional" approach is used. Be sure that the creep stiffness curve is developed at the desired effective design temperature.

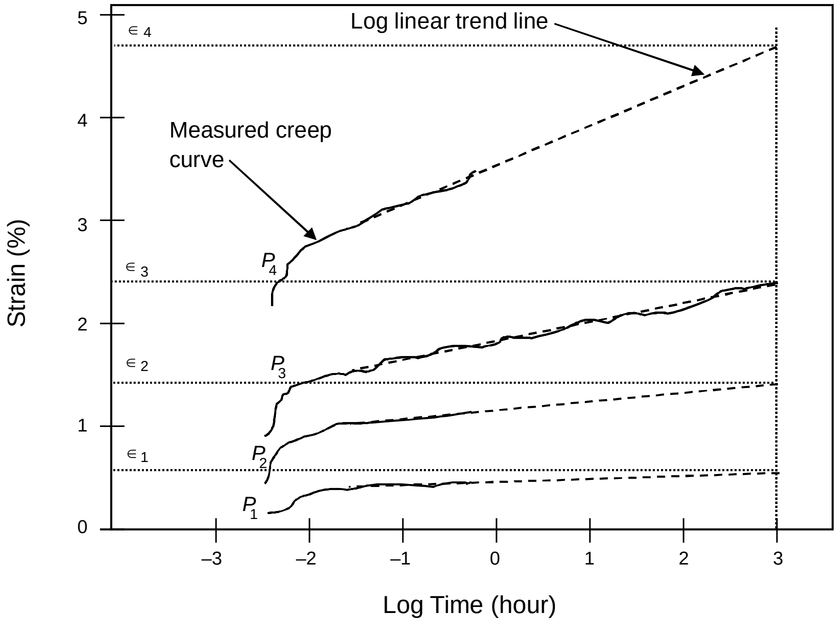


Figure B2-1—Strain Versus Time for Short-Term, Low Strain Creep Tests Used to Estimate Secant Stiffness

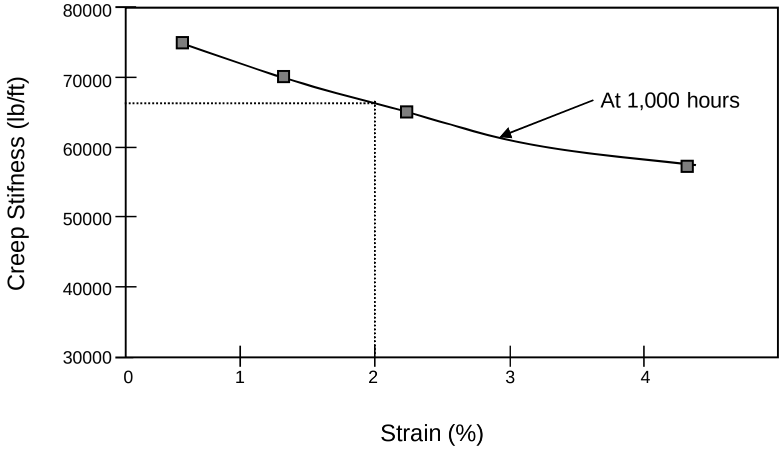


Figure B2-2—Creep Stiffness Determined from the Creep Curves at the Specified Time (see Figure B2-3) as a Function of Strain

B2.2.7. Obtain the creep stiffness at the desired time from the creep stiffness curve as shown in Figure B2-2. The creep stiffness from each creep test at the specified time is calculated as follows:

$$J = \frac{P \times T_{\text{baseline}}}{\in} \tag{B2-1}$$

where:

J = the secant creep stiffness determined at the specified strain level and time,
P = the load level expressed as a percent of T_{baseline},
T_{baseline} = the roll specific tensile strength of the sample used for the creep testing, and
$\in$ = the strain in percent.

These *J* values are then used to generate the plot shown in Figure B2-2.

B2.2.8. To extend the creep stiffness values obtained from the testing to the rest of the product line, a minimum of three products in the product line spanning the range of products in the line (i.e., the primary product, and the low and high end of the line in terms of strength) shall be tested as described in Section B1.7.2. To interpolate to other products between the products tested, determine T_{baseline} for each product tested, plotting the creep stiffness values obtained in Section B2.2.5 as a function of T_{baseline}, as illustrated in Figure B2-3. Creep stiffness values for other products in the product line not tested may be interpolated based on their baseline tensile strengths, if the relationship illustrated in Figure B2-3 is observed for the product line. If not, product specific testing should be conducted for all products in the product line.

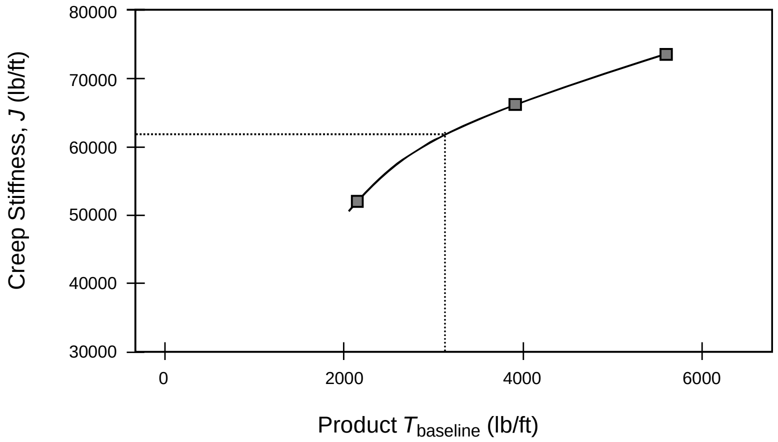


Figure B2-3—Example of Creep Stiffness, *J*, as a Function of T_{baseline}

B2.2.9. Once the values for the creep stiffness are determined for each product in the product line, the stiffness values need to be adjusted to reflect the MARV or minimum value for the geosynthetic, so that a minimum stiffness that accounts for uncertainty in the strength of the material is determined, similar to what is done for the determination of T_{al}. Calculate the design stiffness value as follows:

$$J_{\text{design}} = \frac{J \times T_{\text{MARV}}}{T_{\text{baseline}}} \tag{B2-2}$$

where:

J_{design} = the low strain design stiffness value at the specified time (e.g., J_{EOC}, J_{DL}, etc.);

J_{design} accounts for the variability in the product tensile strength through the use of T_{MARV}. Note that T_{min} may be used in lieu of T_{MARV}.

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ANNEX C

(Mandatory Information)

C1. PRODUCT SPECIFIC TESTING AND DATA INTERPRETATION REQUIREMENTS TO DETERMINE RF_D FOR GEOSYNTHETIC REINFORCEMENTS

C1.1. *General*:

C1.1.1. This annex provides guidance regarding the performance of long-term product specific durability testing that may be conducted for product qualification in lieu of the durability index testing as described in Section 6.4.5. The procedures that follow are required if it is desired to use a value of RF_D less than the default minimum of 1.3, or to determine RF_D for environments that are defined as aggressive.

C1.1.2. This annex has been developed to address PP, PE, HDPE, and PET geosynthetics. While the chemical and biological durability procedures and criteria provided herein may also be applicable to other polymers (e.g., hydrolysis testing as described herein is likely applicable to PA and PVA geosynthetics), additional investigation will be required to establish a detailed protocol and acceptance criteria for these other polymers. These other polymers may be considered for evaluation using this protocol once modifications to the chemical/biological durability aspects of this protocol have been developed and are agreed upon by the approval authority.

C1.2. *Durability Testing Requirements*:

C1.2.1. The product specific durability studies for the determination of RF_D should be conducted in or, if necessary, extrapolated to, the chemical/biological environment anticipated in the reinforced backfill. The anticipated temperature of the environment is also a key variable in assessing the durability of a given product, as temperature can have an exponential effect on the rate of product property change. Higher design temperatures may need to be considered for structures with southern exposures. The effective design temperature will be assumed to be 20°C (68°F).

Therefore, determine RF_D at a temperature of 20°C (68°F) unless otherwise specified and agreed upon by the parties involved.

C1.2.2. Standards are currently not available for determining the effect of chemical/biological activity on long-term geosynthetic reinforcement strength. However, long-term product specific durability testing can be conducted in a manner that is likely to produce safe results.

C1.2.3. Geosynthetic durability may be evaluated using either retrieval and testing of geosynthetics in actual installations or through long-term accelerated laboratory testing. Use of field retrieval data from actual installations requires that the baseline, in terms of tensile strength before and immediately after installation, and possibly other properties, be known with certainty, and that the observation period be of sufficient length to permit extrapolation to the desired design life.

Note C1—The field retrieval approach, in general, is fraught with practical and technical difficulties (see Allen and Elias, 1996; Elias, 2000; and Elias, 2001). Furthermore, long periods of time may be needed for polyolefins to establish trends that can be extrapolated due to the presence of antioxidants, as no loss in strength will be observed until the antioxidants are used up. Elias (2001) suggests that 30 years of in-service time may be required to obtain adequate observational data for polyolefins, and even PET products may require 20 years of in-service observations or more to accomplish this. Because of the very long observation periods required, long-term laboratory durability testing is the more practical approach to dealing with the durability issue. An overview of an appropriate laboratory testing approach for each geosynthetic polymer type is provided herein.

C1.2.4. For polyolefin products in which the fibers/ribs do **not** exhibit micro-cracks or crazes as manufactured, long-term chemical durability testing may consist of elevated temperature oven aging tests to evaluate potential for oxidation effects (FHWA, 1997; Elias, et. al., 1997; Salman, et al., 1998; Elias, et al., 1999). A magnification of ×2,000 to ×3,000 may be needed to observe whether or not micro-cracks or crazes are present (Salman, et al., 1997). If micro-cracks or crazes are present, elevated temperatures may significantly affect the molecular structure of polyolefins in the vicinity of the micro-cracks/crazes, making extrapolation of elevated temperature oxidation behavior to the behavior of the as-manufactured product at ambient temperatures very difficult (Salman, et al., 1998). For polyolefins in which the fibers/ribs exhibit micro-cracks or crazes, a means other than elevated temperature should be considered to accelerate oxidation behavior.

C1.2.5. Oven Aging for Thermo-Oxidation Potential for Polyolefin Geosynthetics:

C1.2.5.1. If oven aging tests are conducted, a forced-air oven is strongly recommended to keep the environment inside the oven as uniform as possible during the entire test duration and to keep oxidation products from building up inside the oven, considering the long durations that are likely to be required. Temperature uniformity inside the oven should be maintained at +1 percent. An oven with horizontal air flow is recommended. Specimens should be placed in the oven parallel to the air flow and spaced no closer together than 13 mm (0.5 in.) apart.

C1.2.5.2. The specimens should not be framed to prevent shrinkage as doing this will create load in the specimen, making the resulting data difficult to interpret.

C1.2.5.3. Oxidation testing using forced-air ovens will produce conservative estimates of long-term product strength due to the rapid air circulation and the relatively high oxygen content in the oven relative to the oxygen content in the ground.

C1.2.6. Hydrolysis Testing for Polyester Geosynthetics:

C1.2.6.1. For polyesters, long-term chemical durability testing should consist of elevated temperature immersion tests to evaluate potential for hydrolysis effects. A reactor similar to that illustrated in Elias, et al. (1999) is recommended for incubating the geosynthetic specimens. A description of the test protocol is provided by Elias, et al. (1999). The reactor should be capable of maintaining temperature uniformity (+1 percent) and stability during long-term use. A minimum solid-to-liquid ratio of 1:40 should be used to size the reactor and to determine the maximum number of specimens that can be placed in the reactor.

C1.2.6.2. Measures should be taken to minimize possibilities for oxidation and reaction with carbon dioxide during the long-term incubation (e.g., replace any air inside the reactor with nitrogen, use de-aired water, keep system well sealed, etc.).

C1.2.6.3. Specimens should be suspended in the solution on a hanger made of a material that will not react with or contaminate the immersion fluid and specimens (e.g., Teflon, stainless steel, etc.). The specimens should not be framed to prevent shrinkage so that an unknown amount of tension is not placed on the specimens. Specimens should each be separated by a distance of at least 13 mm (0.5 in.).

C1.2.6.4. The solution should be intensively stirred to ensure solution uniformity.

C1.2.6.5. For coated polyester products, the immersion tests should be conducted without the coating or the coated specimen ends should not be recoated (i.e., the ends of the core polymer should be left exposed to the immersion liquid).

C1.2.6.6. Elevated temperatures should be used to accelerate the degradation process, which allows the data to be extrapolated to the desired design life.

C1.2.6.7. Hydrolysis data should be submitted for the product at a pH of approximately 7 (i.e., neutral conditions—distilled water), at a pH of 9 or more, and at a pH of 4 or less to facilitate the determination of RF_D. RF_D should be determined at a pH of 7 and at an alkaline pH (i.e., a pH of 9) as a minimum. If very acidic soils are anticipated (i.e., a pH near the bottom limit of pH = 4 for conditions defined as nonaggressive), RF_D should be determined at a pH of 4 as well.

Note C2—EPA 9090 testing or the ASTM equivalent (ASTM D 5322) is not considered adequate for a laboratory testing program to provide an estimate of RF_D. However, EPA 9090 or ASTM D 5322 testing can be used as a first cut screening tool. That is, if any significant degradation of the strength of the product in question is observed for the chemical environment tested, the product would be disqualified for use in that chemical environment unless longer term testing conducted in accordance with this annex is performed. EPA 9090 testing (or ASTM D 5322) could also be used verify the effects of certain environmental variables that are known, based on the literature, to not significantly affect the given material. For example, based on the literature, low or high pH is known to have little effect on polyolefins. This type of testing could be used to verify that the low or high pH does not affect the tensile strength of a polyolefin product, to allow that product to be used in environments that have a pH outside the range defined as a nonaggressive environment.

C1.3. *Requirements for Durability Laboratory Test Parameters and Data Interpretation*:

C1.3.1. Incubation temperatures for the testing should be high enough to adequately accelerate the degradation process, but below any major transitions in polymer behavior (e.g., glass transition, melting). Maximum recommended test temperatures to avoid major transitions are on the order of 70 to 75°C for PP, HDPE, and polyester, except as discussed above for polyolefin products that have micro-cracks or crazes as manufactured. However, exposure to temperatures near the upper end of these ranges could affect the stress-strain behavior of the material due to loss of molecular orientation, or possibly other effects that are not the result of chemical degradation. Therefore, care needs to be exercised when interpreting results from strength testing after exposure to temperatures near the maximum test temperatures indicated above.

C1.3.2. In general, if the stiffness of the material after exposure to the environment is significantly different from that of the virgin material, the stress-strain properties, and possibly the strength, of the material may have been affected by the exposure temperature in addition to the chemical environment. If the stiffness has been affected, the cause of the stiffness change should be thoroughly investigated to determine whether or not the change in stiffness is partially or fully due to the effect of temperature or, alternatively, not use the data obtained at and above the temperature where the stiffness was affected. It is additionally recommended that the Arrhenius plot of the data be checked for linearity (see the discussion of Arrhenius modeling in Sections C1.3.8 and C1.3.9). As a minimum, two to three data points above and below the suspected transition should be obtained and the plot checked for linearity through the entire range of temperatures, if it is desired to validate the use of data above the suspected transition for Arrhenius modeling and extrapolation purposes.

C1.3.3. A minimum of four test temperatures is recommended, typically spaced monotonically at 10°C increments (e.g., see ASTM D 3045), except as discussed above for some polyolefin products.

Note C3—At the lowest test temperature (e.g., 30 to 50°C), incubation times of 2 to 4 years should be anticipated to get data adequate for long-term extrapolation.

C1.3.4. Enough retrievals (e.g., a minimum of four retrievals) should be made at a given test condition to adequately define the property loss as a function of incubation time.

C1.3.5. As a minimum, degradation should be tracked using the tensile strength of the specimens retrieved from the incubation chambers. Full wide width (ASTM D 4595 or D 6637) specimens are preferred; however, single-rib or yarn specimens may be used.

C1.3.6. It is recommended that degradation be tracked by chemical means, if possible, as well as through the use of scanning electron microscope (SEM) micrographs to verify the significance of the mechanical property degradation observed.

C1.3.7. The statistical variation of the measured properties after degradation is likely to be greater than what would be observed for the virgin material. This may require that the number of specimens per retrieval be greater than what the property variation for the virgin material would indicate.

C1.3.8. Extrapolation of chemical durability data for polymers typically utilizes an Arrhenius approach, though there is evidence which suggests that the Arrhenius model does not always work well for geosynthetics. Assuming Arrhenius modeling is appropriate, the slope of the strength degradation versus time plots (transformed mathematically to be linear through zero, first, or second order Arrhenius equations) may be used to characterize the degradation behavior as a function of temperature, allowing the slope at the desired design temperature to be estimated through the Arrhenius extrapolation. The equation order that best fits the data should be used (see Salman, et. al., 1998, for details). The strength retained at a given time at the design temperature can be calculated directly from the linear equation with the extrapolated slope. Note that Arrhenius modeling may also be conducted as a function of reactant (oxygen) concentration and pressure instead of temperature (Shelton and Bright, 1993; Salman, et al., 1998). The extrapolation concept would be similar to that used for temperature. See Shelton and Bright (1993); Salman, et al. (1997); Salman, et al. (1998); Elias, et al. (1999); and Elias (2000) for guidance on Arrhenius modeling techniques as applied to geosynthetics. Also note that since the extrapolation is being conducted over several log cycles of time, uncertainty in the data should be considered when determining the retained strength at the design life and design environment.

C1.3.9. For polyolefin oxidation, Arrhenius modeling will likely need to be conducted in two steps, as there are two main phases in the oxidation process for polyolefins: (1) the induction phase, in which antioxidant consumption is the primary activity and little, if any, product strength loss occurs, and (2) the main polymer oxidation phase, in which oxidative degradation of the polyolefin occurs, resulting in strength loss, and can generally be described by the kinetics of a Basic Auto-oxidation Scheme (Salman, et al., 1997; Elias, et al., 1999). An Arrhenius model for the first phase should be developed so that the induction period t_{ind} at the design temperature or reactant (i.e., oxygen) concentration can be estimated. A second Arrhenius model should then be developed using only the data after the induction period, and time in this case would begin at the end of the induction period at each temperature or reactant concentration tested. This second Arrhenius model is then extrapolated to the design temperature or reactant concentration to estimate the strength loss anticipated at the desired design life minus the induction period. Analysis of the remaining antioxidant content provides an additional method of measuring the duration of the phase 1 oxidation process, particularly at lower temperatures and long durations, since changes in the antioxidant content take place ahead of the reduction in strength. Note that if the estimated induction period at the design environment is greater than the desired design life, this second phase Arrhenius modeling is unnecessary.

C1.3.10. Once the tensile strength at a given design life and design temperature has been estimated from the test data, determine RF_D as follows:

$$RF_D = \frac{T_{\mathrm{baseline}}}{T_D} \qquad (C1\text{-}1)$$

where:

T_{baseline} = the average roll specific ultimate tensile strength for the roll of material used for the durability testing; and

T_D = the extrapolated (i.e., to the required design life) lot specific tensile strength after degradation based on the laboratory aging tests.

In no case should RF_D be less than 1.1.

Note C4—Biological degradation has not proved to be a serious factor in the service life of geosynthetics. This is because the high molecular weight PE, polyester, polypropylene and PA used are not easily broken down by bacteria and fungi. The high tensile strength of soil reinforcements prevents them from damage by roots or burrowing animals such as rabbits. For this reason, in general, it is not necessary to consider biological degradation in defining RF_D. However, the possibility of biological degradation should be reviewed if new polymers other than those described are used. Biological durability, if specifically requested by the approval authority, should be evaluated based on ASTM D 3083-89, except the test should be modified to use ASTM D 4595 or D 6637 as the tensile test method. If any significant tensile strength loss is observed, as determined using ASTM D 4595 or D 6637, additional longer term testing should be performed before the product is further considered for use in reinforcement applications (see Bright, 1993).

C1.4. *Evaluation of Product Lines with Regard to Durability Data*:

C1.4.1. For evaluation of a new product that was not part of the original product line, but, based on the definition of a product line in Sections 3 and 6.3.1, should be considered as part of the original product line, this limited testing program should include laboratory aging tests with a 1000 to 2000-hour incubation period in the same environment used for the full testing program conducted previously, conducted at a temperature near but slightly below any major property transitions. These limited durability test results must show that the durability performance of the product is equal to or better than the performance of the product(s) previously tested. If so, the results from the full testing program used to characterize the product line could be used for the new product. If not, then a full testing and evaluation program for the new product should be conducted.

C1.4.2. For extension of the laboratory aging data obtained on one product in the product line (i.e., the primary product tested, which is typically a product in the middle of the range of products in the product line) to the entire product line as defined herein, a limited laboratory aging program shall be conducted on at least two additional products in the product line. The combination of the three or more products should span the full range of the product line in terms of weight and/or strength. Alternatively, if the primary product tested is the weakest/lightest weight product in the product line, only one secondary product need be tested to characterize the product line. The limited test program described in Section C1.4.1 shall be applied to these additional (secondary) products.

C2. REFERENCES

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Standard Method of Test for

Determining Dynamic Modulus of Hot Mix Asphalt (HMA)

AASHTO Designation: TP 62-07 (2009)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Dynamic Modulus of Hot Mix Asphalt (HMA)

AASHTO Designation: TP 62-07 (2009)[1]

1. SCOPE

1.1. This test method covers procedures for preparing and testing hot mix asphalt (HMA) to determine the dynamic modulus and phase angle over a range of temperatures and loading frequencies.

1.2. This standard is applicable to laboratory-prepared specimens of mixtures with nominal maximum size aggregate less than or equal to 37.5 mm (1.48 in.).

1.3. *This standard may involve hazardous material, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2. ASTM Standard:

- E 4, Standard Practices for Force Verification of Testing Machines

2.3. *Other Document*:

- Chapra, Steven C. and Raymond P. Canale. *Numerical Methods for Engineers.* The McGraw-Hill Companies, Inc., New York, NY, 1985, pp. 404–407.

3. DEFINITIONS

3.1. *complex modulus* (E^*)—a complex number that defines the relationship between stress and strain for a linear viscoelastic material.

3.2. *dynamic modulus* (|*E**|)—the normal value of the complex modulus calculated by dividing the maximum (peak-to-peak) stress by the recoverable (peak-to-peak) axial strain for a material subjected to a sinusoidal loading.

3.3. *phase angle* (ϕ)—the angle in degrees between a sinusoidal applied peak stress and the resulting peak strain in a controlled stress test.

4. SUMMARY OF METHOD

4.1. A sinusoidal (haversine) axial compressive stress is applied to a specimen of asphalt concrete at a given temperature and loading frequency. The applied stress and the resulting recoverable axial strain response of the specimen is measured and used to calculate the dynamic modulus and phase angle.

4.2. Figure 1 presents one schematic of the dynamic modulus test.

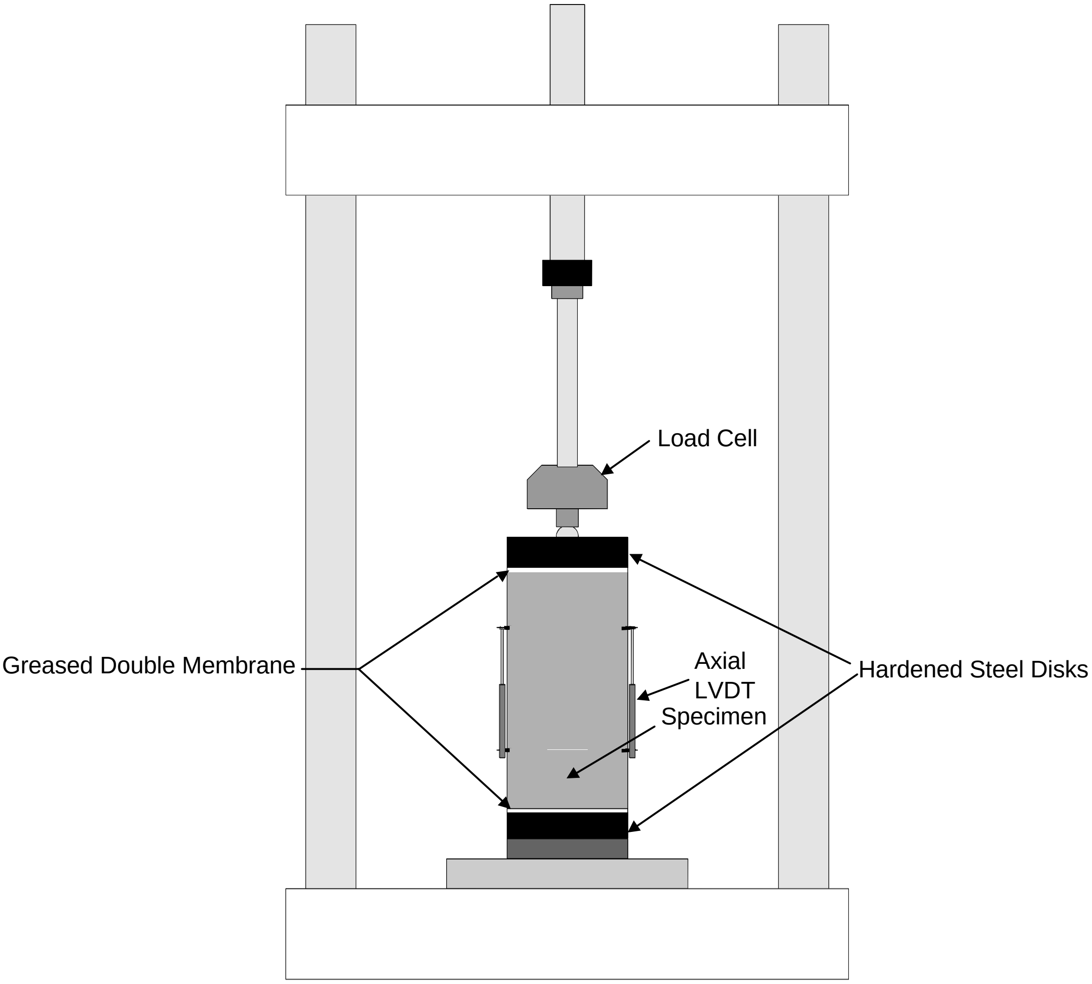

Figure 1—General Schematic of Dynamic Modulus Test

5. SIGNIFICANCE AND USE

5.1. Dynamic modulus values measured over a range of temperatures and frequencies of loading can be shifted into a master curve for characterizing asphalt concrete for pavement thickness design and performance analysis.

5.2. The values of dynamic modulus and phase angle can also be used as performance criteria for HMA design.

6. APPARATUS

6.1. *Dynamic Modulus Test System*—A dynamic modulus test system consisting of a testing machine, environmental chamber, and measuring system.

6.2. *Testing Machine*—A servo-hydraulic testing machine capable of producing a controlled haversine compressive loading. The testing machine should have a capability of applying load over a range of frequencies from 0.1 to 25 Hz and stress level up to 2800 kPa (400 psi). For sinusoidal loads, the standard error of the applied load shall be less than 5 percent. The standard error of the applied load is a measure of the difference between the measured load data and the best-fit sinusoid. The standard error of the load is defined in Equation 1.

$$se(P) = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \hat{x}_i\right)^2}{n-4}}\left(\frac{100\%}{\hat{x}_o}\right) \qquad (1)$$

where:

$se(P)$ = standard error of the applied load,

x_i = measured load at point *i*,

$\hat{x}_i$ = predicted load at point *i* from the best-fit sinusoid,

n = total number of data points collected during test, and

$\hat{x}_o$ = amplitude of the best-fit sinusoid.

6.2.1. *Environmental Chamber*—A chamber for controlling the test specimen at the desired temperature. The environmental chamber shall be capable of controlling the temperature of the specimen over a temperature range from –10 to 60°C (14 to 140°F) to an accuracy of ±0.5°C (±1°F). The chamber shall be large enough to accommodate the test specimen and a dummy specimen with thermocouple mounted at the center for temperature verification.

6.2.2. *Measurement System*—The system shall be fully computer-controlled, capable of measuring and recording the time history of the applied load and the axial deformations. The system shall be capable of measuring the period of the applied sinusoidal load and resulting deformations with a resolution of 0.5 percent. The accuracy and resolution of measurements are summarized in Table 1.

Table 1—Accuracy and Resolution of Measurement System

Measurement	Range	Accuracy	Resolution
Load	0.12 to 25 kN	Error ≤0.0 percent	≤0.0012 kN
Deformation	≥1 mm	Error ≤0.0025 mm	≤0.0002 mm
Inherent Phase Lag between Load and Deformation	Not specified	≤1 degree	Not specified

6.2.2.1. *Load*—The load shall be measured with an electronic load cell in contact with one of the specimen caps. The load cell shall be calibrated in accordance with ASTM E 4. The load measuring system shall have a minimum range of 0 to 25 kN (0 to 5600 lb) with a resolution of 1.2 N (0.24 lb).

6.2.2.2. *Axial Deformations*—Axial deformations shall be measured with linear variable differential transformers (LVDT) mounted between gauge points glued to the specimen, for example, as shown in Figure 2.

The deformations shall be measured at two locations 180 degrees apart, three locations 120 degrees apart, or four locations 90 degrees apart. The measurement setup that calls for four locations set at 90 degrees apart has an advantage over the other two options in that, in case one LVDT does not function properly, LVDT and the LVDT on the opposite side can be dropped, and the remaining two LVDTs can be used to determine the average deformation. The LVDTs shall have a range of ±0.5 mm (±0.02 in.). The deformation measuring system shall have auto zero and selectable ranges as defined in Table 2.

Table 2—Deformation Measuring System Requirements

Range, mm (in.)	Resolution, mm (in.)
±0.5 (0.01969)	0.0100 (0.00039)
±0.25 (0.00984)	0.0050 (0.00020)
±0.125 (0.00492)	0.0025 (0.00010)
±0.0625 (0.00246)	0.0010 (0.00004)

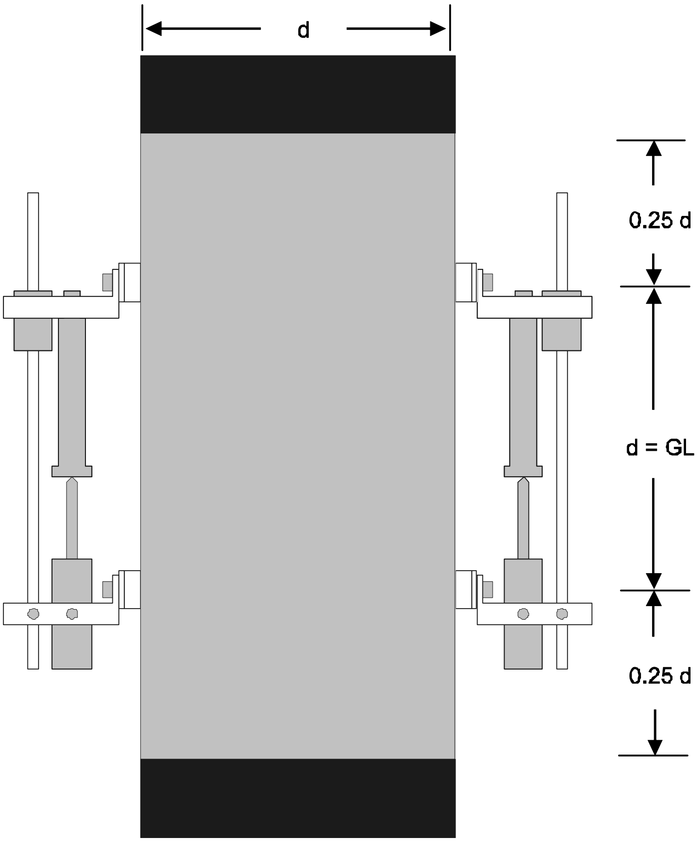

Figure 2—General Schematic of Gauge Points (Not to Scale)

6.2.3. *Loading Platens*—Loading platens, sized 104.5 ± 0.5 mm, are required above and below the specimen to transfer the load from the testing machine to the specimen. Generally, these platens should be made of hardened or plated steel, or anodized high-strength aluminum. Softer materials will require more frequent replacement. Materials that have linear elastic modulus properties and hardness properties lower than that of 6061-T6 aluminum shall not be used.

6.2.4. *End Treatment*—Friction-reducing end treatments shall be placed between the specimen ends and the loading platens. The end treatments shall consist of two Teflon® sheets or two 0.5-mm (0.02-in.) thick latex membranes separated with silicone grease.

6.3. *Superpave Gyratory Compactor*—A gyratory compactor and associated equipment for preparing laboratory specimens in accordance with T 312. The compactor shall be capable of compacting 170-mm (6.7-in.) high specimen.

6.4. *Saw*—A machine for sawing test specimen ends to the appropriate length is required. The saw shall have a diamond cutting edge and shall be capable of cutting specimens to the prescribed dimensions without excessive heating or shock.

Note 1—A diamond masonry saw greatly facilitates the preparation of test specimens with smooth, parallel ends. Both single- or double-bladed diamond saws should have feed mechanisms and speed controls of sufficient precision to ensure compliance with Sections 9.5 and 9.6 of this method. Adequate blade stiffness is also important to control flexing of the blade during thin cuts.

6.5. *Core Drill*—A coring machine with cooling system and a diamond bit for cutting nominal 101.6-mm (4.00-in.) diameter test specimens.

Note 2—A coring machine with adjustable vertical feed and rotational speed is recommended. The variable feeds and speeds may be controlled by various methods. A vertical feed rate of approximately 0.05 mm/rev (0.002 in./rev) and a rotational speed of approximately 450 RPM has been found to be satisfactory for several Superpave mixtures. Use of a standard electric core drill with a holder for the specimen is also acceptable.

7. HAZARDS

7.1. Observe standard laboratory safety precautions when preparing and testing hot mix asphalt (HMA) specimens.

8. TESTING EQUIPMENT CALIBRATION

8.1. The signal conditioning and data acquisition device of the testing system shall be checked to ensure that there is no excess phase shift between load and displacement channels.

8.2. The testing system shall be calibrated prior to initial use and at least once a year thereafter or per manufacturer requirements or per every 200 tests.

8.3. Verify the capability of the environmental chamber to maintain the required temperature within the accuracy specified.

8.4. Verify the calibration of all measurement components (such as load cell and specimen deformation measurement device) of the testing system.

8.5. If any of the verifications yield data that do not comply with the accuracy specified, correct the problem prior to proceeding with testing.

9. TEST SPECIMENS

9.1. *Size*—Dynamic modulus testing shall be performed on test specimens cored from gyratory 150-mm (4-in.) compacted mixtures. The average diameter of the test specimens shall be between 100 and 104 mm (3.94 and 4.1 in.) with a standard deviation of 1.0 mm (0.04 in.). The average height of the test specimen shall be between 147.5 and 152.5 mm (5.81 and 6.00 in.).

9.2. *Aging*—Laboratory-prepared mixtures shall be temperature-conditioned in accordance with the 4-hour short-term oven conditioning procedure in R 30. Field mixtures need not be aged prior to testing.

9.3. *Gyratory Specimens*—Prepare 170-mm (6.7-in.) tall specimens to the required air void content in accordance with T 312.

Note 3—Testing should be performed on test specimens (101.6-mm (4.0-in.) diameter) meeting specific air void tolerances. The gyratory specimen (152.4-mm (6.0-in.) diameter) air void content required to obtain a specified test specimen air void content must be determined by trial and error, achieved by using less or more mixture and compacted to the same height in the gyratory compactor. Generally, the test specimen air void content is 1.5 to 2.5 percent lower than the air void content of the gyratory specimen when the test specimen is removed from the middle as specified in this test method.

9.4. *Coring*—Core the nominal 101.6-mm (4.0-in.) diameter test specimens from the center of the gyratory specimens. Both the core drill and the gyratory specimen should be adequately supported to ensure that the resulting test specimen is cylindrical with sides that are smooth, parallel, and free from steps, ridges, and grooves.

9.5. *Diameter*—Measure the diameter of the test specimen at the mid-height and third points along axes that are 90 degrees apart. Record each of the six measurements to the nearest 1 mm (0.04 in.). Calculate the average and the standard deviation of the six measurements. If the standard deviation is greater than 2.5 mm (0.10 in.), discard the specimen. For acceptable specimens, the average diameter reported to the nearest 1 mm (0.04 in.) shall be used in all material property calculations.

9.6. *End Preparation*—The ends of all test specimens shall be smooth and perpendicular to the axis of the specimen. Prepare the ends of the specimen by sawing with a single- or double-bladed saw. The prepared specimen ends shall meet the tolerances described below. Reject test specimens not meeting these tolerances.

9.6.1. The specimen ends shall have a cut surface waviness height within a tolerance of ±0.05 mm (±0.002 in.) across any diameter. This requirement shall be checked in a minimum of three positions at approximately 120-degree intervals using a straightedge and feeler gauges approximately 8.1 to 12.5 mm (0.32 to 0.49 in.) wide or an optical comparator.

9.6.2. The specimen end shall not depart from perpendicular to the axis of the specimen by more than 1 degree, equivalent to 2.7 mm in 152.4 mm (0.11 in. in 6.10 in.). This requirement shall be checked on each specimen using a machinist's square and feeler gauges.

9.7. *Air Void Content*—Determine the air void content of the final test specimen in accordance with T 269. Reject specimens with air voids that differ by more than 0.5 percent from the target air voids.

Note 4—Considerable time can be saved if the cored test specimens were treated as wet, and the weights in water and saturated surface dry were measured immediately or within a short time period after coring. The test specimens can then be left to dry overnight, the dry weight can be measured the next day, and then they can be immediately prepared for testing.

9.8. *Replicates*—The number of test specimens required depends on the number of axial strain measurements made per specimen and the desired accuracy of the average dynamic modulus. Three replicate specimens should be tested to obtain a desired accuracy limit (e.g., less than ±15 percent of the true dynamic modulus). Table 3 summarizes the estimated accuracy associated with the number of specimens.

Table 3—Estimated Accuracy Related to the Number of Specimens

LVDTs per Specimen	Number of Specimens	Estimated Limit of Accuracy
2	2	±18.0%
2	3	±15.0%
2	4	±13.4%
3	2	±13.1%
3	3	±12.0%
3	4	±11.5%

9.9. *Sample Storage*—If test specimens will not be tested within 2 days, wrap specimens in polyethylene and store in an environmentally protected storage area at temperatures between 5 and 15°C (40 and 60°F). Specimens shall not be stacked during storage.

Note 5—To eliminate effects of aging on test results, it is recommended that specimens be stored no more than 2 weeks prior to testing.

10. TEST SPECIMEN INSTRUMENTATION

10.1. Attach mounting studs for the axial LVDTs to the sides of the specimen with epoxy cement. Figure 3 shows details of the mounting studs and LVDT mounting hardware.

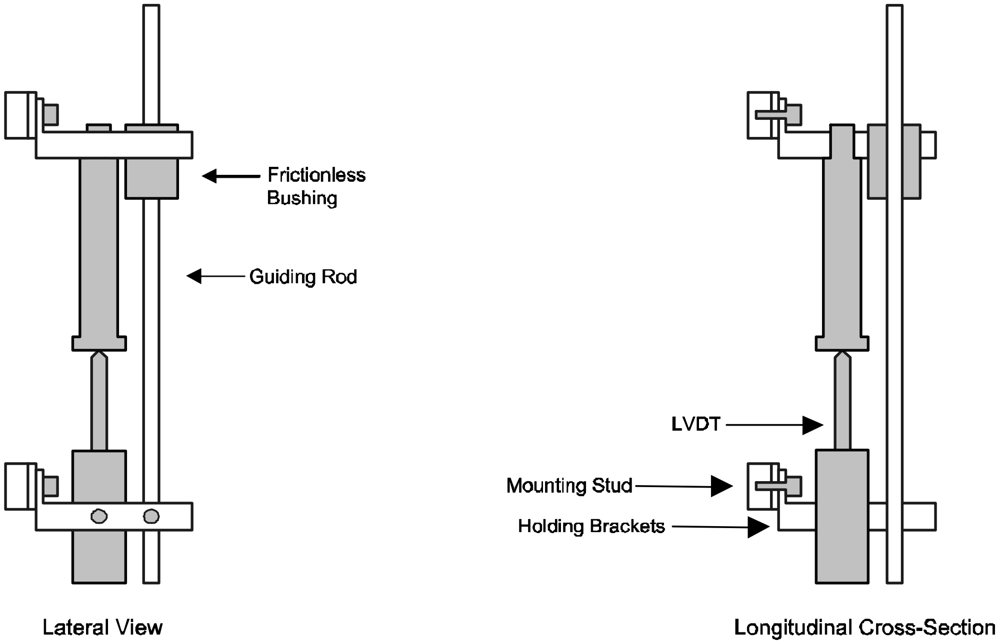

Figure 3—Mounting Hardware Details

Note 6—Quick-setting epoxy, such as Duro Master Mend Extra Strength Quick Set QM-50, has been found satisfactory for attaching studs.

10.2. The gauge length for measuring axial deformations shall be 101.6 mm ± 1 mm (4.00 in. ± 0.04 in.). Suitable alignment and spacing fixture shall be used to facilitate mounting of the axial deformation measuring hardware. The gauge length is measured between the stud centers.

11. PROCEDURE

11.1. The test series for the development of master curves for use in pavement response and performance analysis shall be conducted at –10, 4.4, 21.1, 37.8, and 54°C (14, 40, 70, 100, and 130°F) at loading frequencies of 0.1, 0.5, 1.0, 5, 10, and 25 Hz at each temperature. Each test specimen, individually instrumented with LVDT brackets, should be tested for each of the 30 combinations of temperature and frequency of loading starting with the lowest temperature and proceeding to the highest. Testing at a given temperature should begin with the highest frequency of loading and proceed to the lowest.

11.2. Place the test specimen in the environmental chamber and allow it to equilibrate to the specified testing temperature ±0.3°C (±1°F). A monitoring specimen with a thermocouple mounted at the center shall be used to determine when the specimen reaches the specified test temperature. Minimum recommended equilibrium temperature times are provided as a guideline. Note that these guidelines for equilibrium times are recommended when testing two to four replicates at a time.

Table 4—Recommended Equilibrium Times

Specimen Temperature, °C (°F)	Time from Room Temperature, h 25°C (77°F)	Time from Previous Test Temperature, h
–10 (14)	Overnight	Overnight
4 (40)	Overnight	4 hours or overnight
21 (70)	1	3
37 (100)	2	2
54 (130)	3	1

11.3. Place one of the friction-reducing end treatments on top of the hardened steel disk at the bottom of the loading frame. Place the specimen on top of the lower end treatment, and mount the axial LVDTs to the hardware previously attached to the specimen. Adjust the LVDT to near the end of its linear range to allow the full range to be available for the accumulation of compressive permanent deformation.

11.4. Place the upper friction-reducing end treatment and hardened steel disk on top of the specimen. Center the specimen with the hydraulic load actuator visually in order to avoid eccentric loading.

11.5. Apply a contact load (P_{min}) equal to 5 percent of the dynamic load that will be applied to the specimen. It is acceptable to increase the applied contact stress to 20 kPa to improve machine control effectiveness by applying a load that will maintain positive contact with the specimen but will not damage the specimen.

11.6. Adjust and balance the electronic measuring system as necessary.

11.7. Apply sinusoidal (haversine) loading (P_{dynamic}) to the specimen in a cyclic manner. The dynamic load should be adjusted to obtain axial strains between 50 and 150 microstrain.

Note 7—The dynamic load depends upon the specimen stiffness and generally ranges between 15 and 2800 kPa (2 and 400 psi). Higher load is needed at colder temperatures. Table 5 presents typical dynamic stress levels based on temperature.

Table 5—Typical Dynamic Stress Levels

Temperature, °C (°F)	Range, kPa	Range, psi
–10 (14)	1400 to 2800	200 to 400
4 (40)	700 to 1400	100 to 200
21 (70)	350 to 700	50 to 100
37 (100)	140 to 250	20 to 50
54 (130)	35 to 70	5 to 10

11.8. Test the specimens from lowest to highest temperature, that is, from –10°C (14°F) to 54°C (130°F). At each temperature, apply the loading from highest to lowest frequency, that is, from 25 Hz to 0.1 Hz. At the beginning of testing, precondition the specimen with 200 cycles at 25 Hz at stress level corresponding to Table 5. Then load the specimen as specified in Table 6. A typical rest period between each frequency run is 2 minutes. This rest period shall not exceed 30 minutes for any two frequency runs.

Table 6—Number of Cycles for the Test Sequence

Frequency (Hz)	Number of Cycles
25	200
10	200
5	100
1	20
0.5	15
0.1	15

11.9. The specimen shall be discarded at the end of any testing series at each temperature period. If the cumulative unrecovered permanent strain was found to be greater than 1500 micro units of strain, reduce the maximum loading stress level to half. Keep the test data up to this last resting period, discard the specimen, and use a new specimen for the rest of testing periods under reduced load conditions.

12. CALCULATIONS

12.1. This section presents a standard procedure for calculating both the dynamic modulus, $|E^*(\omega)|$, and the phase angle, $\theta(\omega)$, using data from a specific loading frequency, ω. It also defines four measures of data quality that should be used with the limits in Section 13 to evaluate the reliability of test data.

12.2. The general approach used here involves the least squares fit of a sinusoid, as described by Chapra and Canale in *Numerical Methods for Engineers* (McGraw-Hill, 1985, pp. 404–407). Regression is used because it is easy for most engineers and technicians in the paving industry to understand and apply effectively. This approach is easily performed on a spreadsheet.

12.3. The data produced from each dynamic modulus test at frequency ω_0 are stored in the form of several arrays, one for time $[t_i]$, one for stress $[\sigma_i]$, and one for each of the $j = 1, 2, 3, \ldots m$ strain transducers used [$\in_j$]. The number of i = 1, 2, 3…n points in each array will be equal and will depend upon the number of data points collected per loading cycle and on the total number of cycles for which data has been collected. It is recommended that 50 points per cycle and 5 cycles be used for a total of 250 data points.

12.4. *Analyze Stress Data*. The first step in the analysis is to analyze the data in the stress array. The data analysis is performed on centered stress data which is computed from the raw stress data by subtracting the average stress.

12.4.1. Determine the average stress as:

$$\overline{\sigma} = \frac{\sum_{i=1}^{n} \sigma_i}{n} \qquad (2)$$

where:

$\overline{\sigma}$ = average stress,

σ_i = raw stress point i in the data array, and

n = number of points in the data array.

12.4.2. Then compute the centered stresses by subtracting the average stress from each of the stress measurements:

$$\sigma_i' = \sigma_i - \overline{\sigma} \qquad (3)$$

where:

σ_i' = centered stress at point i in the data array,

σ_i = raw stress point i in the data array, and

$\overline{\sigma}$ = average stress.

12.4.3. From the centered stress data, compute three stress coefficients: offset, in-phase magnitude, and out-of-phase magnitude.

$$A_{\sigma 0} = \frac{\sum_{i=1}^{n} \sigma_i'}{n} \qquad (4)$$

$$A_{\sigma 1} = \frac{2}{n} \sum_{i=1}^{n} \sigma_i' \cos\left(\omega_0 t_i\right) \qquad (5)$$

$$B_{\sigma 1} = \frac{2}{n} \sum_{i=1}^{n} \sigma_i' \sin\left(\omega_0 t_i\right) \qquad (6)$$

where:

$A_{\sigma 0}$ = stress offset coefficient, kPa (psi);

σ_i' = centered stress at point i in the data array;

$A_{\sigma 1}$ = stress in-phase magnitude coefficient, kPa (psi);

ω_0 = frequency of applied stress, rad/s;

t_i = time at point i in the data array, s; and

$B_{\sigma 1}$ = stress out-of-phase magnitude coefficient, kPa (psi).

12.4.4. From the stress coefficients, compute the stress magnitude and the stress phase angle.

$$|\sigma^*| = \sqrt{A_{\sigma 1}^2 + B_{\sigma 1}^2} \tag{7}$$

$$\theta_\sigma = \arctan\left(-\frac{B_{\sigma 1}}{A_{\sigma 1}}\right) \tag{8}$$

where:

$|\sigma^*|$ = stress magnitude, kPa (psi);

$A_{\sigma 1}$ = stress in-phase magnitude coefficient, kPa (psi);

$B_{\sigma 1}$ = stress out-of-phase magnitude coefficient, kPa (psi); and

θ_σ = stress phase angle, degrees.

12.4.5. Compute an array of predicted centered stresses and the standard error of the applied stress.

$$\hat{\sigma}_i' = A_{\sigma 0} + A_{\sigma 1}\cos(\omega_0 t_i) + B_{\sigma 1}\sin(\omega_0 t_i) \tag{9}$$

$$se(\sigma) = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{\sigma}_i' - \sigma_i'\right)^2}{n-4}}\left(\frac{100\%}{|\sigma^*|}\right) \tag{10}$$

where:

$\hat{\sigma}_i'$ = predicted centered stress at point *i*, kPa (psi);

$A_{\sigma 0}$ = stress offset coefficient, kPa (psi);

$A_{\sigma 1}$ = stress in-phase magnitude coefficient, kPa (psi);

ω_0 = frequency of applied stress, rad/s;

t_i = time at point *i* in the data array, s;

$B_{\sigma 1}$ = stress out-of-phase magnitude coefficient, kPa (psi);

$se(\sigma)$ = standard error for the applied stress, percent;

σ_i' = centered stress at point *i* in the data array;

n = number of points in data array; and

$|\sigma^*|$ = stress magnitude, kPa (psi).

12.5. *Analyze Strain Data*. The second step in the analysis is to perform a similar analysis on the data from each of the strain transducers. However, in this case the data are corrected for drift caused by permanent deformation during the test, and centered data based on the average strain for the transducer.

12.5.1. To estimate the drift in the strain data, search each strain transducer array and determine local maximum and minimum values and the time when they occur for each loading cycle. Then determine the slope of the local maximum and minimum values with respect to time using linear regression. The average of these two slopes is the rate of drift D_j for strain transducer *j*.

12.5.2. Determine the average strain for each strain transducer as:

$$\overline{\in}_j = \frac{\sum_{i=1}^{n} \in_{j_i}}{n} \tag{11}$$

where:

$\overline{\in}_j$ = average strain for transducer *j*;

$\in_{j_i}$ = raw strain for transducer *j* at point *i* in data array; and

n = number of points in the data array.

12.5.3. Correct and center the strain data for each transducer by subtracting from the measured strains the rate of drift times the loading time and also subtracting the average strain for that transducer:

$$\in_{j_i}' = \in_{j_i} - D_j t_i - \overline{\in_j} \tag{12}$$

where:

$\in_{j_i}'$ = corrected and centered strain for transducer *j* at point *i* in data array,

$\in_{j_i}$ = raw strain for transducer *j* at point *i* in data array,

D_j = rate of drift for transducer *j*,

t_i = time for point *i* in data array,

$\overline{\in_j}$ = average strain for transducer *j*, and

12.5.4. From the corrected and centered strain data for each strain transducer, compute three strain coefficients: offset, in-phase magnitude, and out-of-phase magnitude.

$$A_{\in j0} = \frac{\sum_{i=1}^{n} \in_{j_i}'}{n} \tag{13}$$

$$A_{\in j1} = \frac{2}{n} \sum_{i=1}^{n} \in_{j_i}' \cos\left(\omega_0 t_i\right) \tag{14}$$

$$B_{\in j1} = \frac{2}{n} \sum_{i=1}^{n} \in_{j_i}' \sin\left(\omega_0 t_i\right) \tag{15}$$

where:

$A_{\in j0}$ = offset coefficient for strain transducer *j*;

$\in_{j_i}'$ = corrected and centered strain for transducer *j* at point *i* in data array;

$A_{\in j1}$ = in-phase magnitude coefficient for strain transducer *j*;

ω_0 = frequency of applied stress, rad/s;

t_i = time for point *i* in data array, s; and

$B_{\in j1}$ = out-of-phase magnitude coefficient for strain transducer *j*.

12.5.5. From the strain coefficients, compute the strain magnitude and the strain phase angle for each transducer.

$$\left|\in_j *\right| = \sqrt{A_{\in_{j1}}^2 + B_{\in_{j1}}^2} \qquad (16)$$

$$\theta_{\in_{j1}} = \arctan\left(-\frac{B_{\in_{j1}}}{A_{\in_{j1}}}\right) \qquad (17)$$

where:

$|\in_j *|$ = strain magnitude for strain transducer *j*;

$A_{\in_{j1}}$ = in-phase magnitude coefficient for strain transducer *j*;

$B_{\in_{j1}}$ = out-of-phase magnitude coefficient for strain transducer *j*; and

$\theta_{\in_j}$ = phase angle for strain transducer *j*, degrees.

12.5.6. For each strain transducer, compute an array of predicted corrected and centered strains and the standard error of the strain data.

$$\hat{\in}_{j_i}' = A_{\in_{j0}} + A_{\in_{j1}}\cos\left(\omega_0 t_i\right) + B_{\in_{j1}}\sin\left(\omega_0 t_i\right) \qquad (18)$$

$$se(\in_j) = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{\in}_{j_i}' - \in_{j_i}'\right)^2}{n-4}}\left(\frac{100\%}{\left|\in_j *\right|}\right) \qquad (19)$$

where:

$\hat{\in}_{j_i}'$ = predicted corrected and centered strain for strain transducer *j* at point *i*;

$A_{\in_{j0}}$ = offset coefficient for strain transducer *j*;

$A_{\in_{j1}}$ = in-phase magnitude coefficient for strain transducer *j*;

ω_0 = frequency of applied stress, rad/s;

t_i = time for point *i* in data array, s;

$B_{\in_{j1}}$ = out-of-phase magnitude coefficient for strain transducer *j*;

$se(\in_j)$ = standard error for strain transducer *j* response, percent;

$\in_{j_i}'$ = corrected and centered strain for transducer *j* at point *i* in data array;

n = number of points in data array; and

$|\in_j *|$ = strain magnitude for strain transducer *j*.

12.5.7. Calculate the average phase angle, strain magnitude, and standard error for all *m* strain transducers, along with two uniformity coefficients representing the variation among the strain transducers:

$$\overline{\theta_{\in}} = \frac{\sum_{j=1}^{m}\theta_{\in_j}}{m} \qquad (20)$$

$$\overline{\left|\in^*\right|} = \frac{\sum_{j=1}^{m}\left|\in_j{}^*\right|}{m} \tag{21}$$

$$se(\in) = \frac{\sum_{j=1}^{m} se(\in_j)}{m} \tag{22}$$

$$U_{\in} = \sqrt{\frac{\sum_{j=1}^{m}\left(\left|\in_j{}^*\right| - \overline{\left|\in^*\right|}\right)^2}{m-1}}\left(\frac{100\%}{\overline{\left|\in^*\right|}}\right) \tag{23}$$

$$U_{\theta} = \sqrt{\frac{\sum_{j=1}^{m}\left(\theta_{\in_j} - \overline{\theta_{\in}}\right)^2}{m-1}} \tag{24}$$

where:

$\overline{\theta_{\in}}$ = average phase angle for all strain transducers, degrees;

m = number of strain transducers;

$\overline{\left|\in^*\right|}$ = average strain magnitude;

$se(\in)$ = average standard error for all strain transducers, percent;

$U_{\in}$ = uniformity coefficient for strain transducers, percent; and

U_{θ} = uniformity coefficient for phase angle, degrees.

12.6. *Compute Phase Angle and Dynamic Modulus*. The final step in the data analysis is to calculate the overall phase angle, $\theta(\omega)$, in degrees, and the complex modulus, $|E^*(\omega)|$, kPa (psi), at the selected frequency, ω:

$$\theta(\omega) = \overline{\theta_{\in}} - \theta_{\sigma} \tag{25}$$

$$\left|E^*(\omega)\right| = \frac{\left|\sigma^*\right|}{\overline{\left|\in^*\right|}} \tag{26}$$

where:

$\theta(\omega)$ = phase angle between applied stress and strain for frequency ω, degrees;

$\overline{\theta_{\in}}$ = average phase angle for all strain transducers, degrees;

θ_{σ} = stress phase angle, degrees;

$|E^*(\omega)|$ = dynamic modulus for frequency ω, kPa (psi);

$|\sigma^*|$ = stress magnitude, kPa (psi); and

$\overline{\left|\in^*\right|}$ = average strain magnitude.

13. DATA QUALITY

13.1. In addition to the dynamic modulus and phase angle, a product of the data analysis described in Section 12 has four data quality indicators: (1) standard error of the applied stress, (2) average standard error for the strain measurements, (3) uniformity coefficient for the strain measurements, and (4) uniformity coefficient for the phase angle measurements.

13.2. These data quality indicators can be used to access the reliability of the data. Table 7 presents recommended limits for the data quality indicators.

Table 7—Recommended Limits for Data Quality Indicators

Indicator	Symbol	Equation	Limit
Standard error of the applied stress	$se(\sigma)$	9	≤10%
Average standard error of the measured strains	$se(\in)$	21	≤10%
Uniformity coefficient for the strain measurements	$U_{\in}$	22	≤20%
Uniformity coefficient for the phase angle measurements	U_{θ}	23	≤3 degrees

Note 8—Recommended limits based on research completed in NCHRP Project 9-29 may be revised in the future.

14. REPORT

14.1. Report the following for each specimen at each combination of temperature and frequency tested:

14.1.1. Test temperature,

14.1.2. Test frequency,

14.1.3. Dynamic modulus (from Equation 26),

14.1.4. Average phase angle between applied stress and measured strain (from Equation 25),

14.1.5. Average strain magnitude (from Equation 21),

14.1.6. Stress magnitude (from Equation 7),

14.1.7. Standard error of the applied stress (from Equation 10),

14.1.8. Average standard error of the measured strains (from Equation 22),

14.1.9. Uniformity coefficient for the strain measurements (from Equation 23), and

14.1.10. Uniformity coefficient for the phase angle measurements (from Equation 24).

APPENDIX

(Nonmandatory Information)

X1. PURPOSE

X1.1. This Appendix presents a procedure for assessing the uniformity of the air void content in test specimens produced for dynamic modulus testing.

X1.2. The approach tests the significance of the difference in mean bulk specific gravity between the top and bottom third of the specimen relative to the middle third.

X1.3. The procedure can be used to determine the height for preparing gyratory specimens with a specific compactor to minimize within sample variations in air voids.

X2. SUMMARY

X2.1. Three test specimens are prepared as described in Section 9 from gyratory specimens produced with the same mixture mass and compacted to the same height.

X2.2. The test specimens are cut into three slices of equal thickness, and the bulk specific gravity of each slice is determined.

X2.3. A statistical hypothesis test is conducted to determine the significance of differences in the mean bulk specific gravity of the top and bottom slices relative to the middle.

X3. PROCEDURE

X3.1. Prepare three test specimens following Section 9 to a target air void content of 5.5 percent. All three specimens shall have air void contents with the range of 5.0 to 6.0 percent.

X3.2. Label the top, middle, and bottom third of each specimen, then saw the specimens at the third points.

X3.3. Determine the bulk specific gravity of each of the nine test section slices in accordance with T 166 for dense- and gap-graded mixtures or T 269 for open-graded mixtures.

X3.4. Assemble a summary table of the bulk specific gravity data where each column contains data for a specific slice, and each row contains the data from a specific core.

X3.5. For each column, compute the mean and variance of the bulk specific gravity measurements using Equations X3.1 and X3.2.

$$\overline{y} = \frac{\sum_{i=1}^{3} y_i}{3} \qquad (X3.1)$$

$$s^2 = \frac{\sum_{i=1}^{3} \left(y_i - \overline{y} \right)^2}{2} \qquad (X3.2)$$

where:

$\bar{y}$ = slice mean,

y_i = measured values, and

s^2 = slice variance.

X3.6. *Statistical Comparison of Means*—Compare the mean bulk specific gravity of the top and bottom slices to the middle slice using the hypothesis tests described below. In the descriptions below, subscripts *t*, *m*, and *b* refer to the top, middle, and bottom slices, respectively.

X3.6.1. Check the top relative to the middle.

X3.6.2. *Null Hypothesis*—Mean bulk specific gravity of the top slice equals the mean bulk specific gravity of the middle slice:

$$\mu_t^2 = \mu_m^2$$

X3.6.3. *Alternative Hypothesis*—Mean bulk specific gravity of the top slice is not equal to the mean bulk specific gravity of the middle slice:

$$\mu_t^2 \neq \mu_m^2$$

X3.6.3.1. *Test Statistic*:

$$t = \frac{(\bar{y}_t - \bar{y}_m)}{0.8165(s)} \qquad (X3.3)$$

where:

$$s = \sqrt{\frac{s_t^2 + s_m^2}{2}} \qquad (X3.4)$$

$\bar{y}_t$ = computed mean for the top slices,

$\bar{y}_m$ = computed mean for the middle slices,

s_t^2 = computed variance for the top slices, and

s_m^2 = computed variance for the middle slices.

X3.6.3.2. *Region of Rejection*—For the sample sizes specified, the absolute value of the test statistic must be less than 2.78 to conclude that bulk specific gravity of the top and middle slices are equal.

X3.6.4. Check the bottom relative to the middle.

X3.6.4.1. *Null Hypothesis*—Mean bulk specific gravity of the bottom slice equals the mean bulk specific gravity of the middle slice:

$$\mu_b^2 = \mu_m^2$$

X3.6.4.2. *Alternative Hypothesis*—Mean bulk specific gravity of the bottom slice is not equal the mean bulk specific gravity of the middle slice:

$$\mu_b^2 \neq \mu_m^2$$

X3.6.4.3. *Test Statistic*:

$$t = \frac{(\bar{y}_b - \bar{y}_m)}{0.8165(s)} \tag{X3.5}$$

where:

$$s = \sqrt{\frac{s_b^{\ 2} + s_m^{\ 2}}{2}} \tag{X3.6}$$

$\bar{y}_b$ = computed mean for the bottom slices,

$\bar{y}_m$ = computed mean for the middle slices,

s_b^2 = computed variance for the bottom slices, and

s_m^2 = computed variance for the middle slices.

X3.6.4.4. *Region of Rejection*—For the sample sizes specified, the absolute value of the test statistic must be less than 2.78 to conclude that bulk specific gravity of the bottom and middle slices are equal.

X4. ANALYSIS

X4.1. Significant differences in the bulk specific gravity of the top and bottom slices relative to the middle indicate a systematic variation in density within the specimen.

X4.2. Specimens with differences of bulk specific gravity for the top and/or bottom slices relative to the middle slices on the order of 0.025 have performed satisfactorily in the dynamic modulus tests.

X4.3. Changing the height of the gyratory specimen can improve the uniformity of the density in the test specimen.

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[1] Approved in November 2002, this standard was first published in 2003, reconfirmed in 2005, revised in 2007, and reconfirmed in 2009.

Standard Method of Test for

Density of In-Place Hot Mix Asphalt (HMA) Pavement by Electronic Surface Contact Devices

AASHTO Designation: TP 68-04 (2008)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Density of In-Place Hot Mix Asphalt (HMA) Pavement by Electronic Surface Contact Devices

AASHTO Designation: TP 68-04 (2008)[1]

INTRODUCTION

This test method describes the procedures for determining the in-place density of hot mix asphalt (HMA) by an electronic surface contact device.

1. SCOPE

1.1. This method covers the in-place determination of the total density and relative compaction of HMA pavements by measuring changes in the electromagnetic field resulting from the compaction process.

1.2. The equipment referenced in this method is a surface contact device that is relatively unaffected by the surface moisture and surface variances in temperature typically encountered during HMA paving operations. If needed, it should include circuitry to measure/compensate for moisture and temperature variances during the material compaction process.

1.3. *This procedure does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens

3. SIGNIFICANCE

3.1. The test method described is useful as a rapid nondestructive technique for determining the in-place density and relative compaction of compacted HMA mixtures.

3.2. The density results obtained by this test method may be applied using three method applications, Method A—Relative, Method B—Screed Calibration, and Method C—Core Calibration. Method C is the most accurate and requires a correlation with a known density sample of the material being measured.

4. INTERFERENCES

4.1. The composition of the HMA mix being tested may significantly affect the measurements. The device should be calibrated to the specific mix design being used in the field.

4.2. This test method exhibits spatial bias. Oversize aggregate particles in the area of the sensor path may cause variations in density readings. The average of at least four measurements at each test location is recommended.

4.3. The surface texture of the material being tested may cause lower than actual density readings.

4.4. Electromagnetic force fields, such as those caused by overhead high tension power lines or large metal objects near the device, may interfere with the device reading.

5. APPARATUS

5.1. *The device shall meet requirements outlined below*:

5.2. The device shall be housed in an enclosure of heavy-duty construction, and designed for taking *in situ* density measurements of HMA pavements.

5.3. The device shall function in the temperature and moisture levels experienced during the placement of HMA pavements.

5.4. The device shall include the internal circuitry suitable for displaying individual measurements to allow operators to record the results.

5.5. The device shall include a continuous measurement mode of operation.

5.6. The device shall employ suitable electronic circuitry to provide power and signal conditioning to the sensor to provide the data acquisition and readout function, and allow calibration of the unit over the expected range of application conditions and materials.

6. TEST SITE PREPARATION

6.1. Since surface conditions can have a significant effect on density measurements, a smooth surface with no excess water (roller water is acceptable) is required for proper testing. The optimum condition for general testing would be a dry, smooth surface, with total contact between the bottom surface of the device and the surface being tested.

6.2. Select a flat, relatively smooth test area on the HMA mat. Brush the surface clear of any sand or stones, which would prevent contact between the surface and the measuring device.

7. CALIBRATION PROCEDURE

7.1. Calibrate the device for each mixture prior to performing tests on materials that are different from the material types used in establishing the most recent calibration. Calibrate a newly acquired or repaired device.

If available, a standard plate or reference base shall be used to ensure that the device is within the manufacturer’s specifications.

7.2. The device should be calibrated on the HMA mat at compaction temperature ranges allowing subsequent readings to be taken as paving progresses at this temperature range. For calibration using core samples, follow the procedure in Section 7.4.3 and refer to manufacturer’s recommended procedures.

7.3. Maneuver the device as per the manufacturer’s recommendations. Several single measurements are averaged to calculate a reading. The location and number of measurements used to calculate a reading will depend on manufacturer’s specifications.

7.4. Calibrate the device following the procedure for Method A, B, or C. All data used for calibration shall be recorded for each mix formula.

7.4.1. *Method A*—This is the relative method. It may be used to track the compaction process during the establishment of roller patterns.

7.4.1.1. Place the device on the asphalt mat at the test location and draw an outline around the probe of the unit, and record compaction measurements and average reading of the un-compacted material exiting the screed.

7.4.1.2. After each roller pass, place the device within the outline and record compaction measurements and average reading.

7.4.1.3. When readings no longer increase with additional passes, record this value and the number of passes.

7.4.1.4. Repeat steps in Sections 7.4.1.2 and 7.4.1.3 after each roller type where compaction is to be monitored.

7.4.2. *Method B*—This is the screed calibration method. It utilizes the percent compaction obtained by the screed to calculate a starting density. This method requires the operator to estimate the percent compaction obtained by the screed; routinely this number is 75–85 percent of the maximum theoretical or voidless density. Operator experience will contribute to the accuracy of the compaction estimate and the success of this method.

7.4.2.1. Estimate the percent compaction obtained by the screed.

7.4.2.2. Multiply the maximum theoretical density of the material by the percent compaction obtained by the screed, in decimal form. Example: the voidless density is 2468 kg/m^3 (154 pcf); the screed compaction is 0.81 percent. The gauge should read 1999 kg/m^3 (124.7 pcf) behind the screed ($2468 \times 0.81 = 1999$ kg/m^3).

7.4.2.3. Measure the density of the mixture exiting the screed and offset the device to obtain the reading calculated in Section 7.4.2.2. Follow manufacturer’s specific recommendations to input the offset.

7.4.3. *Method C*—This is the core calibration method. It uses actual core densities to calibrate the device. This is the most accurate and detailed method and should be reviewed for a general understanding of the calibration process.

7.4.3.1. Identify one to five test locations on the HMA mat. For establishing a control strip, five core locations should be used. For pavement monitoring or quality control, the operator's discretion and manufacturer's recommendations should be followed.

7.4.3.2. Place the device on the asphalt mat at the test location and draw an outline around the probe of the unit. Record the measurements and average reading.

7.4.3.3. Cut a 150-mm (6-in.) diameter core from the area within the device outline where the reading was taken.

7.4.3.4. Repeat steps in Sections 7.4.3.2 and 7.4.3.3 at additional test locations if applicable.

7.4.3.5. In the laboratory, determine the density of each 150-mm (6-in.) diameter core in accordance with T 166 or other applicable methods, and record the results.

7.4.3.6. Record the numeric difference between the average reading obtained with the device and the corresponding core density for each test location.

7.4.3.7. Average the numeric differences from the step in Section 7.4.3.6, and record the average numeric difference.

7.4.3.8. Adjust the device, following the manufacturer's procedures, to account for the average numeric difference. This will calibrate the instrument to the asphalt mat by adding (or subtracting) the average numeric difference.

8. PROCEDURE OF OPERATION

8.1. Ensure that the device is calibrated in accordance with Section 6 of this specification for the site conditions and HMA mixture being used.

8.2. Locate the measurement area away from any known sources of electromagnetic interference such as overhead high-tension power lines or large metal objects. For best results avoid surfaces with large temperature extremes.

8.3. Place the device firmly on the test surface (prepared in accordance with Section 6 of this standard) and trace an outline around the probe (base) of the unit.

8.4. Record the density measurements given by the device. For quality control or pavement monitoring, the number of measurements taken at a location is less critical. More measurements are required when quality assurance applications or where companion cores will be taken. The number of measurements required will depend on the manufacturer's recommendation based on the device capabilities. The number of measurements should be supported with precision statements obtained from similar sites.

8.5. Average the measurements from an individual location to obtain an average density reading.

8.6. Record data in accordance with Section 9 of this standard.

9. RECORDING RESULTS

9.1. Job site identification and test site location data in accordance with standard contractor protocols.

9.2. Device calibration data as specified in Section 7.

9.3. *Immediately record*:

9.3.1. Individual density measurements at each test location, together with the calculated average density reading for the location.

9.3.2. Temperature of the HMA mat at the time of readings, if taken.

9.3.3. Any qualitative observations of testing or material conditions that may affect the accuracy or interpretation of test results.

9.4. Corresponding core density data (if taken) for each test location.

9.5. Dated signature by the test operator.

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[1] Approved in November 2003, this standard was first published in July 2004. Reconfirmed in 2006 and 2008.

Standard Method of Test for

Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: TP 70-10

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Method of Test for

Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

AASHTO Designation: TP 70-10

1. SCOPE

1.1. This test method covers the determination of percent recovery and non-recoverable creep compliance of asphalt binders by means of the Multiple Stress Creep Recovery (MSCR) test. The MSCR test is conducted using the Dynamic Shear Rheometer (DSR) at a specified temperature. It is intended for use with residue from T 240 (Rolling Thin-Film Oven Test (RTFOT)).

Note 1—The majority of the development work on this test method was performed on material conditioned according to T 240 (RTFO).

1.2. The percent recovery value is intended to provide a means for determining the elastic response and stress dependence of polymer modified and unmodified asphalt binders.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- MP 19, Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

2.2. *ASTM Standard*:

- D 8, Standard Terminology Relating to Materials for Roads and Pavements

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. Definitions of terms used in this practice may be found in ASTM D 8, determined from common English usage, or combinations of both.

3.2. *Definitions of Terms Specific to This Standard*:

3.2.1. *creep and recovery*—a standard rheological test protocol whereby a specimen is subjected to a constant load for a fixed time period and then allowed to recover at a constant zero load for a fixed time period.

3.2.2. *non-recoverable creep compliance* (J_{nr})—the residual strain in a specimen after a creep and recovery cycle divided by the stress applied, kPa^{-1}.

4. SUMMARY OF TEST METHOD

4.1. This test method is used to determine the presence of elastic response in an asphalt binder under shear creep and recovery at two stress levels at a specified temperature. For performance-graded (PG) asphalt binders, the specified temperature will typically be the PG high temperature from MP 19, Table 1.

4.2. Asphalt binder is first conditioned using T 240 (RTFOT). A sample of the RTFO-conditioned asphalt is tested using T 315 (DSR). The 25-mm parallel plate geometry is used with a 1-mm gap setting. The sample is tested in creep at two stress levels followed by recovery at each stress level. The stress levels used are 0.1 kPa and 3.2 kPa. The creep portion of the test lasts for 1 second, which is followed by a 9-second recovery. Ten creep and recovery cycles are tested at each stress level.

5. SIGNIFICANCE AND USE

5.1. This method is designed to identify the presence of elastic response in a binder and the change in elastic response at two different stress levels while being subjected to ten cycles of creep stress and recovery. Non-recoverable creep compliance has been shown to be an indicator of the resistance of an asphalt binder to permanent deformation under repeated load.

6. APPARATUS

6.1. Use the apparatus as specified in T 315.

7. PROCEDURE

7.1. *Conditioning*—Condition the asphalt binder in accordance with T 240 (RTFOT).

7.2. *Sample preparation*—The sample for the MSCR test is prepared the same as samples for T 315 using 25-mm plates. The temperature control will also follow the T 315 requirements.

7.2.1. This test may be performed on the same sample that was previously used to determine the DSR properties of the RTFO residue as specified in M 320. When using the previously tested sample to perform this test, a 1-minute relaxation period between the tests is required before running this test. When using a new sample to perform this test, the 1-minute relaxation period is not required.

7.3. *Test protocol*—The test is performed at the selected temperature using a constant stress creep of 1.0-second duration followed by a zero stress recovery of 9.0-second duration. The test is performed at two stress levels, 0.1 kPa and 3.2 kPa. Ten cycles are run at each of the two stress levels for a total of 20 cycles. The commanded full stress for each creep cycle shall be achieved within 0.03 second from the start of the creep cycle as certified by the equipment manufacturer. The stress and strain shall be recorded at least every 0.1 second for the creep cycle and at least every 0.45 second for the recovery cycle on an accumulated basis such that, in addition to other data points, the data points at 1.0 second and 10.0 second for each cycle's local time are explicitly recorded. If the DSR does not record the strain at exactly 1.00 and 10.00 seconds, then the software shall extrapolate prior data to determine the strain value at 1.00 second and 10.00 seconds. Extrapolated data shall include a measured data point no more than 0.05 second prior to the required time for a creep cycle and no more than 0.30 second prior to the required time for a recovery cycle. There are no rest periods between creep and recovery cycles or changes in stress level. The total time required to complete the two-step creep and recovery test is 200 seconds.

7.4. *Analysis*—Analyze and record the creep and recovered percent strain for the 0.1 kPa and 3.2 kPa creep stress levels as follows:

7.4.1. For each of the ten cycles, record the following:

7.4.1.1. The initial strain value at the beginning of the creep portion of each cycle. This strain shall be denoted as $\in_0$.

7.4.1.2. The strain value at the end of the creep portion (i.e., after 1.0 second) of each cycle. This strain shall be denoted as $\in_c$.

7.4.1.3. The adjusted strain value at the end of the creep portion (i.e., after 1.0 second) of each cycle ($\in_1$), which is calculated as follows:

$$\in_1 = \in_c - \in_0$$

7.4.1.4. The strain value at the end of the recovery portion (i.e., after 10.0 second) of each cycle. This strain shall be denoted as $\in_r$.

7.4.1.5. The adjusted strain value at the end of the recovery portion (i.e., after 10.0 seconds) of each cycle ($\in_{10}$), which is calculated as follows:

$$\in_{10} = \in_r - \in_0$$

7.4.2. For each of the ten cycles, calculate the following at the creep stress level of 0.1 kPa:

7.4.2.1. Percent recovery $\in_r(0.1, N)$ for $N = 1$ to 10:

$$\in_r \left(0.1, N\right) = \frac{\left(\in_1 - \in_{10}\right) \times 100}{\in_1}$$

7.4.3. For each of the ten cycles, calculate the following at the creep stress level of 3.2 kPa:

7.4.3.1. Percent recovery $\in_r(3.2, N)$ for $N = 1$ to 10:

$$\in_r\left(3.2, N\right) = \frac{\left(\in_1 - \in_{10}\right) \times 100}{\in_1}$$

---

8. CALCULATION

8.1. Using the results obtained in Sections 7.4.2.1 and 7.4.3.1, determine the average percent recovery for the asphalt binder at creep stress levels of 0.1 kPa and 3.2 kPa as shown in the following equations:

8.1.1. Calculate average percent recovery at 0.1 kPa:

$$R_{0.1} = \frac{SUM\left[\in_r\left(0.1, N\right)\right]}{10} \quad \text{for } N = 1 \text{ to } 10$$

8.1.2. Calculate average percent recovery at 3.2 kPa:

$$R_{3.2} = \frac{SUM\left[\in_r\left(3.2, N\right)\right]}{10} \quad \text{for } N = 1 \text{ to } 10$$

8.1.3. Calculate percent difference in recovery between 0.1 kPa and 3.2 kPa:

$$R_{diff} = \frac{\left[R_{0.1} - R_{3.2}\right] \times 100}{R_{0.1}}$$

8.2. Using the results obtained in Sections 7.4.2.1 and 7.4.3.1, determine the non-recoverable creep compliance between 0.1 kPa and 3.2 kPa as shown in the following equations:

8.2.1. For each of the ten cycles at a creep stress of 0.1 kPa, calculate the non-recoverable creep compliance, $J_{nr}(0.1, N)$, kPa^{-1}, as strain/stress:

$$J_{nr}\left(0.1, N\right) = \frac{\in_{10}}{0.1}$$

8.2.2. For each of the ten cycles at a creep stress of 3.2 kPa, calculate the non-recoverable creep compliance, $J_{nr}(3.2, N)$, kPa^{-1}, as strain/stress:

$$J_{nr}\left(3.2, N\right) = \frac{\in_{10}}{3.2}$$

8.2.3. Calculate the average non-recoverable creep compliance at 0.1 kPa, $J_{nr_{0.1}}$, kPa^{-1}:

$$J_{nr_{0.1}} = \frac{SUM\left[J_{nr}\left(0.1, N\right)\right]}{10} \quad \text{for } N = 1 \text{ to } 10$$

8.2.4. Calculate the average non-recoverable creep compliance at 3.2 kPa, $J_{nr_{3.2}}$, kPa^{-1}:

$$J_{nr_{3.2}} = \frac{SUM\left[J_{nr}\left(3.2, N\right)\right]}{10} \quad \text{for } N = 1 \text{ to } 10$$

8.2.5. Calculate the percent difference in non-recoverable creep compliance between 0.1 kPa and 3.2 kPa, $J_{nr_{diff}}$:

$$J_{nr_{diff}} = \frac{\left[J_{nr_{3.2}} - J_{nr_{0.1}}\right] \times 100}{J_{nr_{0.1}}}$$

9. REPORT

9.1. *Report the following information*:

9.1.1. Sample identification;

9.1.2. PG grade and test temperature, nearest 0.1°C;

9.1.3. Average percent recovery at 0.1 kPa, $R_{0.1}$;

9.1.4. Average percent recovery at 3.2 kPa, $R_{3.2}$;

9.1.5. Percentage difference between average percent recovery at 0.1 kPa and 3.2 kPa, R_{diff}.

9.1.6. Non-recoverable creep compliance at 0.1 kPa, $J_{nr_{0.1}}$, to two significant digits, kPa^{-1};

9.1.7. Non-recoverable creep compliance at 3.2 kPa, $J_{nr_{3.2}}$, to two significant digits, kPa^{-1}; and

9.1.8. Percent difference between non-recoverable creep compliance at 0.1 kPa and 3.2 kPa, $J_{nr_{diff}}$, to nearest 0.1 percent.

10. PRECISION AND BIAS

10.1. *Precision*—The research required to develop precision estimates has not been conducted.

10.2. *Bias*—The research required to establish the bias has not been conducted.

11. KEYWORDS

11.1. Asphalt binders; creep and recovery; creep compliance; Dynamic Shear Rheometer (DSR); elastomer identification; Multiple Stress Creep and Recovery (MSCR) Test; percent recovery; polymer modification.

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATIONS

X1.1. A typical test data plot consisting of ten cycles of creep and recovery at 0.1 kPa creep stress is shown in Figure X1.1. The plot for 3.2 kPa creep stress is similar to Figure X1.1 and will not be shown here. Test data from cycle number 9 are plotted in Figure X1.2 for further clarification.

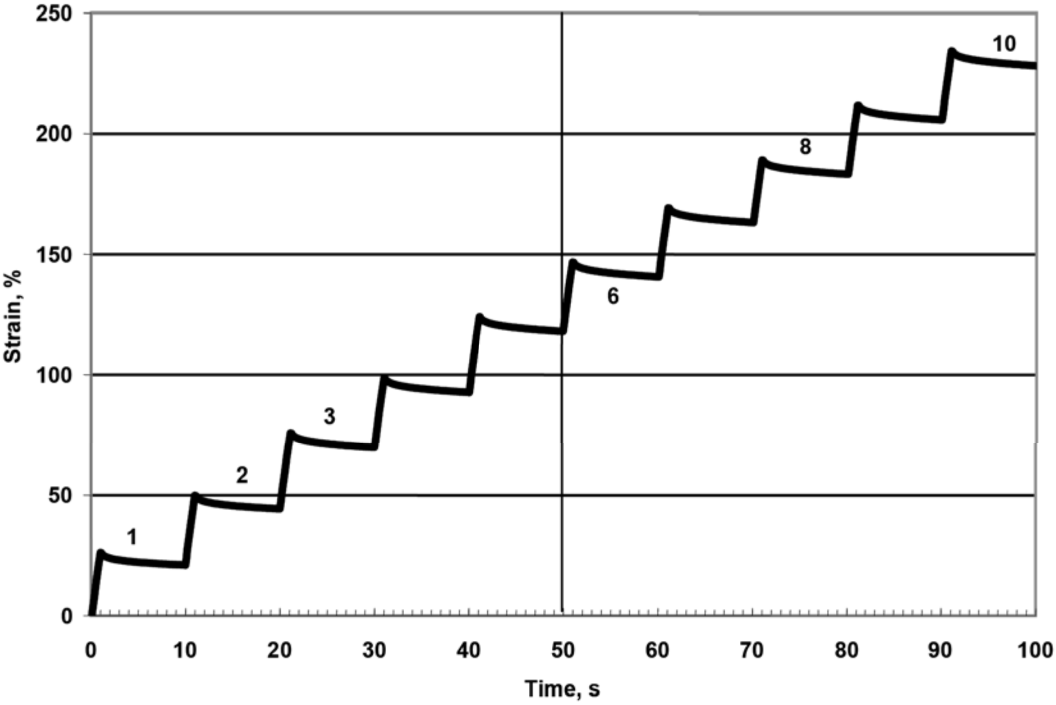

Figure X1.1—Test Data Plot Showing Typical Ten Cycles of Creep and Recovery at Creep Stress of 0.1 kPa

X1.2. *Sample Calculations*:

X1.2.1. Calculation of percent recovery for cycle number 9 (see Figure X1.2):

1. Determine strain at the start (initial strain): $\in_0 = 183\%$
2. Determine strain at 1-second creep end time point: $\in_c = 212\%$
3. Determine adjusted creep end strain at 1-second point: $\in_1 = (\in_c - \in_0) = (212 - 183)\% = 29\%$
4. Determine strain at 10-second recovery end time point: $\in_r = 206.0\%$
5. Determine adjusted recovery end strain at 10-second point:

$$\in_{10} = (\in_r - \in_0) = (206 - 183)\% = 23\%$$

6. Determine percent recovery for cycle number 9 at 0.1 kPa creep stress, $\in_r(0.1, 9)$:

$$\in_r\left(0.1,\,N\right)=\frac{\left(\in_1-\in_{10}\right)\times 100}{\in_1}$$

For cycle number 9 at a creep stress level of 0.1 kPa, the percent recovery will be:

$$\frac{(29-23)\times 100}{29.0}=21\%$$

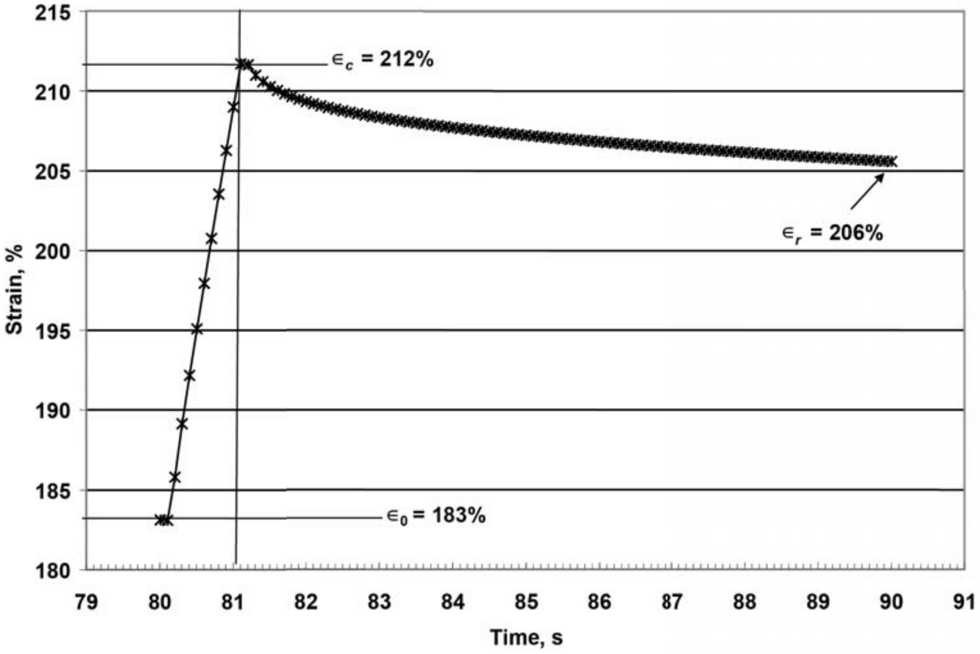

Figure X1.2—Test Cycle No. 9 Data Plot Showing Creep and Recovery at Creep Stress of 0.1 kPa

X1.3. Follow the above example to calculate percent recoveries for all ten cycles for both creep stress levels of 0.1 kPa and 3.2 kPa.

X2. INDICATIONS OF ELASTIC RESPONSE

X2.1. The percent recovery is intended to provide a means for determining the presence of elastic response and stress dependence of polymer modified and unmodified asphalt binders. Figure X2.1 may be used as an indicator of the presence of an elastomeric polymer.

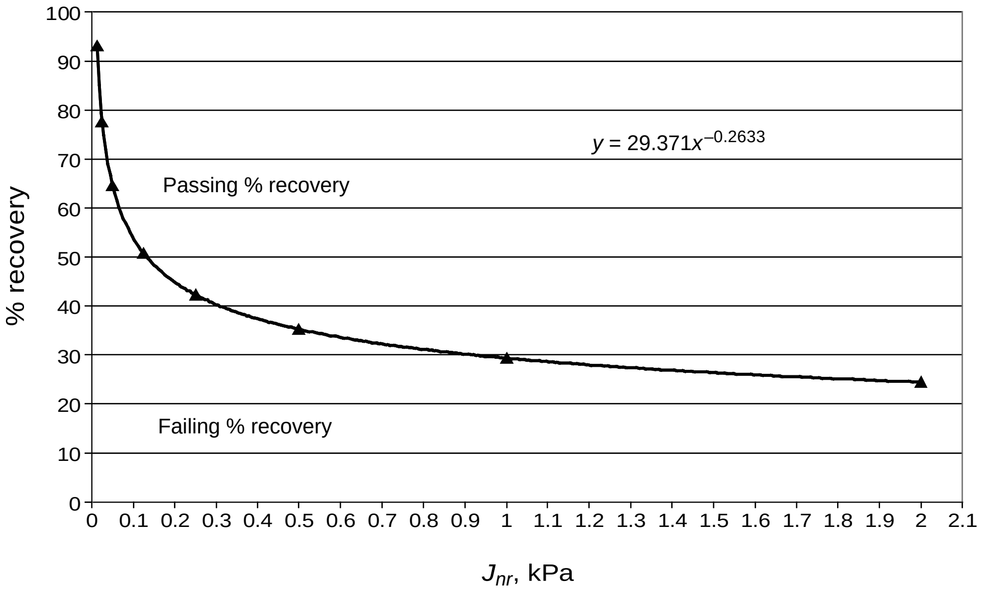

Figure X2.1—Non-recoverable creep compliance versus percent recovery

X2.2. On the graph in Figure X2.1, plot the average percent recovery at 3.2 kPa, $R_{3.2}$, versus the average non-recoverable creep compliance at 3.2 kPa, $J_{nr3.2}$, measured at the same temperature.

X2.3. If the plotted point falls above the line on the graph, the indication is that the asphalt binder is modified with an acceptable elastomeric polymer. If the plotted point falls below the line on the graph, the indication is that the asphalt binder is not modified with an elastomeric polymer.

Standard Method of Test for

Evaluation of Superpave Gyratory Compactor (SGC) Internal Angle of Gyration Using Simulated Loading

AASHTO Designation: TP 71-09[1]
ASTM Designation: D 7115-05

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Evaluation of Superpave Gyratory Compactor (SGC) Internal Angle of Gyration Using Simulated Loading

AASHTO Designation: TP 71-09[1]
ASTM Designation: D 7115-05

1. SCOPE

1.1. This practice covers the procedure for the evaluation of the Superpave Gyratory Compactor (SGC) internal angle of gyration using an instrument capable of simulating loading conditions similar to those created by a hot mix asphalt (HMA) specimen.

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

3. TERMINOLOGY

3.1. *external angle*—the angle formed between the external mold diameter and a stationary reference/axis of the machine frame.

3.2. *internal angle*—the angle formed between the internal mold diameter and a mold end plate as a mold is gyrated in an SGC.

3.3. *top internal angle*—the angle formed between the internal mold diameter and the upper mold end plate as a mold is gyrated in an SGC.

3.4. *bottom internal angle*—the angle formed between the internal mold diameter and the lower mold end plate as a mold is gyrated in an SGC.

3.5. *effective internal angle*—the average of the top internal angle and the bottom internal angle.

3.6. *tilting moment*—a force (F) acting at one end of an SGC mold platen in a direction parallel to the axis of gyration, but acting at some distance (e) away from that axis. The tilting moment at one end of the mold platen is computed as the product of this distance (e) and force (F).

3.7. *total moment*—the sum total (M) of the tilting moment acting at the top of the mold and the tilting moment acting at the bottom of the mold.

3.8. *eccentricity*—the distance (e) away from the axis of gyration at which a force (F) is acting at one end of an SGC mold. This use of the term *eccentricity* is consistent with previous published reports describing the mechanics of gyratory compaction.[2]

3.9. *standard SGC volumetric specimen*—a standard-sized HMA specimen prepared using an SGC for purposes of volumetric mix design. Such a standard specimen, prepared in accordance with T 312, has a diameter of 150 mm and a final compacted height of 115 ± 5 mm.

4. SUMMARY OF PRACTICE

4.1. The internal angle of gyration of an SGC is measured dynamically with an instrument inserted into the SGC mold.

4.2. A load (moment) is induced on the SGC while the internal angle is simultaneously measured. The simulated loading conditions are similar to those created by compaction of a standard SGC volumetric specimen.

4.3. The internal angles at each end of the mold are measured and then averaged to obtain the effective internal angle of gyration.

5. SIGNIFICANCE AND USE

5.1. SGCs are used to produce hot mix asphalt (HMA) mixture specimens in the laboratory to assess and predict pavement performance. In the fabrication of an SGC specimen, loose HMA is placed inside a metal mold, which is then placed into an SGC. A constant consolidation pressure is applied to the sample while the mold gyrates at a nominally constant angle (referred to as the angle of gyration) and rate. Consistency in the density of the HMA specimens produced is very important to the validity of the tests performed. Specimens of a consistent density are produced when an SGC maintains a constant pressure and a known constant angle of gyration during the compaction process.

5.2. There are several manufacturers and models of SGC. Each model employs a unique method of setting, inducing, and maintaining the angle of gyration. Each model also employs a unique calibration system to measure the external angle of gyration. These existing calibration systems cannot be used universally on all of the different SGC models commercially available. Inconsistencies in HMA specimens produced on different SGC models have been attributed to variations in the angle of gyration.

5.3. This practice describes instruments and processes that can be used to independently measure the internal angle of gyration of any manufacturer's SGC model under simulated loading conditions. The external shape of the instrument chassis assures that the points of physical contact between the mold end plates and the instrument occur at a fixed and known distance away from the axis of gyration. As a result, the vertical load is applied at these fixed points, creating tilting moments at each end of the mold.

5.4. Unless otherwise specified, tilting moments corresponding to an eccentricity of 22 mm shall be used to simulate the loading conditions of a standard SGC volumetric specimen.

6. INTERFERENCES

6.1. Debris on the SGC mold, base plates, ram head, reaction surfaces, or on the instrument can cause errant measurement results. Extreme care should be taken to thoroughly clean the SGC, mold, instrument, and any work areas that will be utilized during the measurement procedure. Scarring or irregular surfaces on mold walls and end plates is also known to cause incorrect results. Do not use any equipment that shows signs of damage. The precision required in the execution of this practice necessitates that extreme care must be taken to avoid errors from damaged or improperly maintained equipment.

7. APPARATUS

7.1. The instrument should be capable of being gyrated inside an SGC mold which induces tilting moments at each end of the SGC mold while simultaneously measuring an internal angle of gyration.

7.1.1. *Data Acquisition*—The timing of the data acquisition system may be automatically triggered by the start of the gyration process. Provision for excluding a known number of initial gyrations from the angle measurement may be provided (*initial delay period*), and the angle shall be measured throughout a known number of subsequent gyrations (*data acquisition period*). The durations of the initial delay and the data acquisition periods may be programmable or fixed.

7.1.2. *Display Options*—The angle measurement result(s) may be viewable on a display built into the instrument chassis and/or retrievable from the instrument via a communications port.

7.1.3. *Temperature Measurement*—The instrument may optionally have a means for displaying, recording, or otherwise indicating its internal temperature during the angle measurement process.

7.1.4. *Static Angle Gauge*—A NIST-traceable angle gauge device machined with one or more known angles and used to calibrate and verify the calibration of the angle measurement instrument.

7.1.5. *Wear Protection Plates*—Thin steel plates (optional) which protect the SGC mold end plates from any cosmetic damage by the contact rings.

7.2. *Superpave Gyratory Compactor* (SGC) and associated equipment as described in T 312. The SGC shall be in good repair, with the compaction pressure, specimen height measurement system, and gyration rate verified to be within specifications. The mechanisms used to induce and maintain the angle of gyration shall be set and maintained within the manufacturer’s guidelines.

7.2.1. The SGC molds, mold end plates, base platens, and ram head surface smoothness shall be confirmed to be within the specifications of T 312. Any equipment not meeting these requirements shall not be used.

8. HAZARDS

8.1. Use standard safety precautions and protective clothing for working in a hot mix asphalt laboratory.

9. CALIBRATION AND STANDARDIZATION

9.1. The angle measurement instrument requires periodic verification, calibration, or both. The system shall be standardized prior to initial use and at least once every 12 months. This annual verification is generally considered a factory calibration and includes the following:

9.1.1. Verification of the static angle gauge with a NIST-traceable measurement system.

9.1.2. Verification of the angle measurement instrument.

10. PREPARATION OF APPARATUS

10.1. Before each use of the angle measurement instrument (i.e., on a daily basis), verify the angle measurement system using the static angle gauge. The static angle gauge, which can apply one or more known angles to the instrument, is used to confirm that the instrument is operating within calibration.

Note 1—The instrument and the static angle gauge must be at the same uniform, stable temperature for the verification to be accurate.

10.2. Be sure the probe tips and contact rings on the angle measurement instrument are free of debris.

10.3. Prepare a clean compaction mold assembly.

Note 2—Accumulation of HMA on one or more of the mold surfaces, mold end plates, base platens, or ram head surfaces directly impacts the instrument's ability to accurately measure the angle of gyration. Use mineral spirits or another appropriate solvent to clean these surfaces.

10.4. If the angle measurement is to be made at an elevated temperature, place the SGC mold in an oven at the desired temperature ±5°C for a minimum of 45 minutes prior to making the first angle measurement. Do not place the angle measurement instrument in the oven.

Note 3—The SGC manufacturer may recommend measurement of the angle at an elevated temperature for those SGC models where the angle changes with mold temperature.

Note 4—Instruments typically have a limited operating temperature range. After use in a hot mold, the angle measurement instrument can be cooled by using a fan to blow ambient air over the instrument or by placing it in front of an air conditioner. Elevating the instrument above the table surface so as to permit maximum airflow over the entire instrument will increase the rate of cooling. Do not cool the instrument below room temperature.

10.5. Verify the settings on the compactor. Unless noted otherwise, the SGC shall be initialized to provide specimen compaction using a consolidation pressure of 600 ± 18 kPa and a gyration rate of 30 ± 0.5 rpm.

10.6. Set the number of gyrations on the SGC in accordance with the recommendations of the manufacturer of the angle measurement instrument.

11. PROCEDURE

11.1. The average internal angle is based on four individual angle measurements as follows:

11.1.1. The top internal angle is measured twice. If the two results do not match within 0.02 degrees, discard the results and repeat this step again.

11.1.2. The bottom internal angle is measured twice. If the two results do not match within 0.02 degrees, discard the results and repeat this step again.

11.2. Each of the four individual angle measurements is performed as follows:

11.2.1. Arm the angle measurement instrument for collecting data.

11.2.2. Place the angle measurement instrument inside the SGC mold. Orient the instrument probes or reference base as appropriate to measure the top or bottom angle.

Note 5—The operator may wish to use a mold extruder to elevate the bottom mold plate to a position where insertion of the angle measurement instrument into the SGC mold is easier.

11.2.3. Place the SGC mold inside the SGC.

Note 6—For some SGCs, it may be more convenient to first place the mold in the SGC, and then place the angle measurement instrument in the mold.

11.2.4. Initiate the compaction process. For most SGCs, this is an automatic process consisting of pressing a button to start the compaction process. The SGC automatically applies the ram pressure, induces the angle, and gyrates the mold to the specified number of gyrations.

Note 7—Certain models of Superpave Gyratory Compactor may exhibit erratic behavior when applying compaction pressure to a simulated load device. Consult SGC manufacturer recommendations regarding the use of simulated load devices and specific procedures for initiating and completing the compaction process.

11.2.5. Remove the angle measurement instrument from the SGC mold.

Note 8—Use caution when removing the instrument, especially when using a power extruder. Take care that the instrument does not get caught or damaged during the extrusion process.

11.2.6. Record the angle result reported by the instrument (to the nearest 0.01 degree). Record which angle (*top* or *bottom*) and which replicate (1 or 2) was measured.

12. CALCULATION

12.1. Calculate the average top internal angle as follows:

$$\text{average top internal angle} = \frac{(\text{top internal angle 1} + \text{top internal angle 2})}{2} \tag{1}$$

12.2. Calculate the average bottom internal angle as follows:

$$\text{average bottom internal angle} = \frac{(\text{bottom internal angle 1} + \text{bottom internal angle 2})}{2} \tag{2}$$

12.3. Calculate the effective internal angle as follows:

$$\text{effective internal angle} = \frac{(\text{average top internal angle} + \text{average bottom internal angle})}{2} \tag{3}$$

13. REPORT

13.1. The report shall contain the following information:

13.1.1. *SGC Information*—Manufacturer, model number, serial number, owner, location, number of gyrations, and consolidation pressure used during the angle measurement process;

13.1.2. *Angle Measurement Instrument Identification*—Manufacturer, model number, serial number, date of calibration;

13.1.3. *Due date for next calibration and eccentricity*;

Note 9—Consult the instrument manufacturer's manual for determination of the applied eccentricity for the particular instrument used.

13.1.4. *Results from each of the individual angle measurements*—Express each angle measurement to the nearest 0.01 degree, with notations indicating top or bottom angle; and

13.1.5. *Effective internal angle*.

13.2. The technician performing the test shall sign and date the report.

Note 10—A sample report is provided in Appendix X1.

14. PRECISION AND BIAS

14.1. *Precision*—The precision is based on an ASTM Interlaboratory Study (ILS #151) that was conducted in 2007. ILS #151 involved 27 laboratories, which featured five Troxler (DAVII-HMS) and six Pine Instrument AFLS1 (RAM) internal-angle measuring instruments and the following SGC models: Troxler Electronics 4140, 4141, and 414x; Pine Instrument AFG1, AFG2, AFGB1, and AFGC125X; IPC ServoPac; and Interlaken. Within the study, the internal angle measurements ranged from 1.014 to 1.290 degrees. ILS #151 indicated that the two internal-angle measuring device types (DAVII-HMS and RAM) produced similar results on all SGC models listed.

14.1.1. *Single-Instrument Precision*—The single-operator standard deviation (1s limit) of a single test result has been found to be 0.011 degrees. Therefore, results of two properly conducted measurements by the same operator with the same internal-angle measuring instrument in the same SGC should not differ by more than 0.03 degrees (d2s limit).

14.1.2. *Multi-Instrument Precision*—The multi-instrument standard deviation (1s limit) of a single test result has been found to be 0.015 degrees. Therefore, the results of two properly conducted measurements by different operators using different internal-angle measuring instruments in the same SGC should not differ by more than 0.04 degrees (d2s limit).

14.2. *Bias*—Since there is no accepted reference device suitable for determining the bias in this method, no statement of bias is made.

15. KEYWORDS

15.1. Angle; asphalt; compaction; gyratory; Superpave.

APPENDIX

(Nonmandatory Information)

X1. SAMPLE REPORT

Superpave Gyratory Compactor (SGC)
Internal Angle Evaluation Form

Superpave Gyratory Compactor

Manufacturer: __________ Owner: __________
Model: __________ Location: __________
Serial Number: __________ Total Gyrations: __________

Angle Measurement Instrument

Make and Model: __________ Date of Previous Calibration: __________
Serial Number: __________ Next Calibration Due: __________
Eccentricity (mm): __________

Internal Angle Measurements

Angle Measured (*Top* or *Bottom*)	Angle (report to nearest 0.01 degree)	Comments
Effective Internal Angle:		

Technician: ____________________ Date: ____________________
(sign here)

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[1] This standard was first published in June 2007. Revised in 2009.

[2] Guler, M., Bahia, H. U., Bosscher, P. J., and M. E. Plesha. Device for Measuring Shear Resistance of Hot Mix Asphalt in Gyratory Compactor. In *Transportation Research Record 1723*. TRB, National Academy of Sciences, Washington, DC, 2000, pp. 116–124.

Standard Method of Test for

Quantitative Determination of the Percentage of Lime in Hot Mix Asphalt (HMA)

AASHTO Designation: TP 72-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Quantitative Determination of the Percentage of Lime in Hot Mix Asphalt (HMA)

AASHTO Designation: TP 72-08

1. SCOPE

1.1. This method covers the quantitative determination of the percentage of lime in hot mix asphalt (HMA) by calculation of the calcium hydroxide, $Ca(OH)_2$, recovered from a sample of the mixture. A specimen is obtained through drilling into the HMA and collecting the drilling dust. The specimen is subjected to an acid filter boil and wash and is analyzed using either Atomic Absorption (AA) or Ion Exchange Chromatography (IEC).

1.2. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

2.2. *ASTM Standard*:

- C 25, Standard Test Methods for Chemical Analysis of Limestone, Quicklime, and Hydrated Lime

3. SIGNIFICANCE AND USE

3.1. This test method is useful for determining the amount of lime added to an HMA mixture.

3.2. If the coarse aggregate contains limestone, the limestone aggregate will be dissolved by the acid used in this method and can yield an unrealistically high result. If limestone is present in a relatively minor amount, it is possible to run a background analysis on the raw aggregate. An adjustment can then be made based on the background analysis in order to better approximate the actual results. If the aggregate in the HMA contains an appreciable amount of limestone, this test method is not suitable. Depending upon the concentration, the calcium content of any added lime could be masked by the aggregate concentration. This effect would lead to a significant error in overestimation of the amount of lime added.

4. APPARATUS

4.1. *Atomic Absorption (AA) or Ion Exchange Chromatography (IEC)*—These methods are able to measure the concentration of chemical elements, in this case calcium, in aqueous solutions. AA Spectrometry measures the intensity of a characteristic color imparted to a flame by the presence of calcium ions in the test solution. IEC measures the change in electrical conductivity of the solution. IEC can identify components of mixtures; AA Spectrometry can only measure one element at a time.

4.2. *Balance*—An analytical balance conforming to M 231, Class B.

4.3. *Heating Device*—A small hot plate or other suitable device shall be available for supplying sufficient heat under the flask to bring the solution to a boil. Suitable shields, baffle plates, or sand baths shall be used on the surfaces of the hot plates to minimize localized overheating.

4.4. *Rotary Hammer*—An industrial size hammer drill with a $^{3}/_{8}$-in. carbide drill bit.

4.5. *Miscellaneous Equipment*:

4.5.1. *Automatic Pipette*—Eppendorf or equivalent of adequate capacity to obtain a 1.0-mL sample.

4.5.2. *Filter Funnel*—Buchner or equivalent and filter paper, filter flask, and a vacuum source.

4.5.3. *Glassware*—100-mL and 250-mL flasks.

5. TEST SPECIMENS

5.1. Test specimens may be either laboratory-mixed HMA or sampled from HMA pavements.

5.2. Pavement specimens shall be taken from pavements with a core drill, diamond or carborundum saw, or by other suitable means. Specimens will be further prepared as noted in Section 6.1.

5.3. Specimens shall be free from foreign materials such as foundation material, soil, paper, foil, etc.

5.4. If the core contains more than one pavement layer, it is recommended that the layers be separated by sawing or other suitable means.

6. PROCEDURE

6.1. *Preparation of Specimen*:

6.1.1. A specimen is obtained from the drilling dust of a pavement core or laboratory-mixed HMA sample. Stand the core on a thick piece of wood and use a heavy-duty rotary hammer with a $^{3}/_{8}$-in. carbide bit to drill into the sample.

Note 1—A rotary hammer that utilizes SDS, SDS Max, or spline shank bits is recommended. Devices utilizing straight shank bits have been found to be insufficient. Depending upon the number of samples, it may be worthwhile to make a frame to hold the core.

Note 2—It is recommended to wear safety glasses and protective gloves.

6.1.2. Drill to the depth of the drill flutes. This depth will yield about 15 g of dust. Discard any lumps of the core that may break off.

6.1.3. Take the 15 ± 0.5 g of dust and determine its mass to the nearest 0.01 g. Place the dust in a 250-mL conical flask. Add 100 mL of 4 percent acetic acid and boil the mixture for 30 to 45 min. Filter the mixture through a filter funnel (Buchner or equivalent) and wash the insoluble dust with distilled water.

6.1.4. Transfer the filtrate to a 250-mL volumetric flask. Rinse the filter flask with distilled water and add the washings to the contents of the volumetric flask. Add distilled water to the flask until the total volume of its contents reaches 250 mL. Place a stopper in the flask, and shake it well to mix the contents.

6.1.5. Use a pipette (an Eppendorf automatic pipette or equivalent) accurate to 0.1 mL to take a 1.0-mL aliquot from the volumetric flask, and transfer this specimen to a 100-mL volumetric flask. Fill the flask with distilled water until the total volume of its contents reaches 100 mL. Place a stopper in the flask, and shake it well to mix the contents.

6.2. *Analyze the drilling dust to determine the level of calcium ions present*:

6.2.1. Run AA Spectrometry or IEC (according to the manufacturer's recommendations) on the specimen prepared in Section 6.1.5. Run calcium standards before and after the specimen analysis. If using AA Spectrometry, do not add lanthanum salts.

Note 3—Theories exist that calcium is subject to interference with AA Spectrometry and this condition can be overcome by adding lanthanum salts. However, in this procedure, it has been found to provide an artificially high lime result.

6.2.2. The calcium ion concentration in the specimen should be in the range of 1 to 5 mg/L. If the concentration is outside this range, it indicates the possible presence of limestone aggregate (see Section 3.2).

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7. CALCULATION OF RESULTS

7.1. *Calculate the percentage of lime in the HMA as follows*:

$$L = [[C \times 46.25]/[10 \times W_d \times ((100 - AC)/100)]]/L_c \qquad (1)$$

where:

L = percentage of lime;

C = concentration of calcium from AA or IEC (mg/L);

W_d = mass of the dust, g;

AC = percentage of the binder in the mix, determined by AASHTO T 308; and

L_c = percentage of calcium in the lime from ASTM C 25 to the nearest 0.001 (e.g., 0.955).

7.1.1. Derivation of Equation 1:

The calcium content of the original solution is:

$C \times 100/4$ mg/L or $C \times 25$.

Hydrated lime is calcium hydroxide $Ca(OH)_2$ with a molecular weight of $40 + 2(16 + 1) = 74$.

To convert from mg/L of calcium to mg/L of lime multiply by 74/40 or 1.85.

Therefore, the hydrated lime content is:

$C \times 25 \times 1.85$ mg/L or $C \times 46.25$ mg/L

Hydrated lime is added to the mix as a percentage of the aggregate; therefore, the mass of the aggregate in the dust specimen is included as $[1000 \times W_d \times (100 - AC)/100]$ in grams or $[10 \times W_d \times (100 - AC)/100]$ in milligrams.

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8. REPORT

8.1. *The report shall include the following information*:

8.1.1. Type of specimen tested (obtained from a laboratory-mixed sample or pavement core sample);

Note 4—For core specimens, the height of each test specimen in millimeters (or inches) should be reported.

8.1.2. Date of the test;

8.1.3. Asphalt mixture identification;

8.1.4. Percentage of asphalt binder to the nearest 0.1 percent; and

8.1.5. Percentage of lime to the nearest 0.01 percent.

9. PRECISION AND BIAS

9.1. No precision and bias statements are available at this time.

10. KEYWORDS

10.1. Atomic Absorption Spectrometry; hot mix asphalt; Ion Exchange Chromatography; lime.

Standard Specification for

Detecting the Presence of Phosphorous in Asphalt Binder

AASHTO Designation: TP 78-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Detecting the Presence of Phosphorous in Asphalt Binder

AASHTO Designation: TP 78-09[1]

1. SCOPE

1.1 This qualitative test method can be used to identify the presence of polyphosphoric acid (PPA) in asphalt binder or residue. If PPA is present in the binder, a blue color is developed in approximately 5 minutes. The test method is not quantitative, but it can detect PPA at concentrations as low as 0.1 percent. The test method can only determine the presence of phosphorus. It is not specific for the presence of PPA. A positive test result assumes that the phosphorus is from PPA. Any additive that contains phosphorus will give a false positive for the presence of PPA.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 40, Sampling Bituminous Materials

3. SUMMARY OF TEST METHOD

3.1 Butyl alcohol is used to extract some of the acid present from the asphalt. The extracted acid is then transferred to the water phase. The presence of phosphoric acid is detected by reaction with ammonium molybdate, potassium antimonyl tartrate, and ascorbic acid to form a blue color.

4. SIGNIFICANCE

4.1 Phosphoric acid may be added to asphalt binder to modify the physical properties of the binder. This test method detects the presence of phosphoric acid in the asphalt binder but is not a quantitative test. The result is either positive or negative that phosphoric acid is present.

5. APPARATUS

5.1 *Pipette*—Disposable, plastic transfer pipettes.

5.2 *Containers*—One-ounce cans, test tubes, or small beakers. Disposable cans or glassware are recommended to avoid contamination. If glassware is reused, it must be washed with hot (1 + 3) hydrochloric acid (1 part hydrochloric acid to 3 parts distilled water) and rinsed with distilled water. Commercial detergents should not be used to clean the glassware because they may contain phosphates, which will interfere with the results.

Note 1—One agency found that the cans they were using for this test had been lubricated during the manufacturing process with a lubricant containing phosphates. This resulted in a positive result in this test even with the empty can. If there is doubt about the condition of the containers being used, then take the precaution of running a blank test with no asphalt.

6. REAGENTS AND MATERIALS

6.1 *Antimonyl Tartrate/Ammonium Molybdate Solution*—Dissolve 0.13 g of potassium antimonyl tartrate hydrate [$C_8H_4K_2O_{12}Sb_2 \cdot H_2O$] in 50 mL of distilled water. Add 5.6 g of ammonium molybdate [$(NH_4)_6Mo_7O_{24} \cdot 4\ H_2O$] and swirl until dissolved.

6.2 *Sulfuric Acid Solution*—1 N solution of sulfuric acid [H_2SO_4]. Sulfuric acid solution can be purchased in 1-L polyethylene bottles.

6.3 *Stock Solution*—Mix the antimonyl tartrate/ammonium molybdate solution from Section 6.1 with approximately 950 mL of 1 N sulfuric acid solution. This can be done by adding the solution from Section 6.1 to 1 L of 1 N sulfuric acid if there is sufficient space in the bottle. The exact amount of sulfuric acid is not critical. This solution is stable for 1 year.

6.4 *Ascorbic Acid Color Reagent*—Dissolve 0.50 g of L-ascorbic acid [$C_6H_8O_6$] in 100 mL of the stock solution from Section 6.3. Prepare the reagent fresh daily as needed.

6.5 *Butyl Alcohol*—Isobutanol [$(CH_3)_2CHCH_2OH$] or *n*-butanol [$CH_3(CH_2)_3OH$] may be used.

7. SAMPLING

7.1 Sample the material in accordance with T 40. See Note 2 regarding potential concerns regarding contamination of sampling container.

8. PROCEDURE

8.1 Heat the asphalt and pour 1 to 2 g into a 1-oz can or other small container.

8.2 Place the container in an oven set at 163 ± 10°C for 10 minutes to ensure the asphalt is fluid.

8.3 Remove the container, and immediately add 2 mL of butyl alcohol while stirring the container.

8.4 Continue to stir the container and add 2 mL of distilled water.

8.5 While still stirring the container, add 2 mL of the ascorbic acid color reagent. After the addition of the color reagent, stop stirring and allow the sample to sit for 5 to 10 minutes.

8.6 If phosphoric acid is present in the asphalt, a blue color will develop within 5 to 10 minutes. Decant the solution into a second container if unable to see the color.

Note 2—After 30 minutes, the results are not reliable. The color may either fade or intensify after 30 minutes.

8.7 If a blue color appears, the sample is reported as “positive”. The sample is reported as “negative” if it does not turn blue.

Note 3—The blue color, if present, will be in the aqueous phase, which will be at the bottom. Often the top layer has a brown or green color.

8.8 When new reagents are prepared, prepare and run a blank (asphalt with no phosphoric acid).

9. REPORT

9.1 *This report shall include the following*:

9.1.1 Identification of sample.

9.1.2 “Positive” or “Negative” result.

10. PRECISION AND BIAS

10.1 *Precision*—The research required to develop precision estimates has not been conducted.

10.2 *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

11. KEYWORDS

11.1 Asphalt; phosphoric acid; PPA.

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[1] This provisional test method was adopted and first published in 2009.

Standard Method of Test for

Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)

AASHTO Designation: TP 79-10[1,2]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
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Standard Method of Test for

Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)

AASHTO Designation: TP 79-10[1,2]

1. SCOPE

1.1 This standard describes test methods for measuring the dynamic modulus and flow number for hot mix asphalt (HMA) using the Asphalt Mixture Performance Tester (AMPT). This practice is intended for dense- and gap-graded mixtures with nominal-maximum aggregate sizes up to 37.5 mm.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- PP 60, Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)

2.2 *Other Publication*:

- Equipment Specification for the Simple Performance Test System, Version 3.0, Prepared for National Cooperative Highway Research Program (NCHRP), October 16, 2007

3. TERMINOLOGY

3.1 *dynamic modulus*, |E*|—the absolute value of the complex modulus calculated by dividing the peak-to-peak stress by the peak-to-peak strain for a material subjected to a sinusoidal loading.

3.2 *phase angle*, δ—the angle in degrees between a sinusoidally applied stress and the resulting strain in a controlled stress test.

3.3 *permanent deformation*—the non-recovered deformation in a repeated-load test.

3.4 *confining pressure*—the stress applied to all surfaces in a confined test.

3.5 *deviator stress*—the difference between the total axial stress and the confining pressure in a confined test.

3.6 *flow number*—the number of load cycles corresponding to the minimum rate of change of permanent axial strain during a repeated-load test.

4. SUMMARY OF METHOD

4.1 This test method describes procedures for measuring the dynamic modulus and flow number for HMA.

4.2 In the dynamic modulus procedure, an HMA specimen at a specific test temperature is subjected to a controlled sinusoidal (haversine) compressive stress of various frequencies. The applied stresses and resulting axial strains are measured as a function of time and used to calculate the dynamic modulus and phase angle.

4.3 In the flow number procedure, an HMA specimen at a specific test temperature is subjected to a repeated haversine axial compressive load pulse of 0.1 s every 1.0 s. The test may be conducted with or without confining pressure. The resulting permanent axial strains are measured as a function of the load cycles and numerically differentiated to calculate the flow number. The flow number is defined as the number of load cycles corresponding to the minimum rate of change of permanent axial strain.

5. SIGNIFICANCE AND USE

5.1 The dynamic modulus is a performance-related property that can be used for mixture evaluation and for characterizing the stiffness of HMA for mechanistic-empirical pavement design.

5.2 The flow number is a property related to the resistance of HMA to permanent deformation. It can be used to evaluate and design HMA with specific resistance to permanent deformation.

6. APPARATUS

6.1 *Specimen Fabrication Equipment*—For fabricating dynamic modulus test specimens as described in PP 60.

6.2 *Dynamic Modulus Test System*—Meeting the requirements of the equipment specification for the Simple Performance Test (SPT) System, Version 3.0.

6.3 *Conditioning Chamber*—An environmental chamber for conditioning the test specimens to the desired testing temperature. The environmental chamber shall be capable of controlling the temperature of the specimen over a temperature range from 4 to 60°C to an accuracy of ±0.5°C. The chamber shall be large enough to accommodate the number of specimens to be tested plus a “dummy” specimen with a temperature sensor mounted in the center for temperature verification.

6.4 *Teflon Sheet*—0.25 mm thick, to be used as a friction reducer between the specimen and the loading platens in the dynamic modulus test.

6.5 *Latex Membranes*—100-mm diameter by 0.3 mm thick, for use in confined tests and for manufacturing “greased double latex” friction reducers to be used between the specimen and the loading platens in the dynamic modulus and flow number tests.

6.6 *Silicone Grease*—Dow Corning "Stopcock Grease" or equivalent, for manufacturing "greased double latex" friction reducers.

6.7 *Balance*—Capable of determining mass to the nearest 0.01 g. The balance is used to determine the mass of silicone grease during fabrication of "greased double latex" friction reducers.

7. HAZARDS

7.1 This practice and associated standards involve handling of hot asphalt binder, aggregates, and HMA. It also includes the use of sawing and coring machinery and servo-hydraulic testing equipment. Use standard safety precautions, equipment, and clothing when handling hot materials and operating machinery.

8. STANDARDIZATION

8.1 Items associated with this practice that require calibration or verification are included in the documents referenced in Section 2.2. Refer to the pertinent section of the referenced documents for information concerning calibration or verification.

9. PROCEDURE A—DYNAMIC MODULUS TEST

9.1 *Test Specimen Fabrication*:

9.1.1 Testing shall be performed on 100-mm diameter by 150-mm tall test specimens fabricated in accordance with PP 60.

9.1.2 Prepare at least two test specimens at the target air void content ±0.5 percent and with the aging condition in accordance with PP 60. Use Table 1 to select an appropriate number of specimens based on the uncertainty that can be tolerated in the analysis.

Note 1—The coefficient of variation for properly conducted dynamic modulus tests is approximately 13 percent. The coefficient of variation of the mean dynamic modulus for tests on multiple specimens is given in Table 1.

Table 1—Coefficient of Variation for Mean of Dynamic Modulus Test on Replicate Specimens

Number of Specimens	Coefficient of Variation for Mean, %
2	9.2
3	7.5
4	6.5
5	5.8
6	5.3
7	4.9
8	4.6
9	4.3
10	4.1

9.2 *Test Specimen Instrumentation (Standard Glued-Gauge-Point System)*:

9.2.1 Attach the gauge points to the specimen in accordance with the manufacturer's instructions.

9.2.2 Confirm that the gauge length is 70 mm ± 1 mm, measured center-to-center of the gauge points.

9.3 *Loading Platens and End-Friction Reducers*:

9.3.1 For the dynamic modulus test, the top platen shall be free to rotate.

9.3.2 Either “greased double latex” or Teflon® end-friction reducers can be used in the dynamic modulus test.

9.3.2.1 Teflon end-friction reducers are made from 0.25-mm thick Teflon sheet, cut to a size slightly larger than the loading platen.

9.3.2.2 “Greased double latex” friction reducers are fabricated from 0.3-mm thick latex membranes as described in Annex A.

9.4 *Procedure*:

9.4.1 *Unconfined Tests*:

9.4.1.1 Place the specimens to be tested in the environmental chamber with the “dummy” specimen and monitor the temperature of the “dummy” specimen to determine when testing can begin.

9.4.1.2 Place platens and friction reducers inside the testing chamber. Turn on the AMPT; set the temperature control to the desired testing temperature, and allow the testing chamber to equilibrate at the testing temperature for at least 1 h.

9.4.1.3 When the “dummy” specimen and the testing chamber reach the target temperature, open the testing chamber. Remove a test specimen from the conditioning chamber and quickly place it in the testing chamber.

9.4.1.4 Assemble the specimen to be tested with platens in the following order from bottom to top: bottom loading platen, bottom friction reducer, specimen, top friction reducer, and top loading platen.

9.4.1.5 Install the specimen-mounted deformation-measuring system on the gauge points per the manufacturer’s instructions. Ensure that the deformation-measuring system is within its calibrated range. Ensure that the top loading platen is free to rotate during loading.

9.4.1.6 Close the testing chamber and allow the chamber temperature to return to the testing temperature.

9.4.1.7 Procedures in Sections 9.4.1.3 through 9.4.1.6, including the return of the test chamber to the target temperature, shall be completed in 5 min.

9.4.1.8 Enter the required identification and control information into the dynamic modulus software.

9.4.1.9 Follow the software prompts to begin the test. The AMPT will automatically unload when the test is complete and will display the test data and data quality indicators.

9.4.1.10 Review the data quality indicators as discussed in Section 9.5. Retest specimens with data quality indicators above the values specified in Section 9.5.

9.4.1.11 Once acceptable data have been collected, open the test chamber and remove the tested specimen.

9.4.1.12 Repeat procedures in Sections 9.4.1.3 through 9.4.1.11 for the remaining test specimens.

9.4.2 *Confined Tests*:

9.4.2.1 Assemble each specimen to be tested with the platens and membrane as follows: place the bottom friction reducer and the specimen on the bottom platen. Stretch the membrane over the specimen and bottom loading platen. Install the lower “o-ring” seal. Place the top friction reducer and top platen on top of the specimen and stretch the membrane over the top platen. Install the upper “o-ring” seal. When performing confined tests, the specimen must be vented to atmospheric pressure through the drainage lines. Ensure that the friction reducers have holes to allow air to be vented from inside the membrane.

9.4.2.2 Encase the “dummy” specimen in a membrane.

9.4.2.3 Place the specimen and platen assembly in the environmental chamber with the “dummy” specimen and monitor the temperature of the “dummy” specimen to determine when testing can begin.

9.4.2.4 Turn on the AMPT; set the temperature control to the desired testing temperature, and allow the testing chamber to equilibrate at the testing temperature for at least 1 h.

9.4.2.5 When the “dummy” specimen and the testing chamber reach the target temperature, open the testing chamber. Remove a test specimen and platen assembly and quickly place it in the testing chamber. When performing confined tests, the specimen must be vented to atmospheric pressure through the drainage lines. Properly connect the drainage lines to the loading platens, and ensure they are vented to atmospheric pressure through the bubble chamber to identify leaks.

9.4.2.6 Install the specimen-mounted deformation-measuring system outside the membrane on the gauge points per the manufacturer’s instructions. Ensure that the deformation-measuring system is within its calibrated range. Ensure that the top loading platen is free to rotate during loading.

9.4.2.7 Close the testing chamber, and allow the chamber temperature to return to the testing temperature.

9.4.2.8 Procedures in Sections 9.4.2.5 through 9.4.2.7, including the return of the test chamber to the target temperature, shall be completed in 5 min.

9.4.2.9 Enter the required identification and control information into the dynamic modulus software.

9.4.2.10 Follow the software prompts to begin the test. The AMPT will automatically unload when the test is complete and will display the test data and data quality indicators.

9.4.2.11 Review the data quality indicators as discussed in Section 9.5. Retest specimens with data quality indicators above the values specified in Section 9.5.

9.4.2.12 Once acceptable data have been collected, open the test chamber and remove the tested specimen.

9.4.2.13 Repeat procedures in Sections 9.4.2.3 through 9.4.2.12 for the remaining test specimens.

9.5 *Computations and Data Quality*:

9.5.1 The calculation of dynamic modulus, phase angle, and the data quality indicators is performed automatically by the AMPT software.

9.5.2 Accept only test data meeting the data quality statistics given in Table 2. Table 3 summarizes actions that can be taken to improve the data quality statistic. Repeat tests as necessary to obtain test data meeting the data quality statistics requirements.

Table 2—Data Quality Statistics Requirements

Data Quality Statistic	Limit
Deformation drift	In direction of applied load
Peak-to-peak strain	75 to 125 μstrain for unconfined tests
	85 to 115 μstrain for confined tests
Load standard error	10%
Deformation standard error	10%
Deformation uniformity	30%
Phase uniformity	3º

Note 2—The data quality statistics in Table 2 are reported by the AMPT. If a dynamic modulus test system other than the AMPT is used, refer to the equipment specification for the Simple Performance Test (SPT) System, Version 3.0, for algorithms for the computation of dynamic modulus, phase angle, and data quality statistics.

Table 3—Troubleshooting Guide for Data Quality Statistics

Item	Cause	Possible Solutions
Deformation drift not in direction of applied load	Gauge points are moving apart	Reduce LVDT spring force. Add compensation springs. Reduce test temperature.
Peak-to-peak strain too high	Load level too high	Reduce load level.
Peak-to-peak strain too low	Load level too low	Increase load level.
Load standard error >10%	Applied load not sinusoidal	Adjust tuning of hydraulics.
Deformation standard error >10%	1. Deformation not sinusoidal 2. Loose gauge point 3. Excessive noise on deformation signals 4. Damaged LVDT	1. Adjust tuning of hydraulics. 2. Check gauge points. Reinstall if loose. 3. Check wiring of deformation sensors. 4. Replace LVDT.
Deformation uniformity >30%	1 Eccentric loading 2. Loose gauge point 3. Sample ends not parallel 4. Poor gauge point placement 5. Non-uniform air void distribution	1. Ensure specimen is properly aligned. 2. Check gauge points. Reinstall if loose. 3. Check parallelism of sample ends. Mill ends if out of tolerance. 4. Check for specimen non-uniformity (segregation, air voids). Move gauge points. 5. Ensure test specimens are cored from the middle of the gyratory specimen.
Phase uniformity >3º	1. Eccentric loading 2, Loose gauge point 3. Poor gauge point placement 4. Damaged LVDT	1. Ensure specimen is properly aligned. 2. Check gauge points. Reinstall if loose. 3. Check for specimen non-uniformity (segregation, air voids). Move gauge points. 4. Replace LVDT.

9.6 *Reporting*:

9.6.1 For each specimen tested, report the following:

9.6.1.1 Test temperature.

9.6.1.2 Test frequency.

9.6.1.3 Confining stress level.

9.6.1.4 Dynamic modulus.

9.6.1.5 Phase angle.

9.6.1.6 Data quality statistics.

9.6.2 Attach the AMPT dynamic modulus test summary report for each specimen tested.

10. PROCEDURE B—FLOW NUMBER TEST

10.1 *Test Specimen Fabrication*:

10.1.1 Testing shall be performed on 100-mm diameter by 150-mm tall test specimens fabricated in accordance with PP 60.

10.1.2 Prepare at least three test specimens at the target air void content ±0.5 percent and with the aging condition in accordance with PP 60.

Note 3—The coefficient of variation for the "permanent deformation before flow" in the flow number test is approximately 15 percent. The coefficient of variation for the flow number is approximately 20 percent. The coefficient of variation of the mean for tests on multiple specimens is given in Table 4.

10.2 *Loading Platens and End-Friction Reducers*:

10.2.1 For the flow number test, the top platen shall not be free to rotate.

10.2.2 Prepare two "greased double latex" end-friction reducers for each specimen that will be tested using the procedure specified in Annex A. It is recommended that new friction reducers be used for each test.

Use Table 4 to select an appropriate number of specimens based on the uncertainty that can be tolerated in the analysis.

Table 4—Coefficient of Variation for Mean of Properties from Flow Number Test

	Coefficient of Variation for Mean, %	
Number of Specimens	Permanent Deformation before Flow	Flow Number
2	10.6	14.1
3	8.7	11.5
4	7.5	10.0
5	6.7	8.9
6	6.1	8.2
7	5.7	7.6
8	5.3	7.1
9	5.0	6.7
10	4.7	6.3

10.3 *Procedure:*

10.3.1 *Unconfined Tests*:

10.3.1.1 Place the specimens to be tested in the environmental chamber with the "dummy" specimen and monitor the temperature of the "dummy" specimen to determine when testing can begin.

10.3.1.2 Place platens and "greased double latex" friction reducers inside the testing chamber. Turn on the AMPT, set the temperature control to the desired testing temperature, and allow the testing chamber to equilibrate at the testing temperature for at least 1 h.

10.3.1.3 When the "dummy" specimen and the testing chamber reach the target temperature, open the testing chamber. Remove a test specimen from the conditioning chamber and quickly place it in the testing chamber.

10.3.1.4 Assemble each specimen to be tested with platens in the following order from bottom to top: bottom loading platen, bottom "greased double latex" friction reducer, specimen, top "greased double latex" friction reducer, and top loading platen.

10.3.1.5 Close the testing chamber and allow the chamber temperature to return to the testing temperature. Ensure that the top loading platen is not permitted to rotate during loading.

10.3.1.6 Procedures in Sections 10.3.1.3 and 10.3.1.5, including the return of the test chamber to the target temperature, shall be completed in 5 min.

10.3.1.7 Enter the required identification and control information into the flow number software.

10.3.1.8 Follow the software prompts to begin the test. The AMPT will automatically unload when the test is complete.

10.3.1.9 Upon completion of the test, open the test chamber and remove the tested specimen.

10.3.1.10 Repeat procedures in Sections 10.3.1.4 through 10.3.1.9 for the remaining test specimens.

10.3.2 *Confined Tests*:

10.3.2.1 Assemble each specimen to be tested with the platens and membrane as follows: place the bottom "greased double latex" friction reducer and the specimen on the bottom platen. Stretch the membrane over the specimen and bottom loading platen. Install the lower “o-ring” seal. Place the top “greased double latex” friction reducer and top platen on top of the specimen, and stretch the membrane over the top platen. Install the upper “o-ring” seal. When performing confined tests, the specimen must be vented to atmospheric pressure through the drainage lines. Make sure that the friction reducers have holes to allow air to be vented from inside the membrane.

10.3.2.2 Encase the “dummy” specimen in a membrane.

10.3.2.3 Place the specimen and platen assembly in the environmental chamber with the “dummy” specimen and monitor the temperature of the “dummy” specimen to determine when testing can begin.

10.3.2.4 Turn on the AMPT, set the temperature control to the desired testing temperature, and allow the testing chamber to equilibrate at the testing temperature for at least 1 h.

10.3.2.5 When the “dummy” specimen and the testing chamber reach the target temperature, open the testing chamber. Remove a test specimen and platen assembly and quickly place it in the testing chamber. When performing confined tests, the specimen must be vented to atmospheric pressure through the drainage lines. Properly connect the drainage lines to the loading platens, and make sure they are vented to atmospheric pressure through the bubble chamber to identify leaks.

10.3.2.6 Close the testing chamber and allow the chamber temperature to return to the testing temperature. Ensure that the top loading platen is not permitted to rotate during loading.

10.3.2.7 Procedures in Sections 10.3.2.5 and 10.3.2.6, including the return of the test chamber to the target temperature, shall be completed in 5 min.

10.3.2.8 Enter the required identification and control information into the flow number software.

10.3.2.9 Follow the software prompts to begin the test. The AMPT will automatically unload when the test is complete.

10.3.2.10 Upon completion of the test, open the test chamber, and remove the tested specimen.

10.3.2.11 Repeat procedures in Sections 10.3.2.5 through 10.3.2.10 for the remaining test specimens.

10.4 *Calculations*:

10.4.1 The calculation of the permanent strain for each load cycle and the flow number for individual specimens is performed automatically by the AMPT.

10.4.2 Compute the average and standard deviation of the flow numbers for the replicate specimens tested.

10.4.3 Compute the average and standard deviation of the permanent strain at the load cycles of interest.

10.5 *Reporting*:

10.5.1 Report the following:

10.5.1.1 Test temperature.

10.5.1.2 Average applied deviatory stress.

10.5.1.3 Average applied confining stress.

10.5.1.4 Average and standard deviation of the flow numbers for the specimens tested.

10.5.1.5 Average and standard deviation of the permanent strain at the load cycles of interest.

10.5.2 Attach AMPT flow number test summary report for each specimen tested.

11. KEYWORDS

11.1 Dynamic modulus; flow number; permanent deformation; phase angle; repeated load testing.

ANNEX A—METHOD FOR PREPARING "GREASED DOUBLE LATEX" END-FRICTION REDUCERS FOR FLOW NUMBER TEST

(Mandatory Information)

A1. PURPOSE

A1.1. This annex presents a procedure for fabricating "greased double latex" end-friction reducers for the flow number test.

A1.2. These end-friction reducers are mandatory for the flow number test.

A2. SUMMARY

A2.1. "Greased double latex" end-friction reducers are fabricated by cutting two circular latex sheets from a latex membrane used for confining specimens, applying a specified mass of silicone grease evenly over one of the latex sheets, then placing the second latex sheet over the first.

A3. PROCEDURE

A3.1. Cut a 0.3-mm-thick latex membrane along its long axis to obtain a rectangular sheet of latex. The sheet will be approximately 315 by 250 mm.

A3.2. Trace the circumference of the loading platen on the sheet of latex; then cut along the tracing to form circular latex sheets that are slightly larger than the loading platen. Four circular latex sheets are needed to fabricate friction reducers for the top and bottom of the specimen.

A3.3. Place one circular latex sheet on the balance, and apply 0.25 ± 0.5 g of silicone grease onto the middle of the latex sheet.

A3.4. Spread the silicone grease evenly over the latex sheet by rubbing in a circular motion from the center to the outside of the sheet.

A3.5. Place the second circular latex sheet on top of the silicone grease.

A3.6. If the friction reducer will be used in confined tests, cut or punch a hole through both latex sheets at the location of the vent in the loading platen.

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[1] This provisional test method was adopted and first published in 2009. Revised in 2010.

[2] This provisional test method was developed from NCHRP Project 9-29, Simple Performance Tester for Superpave Mix Design. The name of the device has been changed to the “Asphalt Mixture Performance Tester”. To obtain research documents, refer to the Simple Performance Tester.

Standard Method of Test for

Bulk Specific Gravity of Compacted Bituminous Mixtures Using Water Displacement Measured by Pressure Sensor

AASHTO Designation: TP 82-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Bulk Specific Gravity of Compacted Bituminous Mixtures Using Water Displacement Measured by Pressure Sensor

AASHTO Designation: TP 82-10

1. SCOPE

1.1 This test method covers the determination of bulk specific gravity of compacted bituminous mixtures.

1.2 This method can be used with samples that contain open or interconnecting voids or absorb more than 2.0 percent of water by volume, or both (Note 1).

Note 1—Water absorption by volume is determined using T 166; this specification does not contain a direct determination of the water absorption by volume.

1.3 The bulk specific gravity of compacted bituminous mixtures may be used in calculating the unit mass of the mixture.

1.4 The values stated in SI units are to be regarded as the standard. Unit equivalencies are included for reference and informational purposes only.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2 *ASTM Standard*:

- D 5581, Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus (6 inch-Diameter Specimen)

3. TERMINOLOGY

3.1 *bulk specific gravity (of solids)*—the ratio of the weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of equal density of an equal volume of gas-free distilled water at a stated temperature.

3.2 c*onstant mass*—the mass at which further drying at 52 ± 3°C (125 ±5°F) does not alter the mass by more than 0.05 percent with weighed at 2-h intervals.

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4. TEST SPECIMENS

4.1 Test specimens may be either laboratory-compacted asphalt mixtures or cylindrical cores sampled from asphalt pavements.

4.2 *Size of Specimens*—It is recommended that: (1) the diameter of cylindrically compacted or cored specimens shall be at least equal to four times the maximum size of the aggregate; and (2) the thickness of specimens be at least one and one-half times the maximum size of the aggregate.

4.3 Specimens shall be (1) compacted in accordance with T 245, T 312, or ASTM D 5581, or (2) taken from asphalt pavements with a core drill, diamond or carborundum saw or by other suitable means. Care shall be taken to avoid distortion or cracking of specimens during and after removal from the mold or pavement. Specimens shall be stored in a cool, safe place.

4.4 Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.

4.5 If desired, specimens may be separated from other pavement layers by sawing or other suitable means. Care should be exercised to ensure separation does not damage the specimens.

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5. APPARATUS

5.1 *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231.

5.2 *Water Displacement Measurement Apparatus*—The water displacement measurement apparatus shall be of sufficient size to accept a 100-mm (4-in.) or 150-mm (6-in.) diameter laboratory-molded or field-cored specimen. It shall have the depth adequate to immerse the bituminous specimen throughout its height. The water displacement measurement apparatus must be capable of calculating and displaying the bulk specific gravity based on the displaced water volume and the dry mass of the asphalt sample within 30 s to avoid the influence of absorbed water during the rapid measurement of displacement.

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6. STANDARDIZATION

6.1 The water displacement measurement apparatus requires periodic verification. The unit should be verified once each day before bulk specific gravity measurements are taken. Refer to the manufacturer's recommendations for the verification procedure.

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7. PROCEDURE

7.1 Dry the asphalt specimen to a constant mass (Note 2). Allow the specimen to cool to room temperature, 25 ± 5°C (77 ± 9°F). Weigh and record the dry mass of the specimen to the nearest 0.1 g. Allow the unit to initialize with the appropriate 100-mm (4-in.) or 150-mm (6-in.) sample holder in the chamber. After initialization, enter the dry mass of the asphalt specimen to the nearest 0.1 g on the keypad, and slide the sample holder out of the water. Place the specimen between the holder's rails, and slowly immerse the specimen into the chamber. Samples saturated with water shall initially be dried overnight at 52 ± 3°C (125 ± 5°F) until constant mass is reached. Recently molded laboratory samples, which have not been exposed to moisture, do not require drying.

Note 2—Specimens exposed to moisture shall initially be dried overnight in an oven at 52 ± 3°C (125 ±5°F) to constant mass. Recently molded laboratory samples which have not been exposed to moisture do not require drying.

7.2 Record the bulk specific gravity displayed on the screen of the measurement device, or export the sample data to a printer or computer.

8. REPORT

8.1 *The report shall include the following*:

8.1.1 Bulk specific gravity reported to the nearest 0.001.

9. PRECISION

9.1 Research to develop estimates for the precision of this bulk specific gravity measurement has not been completed.

Standard Method of Test for

Apparent Viscosity of Hot-Poured Bituminous Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument

AASHTO Designation: TP 85-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Apparent Viscosity of Hot-Poured Bituminous Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument

AASHTO Designation: TP 85-10

1. SCOPE

1.1 This test method outlines the procedure for measuring the apparent viscosity of hot-poured bituminous crack sealant at elevated temperature from 150 to 200ºC using a rotational viscometer.

1.2 The rotational viscometer is a rotating spindle-type viscometer that meets the requirements of T 316. This test method can be used for general specification and is especially convenient for use in a field laboratory or a plant site.

1.3 *This standard may involve hazardous material, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the application of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- T 316, Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.2 *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 4402, Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer
- D 5167, Standard Practice for Melting of Hot-Applied Joint and Crack Sealant and Filler for Evaluation
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 145, Standard Specification for Gravity-Convection and Forced-Ventilation Ovens
- E 220, Standard Test Method for Calibration of Thermocouples By Comparison Techniques

2.3 *Sealant Consortium (SC) Standards*:[1]

- SC-1, Guidelines for Graded Bituminous Sealants
- SC-2, Test Method for Measuring Apparent Viscosity of Hot-Poured Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument
- SC-3, Method for the Accelerated Aging of Bituminous Sealants
- SC-4, Sealant Flow and Deformation

- SC-5, Method to Measure Low-Temperature Sealant Flexural Creep Stiffness at Low Temperature by Bending Beam Rheometer
- SC-6, Method to Evaluate Sealant Extensibility at Low Temperature by Direct Tension Test
- SC-8, Blister Method to Predict the Adhesion of Bituminous Sealants

3. TERMINOLOGY

3.1 *hot-poured crack sealants*—hot-poured modified asphaltic materials used in pavement cracks and joints.

3.2 *apparent viscosity*—the ratio of shear stress to shear rate for a liquid. This parameter is a measure of the resistance to flow of the liquid. The SI unit of viscosity is the Pascal second (Pa·s).

4. SUMMARY OF METHOD

4.1 Crack sealant material is homogenized according to ASTM D 5167, cut into cubes no larger than 5 mm by 5 mm, and placed into standard containers. Apparent viscosity is measured utilizing the Brookfield viscometer using Spindle #SC4-27; the spindle shall be attached to the rigid hook attachment and rotates at the speed of 60 rpm. The test shall be conducted at the manufacturer's recommended installation temperature.

5. SIGNIFICANCE AND USE

5.1 This test is intended for bituminous sealants applied to roadway joints and cracks.

5.2 This procedure is designed to simulate the viscosity of crack sealants while pouring the sealant into the cracks.

5.3 Sealants must be homogenized (ASTM D 5167) before measuring the apparent viscosity by this method.

6. APPARATUS

6.1 Brookfield rotational viscometer RV Series Instrument.

6.2 *Brookfield Thermosel*—Maintaining a temperature ranging from 170 to 193°C ± 1°C.

6.3 *Laboratory Oven*—Any laboratory standard oven capable of producing and maintaining a temperature ranging from 170 to 193°C ± 1°C.

6.4 Rigid hook attachment especially designed as an attachment in Brookfield viscometer to measure hot-poured crack sealant viscosity.

6.5 Disposal aluminum containers or standard Brookfield containers.

6.6 The rotational viscometer contains sensors that monitor the applied torque and automatically displays the calculated apparent viscosity. The keypad on the instrument is used to enter the spindle number, zero the signal, and run the test at a selected speed. Torque and viscosity can be recorded manually, or an interface can be used to send the signal from the instrument to a personal computer. Optional software is also available that can be used to program preselected thermal profiles. This software is not needed for the specification test. However, the Thermosel must be used to control the temperature and thereby obtain acceptable reproducibility.

7. HAZARDS

7.1 Standard laboratory caution should be used in handling hot sealant in accordance with ASTM D 5167, and when using the Brookfield Thermosel. Required safety procedures should be followed when chemical agents are used.

8. PREPARATION OF APPARATUS

8.1 The rotational viscometer must be leveled to function properly. A bubble-type level is normally located on top of the viscometer and is adjusted by using leveling screws located on the base. Preparing the device, leveling and aligning of the viscometer on the stand, and setting the temperature of the Thermosel are explained in the operation instructions provided by the manufacturer. The detailed steps for testing are specified in the T 316.

9. CALIBRATION AND STANDARDIZATION

9.1 Temperatures of the ovens should be calibrated in accordance with each user’s quality assurance program.

9.2 Thermometer (temperature detector) should be calibrated every 6 months to ensure precision of ±1°C.

9.3 The accuracy of the viscometer should be checked annually using a certified reference fluid of known viscosity following the procedure recommended by the manufacturer.

10. PREPARATION OF SAMPLES AND TEST SPECIMENS

10.1 All apparent viscosity measurements must be performed on homogenized sealant. Sealant homogenization is conducted in accordance with the procedure presented in ASTM D 5167.

10.2 Once homogenized, hot sealant should be cooled down to room temperature and stored for 24 hours before usage. It is recommended that a can or plastic-lined box be used as a container during the cool-down period. The container must be of sufficient size so that the sealant depth is no greater than 100 mm to allow for rapid cooling.

10.3 Cut 10.5 g of the homogenized sealant into small cubes no larger than 5 mm by 5 mm, and place the cubes in aluminum chambers. Disposable chambers installed in the Thermosel shall be used.

10.4 Preheat Thermosel to test temperature and, unless otherwise noted, use the temperature recommended by the manufacturer.

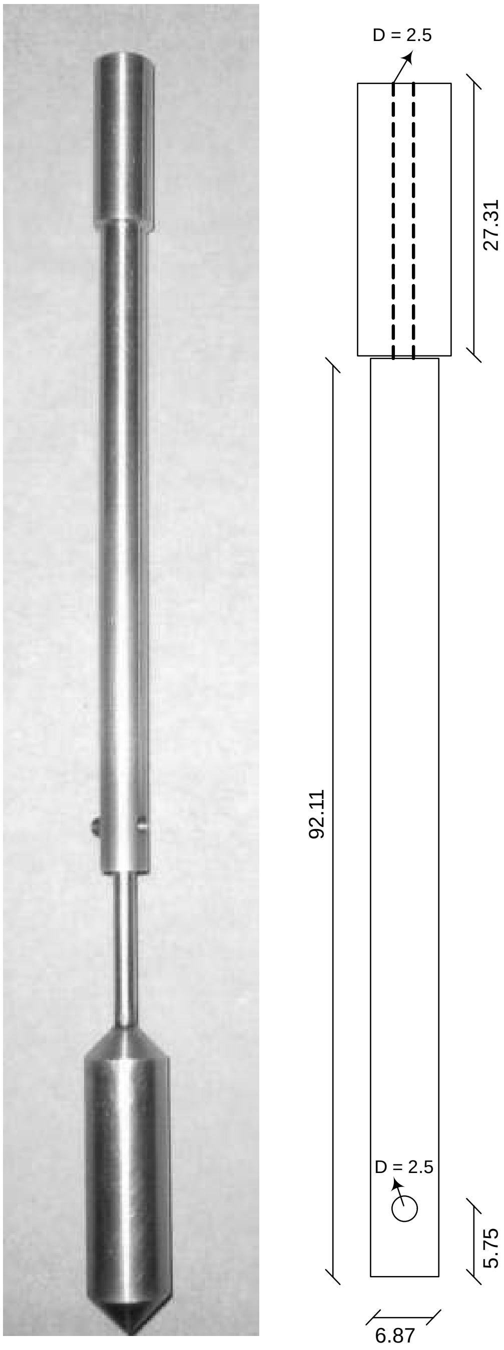
10.5 Place aluminum chamber containing sealant in Thermosel.

10.6 Turn on the viscometer and zero it.

10.7 Allow 5 minutes for sealant to melt.

10.8 Assemble spindle #SC4-27 and attach the spindle to a rigid rod (see Note 1).

Note 1—The current hook which is used for asphalt cement should not be applied to asphalt binder that contains rubber fillers, which would affect the spindle's rotation. Figures 1 through 3 illustrate the spindle and the rigid rod.



(a) (b)

Figure 1—(a) Rigid rod with Spindle Assembled, (b) Schematic of Rigid Rod

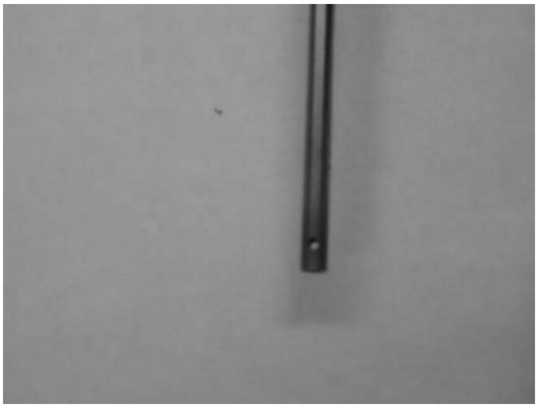


Figure 2—Lower Opening of 2.5 mm to Screw the Spindle to the Rigid Rod

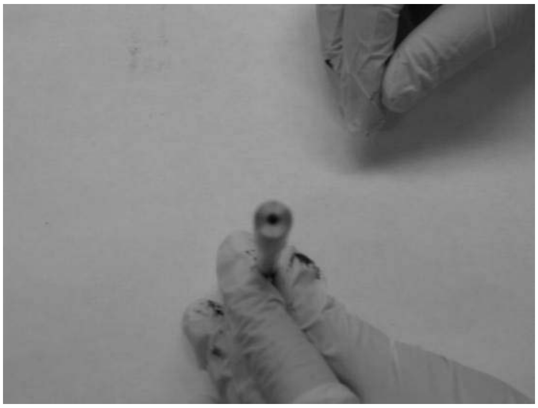


Figure 3—Upper Opening of 2.5 mm to Screw the Rod to the Viscometer Head

10.9 Allow 20 minutes to stabilize the temperature; adjust stirring speed of the spindle to 60 rpm.

10.10 Start testing and record the data right after 30 seconds of stirring. After the data are recorded, stop the test, clean the spindle, and remove the aluminum chamber.

10.11 Insert the next specimen and repeat steps 10.5 to 10.10 until four replicates are tested for each sealant.

11. CALCULATION OF RESULTS

11.1 The viscosity is reported as the average of the best three out of four readings. The Brookfield viscometer measures the apparent of viscosity in centipoise. The measured viscosity may be converted to Pascal seconds by using the conversion factor 1 cps = 0.001 Pa·s.

12. REPORT

12.1 *Report the following information*:

12.1.1 Sealant identification and supplier,

12.1.2 Lot number,

12.1.3 Date received,

12.1.4 Date of apparent viscosity measurement,

12.1.5 Recommended pouring temperature,

12.1.6 Safe heating temperature, and

12.1.7 Any deviations from test temperature.

13. PRECISION AND BIAS

13.1 *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the coefficient of variation that have been found to be appropriate for the conditions of the test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the value given Table 1, Column 3.

13.2 *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the coefficient of variation that have been found to be appropriate for the conditions of the test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as percent of their mean, exceeds the values given in Table 1, Column 3.

13.3 The rotational viscometer test is T 316. The reader is referred to the standard method for points of caution and details regarding the test method.

13.4 Viscosity data obtained with this test method are used to ensure crack sealant's apparent viscosity is low enough to fill cracks and, at the same time, high enough not to flow out of the crack. Ideally, the shear rates during the test should match the shear rates sealant experiences during installation. The rotational speed of the spindle was selected at 60 rpm to resemble field pouring conditions. Changing spindle sizes and rotational speeds affect both the shear rate and the measured apparent viscosity.

13.5 Data should be collected after a specific rotation time. Excessive mixing may cause segregation, especially in the case of a rubber-modified sealant.

13.6 Excessive heating may cause volatiles to be lost from the sample or polymer chains to be degraded, both of which lead to a reduction in measured apparent viscosity. In general, during testing, the sample should not be heated to temperatures greater than the pouring temperature recommended by the manufacturer.

Table 1—Precision Estimates

Condition	Coefficient of Variation, (1s%)[a]	Acceptable Range of Three Test Results, (d2s%)[a]
Single-Operator Precision:		
Average Viscosity (Pa·s)	1.62	5.4[b]
Multilaboratory Precision:		
Average Viscosity (Pa·s)	5.90	16.9

[a] The precision estimates given in Table 1 are based on the analysis of test results from seven sealants with a wide range of rheological properties. The data analyzed include results from seven laboratories that conducted each test in four replicates.

[b] As an example, two tests conducted on the same material yield viscosity results of 3.12, 3.05, 3.15 Pa·s, respectively. The average of these three measurements is 3.11 Pa·s. The acceptable range of results is then 5.4 percent of 3.11 or 0.17 Pa·s. As the greatest difference between each two, 0.1 is less than 0.17, the results are within the acceptable range.

14. KEYWORDS

14.1 Apparent viscosity rotational viscometer; crack; fillers; hot-poured bituminous sealant; joint.

15. REFERENCES

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15.7 Al-Qadi, I. L., E. H. Fini, H. D. Figueroa, J. F. Masson, and K. K. McGhee. Adhesion Testing Procedure for Hot-Poured Crack Sealants, Final Report. No. ICT-08-026, Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-7 and SC-8] http://ict.illinois.edu/Publications/report%20files/ICT-08-026.pdf

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[1] These standards were developed through a pooled-fund study sponsored by several AASHTO member departments, the University of Illinois, Virginia Polytechnic Institute and State University (Virginia Tech), and the National Research Council of Canada. The Sealant Consortium is the designation given to this pooled-fund study. For availability of the individual research reports, see Section 15, References.

Standard Method of Test for

Accelerated Aging of Bituminous Sealants and Fillers with a Vacuum Oven

AASHTO Designation: TP 86-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Accelerated Aging of Bituminous Sealants and Fillers with a Vacuum Oven

AASHTO Designation: TP 86-10

1. SCOPE

1.1 This method applies to bituminous crack sealants and fillers used in the construction and maintenance of roadways.

1.2 The method covers the accelerated aging of the bituminous materials by means of elevated temperatures and vacuum.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish and follow appropriate health and safety practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- D 573, Standard Test Method for Rubber—Deterioration in an Air Oven
- D 5167, Standard Practice for Melting of Hot-Applied Joint and Crack Sealant and Filler for Evaluation
- D 6521, Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 145, Standard Specification for Gravity-Convection and Forced-Ventilation Ovens

2.2 *Sealant Consortium*:[1]

- SC-1, Guidelines for Graded Bituminous Sealants
- SC-2, Test Method for Measuring Apparent Viscosity of Hot-Poured Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument
- SC-4, Sealant Flow and Deformation
- SC-5, Test Method to Measure Low-Temperature Sealant Flexural Creep Stiffness at Low Temperature by Bending Beam Rheometry
- SC-6, Test Method to Evaluate Sealant Extensibility at Low Temperature by Direct Tension Test
- SC-8, Blister Method to Predict the Adhesion of Bituminous Sealants

3. TERMINOLOGY

3.1 *bituminous sealants and fillers*—polymer- or rubber-modified bitumens most often formulated with a mineral filler.

4. SUMMARY OF METHOD

4.1 Crack sealant material is placed in a stainless steel pan and aged at 115°C for 16 hours under a vacuum of 29.9 in. of mercury.

5. SIGNIFICANCE AND USE

5.1 This procedure is designed to simulate the aging and weathering of bituminous sealants and fillers.

5.2 Materials aged with this procedure are best used to evaluate sub-zero characteristics.

5.3 For materials with different bitumen source, polymer grade, and filler types and content, there is no unique correlation between the accelerated conditions and the time of in-service weathering. The accelerated aging leads to sealant rheology typical of sealants weathered 1 to 10 years in the field.

5.4 Sealants must be remixed before being aged by this method.

6. APPARATUS

6.1 *Vacuum Oven*—Oven with a vacuum valve, a bleed valve, and a pressure gauge in inches of mercury. The oven must be capable of maintaining a vacuum of 29.9 in. of mercury and a uniform temperature of 115 ± 1°C. Refer to ASTM E 145 to verify temperature uniformity. The oven should be of a size sufficient to accommodate a minimum of eight sample pans of 6 in. on two shelves.

6.2 *Vacuum Pump*—A one or two-stage mechanical pump capable of achieving a vacuum of 99.9 percent or better in 10 minutes or less. See Note 1.

Note 1—At sea level, the achievable vacuum is 29.92 in. of mercury. See the appendix for the effect of elevation on the achievable vacuum reading.

6.3 *Laboratory Oven*—Calibrated Type IIA oven specified in ASTM E 145. This oven can produce and maintain a temperature of 180 ± 0.5°C.

6.4 *Stainless Steel Pans*—Pans of sufficient dimensions such that 30 g of melted sealant will provide a film about 2 mm thick. See Note 2.

Note 2—PAV pans, used in ASTM D 6521, work well for the purpose of Section 6.4.

7. HAZARDS

7.1 Standard laboratory caution should be used in handling and remixing hot sealant in accordance to ASTM D 5167.

8. VERIFICATION AND CALIBRATION

8.1 Temperature and vacuum control of the ovens should be calibrated according to each user's quality assurance program.

8.2 *Temperature Detector*—Verify the calibration of the temperature-sensing device to 0.1°C every 6 months.

8.3 *Vacuum Gauge*—Calibrate the vacuum gauge to an accuracy of 1percent every 6 months.

8.4 Verify that the sought temperature is obtained within 1 hour after the application of vacuum. An example is shown in Figure 1.

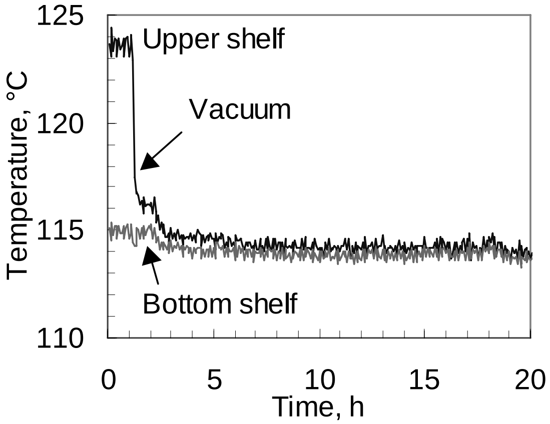

Figure 1—Typical Change in Temperature over Time at a Top and Bottom Shelf of a Vacuum Oven before and after Evacuation

9. PREPARATION

9.1 Apply vacuum and preheat the vacuum oven to 115 ± 1°C. This typically takes 2 to 4 hours.

9.2 Preheat the laboratory oven to 180 ± 5°C.

9.3 Remix 400 to 500 g of material according to ASTM D 5176. Pour 30 ± 0.5 g of hot material into a stainless steel pan. This provides a sealant film about 2 mm thick. See Note 3.

Note 3—At the same time, samples can be poured for other tests, including the tracking test (TP 85 [SC-2]), the low-temperature tests (TP xx [SC-4] and TP 87 [SC-5]), and the adhesion test (TP 88 [SC-6]).

10. PROCEDURE

10.1 Close the vacuum valve on the vacuum oven and slowly open the bleed valve. Once atmospheric pressure is reached, open the door and place the sealant pan in the oven. The oven door must be left opened for less than 1 minute. Re-apply vacuum by opening the vacuum valve. See Note 4.

Note 4—During this step, the vacuum pump must be left running.

10.2 Start timing once the vacuum has reached 29 in. of mercury. Maintain a vacuum better than 29 in. of mercury and a temperature of 115 ± 1°C for 16 hours ± 10 minutes.

10.3 After 16 hours, slowly release the vacuum with the bleed valve, and transfer the pan to the oven preheated to 180°C. Heat the sealant for 5 minutes or until it is sufficiently fluid to pour into shape for the tests according to SC-2, SC-4, SC-5, or SC-6. Pans may be scraped to collect maximum amount of sealant. See Note 5.

Note 5—Allow 24 hours at room temperature before an evaluation of the properties according to TP xx, TP 87, or TP 88 [SC-4, SC-5, or SC-6].

11. REPORT

11.1 *Report the following information*:

11.1.1 Sealant name and supplier,

11.1.2 Lot number, date received,

11.1.3 Date aged,

11.1.4 Aging temperature and vacuum,

11.1.5 Total aging time in hours and minutes, and

11.1.6 Any deviations from test temperature and vacuum.

12. PRECISION AND BIAS

12.1 The precision and the bias for this method of test have not been measured.

13. KEYWORDS

13.1 Aging; cracks; guidelines; joints; maintenance; pavement; roadways; sealant; specification.

14. REFERENCES

14.1 Al-Qadi, I. L., J. F. Masson, E. Fini, S. H. Yang, and K. K. McGhee. Development of Performance-Based Guidelines for Selection of Bituminous-Based Hot-Poured Pavement Crack Sealant: An Executive Summary Report. VTRC 09-CR7. Virginia Transportation Research Council, Charlottesville, VA, 2009. [Reference for SC-1–7] http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=09-CR7

14.2 Al-Qadi, I. L., E. H. Fini, K. K. McGhee, and M. A. Elseifi. Development of Apparent Viscosity Test for Hot-Poured Crack Sealants, Final Report. No. ICT-08-027, Illinois Center for Transportation, Rantoul, IL, December 2008(b). [Reference for SC-2] http://ict.illinois.edu/Publications/report%20files/ICT-08-027.pdf

14.3 Al-Qadi, I. L., J. F. Masson, A. Loulizi, P. Collins, J. R. Woods, S. Bundalo-Perc, and K. K. McGhee. Long-Term Accelerated Aging and Low Temperature BBR Testing of Sealants, Interim

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APPENDIX

(Nonmandatory Information)

X1. EFFECT OF ELEVATION ON THE ACHIEVABLE VACUUM READING

X1.1. The vacuum reading on the oven gauge depends on the atmospheric pressure outside the oven, which depends on elevation (excluding the effect of weather on pressure). The maximum achievable vacuum reading (P) at an elevation h is given by

$$P(h) = P_0 \exp(-mgh/kT)$$

where:

P_0 = the pressure at sea level,
m = the average molar mass of dry air,
g = the acceleration due to gravity,
k = the Boltzmann constant, and
T = the temperature in Kelvin.

X1.2. Considering a laboratory temperature of 22°C and vacuum readings in inches of mercury, the above equation can be simplified to

$$P(h) = 29.92 \exp(-hc)$$

where:

h = the elevation in ft, and
c = 0.000351 ft^{-1}.

If the elevation is taken in meters, *c* is 0.0001151 m^{-1}.

As examples, in Denver, CO, the elevation is 5433 ft and the maximum attainable vacuum is 24.7 in Hg. In Edmonton, AB, with an elevation of 650 m, the achievable vacuum is 27.8 in Hg; and in Ottawa, ON, the elevation is 188 m, so the achievable vacuum is 29.3 in Hg.

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[1] These standards were developed through a pooled-fund study sponsored by several AASHTO member departments, the University of Illinois, Virginia Polytechnic Institute and State University (Virginia Tech), and the National Research Council of Canada. The Sealant Consortium is the designation given to this pooled-fund study. For availability of the individual research reports, see Section 14, References.

Standard Method of Test for

Measure Low-Temperature Flexural Creep Stiffness of Bituminous Sealants and Fillers by Bending Beam Rheometer (BBR)

AASHTO Designation: TP 87-10

**American Association of State Highway and Transportation Officials
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Standard Method of Test for

Measure Low Temperature Flexural Creep Stiffness of Bituminous Sealants and Fillers by Bending Beam Rheometer (BBR)

AASHTO Designation: TP 87-10

1. SCOPE

1.1 This method applies to bituminous sealants used in the construction and maintenance of roadways.

1.2 The method is used to determine the bituminous sealant flexural stiffness. It can be used on unaged material or on material aged using TP 86. The test apparatus is designed for testing within the temperature range from –4 to –40°C.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 This standard covers the determination of flexural stiffness in bituminous sealants using the bending beam rheometer and by conducting the creep test.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- TP 86, Accelerated Aging of Bituminous Sealants and Fillers with a Vacuum Oven

2.2 *ASTM Standards*:

- D 5167, Standard Practice for Melting Hot-Applied Joint and Crack Sealant and Filler for Evaluation
- D 6373, Standard Specification for Performance Graded Asphalt Binder
- D 6648, Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 145, Standard Specification for Gravity-Convection and Forced-Ventilation Ovens

2.3 *Sealant Consortium (SC)*:[1]

- SC-1, Guidelines for Graded Bituminous Sealants
- SC-2, Test Method for Measuring Apparent Viscosity of Hot-Poured Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument
- SC-3, Test Method for Accelerated Aging of Bituminous Sealants

- SC-4, Sealant Flow and Deformation
- SC-5, Test Method to Measure Low-Temperature Sealant Flexural Creep Stiffness at Low Temperature by Bending Beam Rheometer
- SC-6, Test Method to Evaluate Sealant Extensibility at Low Temperature by Direct Tension Test
- SC-7, Test Method for Measuring Adhesion of Hot-Poured Crack Sealant Using Direct Adhesion Tester

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3. TERMINOLOGY

3.1 *bituminous sealants*—hot-poured modified asphaltic materials used in pavement cracks and joints.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *contact load, n*—the load, P_c, required to maintain positive contact between the test specimen, supports, and the loading shaft, 35 ± 10 mN.

3.2.2 *flexural creep compliance, D(t), n*—the ratio obtained by dividing the maximum bending strain in a beam by the maximum bending stress. The flexural creep stiffness is the inverse of the flexural creep compliance.

3.2.3 *flexural creep stiffness, S(t), n*—the creep stiffness obtained by fitting a second order polynomial to the logarithm of the measured stiffness at 8.0, 15.0, 30.0 60.0, 120.0, and 240.0 seconds and the logarithm of time.

3.2.4 *measured flexural creep stiffness,* $S_m(t)$, *n*—the ratio obtained by dividing the measured maximum bending stress by the measured maximum bending strain. Flexural creep stiffness has been used historically in asphalt technology while creep compliance is commonly used in studies of viscoelasticity.

3.2.5 *average creep rate*—the average creep rate obtained by fitting the power law model of the logarithm of the strain versus the logarithm of time. The average creep rate is the absolute value of the exponents of the power law model.

3.2.6 *test load, n*—the load, P_t, of 240 seconds duration is used to determine the stiffness of the crack sealant being tested, 980 ± 50 mN.

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4. SUMMARY OF PRACTICE

4.1 The bending beam rheometer is used to measure the midpoint deflection of a simply supported prismatic beam of bituminous crack sealant subjected to a constant load applied to the midpoint of the test specimen. The device operates only in the loading mode.

4.2 A prismatic test specimen is placed in the controlled temperature fluid bath and loaded with a constant test load for 240.0 seconds and unloaded for 480.0 seconds. The test load (980 ± 50 mN) and the midpoint deflection of the test specimen are monitored versus time using a computerized data acquisition system.

5. SIGNIFICANCE AND USE

5.1 This test is intended for bituminous sealants applied to roadway joints and cracks.

5.2 The test temperature is determined as the lowest temperature experienced by the pavement surface in the geographical area for which the sealant is intended.

5.3 The flexural creep stiffness or flexural creep compliance, determined from this test, describes the low-temperature stress-strain-time response of crack sealant at the test temperature.

5.4 The average creep rate determined from this test gives an indication of the rate of deformation of crack sealant at the test temperature.

5.5 Sealants must be homogenized before being used to conduct this test.

6. APPARATUS

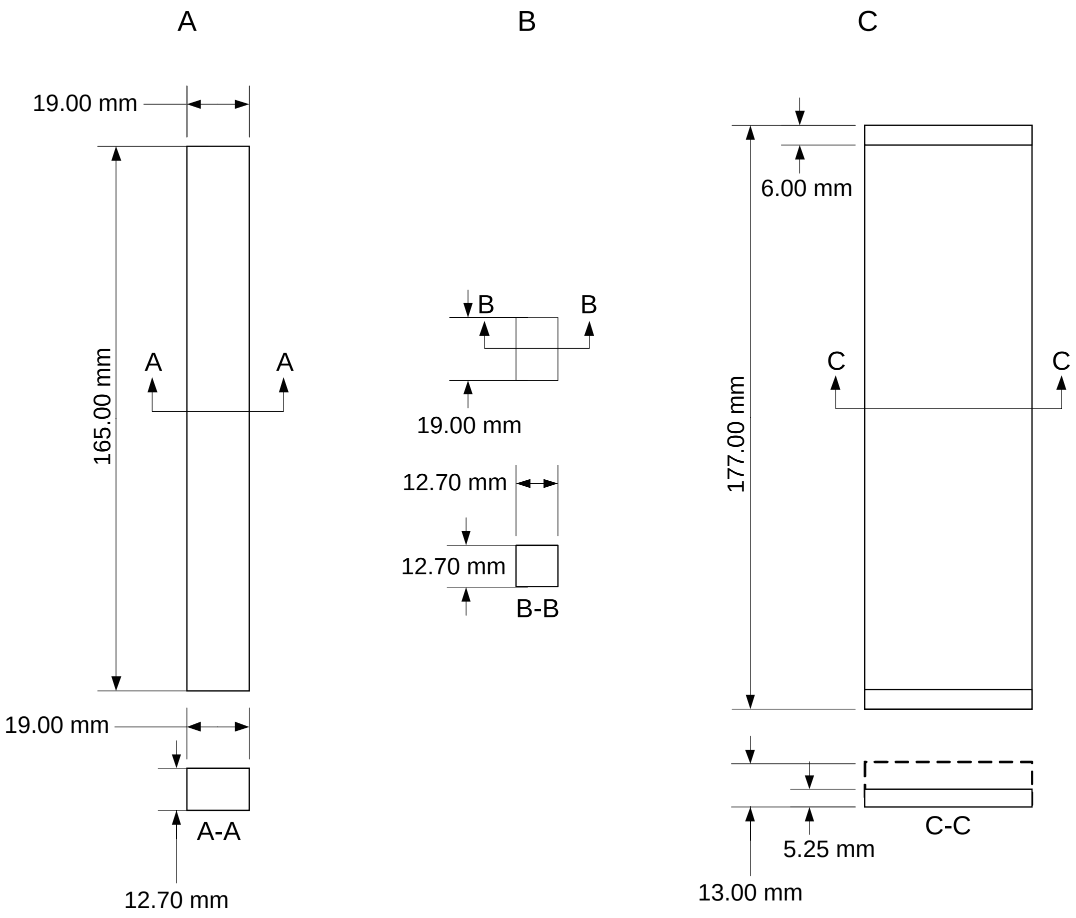
6.1 A crack sealant bending beam rheometer (CSBBR) test system consists of the following: (1) a modified bending beam rheometer with a controlled temperature liquid bath that maintains the test specimen at the test temperature, (2) test specimen molds, and (3) items for verifying and calibrating the system.

6.2 *Modified Bending Beam Rheometer*—A CSBBR is modified from a typical BBR. The CSBBR has a modified loading frame system that can accommodate a specimen 12.7 mm in height to operate a three-point bending beam test that applies a constant test load for 240.0 seconds and unloads for 480.0 seconds. The specification required by the CSBBR system is in accordance with T 313. The updated version software can be obtained from the instrument manufacturer.

6.3 *Test Specimen Molds*—Test specimen molds with interior dimensions of 12.70 ± 0.05 mm wide by 12.70 ± 0.05 mm deep by 102.0 ± 0.5 mm long and fabricated from aluminum or stainless steel (Figure 1).

6.3.1 The thickness of the two spacers used for each mold (small end pieces used in the metal molds) shall be measured with a micrometer and shall not vary from each other in thickness by more than 0.05 mm.

Note 1—Small errors in the thickness of the test specimen can have a significant effect on the calculated stiffness because the calculated stiffness is a function of the thickness, h, raised to the third power.



IT	QTY	DESCRIPTION
A	2	Side Bar
B	2	Spacer Bar
C	1	Bottom Plate

Figure 1—Dimension for Crack Sealant Bending Beam Rheometer Mold and Modified Specimen Support

6.4 *Items for Calibration*—Items remain the same as T 313 except for the thickness dimension of the stainless steel beam used for calibration. The new calibration kits can be obtained from the instrument manufacturer.

6.5 *Calibrated Thermometers*—Calibrated liquid-in-glass thermometers to verify the temperature transducer of suitable range with subdivisions of 0.1°C.

6.6 *Laboratory Ovens*—Two standard laboratory ovens capable of producing and maintaining a temperature of 200 ± 0.5°C.

7. REAGENTS AND MATERIALS

7.1 *Bath Fluid*—A bath fluid that is not absorbed by or does not affect the properties of the crack sealant being tested. The bath fluid shall be optically clear at the test temperature.

7.2 *Binder Clip*—A binder clip is used to hold the aluminum mold to maintain the size of the sample to prevent shrinkage during sealant cooling.

7.3 *Release Agent*—A proper release agent prevents bituminous crack sealant from sticking to the mold. Using a spray type silicon-based release agent is recommended.

7.4 *Solvent*—A solvent can properly clean the molds, end tabs, and plates. The parts cleaned by the solvent shall be submerged in the ethanol prior to use. Cleaning ensures the proper bond between sealant and end tabs.

7.5 *Cleaning Cloths*—Cloths for wiping molds, end tabs, and plates.

8. HAZARDS

8.1 Standard laboratory caution should be used in handling hot bituminous sealant in accordance with ASTM D 5167, and required safety procedures should be followed when chemical agents are used.

9. VERIFICATION AND CALIBRATION

9.1 *Bending Beam Rheometer (BBR)*—Follow the procedure as stated in T 313.

9.2 *Oven and Freezer*—Calibrate the temperature with a thermometer that meets the requirements of ASTM E 1. The thermometer calibration can be verified according to ASTM E 77.

10. SAMPLES PREPARATION

10.1 *Preparation of Molds*:

10.1.1 Spread a very thin layer of release agent on the interior faces of four mold sections to prevent the crack sealant from sticking to the metal end pieces. Assemble the mold and use binder clips to hold the pieces of the mold together.

10.1.2 Preheat the oven to a temperature 50°C lower than recommended pouring temperature at least 1 hour before testing. Place the mold on the ceramic tiles into the oven 15 minutes before pouring the crack sealant.

10.2 *Preparation of Test Specimens*:

10.2.1 Laboratory-aged samples shall be obtained in accordance with appropriate test methods.

10.2.2 Heat four cans of bituminous crack sealant, which contain 35 g of bituminous sealant each, in an oven set at the sealant manufacturer-recommended pouring temperature until the sealant is sufficiently fluid to pour. (Do not heat the sealant more than 30 minutes.) Each can of sealant will be poured into its own mold.

10.3 *Molding Test Specimens*—Prepare four replicates for each tested sealant. Prior to pouring the sealant, take one preheated mold and one ceramic tile from the oven. With the preheated mold on the ceramic tile, firmly stir the sealants prior to pouring into the molds to ensure the homogeneity of the sealant. Begin pouring the sealant from one end of the mold and move toward the other end, slightly overfilling the mold. When pouring, hold the sample container 20 to 30 mm from the top of the mold, pouring continuously toward the other end in a single pass. Repeat the same procedure for the other three molds. With the filled mold still on the preheated ceramic tile, allow to cool for 1 hour to room temperature. After cooling to room temperature, trim the exposed face of the cooled specimens even with the top of the mold using a hot knife.

10.4 *Storing and Demolding Test Specimens*:

10.4.1 Store all test specimens in their molds at room temperature prior to testing. Testing shall be completed within 4 hours after specimens are poured.

10.4.2 Just prior to demolding, cool the molds containing the test specimens in a cold fluid bath that has the same temperature as the selected test temperature for no longer than 5 minutes and only long enough to stiffen the test specimen so that it can be readily demolded without distortion. A 15-minute interval between each sample is desired prior to placing the sample into the cold chamber bath. Do not cool the molds containing the specimens in the test bath because it may cause temperature fluctuations in the bath to exceed ±0.2°C.

10.4.3 Immediately demold the specimen when it is sufficiently stiff to demold without distortion, by disassembling the mold. To avoid distorting the specimen, demold the specimen by sliding the metal side pieces from the specimen.

Note 2—During demolding, handle the specimen with care to prevent distortion. Full contact at specimen supports is assumed in the analysis. A warped test specimen may affect the measured stiffness.

11. PROCEDURE

11.1 All sealants to be tested must undergo the aging process. Follow the procedure described TP 86. It is recommended that a minimum of 150 g of bituminous sealant be prepared for a set of tests.

11.2 Select the appropriate test temperature for the crack sealant specimen. After demolding, immediately place the test specimen in the testing bath and condition it at the testing temperature. The test specimen shall remain submerged in the bath fluid at the test temperature ±0.1°C for the entire 60 ± 5 minutes.

11.3 Check the adjustment of the contact load and test load prior to testing each set of test specimens. The 12.7-mm thick stainless steel beam shall be used for checking the contact load and test load.

11.3.1 Place the 12.7-mm steel beam in position on the beam supports. Using the test load regulator valve, gently increase the force on the beam to 980 ± 50 mN.

11.3.2 Switch from the test load to the contact load and adjust the force on the beam to 35 ± 10 mN. Switch between the test load and contact load four times to ensure that the load is stable.

11.3.3 When switching between the test load and contact load, watch the loading shaft and platform for visible vertical movement. The loading shaft shall maintain contact with the steel beam when switching between the contact load and test load, and the contact load and test load shall be maintained at 35 ± 10 mN and 980 ± 50 mN, respectively.

11.4 Enter the specimen identification information, including the elapsed time the specimen has been conditioned in bath at the test temperature, and other information, as appropriate, into the computer that controls the test system.

11.5 After conditioning, place the test specimen on the test supports and gently position the back side of the test specimen against the alignment pins. Initiate the test.

11.6 The bath temperature shall be maintained at the selected test temperature ±0.1°C during the test; otherwise the test shall be rejected.

11.7 The contact load shall be applied by gently increasing the load to 35 ± 10 mN. While applying the contact load, the load on the beam shall not exceed 45 mN, and the time to apply and adjust the contact load shall be no greater than 10 seconds.

11.8 With the contact load applied to the test specimen, activate the automatic test system, which is programmed to proceed as follows:

11.8.1 Apply a 980 ± 50 mN seating load for 1 ± 0.1 seconds.

11.8.2 Reduce the load to the 35 ± 10 mN contact load, and allow the test specimen to recover for 480 ± 0.1 seconds. At the end of the test, the operator shall monitor the computer screen to verify that the load on the test specimen returns to 35 ± 10 mN. If it does not, the test shall be rejected.

11.8.3 Apply a 980 ± 50 mN test load to the test specimen. The software shall record the test load at 0.5-second intervals from 0.5 to 240 seconds and calculate the average of the recorded load values. Between 0.5 and 5 seconds, the test load shall be within ±50 mN of the average test load and, for the remaining times, within ±10 mN of the average test load. The actual load on the test specimen as measured by the load cell shall be used to calculate the stress in the test specimen.

11.8.4 Remove the test load, return to the 35 ± 10 mN contact load, and collect the data for 480 seconds.

11.8.5 Remove the specimen from the supports and proceed to the next test.

12. CALCULATIONS

12.1 *Deflection of an Elastic Beam*—Using the elementary bending theory, the midspan deflection of an elastic prismatic beam of constant cross section loaded in three-point loading can be obtained by applying Equations 1 and 2 as follows:

$$\delta = PL^3/48EI \qquad (1)$$

where:

δ = deflection of beam at midspan, mm;

P = load applied, N;

L = span length, mm;

E = modulus of elasticity, MPa; and

I = moment of inertia, mm^4.

and

$I = bh^3/12$ *(2)*

where:

b = width of beam, mm; and

h = thickness of beam, mm.

Note 3—The test specimen has a span-to-depth ratio of 10 to 1, and the contribution of shear to deflection of the beam can be neglected.

12.2 *Elastic Flexural Modulus*—According to elastic theory, calculates the flexural modulus of a prismatic beam of constant cross section loaded at its midspan. Therefore:

$E = PL^3/4bh^{3\delta}$ *(3)*

where:

E = flexural creep stiffness, MPa;

P = load, N;

L = span length, mm;

b = width of beam, mm;

h = depth of beam, mm; and

δ = deflection of beam, mm.

12.3 *Maximum Bending Stress*—The maximum bending stress occurs at the top and bottom of the beam at its midspan. Therefore:

$\sigma = 3PL/2bh^2$ *(4)*

where:

σ = maximum bending stress in beam, MPa;

P = constant load, N;

L = span length, mm;

b = width of beam, mm; and

h = depth of beam, mm.

12.4 *Maximum Bending Strain*—The maximum bending strain in the beam occurs at the top and bottom of the beam at its midspan. Therefore:

$\in = 6\delta h/L^2$ mm/mm *(5)*

where:

$\in$ = maximum bending strain in beam, mm/mm;

δ = deflection of beam, mm;

h = thickness of beam, mm; and

L = span length, mm.

12.5 *Linear Viscoelastic Stiffness Modulus*—According to the elastic-viscoelastic correspondence principle, it can be assumed that if a linear viscoelastic beam is subjected to a constant load applied at $t = 0$ and held constant, the stress distribution in the beam would be the same as that in a linear elastic beam under the same load. Further, the strains and displacements depend on time and are derived from those of the elastic case by replacing E with $1/D(t)$. Since $1/D(t)$ is numerically equivalent to $S(t)$, rearranging the elastic solution results in the following relationship for stiffness:

$$S(t) = PL^3/4bh^3\delta(t) \qquad (6)$$

where:

$S(t)$ = time-dependent flexural creep stiffness, MPa;
P = constant load, N;
L = span length, mm;
b = width of beam, mm;
h = depth of beam, mm;
$\delta(t)$ = deflection of beam, at time t, mm; and

$\delta(t)$ and $S(t)$ indicate that the deflection and stiffness, respectively, are functions of time.

13. REPORT

13.1 *Report the following information*:

13.1.1 Sealant name and supplier;

13.1.2 Test sample ID;

13.1.3 Date of aging (dd/mm/yy);

13.1.4 Date of test (dd/mm/yy);

13.1.5 Time of demolding (hour, minute);

13.1.6 Time of conditioning (hour, minute);

13.1.7 Time test load applied for each sample (hour, minute);

13.1.8 Test temperature;

13.1.9 Maximum and minimum temperature during the test;

13.1.10 Any deviations from test load and temperature;

13.1.11 Measured stiffness modulus; and

13.1.12 Average creep rate.

14. PRECISION AND BIAS

14.1 Confidence intervals of 95 percent should be constructed around the average of the calculated stiffness from the results of the four replicates. The closest three measurements will then be used to calculate the coefficient of variation while the fourth replicate will be discarded. A coefficient of variation less than 10 percent is desirable.

15. KEYWORDS

15.1 Average creep rate; crack; creep compliance; direct tension test; hot-poured bituminous sealant; joint; stiffness.

16. REFERENCES

16.1 Al-Qadi, I. L., J. F. Masson, E. Fini, S. H. Yang, and K. K. McGhee. Development of Performance-Based Guidelines for Selection of Bituminous-Based Hot-Poured Pavement Crack Sealant: An Executive Summary Report. VTRC 09-CR7. Virginia Transportation Research Council, Charlottesville, VA, 2009. [Reference for SC-1–7] http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=09-CR7

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1. SCOPE

1.1 This test method applies to bituminous sealants used in the construction and maintenance of roadways.

1.2 The test method is used to determine the extensibility and strain energy density (SED) of sealants at low temperature. It can be used with un-aged material or with material aged using TP 86. The test apparatus is designed for testing within the temperature range from –4 to –40°C.

1.3 This standard covers the determination of extensibility and percent modulus decay in bituminous sealants with the use of direct tension testing and by applying the tensile stress-strain test.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- TP 86, Accelerated Aging of Bituminous Sealants and Fillers with a Vacuum Oven

2.2 *ASTM Standards*:

- D 5167, Standard Practice for Melting Hot-Applied Joint and Crack Sealant and Filler for Evaluation
- D 6373, Standard Specification for Performance Graded Asphalt Binder
- D 6723, Standard Test Method for Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 77, Standard Test Method for Inspection and Verification of Thermometers
- E 145, Standard Specification for Gravity-Convection and Forced-Ventilation Ovens

2.3 *Sealant Consortium (SC)*:[1]

- SC-1, Guidelines for Graded Bituminous Sealants
- SC-2, Test Method for Measuring Apparent Viscosity of Hot-Poured Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument
- SC-3, Method for the Accelerated Aging of Bituminous Sealants
- SC-4, Sealant Flow and Deformation

- SC-5, Method to Measure Low-Temperature Sealant Flexural Creep Stiffness at Low Temperature by Bending Beam Rheometer
- SC-6, Method to Evaluate Sealant Extensibility at Low Temperature by Direct Tension Test
- SC-7, Test Method for Measuring Adhesion of Hot-Poured Crack Sealant Using Direct Adhesion Tester

2.4 *Other Documents*:

- Dowling, N. E. *Mechanical Behavior of Materials*, Second Edition. Prentice Hall, Upper Saddle River, NJ, 1999.

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3. TERMINOLOGY

3.1 *bituminous sealants*—hot-poured modified asphaltic materials used in pavement cracks and joints.

3.2 *effective gauge length*—elongation of a standard dog bone-shaped test specimen due to an applied axial load P is equivalent to that of a simple rectangular specimen with the same cross-sectional dimensions of the restricted section. Effective gauge length, L_e, is defined as the length of the simple rectangular specimen and has been determined to be 20.3 mm.

3.3 *tensile stress*—tensile load divided by the true area of cross section of the specimen.

3.4 *tensile strain*—change in the effective gauge length by the application of tensile load divided by the original unloaded effective gauge length.

3.5 *brittle material*—the stress-strain curve is linear up to fracture at about 1 to 2 percent elongation.

3.6 *brittle-ductile material*—the stress-strain curve is curvilinear and the stress is gradually reduced after the peak point. The failure happens by gradually breaking the molecular bond within the material.

3.7 *ductile material*—the material does not rupture in the direct tension test but elongates due to high strain.

3.8 *rubbery behavior*—materials that exhibit rubbery behavior can be stretched to extreme elongation without rupture.

3.9 *percent modulus decay*—the percentage modulus deduction after 10 seconds of loading.

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4. SUMMARY OF PRACTICE

4.1 This practice contains the procedure to measure the extensibility and the strain energy density of a bituminous sealant or filler using direct tension test (DTT). The material is bonded between two end tabs made of Plexiglas and subjected to a constant strain rate at a specific temperature.

4.2 The test method is developed to select the bituminous sealant at temperatures where they exhibit rubbery behavior.

4.3 A linear variable differential transformer (LVDT) is used to measure the elongation of the test specimen as it is pulled in tension at a constant strain rate of 6 percent/minute (1.2 mm/minute). A load cell is used to monitor the load during the test. The stress and strain at the point of rupture or peak load are reported.

5. SIGNIFICANCE AND USE

5.1 This test is intended for bituminous sealants applied to roadway joints and cracks.

5.2 The test temperature is determined to be the lowest temperature experienced by the pavement surface in the geographical area for which the sealant is intended.

5.3 The sealant extensibility is a parameter of the capacity of sealant to sustain large deformations due to crack expansion at low temperature without fracture.

5.4 The percent modulus decay is an indication of how fast the sealant can release the imposed loading. A higher percentage decay represents that the sealant can relax the load faster.

5.5 This method is intended for aged sealants, which could become stiffer or softer with age.

6. APPARATUS

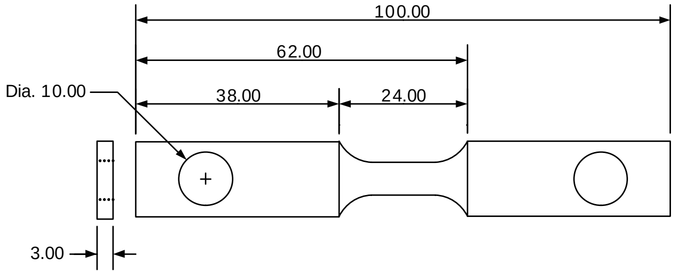
6.1 *Direct Tension Test (DTT) Device*—The DTT system consists of two metal grips to hold the specimen, an environment chamber, a loading device, and a control and data acquisition system. The instrument must meet the requirements stated in T 314.

6.2 *Specimen End Tabs and Gripping System*—End tabs made from Plexiglas material having dimensions as described in Figure 1 that shall be bonded to both ends of the test specimen to transfer the tensile load to the sealant. The manufacturing requirement of the end tabs and the gripping system shall meet the requirement in T 314.

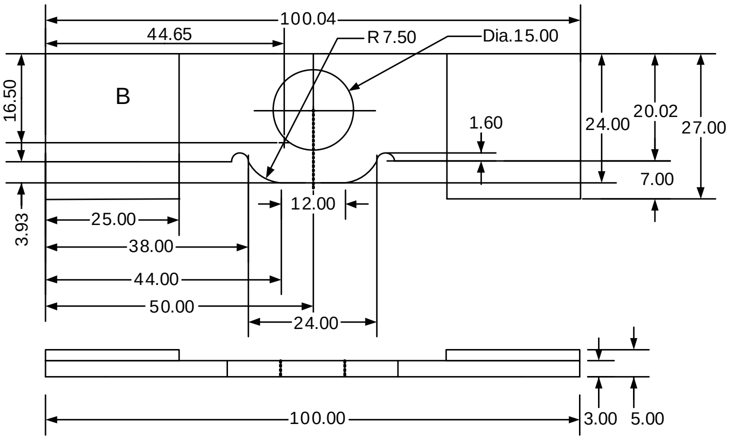
6.3 *Chiller and Test Chamber*—A calibrated circulated temperature control system shall have temperature range from –4 to –40°C. The insulated test chamber shall be capable of maintaining a temperature of ± 0.1°C.

6.4 *Specimen Molds*—The specimen molds should be made from aluminum. Molds shall have dimension as specified in Figure 1. A silicon-based release agent as described later in Section 7.2 shall be used to prevent sealant from adhering to the aluminum molds.

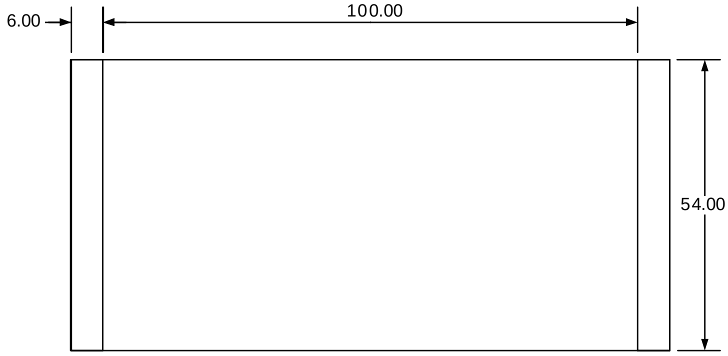
6.5 *Laboratory Ovens*—Two forced-air convection ovens capable of producing, reaching, and maintaining a temperature of 200 ± 0.5°C for heating sealant and molds.



End Insert



Mold Half



Mold Base

Figure 1—Dimension for DTT, End Insert, and Mold

7. REAGENTS AND MATERIALS

7.1 *Fluid for Test Chamber*—A fluid that is not absorbed by or does not affect the properties of the crack sealant being tested. The bath fluid shall be optically clear at the test temperature. Ethyl alcohol is suggested to use as a fluid for temperature control. The aqueous mixture of potassium acetate and deionized water used in T 314 has been found to form turbid solution at temperature of –40°C.

7.2 *Release Agent*—A proper release agent to prevent crack sealant sticking to the mold. A silicon-based released agent is recommended.

7.3 *Solvent*—A solvent can properly clean the molds, end tabs, and plates. The parts cleaned by the solvent shall be submerged in the ethyl alcohol prior to use. This ensures the proper bond between sealant and end tabs.

7.4 *Cleaning Cloths*—Cloths for wiping molds, end tabs, and plates.

8. HAZARDS

8.1 Standard laboratory caution should be used in handling hot sealant in accordance to ASTM D 5167, and required safety procedures should be followed when chemical agents are used.

9. VERIFICATION AND CALIBRATION

9.1 *DTT*—Follow the procedure as stated in T 314.

9.2 *Oven and Freezer*—Calibrate the temperature with a thermometer that meets the requirements of ASTM E 1. The thermometer calibration can be verified according to ASTM E 77.

10. SAMPLES PREPARATION

10.1 Sample and prepare sealant according to ASTM D 5167. See Note 1.

Note 1—It is advantageous to sample about 500 g of sealant and sequentially pour specimens for all the tests, including the aging test (SC-3), the low-temperature tests (SC-4 and SC-5), and the adhesion test (SC-6).

10.2 Anneal the sealant from which the test specimen is obtained by heating for 30 minutes. After 15 minutes, place the sealant in the oven, remove the sealant from the oven shortly, and stir the sealant by spatula to prevent segregation.

10.3 Follow the procedure in Sections 9.2 to 9.6 of T 314 with the following modification. See Notes 2 and 3.

Note 2—If spray-type silicon-based release agent is used, start from one side of the mold and slowly move toward the other side. Only one spray should be applied to the mold.

Note 3—Place the molds and end tab assembly on top of a ceramic tile heated to 50°C lower than sealant pouring temperature. The ceramic tile should be placed in the preheated oven for 15 minutes.

11. CONDITIONING

11.1 Follow the procedure as stated in T 314.

12. PROCEDURE

12.1 Bring the DTT chamber to the test temperature (see Note 4).

Note 4—Select test temperatures in accordance with the material specification, e.g., SC-1, ASTM D 6373-99.

12.2 Prepare four test specimens according to Section 10.

12.3 Follow the procedure in Sections 12.2 to 12.3 of T 314 with the modifications in Notes 5 and 6.

Note 5—Adjust the load frame to allow 20-mm traveling distance; then place the specimen on the loading pin. Remove the slack between the specimen and the loading pins.

Note 6—Manually adjust the thumb wheel on the control box to apply tension in the specimen until a load of 1 ± 0.5 N is shown on the screen. Then calibrate the stroke and load back to zero.

12.4 Set the strain rate to 6 percent/minute (1.2 mm/minute) and start the test.

12.5 After the specimen fractures, degradation is observed, or maximum traveling distance is reached (whichever comes first), stop the test and remove the specimen from the loading frame.

12.6 *The extensibility is identified as follows*:

12.6.1 When the specimen fractures (breaks into two pieces), the extensibility is easily identified as the strain at peak load (maximum stress).

12.6.2 When the specimen does not fracture, but reaches a maximum stress and then flows without fracture, the extensibility is recorded as the strain corresponding to the maximum stress.

12.6.3 When the specimen does not fracture or load reduction is not observed, the extensibility is recorded as the strain at the end of the traveling distance.

12.7 Repeat steps 12.3 to 12.6 for the remaining three specimens.

12.8 After testing is complete, discard the bituminous portions of the spent specimens and clean the end tabs by soaking them in solvent and wiping with a soft cloth. After wiping the end tabs, use a detergent soap solution to remove any oil film residue left by the cleaner material. Alternatively, use a degreasing spray cleaner. Clean the end tabs thoroughly. A grease film on the sealant bonding area can create a weak bond causing bond failures.

13. CALCULATIONS

13.1 For each test result, calculate the engineering stress-strain:

$$\sigma_f = \frac{P_f}{A_0} \quad (1)$$

$$\varepsilon_f = \frac{\Delta L_f}{L_e} \quad (2)$$

where:

σ_f = peak stress;

P_f = measured load at peak;

A_0 = original cross-sectional area (= 18 mm^2);

ε_f = measured strain at peak load;

ΔL_f = measured elongation at failure (ΔL); and

L_e = effective gauge length (= 20.3 mm).

13.2 For each test result, calculate the true stress-strain:

$$\tilde{\varepsilon} = \frac{\Delta L_f}{L_0} \tag{3}$$

$$\tilde{\sigma} = \frac{P_f}{A_i} + \frac{P \times e^{(\dot{\varepsilon} t)}}{A_0} \tag{4}$$

where:

$\tilde{\varepsilon}$ = true strain;

ΔL_f = measured elongation at failure (ΔL); and

L_0 = effective gauge length (= 20.3 mm).

$\tilde{\sigma}$ = true stress;

P_f = measured load at peak;

$\dot{\varepsilon}$ = strain rate; and

A_0 = original cross-sectional area (= 18 mm^2).

13.3 The extensibility is identified as $\tilde{\varepsilon}$.

13.4 Select the three test results that give the best coefficient of variation of the extensibility. Calculate the mean and standard deviation for SED from the selected three test results.

13.5 *Calculate the percent modulus decay*:

13.5.1 From the Boltzman superposition principle, the stress-strain relationship for a viscoelastic material can be expressed as Equation 5.

$$\sigma(t) = \int_0^t E(t - t') \frac{d\varepsilon(t')}{dt'} dt' \tag{5}$$

where:

$\sigma(t)$ = stress history;

$E(t)$ = the relaxation modulus; and

$\varepsilon(t)$ = strain history.

13.5.2 The Prony series (generalized Kelvin model) is used to describe the viscoelastic behavior of hot-poured crack sealants as presented in Equation 6.

$$E(t) = E_0 - \sum_{i=1}^{K} E_i \left(1 - e^{-t/\tau_i}\right) \tag{6}$$

where:

$E(t)$ = the relaxation modulus at time t,

E_i = material constants, and

τ_i = retardation times.

13.5.3 Substituting Equation 6 into Equation 5, the expression of the stress becomes:

$$\sigma(t) = E_0\varepsilon(t) - \int_0^t \sum_i^N E_i \left(1 - e^{\frac{-(t-t')}{\tau_i}}\right) \frac{d\varepsilon(t')}{dt'} dt' \qquad (7)$$

13.5.4 In the DT test, sealant is subjected to a constant strain rate beginning at time zero, $\varepsilon(t) = \begin{Bmatrix} 0 \text{ for } t < 0 \\ \\ \dot{\varepsilon}t \text{ for } t \ \geq \ 0 \end{Bmatrix}$, with $\dot{\varepsilon}$ as the strain rate. The above convolution integral can then be solved as follows:

$$\sigma(t) = E_0\varepsilon(t) - \sum_i^N E_i R \left[t - \tau_i \left(1 - e^{\frac{-t}{\tau_i}}\right)\right] \qquad (8)$$

13.5.5 The equation is used to fit the experimental data by means of the nonlinear least squares (NLS) technique to obtain the material constants E_0, E_i, and τ_i.

13.6 The percent modulus reduction after 10 seconds of loading is calculated as follows:

$$M_{10} = \frac{E(10) - E(0)}{E(0)} \times 100 \qquad (9)$$

14. REPORT

14.1 *Report the following information about the material*:

14.1.1 Sealant name and supplier,

14.1.2 Lot number,

14.1.3 Date received, and

14.1.4 Date sampled according to ASTM D 5167.

14.2 *Report the following information about the test procedure*:

14.2.1 Date and time of test,

14.2.2 Test temperature,

14.2.3 Rate of elongation,

14.2.4 Average extensibility,

14.2.5 Average SED and their standard deviation,

14.2.6 Peak load, and

14.2.7 Type of fracture (fracture or no fracture).

15. PRECISION AND BIAS

15.1 Confidence intervals of 95 percent should be constructed around the average of the calculated extensibility from the results of the four replicates. The closest three measurements will then be used to calculate the coefficient of variation while the fourth replicate will be discarded. A coefficient of variation less than 15 percent is desirable.

16. KEYWORDS

16.1 Crack; direct tension test; extensibility; hot-poured bituminous sealant; joint; low temperature; pavement maintenance; strain energy density.

17. REFERENCES

17.1 Al-Qadi, I. L., J. F. Masson, E. Fini, S. H. Yang, and K. K. McGhee. Development of Performance-Based Guidelines for Selection of Bituminous-Based Hot-Poured Pavement Crack Sealant: An Executive Summary Report. VTRC 09-CR7. Virginia Transportation Research Council, Charlottesville, VA, 2009. [Reference for SC-1–7]
http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=09-CR7

17.2 Al-Qadi, I. L., E. H. Fini, K. K. McGhee, and M. A. Elseifi. Development of Apparent Viscosity Test for Hot-Poured Crack Sealants, Final Report. No. ICT-08-027, Illinois Center for Transportation, Rantoul, IL, December 2008(b). [Reference for SC-2]
http://ict.illinois.edu/Publications/report%20files/ICT-08-027.pdf

17.3 Al-Qadi, I. L., J. F. Masson, A. Loulizi, P. Collins, J. R. Woods, S. Bundalo-Perc, and K. K. McGhee. Long-Term Accelerated Aging and Low Temperature BBR Testing of Sealants, Interim Report No. B5508-5, National Research Council of Canada, 2004, 262 pp. [Reference for SC-3 – printed document only]

17.4 Collins, P., M. Veitch, J. F. Masson, and I. L. Al-Qadi. Deformation and Tracking of Bituminous Sealants in Summer Temperatures: Pseudo-Field Behavior. International Journal of Pavement Engineering, Vol. 9, No. 1, 2008, pp. 1–8. [Reference for SC-4]

17.5 Al-Qadi, I. L., S. H. Yang, M. A. Elseifi, S. Dessouky, A. Loulizi, J. F. Masson, and K. K. McGhee. Characterization of Low Temperature Creep Properties of Crack Sealants Using Bending Beam Rheometry, Final Report. No. ICT-08-029, Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-5]
http://ict.illinois.edu/Publications/report%20files/ICT-08-029.pdf

17.6 Al-Qadi, I. L., S. H. Yang, J. F. Masson, and K. K. McGhee. Characterization of Low Temperature Mechanical Properties of Crack Sealants Utilizing Direct Tension Test, Final Report.

No. ICT-08-028, Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-6] http://ict.illinois.edu/Publications/report%20files/ICT-08-028.pdf

17.7 Al-Qadi, I. L., E. H. Fini, H. D. Figueroa, J. F. Masson, and K. K. McGhee. Adhesion Testing Procedure for Hot-Poured Crack Sealants, Final Report. No. ICT-08-026, Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-7 and SC-8] http://ict.illinois.edu/Publications/report%20files/ICT-08-026.pdf

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[1] These standards were developed through a pooled-fund study sponsored by several AASHTO member departments, the University of Illinois, Virginia Polytechnic Institute and State University (Virginia Tech), and the National Research Council of Canada. The Sealant Consortium is the designation given to this pooled-fund study. For availability of the individual research reports, see Section 17, References.

Standard Method of Test for

Measuring Adhesion of Hot-Poured Crack Sealant Using Direct Adhesion Tester

AASHTO Designation: TP 89-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Measuring Adhesion of Hot-Poured Crack Sealant Using Direct Adhesion Tester

AASHTO Designation: TP 89-10

1. SCOPE

1.1 The direct adhesion test is used to determine the adhesion strength of hot-poured crack sealant at the application temperatures.

1.2 The adhesion test is a test of fracture. The object of the test is to apply tensile forces to the interface between sealant and aluminum end pieces. Sealant is confined between two half-cylindrical aluminum end pieces. The applied force and displacement can be recorded as functions of time. Energy required to break the bond can be calculated by measuring the area under the load-displacement curve. This energy can be considered a measure of bonding. In addition, the maximum force to failure can be reported as adhesion strength.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish and follow appropriate health and safety practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D 5167, Standard Practice for Melting Hot-Applied Joint and Crack Sealant and Filler for Evaluation
- D 5329, Standard Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements
- D 6690, Standard Specification for Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques

2.2 *Sealant Consortium (SC) Standards*:[1]

- SC-1, Guidelines for Graded Bituminous Sealants
- SC-2, Test Method for Measuring Apparent Viscosity of Hot-Poured Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument
- SC-3, Test Method for Accelerated Aging of Bituminous Sealants and Fillers with a Vacuum Oven

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- SC-7, Test Method for Measuring Adhesion of Hot-Poured Crack Sealant Using Direct Adhesion Tester

3. TERMINOLOGY

3.1 *hot-poured crack sealants*—hot-poured modified asphaltic materials used in pavement cracks and joints.

3.2 *adhesion*—the maximum force and energy required to separate bituminous sealant from a standard substrate.

4. SUMMARY OF METHOD

4.1 Crack sealant material is homogenized, following the procedure given in ASTM D 5176. For each test including four replicates, cut 40 g of sealant and heat to the manufacturer's recommended pouring temperature. Sealant will be poured in the mold placed between the two half-cylindrical aluminum end pieces. The mold confines the sealant at the bottom and between the two aluminum end pieces at the sides.

5. SIGNIFICANCE AND USE

5.1 This procedure is designed to measure the adhesion of hot-poured sealant to aggregate.

5.2 Sealants must be re-homogenized (ASTM D 5176) before measuring the adhesion by this method.

6. APPARATUS

6.1 Modified Direct Tension Tester (DTT) machine;

6.2 Chiller that can reach –40 ± 0.5°C;

6.3 *Laboratory Oven*—Any standard laboratory oven capable of producing and maintaining temperature ranging from 170 to 193°C ± 0.5°C;

6.4 Release Agent; and

6.5 Four test setups, four molds, and a rubber band.

7. HAZARDS

7.1 Standard laboratory caution should be used in handling hot sealant in accordance to ASTM D 5167, and when using the Direct Tension Tester (DTT). Required safety procedures should be followed when chemical agents are used.

8. PREPARATION OF APPARATUS

8.1 The DTT bath must be adjusted to specific temperature. The sitting posts must be leveled to function properly.

9. CALIBRATION AND STANDARDIZATION

9.1 Temperature of the ovens should be calibrated according to each user's quality assurance program.

9.2 Temperature of the chiller should be calibrated according to each user's quality assurance program.

9.3 *Thermometer (temperature detector)*—Verify the calibration of the temperature-sensing device to ±0.1°C every 6 months.

10. PREPARATION OF SAMPLES AND TEST SPECIMENS

10.1 All adhesion strength measurements must be performed on re-homogenized sealant. Follow the procedure for homogenization given in ASTM D 5176. It is recommended that a minimum of 400 g of sealant be homogenized.

10.2 Once homogenized, hot sealant should be molded, cooled, and stored for later use. To store the sealant, it is recommended that a can or plastic-lined box be used as a container. The mold must be of sufficient size that the sealant depth is no greater than 100 mm to allow for rapid cooling.

10.3 Adjust the oven's temperature to recommended pouring temperature for sealant being tested.

10.4 Turn on the DTT machine, load the program, and cool the chiller to test temperature.

10.5 Place a half cylinder of aluminum end piece in each grip and tighten it.

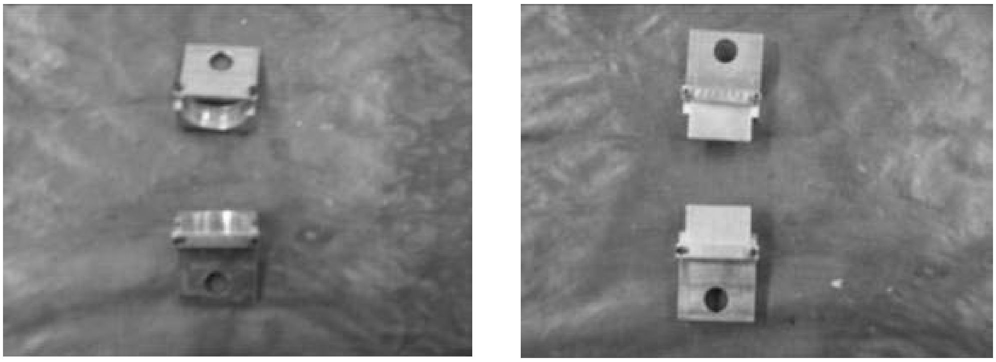

Figure 1—Place Each End Piece in One Grip and Tighten It

Figure 2—Spray Release Agent on the Mold

10.6 Assemble the setup, which is composed of an aluminum end piece on each side and an aluminum mold in between. Wrap a rubber band around the setup to keep all the components in place.

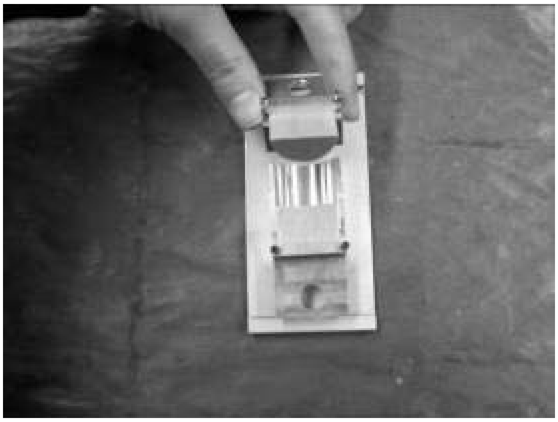

Figure 3—Place Two End Pieces on the Mold

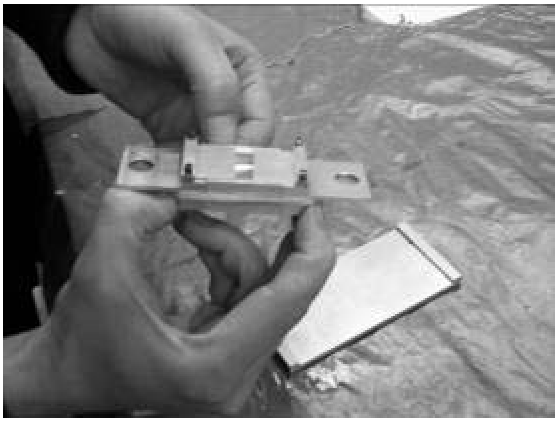

Figure 4—Using a Rubber Band, Hold the Assembly in Place

10.7 Place the notch on the edge of one of the aluminum end piece.

10.8 Prepare a can of sealant by cutting 35 g of homogenized sealant for each set of four samples.

10.9 Place the can in the oven for 15 minutes, remove it from the oven, stir the sealant thoroughly, and place it back in the oven for another 15 minutes.

Figure 5—Heat 35 g of Homogenized Sealant at Recommended Pouring Temperature for 30 minutes.

10.10 Remove the can from the oven, stir the sealant thoroughly, and pour into all the assembled setups. Use four replicates for each sealant. Care should be taken in filling up the molds to prevent any trapped air bubbles in the sample.

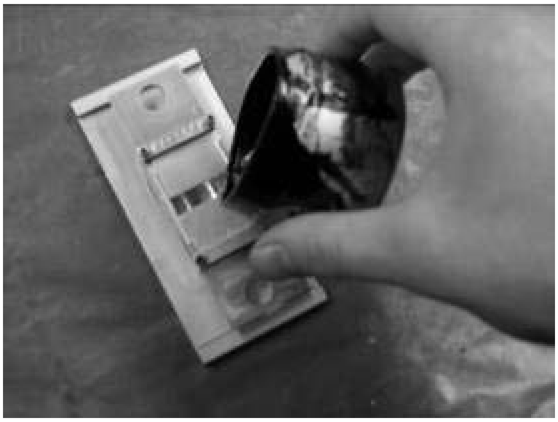

Figure 6—Remove the Sealant from the Oven, Mix Thoroughly, and Pour It in the Mold from One Corner

10.11 Let samples set 1 hour at room temperature.

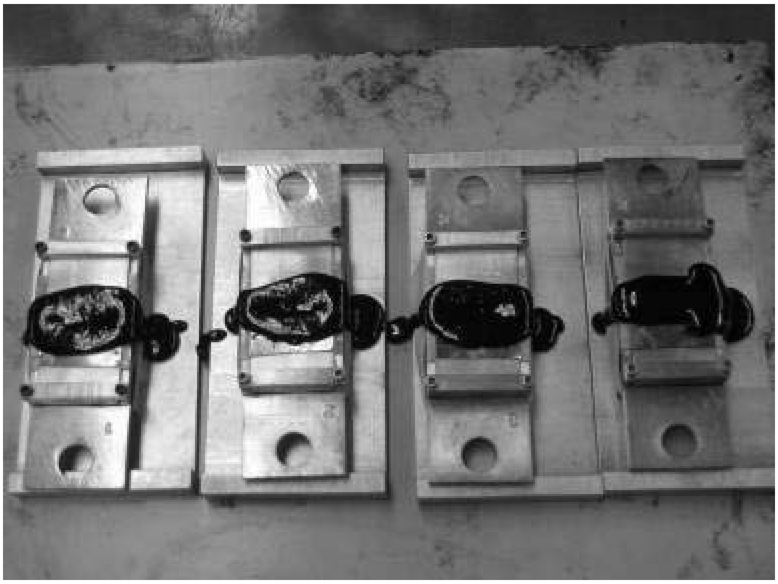

Figure 7—Let Sealant Set for 1 Hour at Room Temperature

10.12 Trim the excessive sealant away with a hot spatula. Move spatula once over and parallel to the interface of the sample; trimming direction shall not be changed during trimming. Use well-heated spatula to prevent any shearing of the sealant.

Figure 8—Trim the Extra Sealant Away Using a Heated Spatula

10.13 Use two tongs to grab the plate underneath the specimen, and place the specimens in the cooling bath.

Figure 9—Grab the Base Plate with Two Tongs, and Place It in Cooling Bath

10.14 Remove the plates underneath each specimen, and leave specimens in the bath for 15 minutes.

Figure 10—Remove the Base Plates

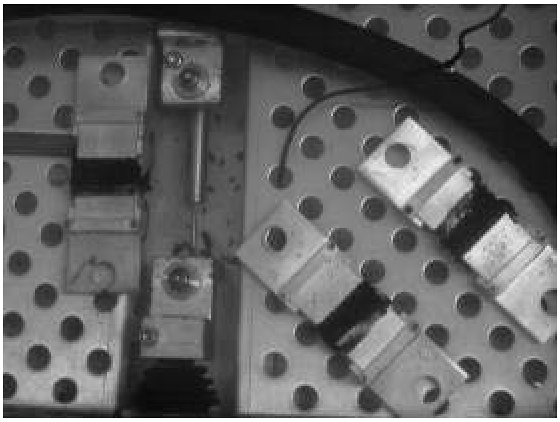

Figure 11—Leave the Specimens in Cooling Bath for 15 minutes.

10.15 Remove one specimen at a time from the bath; place it on a flat surface.

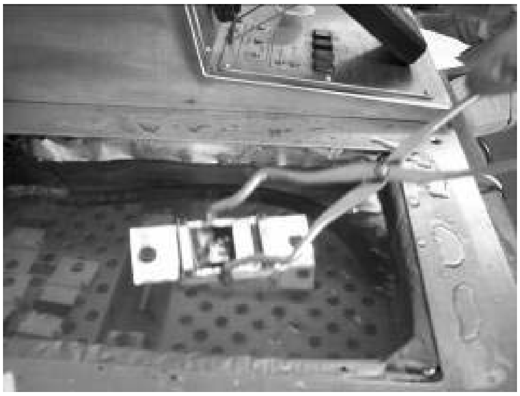

Figure 12—Holding Its Center with Tongs, Remove One Specimen at a Time

10.16 Flip the specimen, remove the rubber band, and keep the two end pieces in place using the index fingers. Remove the mold with your thumb.

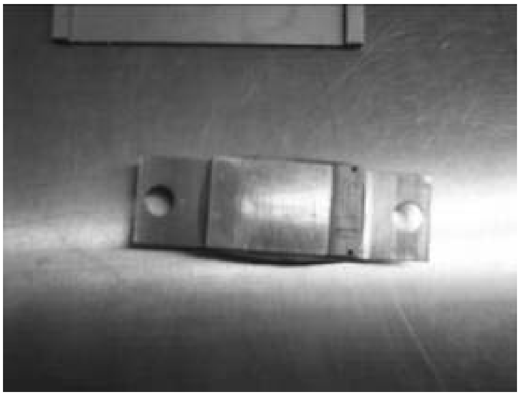

Figure 13—Flip the Specimen on a Flat Surface

Figure 14—Remove the Rubber Band

Figure 15—Remove the Mold While Keeping the Two End Pieces in Place

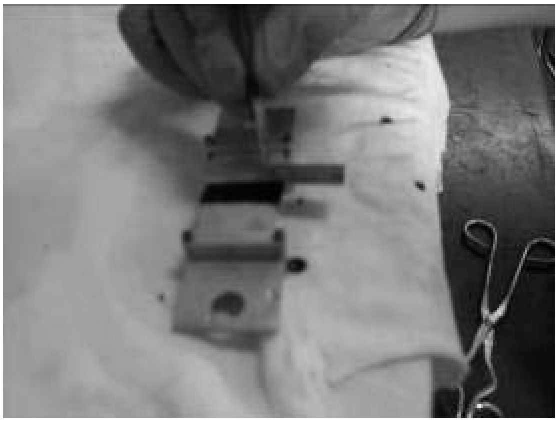

Figure 16—Flip Back the Specimen, and Push the Notch Horizontally Until It Comes Off

10.17 Place the specimen back in the bath.

Figure 17—Grab the Specimen from Two Corners, and Place It Back in the Bath

10.18 Repeat step 8.16 until all specimens are de-molded.

10.19 Leave the samples for 45 minutes in the bath prior to testing.

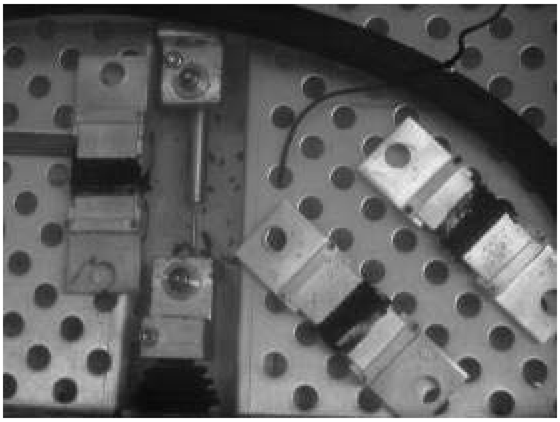

Figure 18—Leave the Specimens for 45 minutes in the Bath

10.20 Open the DTT's test builder program, adjust the machine so the sample can sit freely on the posts, and place the specimen on the posts. Care should be taken not to disturb the specimen.

10.21 Run the test and record the data.

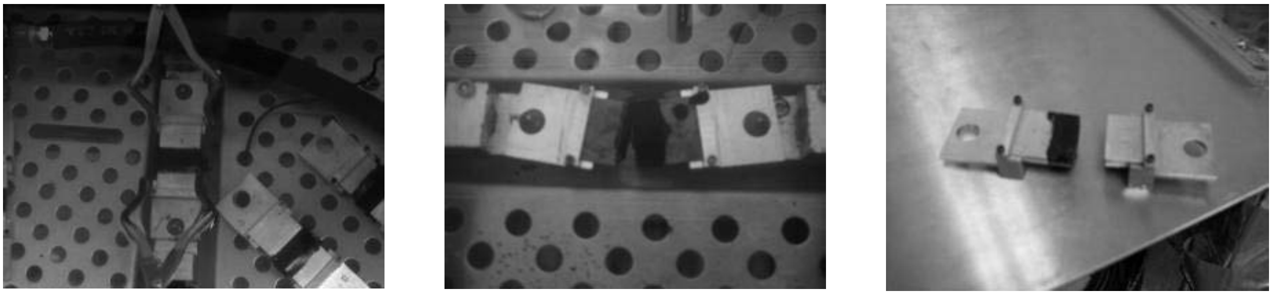

Figure 19—Turn on the DTT Machine, Load Adhesion Program, Mount the Specimen, Tare the Load to Zero, Run the Test, and Record the Data

11. CALCULATION OF RESULTS

11.1 Find the maximum load ($P_{\max}$) to failure and its correspondent displacement.

11.2 Find the bonding energy (E), by calculating the area under the load-displacement curve up to the maximum load and dividing it by the cross-section area of the aluminum end piece.

11.3 Report the $P_{\max}$ and E as the selection thresholds.

12. REPORT

12.1 *Report the following information*:

12.1.1 Sealant identification and supplier,

12.1.2 Lot number,

12.1.3 Date received,

12.1.4 Date of apparent viscosity measurement,

12.1.5 Recommended pouring temperature,

12.1.6 Safe heating temperature, and

12.1.7 Any deviations from test temperature.

13. PRECISION AND BIAS

13.1 *Single Operator Precision (Repeatability)*—The results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the value given Table 1.

Table 1—Precision Estimates

Condition	Coefficient of Variation, (1s%)[a]
Single-Operator Precision:	
Average Viscosity (Pa·s)	19.3

[a] The precision estimates given in Table 1 are based on the analysis of test results from seven sealants with a wide range of rheological properties. The data analyzed include results from two operators in the same laboratories who conducted each test in four replicates.

14. KEYWORDS

14.1 Adhesion; bond; crack; fillers; hot-poured bituminous sealant; joint.

15. REFERENCES

15.1 Al-Qadi, I. L., J. F. Masson, E. Fini, S. H. Yang, and K. K. McGhee. *Development of Performance-Based Guidelines for Selection of Bituminous-Based Hot-Poured Pavement Crack Sealant: An Executive Summary Report*. VTRC 09-CR7. Virginia Transportation Research Council, Charlottesville, VA, 2009. [Reference for SC-1–7] http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=09-CR7

15.2 Al-Qadi, I. L., E. H. Fini, K. K. McGhee, and M. A. Elseifi. *Development of Apparent Viscosity Test for Hot-Poured Crack Sealants, Final Report*. No. ICT-08-027. Illinois Center for Transportation, Rantoul, IL, December 2008(b). [Reference for SC-2] http://ict.illinois.edu/Publications/report%20files/ICT-08-027.pdf

15.3 Al-Qadi, I. L., J. F. Masson, A. Loulizi, P. Collins, J. R. Woods, S. Bundalo-Perc, and K. K. McGhee. *Long-Term Accelerated Aging and Low Temperature BBR Testing of Sealants*. Interim Report No. B5508-5. National Research Council of Canada, 2004, 262 pp. [Reference for SC-3 – printed document only]

15.4 Collins, P., M. Veitch, J. F. Masson, and I. L. Al-Qadi. Deformation and Tracking of Bituminous Sealants in Summer Temperatures: Pseudo-Field Behavior. *International Journal of Pavement Engineering*, Vol. 9, No. 1. Taylor and Francis Limited, London, England, 2008, pp. 1–8. [Reference for SC-4]

15.5 Al-Qadi, I. L., S. H. Yang, M. A. Elseifi, S. Dessouky, A. Loulizi, J. F. Masson, and K. K. McGhee. *Characterization of Low Temperature Creep Properties of Crack Sealants Using Bending Beam Rheometry, Final Report*. No. ICT-08-029, Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-5] http://ict.illinois.edu/Publications/report%20files/ICT-08-029.pdf

15.6 Al-Qadi, I. L., S. H. Yang, J. F. Masson, and K. K. McGhee. *Characterization of Low Temperature Mechanical Properties of Crack Sealants Utilizing Direct Tension Test, Final Report*. No. ICT-08-028. Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-6] http://ict.illinois.edu/Publications/report%20files/ICT-08-028.pdf

15.7 Al-Qadi, I. L., E. H. Fini, H. D. Figueroa, J. F. Masson, and K. K. McGhee. *Adhesion Testing Procedure for Hot-Poured Crack Sealants, Final Report*. No. ICT-08-026. Illinois Center for Transportation, Rantoul, IL, December 2008. [Reference for SC-7 and SC-8] http://ict.illinois.edu/Publications/report%20files/ICT-08-026.pdf

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[1] These standards were developed through a pooled-fund study sponsored by several AASHTO member departments, the University of Illinois, Virginia Polytechnic Institute and State University (Virginia Tech), and the National Research Council of Canada. The Sealant Consortium is the designation given to this pooled-fund study. For availability of the individual research reports, see Section 15, References.

Standard Method of Test for

Measuring Interfacial Fracture Energy of Hot-Poured Crack Sealant Using a Blister Test

AASHTO Designation: TP 90-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Measuring Interfacial Fracture Energy of Hot-Poured Crack Sealant Using a Blister Test

AASHTO Designation: TP 90-10

1. SCOPE

1.1 The blister test is used to determine the interfacial fracture energy (IFE) of hot-poured crack sealant at the application temperatures.

1.2 The blister test is a test of fracture. The object of the test is to apply tensile forces using hydrostatic pressure at the interface between sealant and aluminum. Sealant is molded on top of an aluminum disk. The applied hydrostatic pressure and displacement can be recorded as functions of time. Interfacial fracture energy required to break the bond can be calculated using the load-displacement curve through fracture energy concept. This energy can be considered a measure of bonding.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish and follow appropriate health and safety practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D 5167, Standard Practice for Melting Hot-Applied Joint and Crack Sealant and Filler for Evaluation
- D 5329, Standard Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements
- D 6690, Standard Specification for Joint and Crack Sealants, Hot Applied, for Concrete and Asphalt Pavements
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E 220, Standard Test Method for Calibration of Thermocouples by Comparison Techniques

2.2 *Sealant Consortium (SC) Standards*:[1]

- SC-1, Guidelines for Graded Bituminous Sealants
- SC-2, Test Method for Measuring Apparent Viscosity of Hot-Poured Crack Sealant Using Brookfield Rotational Viscometer RV Series Instrument

- SC-3, Method for the Accelerated Aging of Bituminous Sealants
- SC-4, Sealant Flow and Deformation
- SC-5, Method to Measure Low-Temperature Sealant Flexural Creep Stiffness at Low Temperature by Bending Beam Rheometer
- SC-6, Method to Evaluate Sealant Extensibility at Low Temperature by Direct Tension Test
- SC-7, Test Method for Measuring Adhesion of Hot-Poured Crack Sealant Using a Direct Adhesion Test

3. TERMINOLOGY

3.1 *hot-poured crack sealants*—hot-poured modified asphaltic materials used in pavement cracks and joints.

3.2 *interfacial fracture energy (IFE)*—the energy required to separate bituminous sealant from a substrate.

4. SUMMARY OF METHOD

4.1 Crack sealant material is homogenized following the procedure given in ASTM D 5167. For each test, including four replicates, cut 320 g of sealant and heat to the manufacturer's recommended pouring temperature. Sealant will be poured in the mold assembled on top of an annular-shaped disk of substrate. An aluminum plug will be inserted into the orifice of the substrate to close it. The sealant will be poured on top of the plugged substrate to provide a film of 4.6 mm thickness.

5. SIGNIFICANCE AND USE

5.1 This procedure is designed to measure the adhesion strength of hot-poured sealant to aggregate.

5.2 Sealants must be re-homogenized (ASTM D 5167) before measuring adhesion by this method.

6. APPARATUS

6.1 Modified direct tension test (DTT) machine;

6.2 Chiller that can reach –40 ± 0.5°C;

6.3 *Laboratory Oven*—Any standard laboratory oven capable of producing and maintaining temperature ranging from 170 to 193°C ± 0.5°C;

6.4 Release agent; and

6.5 Four test setups, four molds, four plugs, and four rubber bands.

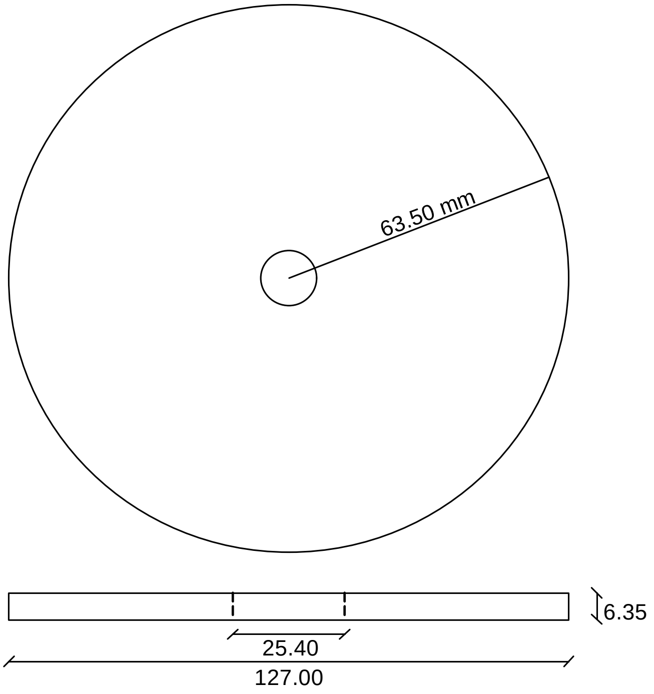

Figure 1—Schematic of the Aluminum Disk

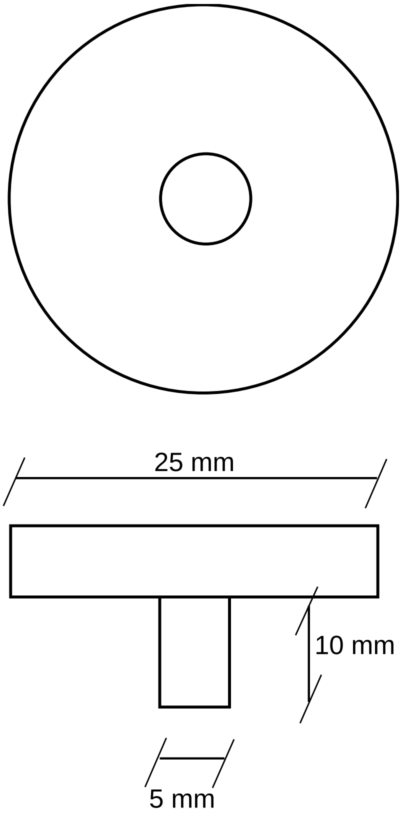

Figure 2—Schematic of the Plug

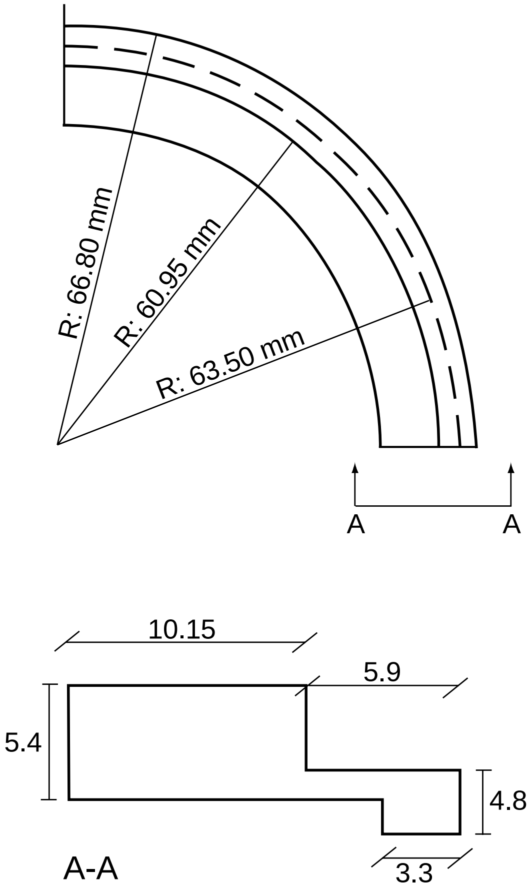

Figure 3—Schematic of One Section of the Four-Piece Mold

7. HAZARDS

7.1 Standard laboratory caution should be used in handling hot sealant in accordance to ASTM D 5167, and when using the Direct Tension/Blister Tester (DTT/Blister). Required safety procedures should be followed when chemical agents are used.

8. PREPARATION OF APPARATUS

8.1 The DTT bath must be adjusted to specific temperature. The test setup must be leveled to function properly.

9. CALIBRATION AND STANDARDIZATION

9.1 Temperature of the ovens should be calibrated according to each user's quality assurance program.

9.2 Temperature of the chiller should be calibrated according to each user's quality assurance program.

9.3 *Thermometer (temperature detector)*—Verify the calibration of the temperature-sensing device to ±0.1°C every 6 months.

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10. PREPARATION OF SAMPLES AND TEST SPECIMENS

10.1 All adhesion strength measurements must be performed on re-homogenized sealant. Follow the procedure for homogenization given in ASTM D 5167. It is recommended that a minimum of 400 g of sealant be homogenized.

10.2 Once homogenized, hot sealant should be molded, cooled, and stored for later usage. To store the sealant, it is recommended that a can or plastic-lined box be used. The mold must be of sufficient size that the sealant depth is no greater than 100 mm to allow for rapid cooling.

10.3 Adjust the oven’s temperature to recommended pouring temperature for sealant being tested.

10.4 Turn on the DTT/Blister machine, load the program, and cool the chiller to test temperature.

10.5 Use a compass to draw a circle 27 mm in diameter on adhesive-backed fluoropolymer (FEP) film.

10.6 Punch out the circle using a sharp manual punch.

10.7 Peel the FEP film and place it on a level surface, adhesive side up.

10.8 Place the needle on the center (marked with the compass) of the FEP film.

10.9 Place the flat side of the plug on top of the needle and let the needle go through the plug.

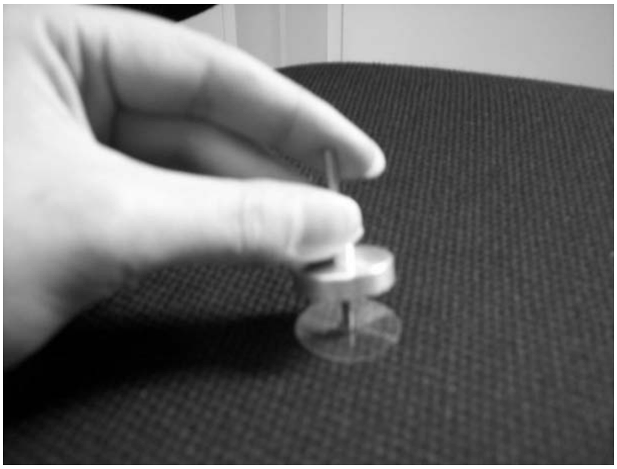

Figure 4—Performing Steps 10.7 through 10.9

10.10 Press the plug on the film gently to make sure it has adhered to the film.

10.11 Spray release agent on the plug while keeping it inclined.

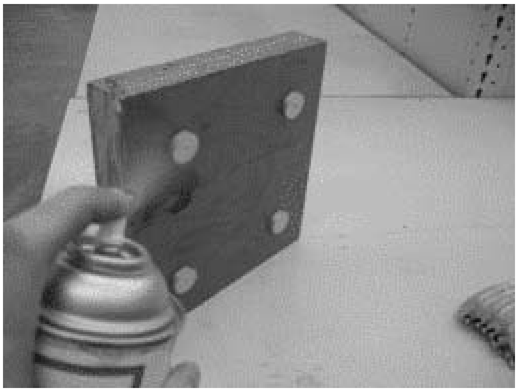

Figure 5—Spraying Release Agent on the Plugs

10.12 Taking care not to contaminate the surface of the disk, place the plug on top of annular disk.

Figure 6—Placing the Plug on the Annular Disk and Pulling It from Underneath until the Disk Fits in the Orifice and the Film Edges Set on the Disk

10.13 Place the aluminum disk and the plug on a setting board.

10.14 Spray release agent on the molds.

Figure 7—Spraying Release Agent on the Molds

10.15 Assemble the mold on top of the disk.

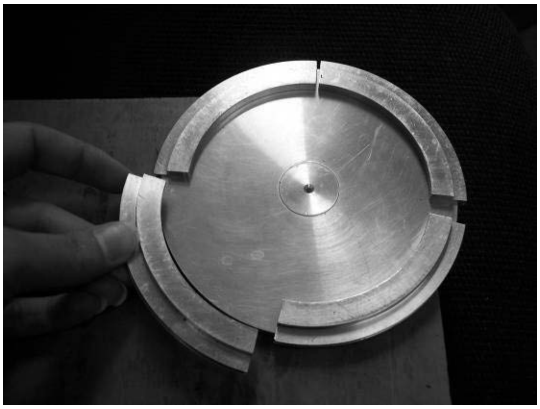

Figure 8—Assembling the Molds on Top of the Disk

10.16 Wrap the mold with a rubber band stretched through the groove around the mold, to keep the components in place.

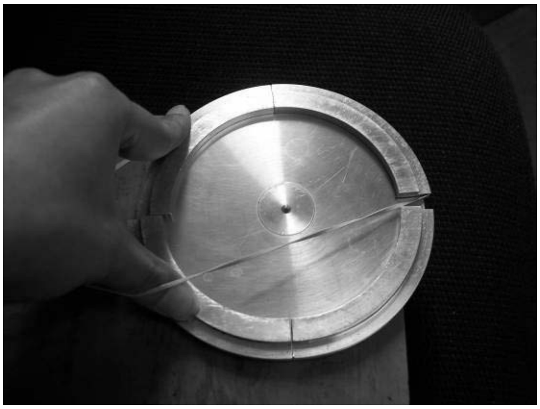

Figure 9—Using Rubber Band to Keep the Mold Together

10.17 Prepare four cans of sealant by cutting 80 g of homogenized sealant for each.

10.18 Place the can in the oven for 15 minutes, remove it from the oven, stir the sealant thoroughly, and place it back in the oven for another 15 minutes.

Figure 10—Heating 35 g of Homogenized Sealant at Recommended Pouring Temperature for 30 min.

10.19 Remove the can from the oven, stir the sealant thoroughly, and pour into all the assembled setups. Use four replicates for each sealant; care should be taken in filling up the molds to prevent any trapped air bubbles in the sample.

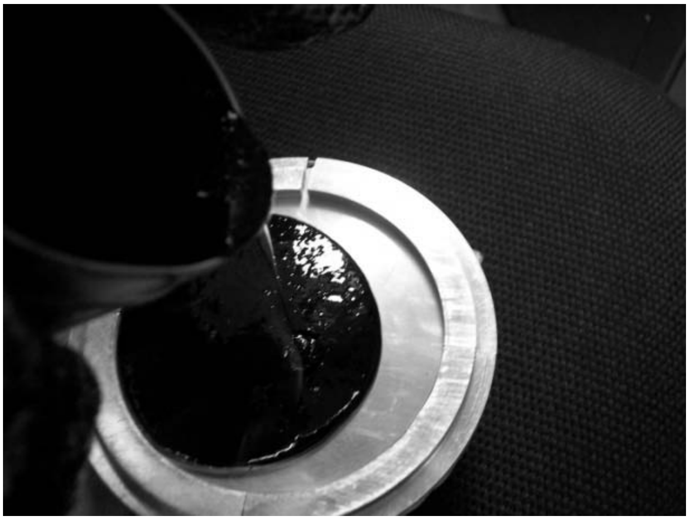

Figure 11—Pouring Sealant onto the Center Top of the Plug so that the Sealant Flows to Fill the Mold

10.20 Let samples set 1 hour at room temperature.

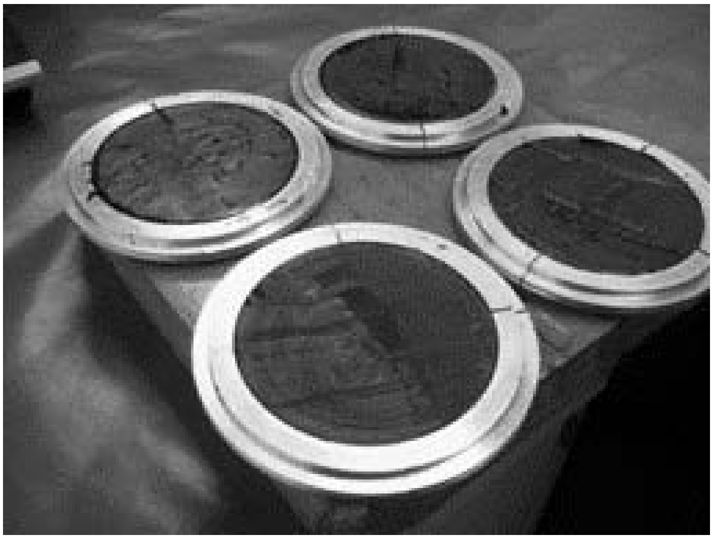

Figure 12—Sealant Setting for 1 Hour at Room Temperature

10.21 Trim the excessive sealant away with a heated putty knife. Move putty knife once over and parallel to the interface of the sample; trimming direction shall not be changed during trimming. Use well-heated putty knife to prevent any shearing of the sealant.

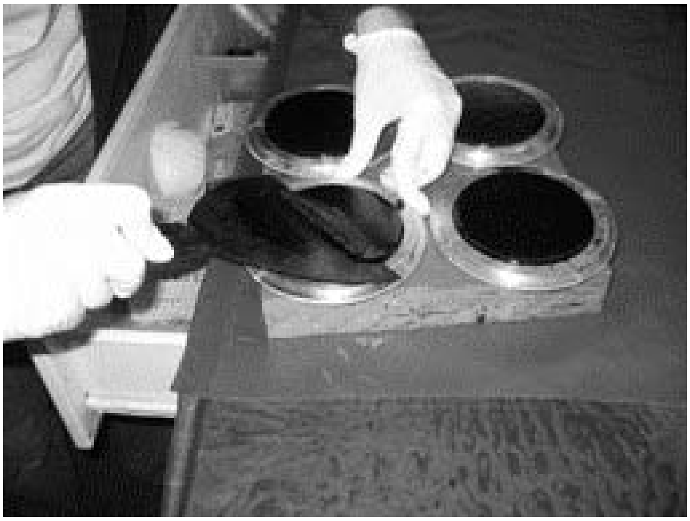

Figure 13—Trimming Excess Sealant with a Heated Putty Knife

10.22 Place the specimens on the cooling rack. Care should be taken not to disturb the specimen.

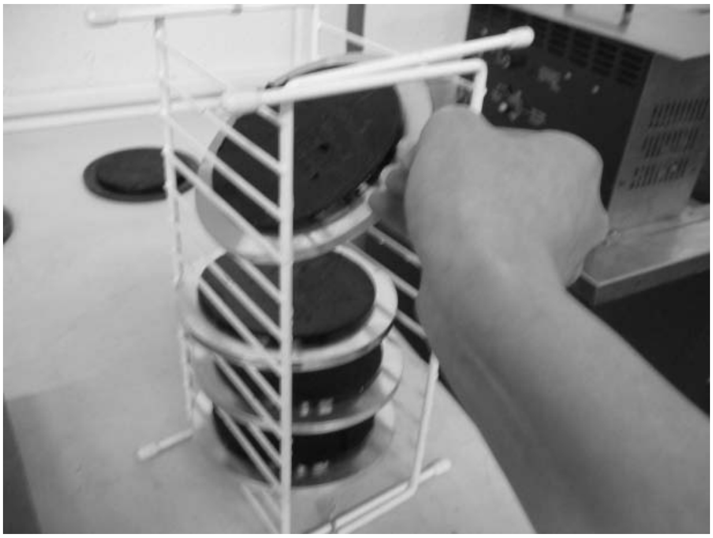

Figure 14—Placing the Disks on the Rack with Clearance between Each Specimen

10.23 Place the rack in the cooling bath for 15 minutes.

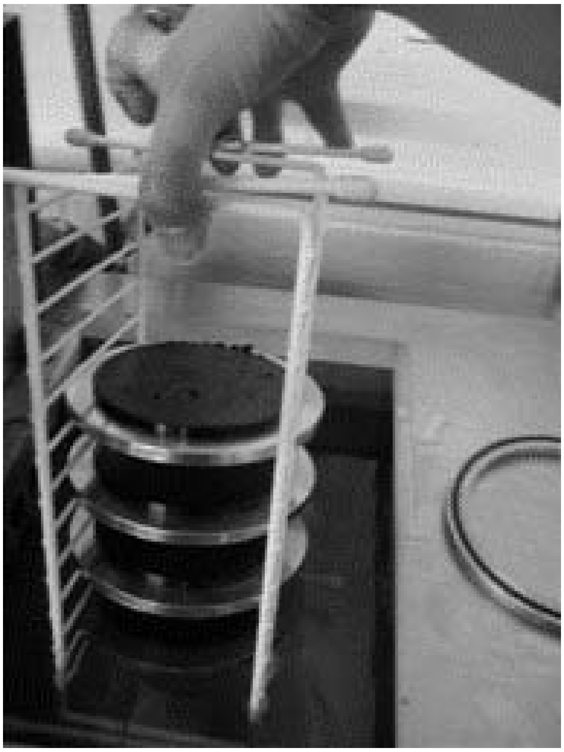

Figure 15—Placing the Rack in the Bath for 15 minutes.

10.24 Remove the rubber band and disassemble the mold gently.

Figure 16—Removing the Molds

10.25 Remove the plug and place the specimen back in the bath.

Figure 17—Removing the Plug from Each Specimen

10.26 Repeat steps 10.24 and 10.25 until all specimens are de-molded.

10.27 Leave the specimens in the cooling bath for 45 minutes before running the test.

10.28 Open the DTT/Blister's test builder program; open the outlet valve to prevent pressure from being applied to the specimen before the test starts. Place the specimen on the setup and clamp the specimen tightly.

10.29 Run the test and record the data.

Note 1—It is recommended that failure surfaces be examined for each replicate to ensure adhesive failure occurred. If sealant breakage occurred, discard the data.

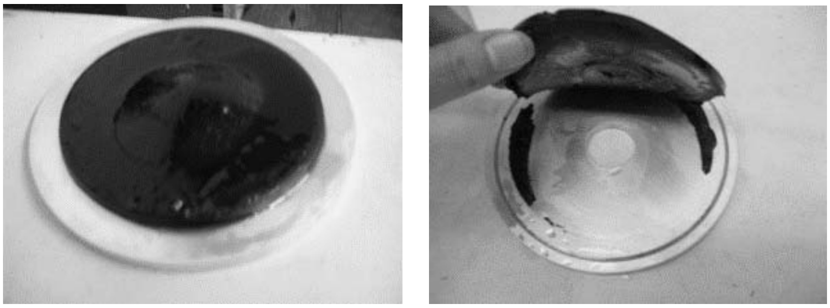

Figure 18—Removing the Specimen and Verifying that the Type of Failure Was Adhesive Failure, in which Sealant Separates from the Disk

11. CALCULATION OF RESULTS

11.1 Find the maximum load ($P_{\max}$) to failure and its correspondent displacement.

11.2 Find the IFE by multiplying half of the maximum load and corresponding displacement.

11.3 Report the IFE as the selection thresholds.

12. REPORT

12.1 *Report the following information*:

12.1.1 Sealant identification and supplier,

12.1.2 Lot number,

12.1.3 Date received,

12.1.4 Date of apparent viscosity measurement,

12.1.5 Recommended pouring temperature,

12.1.6 Safe heating temperature, and

12.2 Any deviations from test temperature.

13. PRECISION AND BIAS

13.1 *Single-Operator Precision (Repeatability)*—The results obtained in the same laboratory by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the value given Table 1.

Table 1—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]
Single-Operator Precision:	
Average IFE (J/m^2)	8.77

[a] The precision estimate given in Table 1 is based on the analysis of test results from 12 sealants with a wide range of rheological properties. The data analyzed include results from two operators in the same laboratory who conducted each test in four replicates.

14. KEYWORDS

14.1 Adhesion; blister; bond; crack; fillers; hot-poured bituminous sealant; interfacial fracture energy; joint.

15. REFERENCES

15.1 Al-Qadi, I. L., J. F. Masson, E. Fini, S. H. Yang, and K. K. McGhee. *Development of Performance-Based Guidelines for Selection of Bituminous-Based Hot-Poured Pavement Crack Sealant: An Executive Summary Report.* VTRC 09-CR7. Virginia Transportation Research Council, Charlottesville, VA, 2009. [Reference for SC-1–7] http://vtrc.virginiadot.org/PubDetails.aspx?PubNo=09-CR7

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[1] These standards were developed through a pooled-fund study sponsored by several AASHTO member departments, the University of Illinois, Virginia Polytechnic Institute and State University (Virginia Tech), and the National Research Council of Canada. The Sealant Consortium is the designation given to this pooled-fund study. For availability of the individual research reports, see Section 15, References.

Standard Specification for

Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300- to 900-mm (12- to 36-in.) Diameter

AASHTO Designation: MP 20-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300- to 900-mm (12- to 36-in.) Diameter

AASHTO Designation: MP 20-10

1. SCOPE

1.1. This specification covers the requirements and methods of tests for steel-reinforced polyethylene (PE) ribbed pipe, couplings, and fittings for use in surface and subsurface drainage applications.

1.1.1. Nominal sizes of 300 to 900 mm (12 to 36 in.) are included.

1.1.2. Materials, workmanship, dimensions, pipe stiffness, impact resistance, tensile strength of seams, shape stability, joining systems, and form of markings are specified.

1.2. Steel-reinforced PE ribbed pipe is intended for surface and subsurface drainage applications where soil provides support to its flexible walls. Its major use is to collect or convey drainage water by open gravity flow as culverts, storm drains, etc.

Note 1—When PE pipe is to be used in locations where the ends may be exposed, consideration should be given to protection of the exposed portions due to combustibility of the PE and the effects of prolonged exposure to ultraviolet radiation.

1.3. This specification only deals with this pipe's materials requirements. There is no currently accepted AASHTO design methodology for this pipe, and the users of this pipe must assure themselves that this pipe material will perform adequately under installation and design methods chosen by the user. This specification does not include requirements for bedding, backfill, or earth cover load. Successful performance of this product depends upon proper type of bedding and backfill, and care in installation. Appropriate construction and installation procedures are provided by Section 30 of the *AASHTO LRFD Bridge Construction Specifications.* Upon request of the user or engineer, the manufacturer shall provide profile wall section detail required for a full engineering evaluation.

1.4. *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. Customary Units are shown in parentheses and may not be exact equivalents.

1.5. The following precautionary caveat pertains only to the test method portion, Section 9, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standard*:

- *LRFD Bridge Construction Specification*, Sections 26 and 30

2.2. *ASTM Standards*:

- A653/A653M-09, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
- D 618, Standard Practice for Conditioning Plastics for Testing
- D 638, Standard Test Method for Tensile Properties of Plastics
- D 883, Standard Terminology Relating to Plastics
- D 2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D 2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D 2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D 3212, Standard Specification for Joints for Drains and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- D 3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- F 412, Standard Terminology Relating to Plastic Piping Systems
- F 477, Standard Specification for Elastomeric Seals (Gaskets) for Jointing Plastic Pipe
- F 2136, Standard Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

3. TERMINOLOGY

3.1. The terminology used in this standard is in accordance with the definitions given in ASTM D 883 and ASTM F 412 unless otherwise specified.

3.2. *crack*—Any break or split that extends through the wall.

3.3. *crease*—An irrecoverable indentation, generally associated with a loss in shape stability.

3.4. *delamination*—A gap extending through the welded lap seam between two adjacent wrap widths.

3.5. *encapsulation thicknesses*—The thicknesses of the high density polyethylene (HDPE) covering on both sides of the steel reinforcement as well as the thickness of the closure at the top (outside) of the rib and the thickness of the profile directly under (inside) the reinforcement (see Figure 2).

3.6. *gravity flow*—A condition in which liquid flow through a piping system results from a downward pipeline slope, but flow is less than full, except during conditions when the system may become temporarily surcharged, in which case the system is subject to temporary internal hydrostatic pressure that is limited to 74 kPa.

3.7. *polyethylene (PE) plastics*—Plastics based on polymers made with ethylene as essentially the sole monomer (ASTM D 883).

3.8. *reworked plastic*—A plastic from a processor's own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D 883).

3.9. *seam*—The portion of the helically wrapped strip that overlaps and is fused to adjacent helically wrapped strips (see Figure 1).

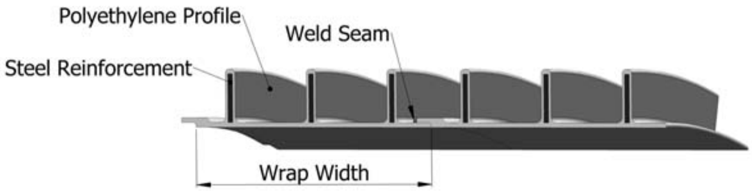


Figure 1—Cross-Section of Profile

3.10. *shape stability*—A general measure of the pipe's ability to maintain geometric and structural stability while deflected and carrying a load equal to or greater than 75 percent of its peak load carrying capability. Peak load-carrying capability is identified as the maximum load in the load/deflection curve as measured during the flattening test as described in Section 9.2.

3.11. *steel-reinforced thermoplastic pipe*—Ribbed thermoplastic pipe with steel reinforcing strips encapsulated within the ribs (see Figure 1).

3.12. *slow crack growth*—A phenomenon by which a stress crack may form. A stress crack is an external or internal crack in plastic caused by tensile stresses less than its short-term mechanical strength.

3.13. *virgin polyethylene material*—PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

3.14. *wrap width*—The width the helically wrapped strip covers when measured across the strip, perpendicular to the ribs (see Figure 1).

3.15. *waterway wall*—The minimum wall thickness separating the inner and outer surfaces of the pipe wall, which is measured between pipe ribs (see Figure 2).

4. CLASSIFICATION

4.1. The steel-reinforced PE ribbed pipe covered by this specification is classified as follows:

4.1.1. *Type S*—This pipe shall have a full circular cross section with an essentially smooth inner wall.

4.1.2. *Type SP*—This pipe shall be Type S with perforations.

4.2. Perforations are described in Section 7.5.

5. ORDERING INFORMATION

5.1. Orders using this specification shall include the following information as necessary to adequately describe the desired product:

5.1.1. AASHTO designation and year of issue;

5.1.2. Perforation, if applicable (Section 7.5);

5.1.3. Diameter and length required, either total length or length of each piece and number of pieces;

5.1.4. Certification, if desired (Section 12.1); and

5.1.5. Type of pipe joint (Section 7.12.1).

6. MATERIALS

6.1. *Polyethylene Materials*:

6.1.1. *Pipe and Fittings*—Pipe and fittings shall be made of virgin PE, conforming to the requirements of ASTM D 3350 and having a cell classification of 334452 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided the product requirements are met.

6.1.2. *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D 3350 and a having a cell classification of 213320 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met. For slow crack resistance, acceptance of resins shall be determined by using the notched, constant ligament-stress (NCLS) test according to the procedure described in Section 9.6. The average failure time of the five test specimens must exceed 24 hours with no single test specimen's failure time less than 17 hours.

6.1.3. *Injection Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D 3350 and having a cell classification of 324452 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.4. *Carbon Black Content*—The carbon black content shall not exceed 4 percent of the total PE compound weight.

6.1.5. *Other Materials*—It is permissible to use materials other than the cell classification in Section 6.1.1 as part of the welding processes, provided these materials have higher cell classifications in one or more properties and in no way compromise the performance of the pipe products in the intended use.

6.1.6. *Rework Plastics*—In lieu of virgin PE, it is permissible to use clean reworked plastic generated from the manufacturer's own pipe production, provided that it meets the cell class requirements as described in Section 6.1.1.

6.2. *Steel Materials*:

6.2.1. *Steel Material*—The steel material shall be cold- or hot-rolled, formable steel meeting the requirements of ASTM A 653, meeting the strength requirements of Table 4 for the grade defined by the manufacturer as required for their pipe's design. The steel shall have a galvanized coating. All steel materials shall be galvanized per the requirements of ASTM A 653/A 653M with a G60 minimum coating weight.

Note 2—The actual strength of the steel and the rib dimensions are dependent on the manufacturer's design. If requested by the purchaser, the manufacturer shall provide before purchase and delivery their pipe design and certify with delivery that the grade of steel and rib dimensions in the pipe supplied conform to their design...

6.2.2. *Gaskets*—Elastomeric gaskets shall meet the requirements of ASTM F 477.

6.2.3. *Industrial Sealant*—Sealants, such as moisture cure urethane or asphalt-based sealant materials used for repairs or assembly of the internal coupling joint, as recommended by the manufacturer, may be used.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. Visible defects shall not affect the wall integrity or the encapsulation of the steel reinforcement. The steel reinforcing materials shall not be exposed.

7.2. *Visible Defects*—Cracks, creases, delaminations, and unpigmented or nonuniformly pigmented pipe that are visible by the unaided eye are not permissible in the pipe or fittings.

7.3. There shall be no evidence of delamination when tested in accordance with Section 9.2.

7.4. *Pipe Dimensions and Tolerances*:

7.4.1. *Inside Diameter*—The tolerance on the inside diameter shall be ±2.0 percent, when measured in accordance with Section 9.8.1. Pipe dimensions (for both perforated and nonperforated pipe) shall comply with Table 1.

7.4.1.1. Other diameters that are within the range of pipe sizes shown in Table 1 are permissible. The minimum wall thickness and other properties shall be interpolated from the adjacent values given in Table 1.

Table 1—Nominal Pipe Sizes, Inside Diameters, and Minimum Waterway Wall Thicknesses

Nominal Pipe Size, mm (in.)	Inside Diameter, mm [in.] [a]	Minimum Waterway Wall Thickness, t_1, mm [in.]	Minimum Encapsulation Thickness (Bottom), t_2, mm [in.]
300 (12)	300 [11.81]	1.1 [0.043]	0.9 [0.035]
375 (15)	375 [14.76]	1.2 [0.047]	1.0 [0.039]
450 (18)	450 [17.72]	1.3 [0.051]	1.3 [0.051]
600 (24)	600 [23.62]	1.5 [0.059]	1.5 [0.059]
750 (30)	750 [29.53]	1.5 [0.059]	1.5 [0.059]
900 (36)	900 [35.43]	1.7 [0.067]	1.7 [0.067]

[a] Conversions of SI units to U.S. Customary units in this table are "soft" conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

7.4.2. *Waterway Wall*—Minimum waterway wall thickness shall be as required in Table 1 when measured in accordance with Section 9.8.2.

7.4.3. *Length*—The pipe shall be sold in any length agreeable to the user. Length shall not be less than 99 percent of the specified length, when measured in accordance with Section 9.8.3.

7.4.4. *Encapsulation Thickness*—The minimum thickness of the HDPE encapsulation at the sides, top (outside), and bottom (inside) of the reinforcement shall be as shown in Figure 2. Factory cut pipe ends shall have the cut rib ends encapsulated to meet the requirements of Figure 2 for the top (outside) of the ribs. Encapsulation thicknesses shall be measured in accordance with Section 9.8.4.

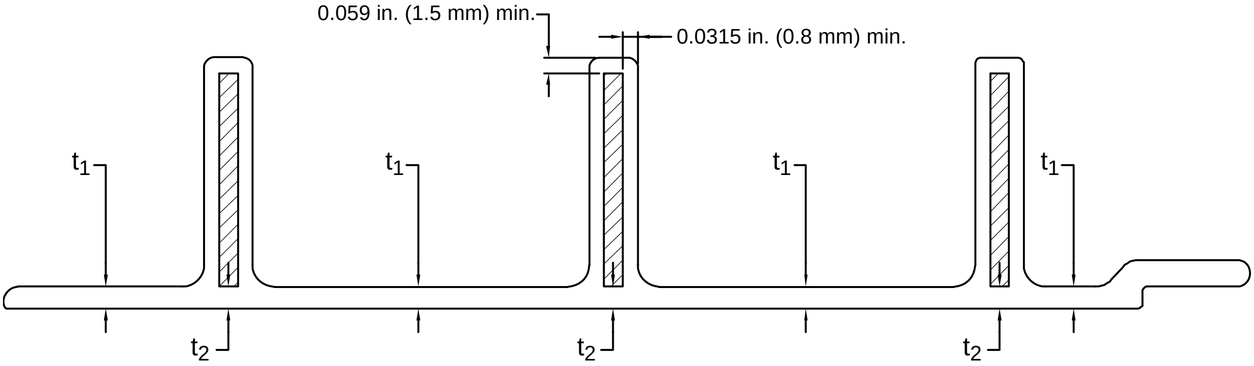


Figure 2—Schematic Representation of Steel-Reinforced Thermoplastic Pipe Profile

7.5. *Perforations*—When perforated pipe is specified, the perforations shall be cleanly cut and uniformly spaced along the length and circumference of the pipe. Circular perforations shall be a minimum of 5 mm (0.2 in.) and shall not exceed 10 mm (0.4 in.) in diameter. The water inlet area shall be a minimum of 30 cm^2/m (1.5 $in.^2$/ft) for pipe sizes 300 to 450 mm (12 to 18 in.) and 40 cm^2/m (2.0 $in.^2$/ft) for pipe sizes larger than 450 mm (18 in.). All measurements shall be made in accordance with Section 9.8.5. The perforations shall be cleanly cut so as not to restrict the inflow of water. Pipe connected by bell and spigot joints may not be perforated in the area of the bells and spigots. Perforations shall be located in the waterway wall portion of the pipe between the ribs and shall not cut into encapsulation of the reinforcement, the radius between this encapsulation and the waterway wall, or the fused seam. The reinforcing steel material shall not be exposed by these perforations.

7.6. *Pipe Stiffness*—The pipe shall have minimum pipe stiffness at 5 percent deflection as listed in Table 2. Pipe stiffness shall be tested in accordance with Section 9.1.

Table 2—Pipe Stiffness and Shape Stability Limits

Nominal Inside Diameter, mm (in)	Pipe Stiffness, kPa [psi] [a]	Shape Stability Limit, %
300 (12)	345 [50]	20
375 (15)	290 [42]	20
450 (18)	276 [40]	20
600 (24)	234 [34]	20
750 (30)	193 [28]	20
900 (36)	152 [22]	20

[a] Conversions of SI units to U.S. Customary units in this table are “soft” conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

Note 3—The 5 percent deflection on criteria was selected for testing convenience and should not be considered as a limitation with respect to in-use deflection.

7.7. *Pipe Flattening*—There shall be no evidence of splitting, cracking, or breaking when tested in accordance with Section 9.2. Additionally, there shall be no separation or delamination of the spiral seam or the rib at the top of its junction with the waterway wall of the pipe when tested in accordance with Section 9.7.

7.8. *Shape Stability*—In the flattening test described in Section 9.2, the load shall not decrease with increasing deflection until after the percentage shape stability limit tabulated for the relevant diameter (in Table 2) has been exceeded. Additionally, if the peak load is reached before 20 percent deflection, the load at 20 percent deflection shall be a minimum of 75 percent of the peak load. Shape stability limit is calculated as follows:

$$SSL = \frac{\Delta Y}{ID} \times 100\%$$

where:

SSL = shape stability limit

ΔY = change in vertical deflection

ID = inside diameter of pipe

7.9. *Impact*—There shall be no evidence of splitting, cracking, or breaking when tested in accordance with Section 9.3. Additionally, there shall be no separation of the spiral seam or the rib at its junction with the waterway wall when tested in accordance with Section 9.7.

7.10. *Tensile Strength of Seam*—There shall be no breaking or separation of the weld when tested in accordance with Section 9.4.

7.11. *Fitting Requirements*:

7.11.1. Only fittings supplied or recommended by the manufacturer shall be used. Fabricated fittings shall be supplied with joints compatible with the overall system requirements. A bell-and-spigot joint is an example of a typical design.

7.11.2. All fittings shall be within an overall length dimensional tolerance ±12 mm (0.5 in.) of the manufacturer's specified dimensions when measured in accordance with Section 9.8.3.

7.11.3. The fittings shall not impair the overall integrity or function of the pipe.

7.11.4. Common fittings include in-line joint fittings, reducers, and branch or complimentary assembly fittings such as tees and wyes. These fittings shall be installed or coupled to the pipe by various methods.

7.11.5. Fittings shall not reduce the inside diameter of the pipe being joined by more than 12 mm (0.5 in.). Reducer fittings shall not reduce the cross-sectional area of the small size diameter by more than 3 percent.

7.12. *Jointing Requirements*:

7.12.1. Pipe joints and couplings shall be bell and spigot or screw-on collar. Only couplings supplied or recommended by the manufacturer shall be used. Couplings shall be supplied with joints compatible with the overall system requirements.

7.12.1.1. Other types of couplings or fastening devices that are equally effective as those described in Section 7.12.2.1 and that comply with the soil-tight joint performance criteria of the *AASHTO LRFD Bridge Construction Specification*, Section 26.4.2.4, may be used when approved by the purchaser. An example of another type of coupler is a split-collar coupling, which shall match the pipe profile and shall provide sufficient longitudinal strength to preserve pipe alignment and prevent separation at the joints. Split-collar couplings shall engage at least three full ribs on each pipe section.

7.12.1.2. *Internal Coupling, Sealant Type*—Joint seal is affected by applying an industrial sealant between the external surface of the coupling and the internal surface of the pipe. This jointing system may be used when approved by the purchaser.

7.12.1.3. Other types of jointing methods such as flanging, internal coupling (gasket type), extrusion welding, electro-fusion, butt fusion, and others may be used when approved by the purchaser.

7.12.2. *Joint Tightness*—The pipe or fitting joint shall meet the requirements defined as one of the following types:

7.12.2.1. *Soil-tight Joints*—Soil-tight joints are specified as a function of opening size (maximum dimension normal to the direction that soil may infiltrate), channel length (length of the path along which the soil may infiltrate), and backfill particle size. If the size of the opening exceeds 3 mm ($^1/_8$ in.), the length of the channel must be at least four times the size of the opening. No opening may exceed 25 mm (1 in.). Backfill material containing a high percentage of fine-graded soils requires investigation for the specific type of joint to be used to guard against soil infiltration.

7.12.2.2. *Silt-Tight Joints*—A silt-tight joint is resistant to infiltration of particles that pass the No. 200 sieve. Silt-tight joints are specified to provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an elastomeric rubber seal or geotextile wrap. Geotextile wraps are manufactured to tolerances that assure silt will not pass through them. The successful performance of these wraps in the field is dependent on their installation. If a geotextile wrap is specified for use, the material specified should meet M 288, with an Apparent Opening Size (AOS) > 70.

For joints that utilize an elastomeric rubber seal, silt-tight performance shall have been demonstrated in a laboratory test to meet the hydrostatic requirements of ASTM D 3212, with the exception that the hydrostatic test pressure shall be a minimum of 14 kPa (2 psi).

7.12.2.3. *Leak-Resistant Joints*—Leak-resistant joints shall be bell and spigot and utilize an elastomeric rubber seal meeting the requirements of ASTM F 477. Alternative methods of joining (e.g., external joint wraps) shall be allowed provided the requirements of Section 7.12.2.3.1 are achieved.

7.12.2.3.1. Leak resistance shall be verified in the lab by meeting all of the requirements of ASTM D 3212. The hydrostatic test pressure and vacuum specified in the test method shall be 74 kPa (10.8 psi).

7.12.3. *Special Design Joints*—Special design joints shall include joints requiring special strength in bending or shear, pull-apart capabilities, or unusual features such as restrained joints placed on severe slopes, welded joints, flanged and bolted joints for high pressures, high heads, or velocities. Watertight joints that provide zero leakage for a specified head or pressure application are included in this type of joint.

7.13. *Stub Compression Test*—Profile compression capacity in any specimen in the stub compression test shall not be less than 50 percent of the gross cross section of the steel reinforcing area times the minimum specified yield strength of the steel when tested in accordance with Section 9.9. The stub compression test, T 341, shall be a material and wall design qualification test conducted once a year or whenever there are changes in wall design or material distribution. Computing the minimum capacity requires determining the cross-sectional area of the pipe wall. This can be accomplished conveniently by optically scanning the profile and determining the section properties using a computer drafting program.

8. CONDITIONING

8.1. *Conditioning*—Condition the specimen prior to test at 21 to 25ºC (70 to 77°F) for not less than 24 hours in accordance with Procedure A in ASTM D 618 for those tests where conditioning is required, and unless otherwise specified.

8.2. *Conditions*—Conduct all tests at a laboratory temperature of 21 to 25ºC (70 to 77°F) unless otherwise specified herein.

9. TEST METHODS

9.1. *Pipe Stiffness*—Select a minimum of two pipe specimens and test for pipe stiffness $F/\Delta y$, as described in ASTM D 2412, except for the following conditions:

1. The length of the test specimen shall be a whole number of wraps, with a minimum length of four wrap widths or half the pipe diameter, whichever is greater.
2. Randomly orient each specimen in the loading machine.
3. Testing speed of the specimens shall be 12.5 mm per minute (0.5 in. per minute) for testing up to 5 percent deflection. For flattening beyond 5 percent deflection (see Section 9.2), it is permissible to increase test speeds up to 125 mm per minute (5 in. per minute).
4. The deflection indicator shall be readable and accurate to ±0.02 mm (0.001 in.).
5. The beginning point for deflection measurement shall be at a load of 20 ± 5 newtons (4.5 ± 1.1 lbf). The point shall be considered as the origin of the load deflection curve.

9.2. *Flattening*—Flatten the two pipe samples from Section 9.1 until the vertical inside diameter is reduced by 20 percent. The length of the test specimen and the rate of loading shall be the same as in Section 9.1. Examine the specimen with the unaided eye for cracking, splitting, or delamination. It is permissible for the ribs to lean during this test only to the extent that neither the above requirements nor the shape stability requirements (Section 7.8) are failed.

9.3. *Impact*—Test pipe specimens in accordance with ASTM D 2444 except that six specimens shall be tested. Specimens shall be at least four wrap widths in length and impact points shall be at least 152 mm (6 in.) from the end of the specimen. Impact resistance shall not be less than 136 J. Tup B and a flat plate specimen holder shall be used. Condition the specimens for 24 hours at a temperature of 0 ± 1°C (32 ± 2°F), and conduct all tests within 60 seconds of removal from this atmosphere.

9.4. *Tensile Strength of Seam—Test in accordance with ASTM D 638, with the following conditions*:

1. The sample shall be prepared according to the dimensions for Type I specimens, with the weld seam arranged centrally and perpendicular to the tensile test axis.
2. All steel reinforcement shall be removed from the profile.
3. It is permissible to reduce the height of the HDPE ribs to no less than 2.5 mm (0.1 in.) if required to facilitate testing.

9.5. *Joint Integrity*—Assemble each fitting or coupling to the appropriate pipe in accordance with the manufacturer's recommendations. Use pipe samples at least 300 mm (12 in.) in length. Assemble a specimen at least 600 mm (24 in.) in length with the connection at the center. Load the connected pipe and fitting between parallel plates at the rate of 12.5 mm per minute (0.5 in. per minute) until the vertical inside diameter is reduced by at least 20 percent of the nominal diameter of the pipe. Inspect for splitting, cracking, delamination, or other damage while at the specified deflection and after load removal.

9.6. *Slow Crack Growth Resistance of Resin Compounds*—Test basic resin compounds for stress crack resistance in accordance with the ASTM F 2136, the NCLS test, except for the following modifications:

9.6.1. The applied stress for the NCLS test shall be 4100 kPa (600 psi).

9.6.2. Resin test specimens shall be plaques molded from the reground resin from the rotomolded or injection-molded parts.

Note 4—The notched depth of 20 percent of the nominal thickness of the specimen is critical to this procedure.

9.7. *Delamination*—Test the fusion of the weld between the inner and outer wall of the wrap width with a probe or knife point. It shall not be possible to separate cleanly the two walls at the lap seam weld. Test samples at eight equally spaced points around its circumference.

9.8. *Dimensions*:

9.8.1. *Inside Diameter*—Measure the inside diameter of three specimens, each a minimum of 300 mm (12 in.) long with any suitable device accurate to 0.8 mm (0.03 in.), at two positions, namely, any point in the circumferential direction and 90 degrees from this point, and average the six measurements. Inside diameter shall meet the requirements of Section 7.4.1.

9.8.2. *Waterway Wall*—Locate and measure the wall thickness between the ribs at four equally spaced locations around the circumference of the pipe, in accordance with ASTM D 2122.

9.8.3. *Length*—Measure pipe with any suitable device accurate to ±6.0 mm in 3 m (±0.25 in. in 10 ft). Make all measurements on the pipe while it is resting on a relatively flat surface, in a straight line, with no external tensile or compressive forces exerted on the pipe. These measurements may be taken at ambient temperatures.

9.8.4. *Encapsulation Thickness*—Locate and measure the encapsulation thickness by cutting a cross section and measuring in accordance with ASTM D 2122.

9.8.5. *Perforations*—Measure dimensions of perforations on a straight profile specimen with no external forces applied. Make linear measurements with instruments accurate to 0.2 mm (0.08 in.).

9.9. *Stub Compression Capacity*:

9.9.1. Determine the stub compression capacity of the pipe section in accordance with T 341. Conduct four tests on specimens cut from the same ring of pipe at 90 degree intervals around the circumference.

10. INSPECTION AND RETEST

10.1. *Inspection*—Inspection of the material shall be made as agreed upon by the purchaser and the seller as part of the purchase contract.

10.2. *Retest and Rejection*—Retesting in the event of a test failure shall be conducted on samples from the failed lot only under an agreement between purchaser and seller. There shall be no changes to the test procedures or the requirements.

11. MARKING

11.1. *All pipe shall be clearly marked at intervals of no more than 3.5 m (11.5 ft) as follows*:

11.1.1. Manufacturer's name or trademark.

11.1.2. AASHTO MP 20.

11.1.3. Nominal inside diameter.

11.1.4. The plant designation code.

11.1.5. The date and location of manufacture or an appropriate production code. If a date code is used, a durable manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

Note 5—A durable sticker is one that is substantial enough to remain in place and be legible through installation of the pipe.

11.2. Fittings shall be marked with the designation number of this specification, AASHTO MP 20, and with the manufacturer's identification symbol.

12. QUALITY ASSURANCE

12.1. A manufacturer's certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results and the date each test was completed shall be furnished upon request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL/QUALITY ASSURANCE PROGRAM

X1.1. *Scope*:

X1.1.1. As required in Sections 10 and 12, the acceptance of these products relies on the adequate inspection and certification agreed to between the buyer and the seller/manufacturer. This appendix should serve as a guide for both the manufacturer and the user. It places the responsibility on the manufacturer to control the quality of the material they produce and to provide the quality control.

X1.2. *Program Requirements*:

X1.2.1. The manufacturing company must have a quality control plan approved by the specifying agency.

X1.2.2. The manufacturing plant must have an approved quality control plan.

X1.2.3. The plant must have an approved laboratory, either within the company or an independent laboratory.

X1.2.4. The manufacturing plant(s) must have a designated quality control technician.

X1.3. *Quality Control Plan*:

X1.3.1. The manufacturer must supply to the specifying agency a written quality control plan that shows how the producer will control the equipment, materials, and production methods to insure that the specified products are supplied. The following information must be included in the plan:

X1.3.1.1. Titles of the personnel responsible for production quality at the plant(s).

X1.3.1.2. The physical location of the plant(s).

X1.3.1.3. The methods of identification of each lot of material during manufacturing, testing, storage, and shipment. The method of identification shall allow the specifying agency to trace the finished product to the material provider.

X1.3.1.4. The method of sampling and testing of raw materials and of finished product, including lot sizes and types of tests performed.

X1.3.1.5. A plan for dealing with nonconforming product, including how the manufacturer plans to initiate immediate investigation and how corrective action will be implemented to remedy the cause of the problem.

X1.4. *Approved Laboratory*:

X1.4.1. All tests must be conducted at laboratories approved by the specifier. Each manufacturer may establish and maintain its own laboratory for performance of quality control testing or may utilize an approved independent laboratory. Records of instrument calibration and maintenance and sample collection and analysis must be maintained at the laboratory.

X1.5. *Quality Control Technician*:

X1.5.1. All samples must be taken and tested by quality control technicians designated by the manufacturer. The designated quality control technicians will be responsible for overall Quality Control at the manufacturing plant.

X1.6. *Annual Update*:

X1.6.1. An annual update may be required. The annual update may be submitted by the manufacturer to the specifying agency by December 31 of each calendar year.

X1.7. *Plant Approval*:

X1.7.1. The plant approval process requires the manufacturer to submit an annual update to the specifying agency. The update must identify the specific product manufactured at the plant.

X1.7.2. The specifying agency will review the manufacturer's written quality control plan, and a plant inspection may be scheduled. This inspection will verify that the quality control plan has been implemented and is being followed and that at least one designated quality control technician is on-site and will be present when material is being produced under this program. The laboratory will be inspected and approved if it meets the requirements.

X1.8. *Sampling and Testing*:

X1.8.1. The quality assurance plan approved for each manufacturer, or manufacturer's location, or both, shall detail the methods and frequency of sampling and testing for all raw materials and products purchased or manufactured at that location. All testing shall be in accordance with current specifications and procedures referenced in MP 20.

X1.8.2. Samples of materials and pipe may be taken by the specifying agency.

X1.8.3. The specifying agency may require an annual third-party independent assurance test.

X1.9. *Sample Identification and Record Keeping*:

X1.9.1. Manufacturer's quality control samples are to be uniquely identified by the producing plant.

X1.9.2. Quality control and quality assurance data are to be retained by the manufacturer for 2 years and made available to the specifying agency upon request.

X1.9.3. Quality control test reports shall include the lot identification.

X1.9.4. Unless requested at the time of ordering, test reports do not have to be filed for specific projects.

X1.9.5. Reports shall indicate the action taken to resolve nonconforming product.

Standard Practice for

Pipe Joint Selection for Highway Culvert and Storm Drains

AASHTO Designation: PP 63-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Pipe Joint Selection for Highway Culvert and Storm Drains

AASHTO Designation: PP 63-09[1]

1. SCOPE

1.1. Pipe joint design considerations are a critical component for the overall performance of culvert and storm drain installations. Experience has shown that the component responsible for many culvert and sewer performance problems and failures can be traced back to the pipe joint. The structural and hydraulic performance of the joint affects the stability of backfill and soil envelope around the pipe, the line and grade of the culvert, integrity of the overlying embankment and pavement, and compliance to storm and sanitary sewer permits. This practice is to provide clear definitions of joint performance terms, rational design methodology to determine appropriate joint performance requirements, and uniform criteria for manufacturers’ joint qualification and contractors' post-installation pipe joint testing.

1.2. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 36, Corrugated Steel Pipe, Metallic-Coated, for Sewers and Drains
- M 198, Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants
- M 288, Geotextile Specification for Highway Applications
- M 294, Corrugated Polyethylene Pipe, 300- to 1500-mm Diameter
- M 304, Poly(Vinyl Chloride) (PVC) Profile Wall Drain Pipe and Fittings Based on Controlled Inside Diameter
- M 315, Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets
- *AASHTO LRFD Bridge Construction Specifications*

2.2. *ASTM Standards*:

- C 443, Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets
- C 497, Standard Test Methods for Concrete Pipe, Manhole Sections, or Tile
- C 877, Standard Specification for External Sealing Bands for Concrete Pipe, Manholes, and Precast Box Sections
- C 924, Standard Practice for Testing Concrete Pipe Sewer Lines by Low-Pressure Air Test Method

- C 969, Standard Practice for Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines
- C 1091, Standard Test Method for Hydrostatic Infiltration Testing of Vitrified Clay Pipe Lines
- C 1103, Standard Practice for Joint Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines
- C 1619, Standard Specification for Elastomeric Seals for Joining Concrete Structures
- D 3212, Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- F 477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- F 1417, Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *brownfields*—abandoned industrial or commercial sites with some soil contamination from previous use, now available for new construction.

3.1.2. *erodible conditions*—soil or backfill materials or conditions where the soil or backfill surrounding the pipe may be removed by the flow of liquid (water) leaking from the pipe or pipe joint.

3.1.3. *exfiltration*—the passage of fluid from a pipe section through small openings or leaks in the pipe wall or in the joint. Fluid that enters the pipe backfill may change the structural characteristics of the backfill or cause migration of the backfill or surrounding soils.

3.1.4. *infiltration*—the passage of fluid into a pipe section through small openings in the pipe wall or in the joint. Extraneous flow entering a pipe system may cause migration of the backfill or surrounding soils into the pipe and change the structural characteristics of the backfill.

3.1.5. *leakage rate*—an amount of infiltration or exfiltration within the pipe system. A maximum leakage rate may be established as a condition of project compliance to assure structural quality and proper installation.

3.1.6. *leak resistance*—Leak resistance refers to a system that is not completely (100 percent) watertight, but allows some defined allowable rate of water leakage into and out of the system.

3.1.7. *leak-resistant joint*—a joint that limits water leakage at a maximum rate of 200 gallons/inch-diameter/mile/day for the pipeline system for the project specified head or pressure.

3.1.8. *post-installation test*—leakage test conducted after pipe installation and backfill utilizing air or water to verify project specification compliance when required as a condition of project acceptance.

3.1.9. *proof of design*—laboratory or in-plant tests for leakage through the pipe or pipe joint under pressure or vacuum that verifies the performance of the pipe joint in a specific test. This type of test may not directly correlate to field performance.

3.1.10. *restrained joints*—joints used for applications in which the joint may be subject to significant tensile and shear forces and moments. Examples of these applications are installations on slopes, sites where differential settlement may occur, and pipes for high pressures and high heads or velocities.

3.1.11. *silt-tight joint*—a joint that is resistant to infiltration of particles that are smaller than particles passing the No. 200 sieve. Silt-tight joints provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an elastomeric rubber seal or geotextile.

3.1.12. *silt-tightness*—refers to a pipe system's resistance against fine soil migration through the openings of the joint.

3.1.13. *soiltight joint*—a joint that is resistant to infiltration of particles larger than those retained on the No. 200 sieve. Soiltight joints provide protection against infiltration of backfill material containing a high percentage of coarse grain soils, and are influenced by the size of the opening (maximum dimension normal to the direction that the soil may infiltrate) and the length of the channel (length of the path along which the soil may infiltrate).

3.1.14. *soiltightness*—refers to a pipe system's resistance to coarse grained soil migration through the openings of the joint.

3.1.15. *special design joint*—joints requiring special strength in bending or shear, pull-apart capabilities, or unusual features such as restrained joints placed on severe slopes, welded joints, or flanged and bolted joints for high pressures, high heads, or velocities, etc., typically described within special provisions of the project specifications.

3.1.16. *watertight joint*—a joint that provides zero leakage of water infiltration and exfiltration for a specified head or pressure application. Watertight joints typically utilize a resilient rubber seal of some type and are capable of passing a laboratory hydrostatic pressure and vacuum test of at least 10.8 psi without leakage.

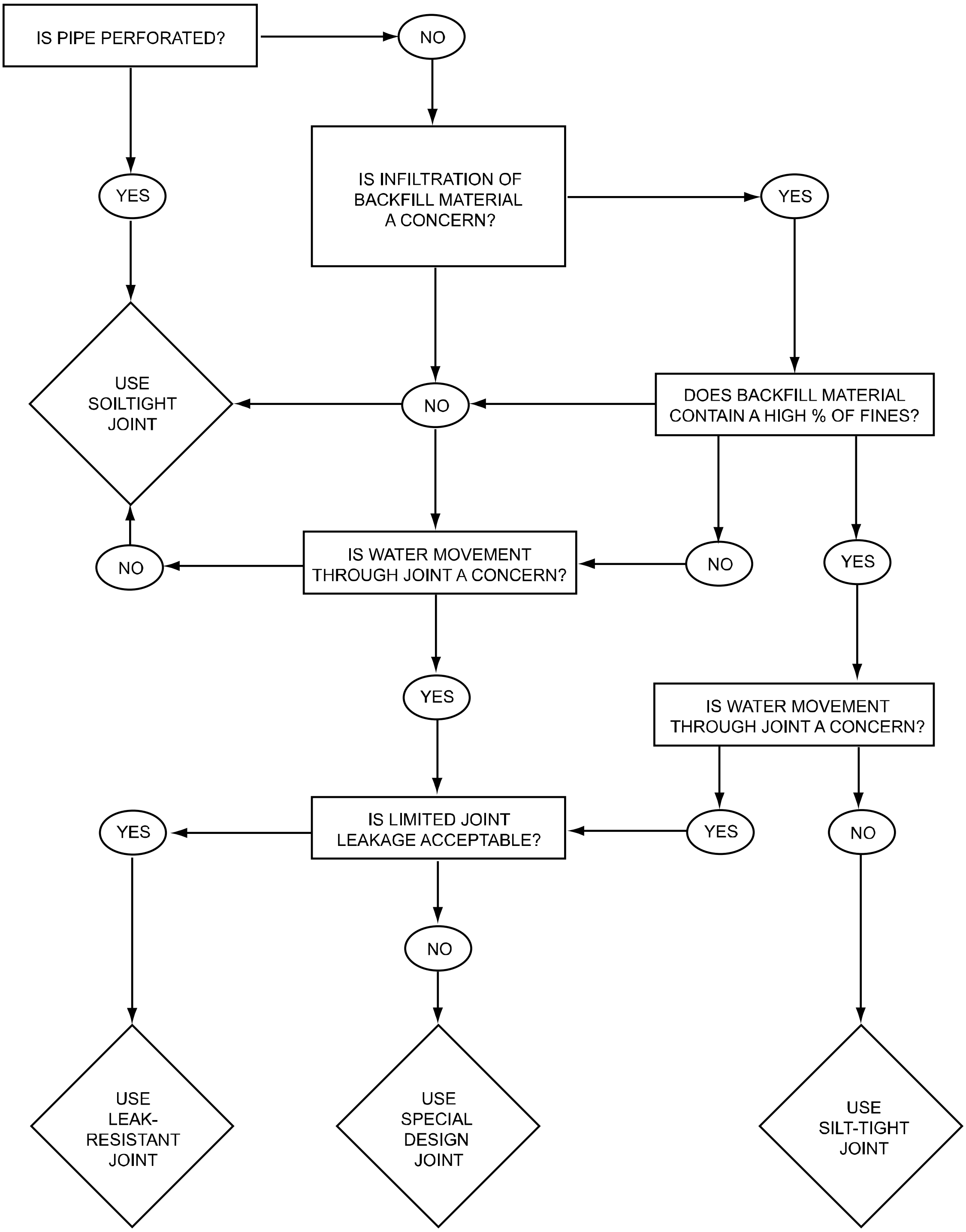
3.1.17. *watertightness*—refers to a system that has zero leakage or infiltration. This is most commonly applied to joints when lab-tested hydrostatically to a specified pressure and/or vacuum specified by the joint standard.

4. SUMMARY OF PRACTICE

4.1. This practice establishes accepted definitions and performance criteria for the joints of buried pipe. Guidance is provided on the selection process for the appropriate joint, and the standard procedures for verifying performance of the joint, both at the plant and in the field when specified, to ascertain that it meets the required performance criteria. The purpose of this practice is to produce consistent performance levels regardless of the piping material used on the project.

5. PROCEDURE

5.1. Examine the Pipe Joint Selection Process Flowchart in Figure 1. The first consideration in the pipe joint selection decision process is to determine whether the pipe for the application is solid or perforated. If the pipe is perforated, then the joint shall have openings no larger than the perforations in the pipe wall.



LEAKAGE RATE (MAXIMUM)
–200 gal/in.-dia/mi/day

Figure 1—Pipe Joint Selection Process Flowchart

5.1.1. For non-perforated pipe, a determination must be made as to the acceptability of allowing infiltration and/or exfiltration through the pipe joint. If infiltration of backfill material is not a concern and water movement through the joint is not a concern, then the default or soiltight joint should be selected for this type of application. The purpose of the soiltight joint is to maintain backfill integrity and pipe alignment and to join the ends/sections of pipe together to allow a continuous flow of water while maintaining the interior required gap between sections. This joint will limit the infiltration of soil particles in the backfill material to particles that will pass through a No. 200 sieve.

5.1.2. For non-perforated pipe where infiltration of backfill material is a concern, the designer should examine the composition of the backfill material. If there is a high percentage of soil fines (Note 1) finer than the No. 200 sieve, then a silt-tight joint should be selected for most applications.

Note 1—A high percentage of fines are defined as more than 35 percent passing the No. 200 sieve.

5.1.3. If water movement through a joint is a concern, a leak-resistant joint or a special design joint should be selected.

5.1.4. If limited joint leakage is acceptable, a leak-resistant joint shall be specified. This joint will limit water leakage at a maximum rate of 200 gallons/inch-diameter/mile/day for the pipeline system for a specified head or pressure.

5.1.5. If limited joint leakage is not acceptable, a special design joint shall be specified.

5.2. Sections 8 and 9 should be consulted once the type of joint has been selected. These sections present various methods for constructing a soiltight, silt-tight, leak-resistant, or special design joint for each type of pipe material.

5.3. To ensure proper joint performance, the pipe joint integrity shall be established by the pipe joint manufacturer prior to shipping the pipe, and further verified in the field by the contractor as witnessed by the project inspector. The manufacturer shall perform plant verification tests when specified in accordance with the Plant Test Requirements for the appropriate pipe material in Section 6. This will ensure a suitable pipe joint is being delivered to the job site. Upon completion of the installation of the pipe, field verification of any leakage requirements by visual inspection or applicable testing shall be performed by the contractor and/or engineer when specified in accordance with the Field Test Requirements outlined for the appropriate pipe material in Section 7. Failure to pass either one of these requirements when specified is cause for rejection of the pipe.

6. PLANT TEST REQUIREMENTS

6.1. *Soiltight Joint*:

6.1.1. Soiltight joints are specified as a function of opening size (maximum dimension normal to the direction that soil may infiltrate), channel length (length of the path along which the soil may infiltrate), and backfill particle size. If the size of the opening exceeds $^1/_8$ in., the length of the channel must be at least four times the size of the opening. No opening may exceed 1 in.

6.1.2. *Concrete Pipe*:

6.1.2.1. Concrete pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications.

6.1.2.2. Plain joints utilizing mortar, mastic, external geotextile wraps, and rubber gaskets are all considered soiltight joints when assembled correctly in the field.

6.1.3. *Corrugated Metal Pipe*:

6.1.3.1. Corrugated metal pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications.

6.1.3.2. Externally banded corrugated or partially corrugated metal pipe bands that are a minimum of 7.5 in. wide and used with annularly corrugated pipe ends are considered soiltight when the assembled dimensions meet the requirements of the *AASHTO LRFD Bridge Construction Specifications*, Section 26.

6.1.3.3. Corrugated metal pipe joints with a bell and spigot configuration conforming to Section 9.1.7 of M 36 are considered soiltight when assembled dimensions meet the requirements of *AASHTO LRFD Bridge Construction Specifications*, Section 26. Pipe shall be visually inspected to verify minimum requirements.

6.1.4. *Plastic Pipe*:

6.1.4.1. Plastic pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.2. *Silt-Tight Joint*:

6.2.1. A silt-tight joint is resistant to infiltration of particles that pass the No. 200 sieve. Silt-tight joints are specified to provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an Elastomeric rubber seal or geotextile wrap. Geotextile wraps are manufactured to tolerances that assure silt will not pass through them. The successful performance of these wraps in the field is dependent on their installation. If a geotextile wrap is specified for use, the material specified should meet M 288 with an Apparent Opening Size (AOS) > 70.

6.2.2. *Concrete Pipe*:

6.2.2.1. Concrete pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.2.2.2. Concrete pipe joint designs meeting silt-tight joint requirements that utilize a rubber gasket or mastic filler as the sole method of sealing shall verify compliance to the silt-tight requirements by requiring the joint design be subjected to a production pipe proof test by a plant hydrostatic test described in Section 6.2.2.3. Upon successful proof testing of the joint design, further joint acceptance of the pipe to be furnished to the project shall be based on joint dimensional verification and certification that the joint configuration and gasket or mastic filler conforms to the approved joint.

6.2.2.3. *Plant Proof-of-Design Test*—Plant proof-of-design test for silt-tight joints shall be in accordance with M 315 (ASTM C 443) except the maximum hydrostatic test pressure shall not be greater than 2 psi for the straight and deflected position.

6.2.2.4. Concrete pipe joint designs meeting silt-tight joint requirements that utilize an external joint wrap as the sole method of sealing shall verify compliance to the silt-tight requirements by having the joint design include the placement around the entire circumference of the joint by either (a) external sealing bands per ASTM C 877 or (b) 12-in. wide geotextile separation fabric meeting requirements of Section 6.2.1 of this standard.

6.2.3. *Corrugated Metal Pipe*:

6.2.3.1. Corrugated metal pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.2.3.2. Corrugated metal joints, including the bell and spigot configuration, are considered silt-tight when they are wrapped around their entire circumference with a minimum 12-in. wide geotextile separation fabric meeting the requirements of Section 6.2.1 of this standard. Pipe shall be visually inspected to verify minimum requirements.

6.2.3.3. Externally banded corrugated or partially corrugated metal pipe bands that are a minimum of 10.5 in. wide and fully corrugated with annularly corrugated pipe ends are considered silt-tight when the assembled dimensions meet the requirements of the *AASHTO LRFD Bridge Construction Specifications*, Section 26.

6.2.3.4. Bell and spigot joints that use an elastomeric gasket as the sole means of sealing the joint shall meet the performance requirements of ASTM D 3212, with the exception that the maximum hydrostatic test pressure shall be a minimum of 2 psi.

6.2.3.5. Silt-tight joints shall meet the requirements of *AASHTO LRFD Bridge Construction Specifications*, Section 26 for erodible soils.

6.2.4. *Plastic Pipe*:

6.2.4.1. Plastic pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.2.4.2. Silt-tight joints shall utilize an elastomeric rubber seal meeting the requirements of ASTM F 477. Alternative methods of joining (e.g., external joint wraps) shall be allowed provided the requirements of Section 6.2.4.3 are achieved.

6.2.4.3. Silt-tight performance shall be verified by meeting the requirements of ASTM D 3212, with the exception that the hydrostatic test pressure shall be a minimum of 2 psi.

6.3. *Leak-Resistant Joint*:

6.3.1. A leak-resistant joint is specified when water leakage into or out of the pipeline system is a concern. Leak-resistant joints limit water leakage at a maximum rate of 200 gallons/inch-diameter/mile/day for a specified head or pressure.

6.3.2. *Concrete Pipe*:

6.3.2.1. Concrete pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.3.2.2. Concrete pipe joint designs meeting leak-resistant joint requirements that utilize a rubber gasket or mastic filler as the sole method of sealing shall verify compliance to the leak resistant requirements by having the joint design, represented by a production pipe, proof tested by a plant hydrostatic test described in Section 6.3.2.3. Upon successful proof testing of the joint design, further joint acceptance of the pipe to be furnished to the project shall be based on joint dimensional verification and certification that the joint configuration and gasket conforms to the approved joint.

6.3.2.3. *Plant Proof-of-Design Test*—Plant proof-of-design test for a leak-resistant joint shall be in accordance to M 315 (ASTM C 443), with the maximum test pressures of 10.8 psi in the straight alignment and 10 psi in the deflected alignment.

6.3.2.4. Concrete pipe joint designs meeting leak-resistant joint requirements and utilizing an external joint wrap as the sole method of sealing shall verify compliance to the leak-resistant requirements by requiring that the joint design include the placement around the entire circumference of the joint by an external sealing band as specified by ASTM C 877 Type 1 or Type 2.

6.3.3. *Corrugated Metal Pipe*:

6.3.3.1. Corrugated metal pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications.

6.3.3.2. *Plant Proof-of-Design Test*—AASHTO standards have not yet been developed to demonstrate a plant proof-of-design test for corrugated metal pipe. A suitable plant proof-of-design test is recommended to be provided by the manufacturer. This plant proof-of-design should test the leak-resistant joint under conditions more severe than expected in the field in order to allow for the greater installation variables that occur in the field compared with plant testing. Pipe pressures for the plant proof-of-design test are recommended to be on the same order as required for concrete pipe and plastic pipe.

6.3.4. *Plastic Pipe*:

6.3.4.1. Plastic pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.3.4.2. Leak-resistant joints shall be bell and spigot and utilize an elastomeric rubber seal meeting the requirements of ASTM F 477. Alternative methods of joining (e.g., external joint wraps) shall be allowed provided the requirements of Section 6.3.4.3 are achieved.

6.3.4.3. *Plant Proof-of-Design Test*—Plant proof-of-design test for leak resistance shall be verified in the lab by meeting all of the requirements of ASTM D 3212. The hydrostatic test pressure and vacuum specified in the test method shall be 10.8 psi.

6.4. *Special Design Joint*:

6.4.1. *Concrete, Corrugated Metal, and Plastic Pipe*:

6.4.2. Special design joints are joints requiring special strength in bending or shear, pull-apart capabilities, or unusual features such as restrained joints placed on severe slopes, welded joints, flanged and bolted joints for high pressures, high heads, or velocities. These joints are typically described within the special provisions of the project specifications. Watertight joints that provide zero leakage for a specified head or pressure application are included in this category.

6.4.3. Special design pipe joints shall be inspected to ensure dimensions and tolerances are in accordance with the design joint. Pipe, gaskets, wraps, and all other material used to make and seal the joint shall be inspected for compliance to their respective specifications. All measurements shall be made in accordance with AASHTO and ASTM standards.

6.4.4. Special design pipe joints shall be tested in accordance to the project specifications.

7. FIELD TEST REQUIREMENTS

A minimum of five percent of all installed pipe joints will be inspected unless otherwise specified by an agency.

7.1. *Soiltight Joints*:

7.1.1. *Concrete, Corrugated Metal, and Plastic Pipe*:

7.1.1.1. Installed pipe joints shall have a visual or video inspection in the field to ensure compliance to the project specifications. Open joints or joints that are flowing particles larger than those particles retained on a No. 200 sieve shall be repaired or replaced as necessary to comply with the requirements of this standard. (See *AASHTO LRFD Bridge Construction Specifications*, Sections 26, 27, and 30 on cracks and joint defects.)

Note 2—If particles larger than those retained on a No. 200 sieve are restricted from passing through the joint, then the joint has performed its intended design function. However, if there is a significant presence of particles smaller than those retained on a No. 200 sieve passing through the joint, it may mean that the initial design assumption of a soiltight joint requirement was incorrect, and remedial action may need to be taken.

7.2. *Silt-Tight Joints*:

7.2.1. *Concrete, Corrugated Metal, and Plastic Pipe*:

7.2.1.1. Installed pipe joints shall have a visual or video inspection in the field to ensure compliance to the project specifications. Open joints or joints showing sediment as a result of flowing infiltration or exfiltration of particles shall be repaired or replaced as necessary to comply with the requirements of this standard. (See *AASHTO LRFD Bridge Construction Specifications*, Sections 26, 27, and 30 on cracks and joint defects.)

7.3. *Leak-Resistant Joints*:

7.3.1. *Concrete, Corrugated Metal, and Plastic Pipe*:

7.3.1.1. Installed pipe joints shall have a visual or video inspection to ensure compliance to the project specifications. Open joints or joints showing sediment as a result of measurable infiltration or exfiltration shall be repaired or replaced as necessary to comply with the requirements of this standard. If joints are showing leakage or the pipeline is required by specification to be tested, they shall be tested in accordance with the specific project specifications. Testing procedures that may be used for concrete, corrugated metal, or plastic pipe sections are listed below. (See *AASHTO LRFD Bridge Construction Specifications*, Sections 26, 27, and 30 on cracks and joint defects.)

7.3.1.2. Installed pipe joints shall be tested to meet the performance requirements of a leak-resistant joint as specified in accordance with ASTM C 969.

7.3.1.3. As an alternative, concrete pipe joints may be tested in accordance with ASTM C 924. Concrete pipelines with diameters of 27 in. or greater are permitted to utilize successful completion of ASTM C 1103 to verify compliance to project specifications.

7.3.1.4. As an alternative, plastic pipe joints may be tested in accordance with ASTM F 1417.

7.4. *Special Design Joint*:

7.4.1. *Concrete, Corrugated Metal, and Plastic Pipe*:

7.4.1.1. Pipe joints shall have a visual or video inspection in the field to ensure compliance to the project specifications. Open joints or joints showing sediment as a result of measurable infiltration or exfiltration, when prohibited by project specification, shall be repaired or replaced as necessary to comply with the requirements of this standard.

7.4.1.2. Installed pipe joints shall be tested in accordance with project specifications.

7.4.1.3. *AASHTO LRFD Bridge Construction Specifications*, Section 26 covers standard and special strength requirements for use with soft foundations, slope drains, and curvilinear installations. Strength and performance limits beyond these may be specified as required.

7.4.1.4. When restrained joints are required, separation of the joint shall not exceed the limit specified on the project plans or in the specifications.

8. ENGINEERING DESIGN CONSIDERATIONS

8.1. *Joint Selection Criteria*—Joint selection should be based on the following criteria:

8.1.1. *Soiltight Joint*—Soiltight joints may be specified where the passage of water through the joint to or from the surrounding soil is acceptable or even desirable, and where the migration of backfill or soil through the joint is not likely due to the backfill gradation or low migration probability of the soil. Openings in the joint should be of such size that the surrounding material could not pass into the pipe. Perforated pipe may have soiltight joints provided the openings in the joint are no larger than the perforations in the pipe. Perforated pipe utilizing a geotextile wrap should have the wrap extend over the entire joint assembly.

8.1.2. *Silt-tight Joint*—Silt-tight joints may be specified where the passage of water through the joint to or from the surrounding soil is acceptable, but the infiltration or fines from the surrounding backfill or soil is precluded. Silt-tight joints can incorporate an appropriate geotextile wrap, a rubber gasket, or both. Silt-tight joints that employ a rubber gasket as the sole means to seal the joint to silt-tightness should pass a 2 psi laboratory test utilizing the test specified in Section 6.

8.1.3. *Leak-resistant Joint*—Leak-resistant joints may be specified where only very limited joint leakage is acceptable. These joints should be required when it is undesirable to allow leakage of storm water from the pipe into the surrounding soil, or leakage of groundwater from the surrounding soil into the pipe. The acceptable leakage rate should be shown in the project specifications as defined by the design engineer. Leak-resistant joints provide additional assurance against soil migration into the pipe.

8.1.3.1. Leak-resistant joints require careful inspection to assure compliance to allowable leakage rate. If any visible leakage is seen or if required by project specifications, additional field leakage testing is required. Successful completion of this testing is required for pipeline acceptance.

8.1.3.2. The designer should be aware of sewer projects that may require allowable leakage rates less than the leak-resistant joint described herein due to specific permit requirements or local ordinances. Some examples are sanitary sewers, pipelines in potable water well-head protected areas, or conduits buried in or transporting hazardous effluents. In such cases, special joints will be required.

8.1.4. *Special Joints*—Special joints may include restrained joints, welded joints, or any special configuration required to meet specific project demands not described in this practice.

8.1.4.1. Restrained joints may be required when pipe is installed on a steep slope or where internal pressure or force may generate pull-apart forces. Installations such as slope drains may require some restraint to prevent pull-apart. Restraints are normally mechanical in design, utilizing restraining systems across the pipe joint or by employing corrugated pipe bands for corrugated metal pipe.

8.1.4.2. Welded joints may be required where leakage is completely unacceptable. Field welding of steel pipe should be done as specified by M 36, Sections 7.4 and 7.6. Thermoplastic pipe may be welded using butt fusion, extrusion welding, or resistance welding.

8.2. *Joint Testing*—Pipe joint test requirements are divided between manufacturer's laboratory (plant) proof-of design testing and joint specification verification tests, and post-installation testing to verify pipeline performance and project specification compliance. Basic requirements are given in Table 1.

Table 1—Proposed AASHTO Pipe Joint Descriptions and Test Procedures

Joint Type	Joint Description	Laboratory Test	Field Test
Soiltight	Soiltight joints prohibit the migration of soil larger than No. 200 sieve through the joint. Soil-tight joints are specified as a function of opening size, channel length, and backfill particle size. If the size of the opening exceeds 3 mm, the length of the channel must be at least four times the size of the opening. Soiltight joints may utilize connecting bands, elastomeric rubber seals, geotextile wrap, or applied bulk mastic sealant.	Assemble a typical joint and measure openings.	Visual for proper assembly.
Silt-tight	Silt-tight joints prohibit the migration of soil smaller than No. 200 sieve through the joint. Silt-tight joints may utilize connecting bands, elastomeric rubber seals, geotextile wrap, or all of these.	Geotextile wrap shall meet AASHTO M 288, Table 2, with an Apparent Opening Size (AOS) > 70. Gasket shall meet respective pipe joint standard. Joints utilizing gasket only as silt-tight seal shall be designed to pass a laboratory test of 2 psi.	Visual for excessive leakage or leakage carrying soil fines.
Leak-Resistant	Leak-resistant joints are specified where only very limited joint leakage is acceptable The allowable rate is to be shown in the project specifications. Leak-resistant joints may utilize connecting bands, elastomeric rubber seals, impervious wrap, or all of these.	Impervious wraps shall meet ASTM C 877 Type 1 or 2. Gaskets shall meet respective pipe joint standard. Joints meeting leak - resistant criteria shall be designed to pass a laboratory test/proof-of-design test that demonstrates compliance with the leakage rate at the specified head or pressure.	Visual for leakage and/or specified standard test methods for installation acceptance of gravity sewer lines using low-pressure air or water, or vacuum.
Special	Special joints are any joint system or performance requirements not mentioned within this practice. These joints typically require a special provision to be written into the project specifications to cover the unique aspects of the joint system needed. Some examples of special joints are pressure-rated joints, restrained joints, welded joints.	As specified in project documents.	As specified in project documents.

9. RATIONALE

9.1. Joint specifications for the various pipe materials have been developed largely independent of one another. While many similarities exist among the separate joint specifications, there are also key differences due to the differing joint configurations and designs of the various pipe materials. Though each pipe material may have its own plant or laboratory verification test, it is important that all pipes in a given joint classification perform to a defined and consistent level once installed.

9.2. Upon installation, joints may be tested to a specified performance level. In the past, buried pipes have been specified as meeting soiltight, silt-tight, or watertight joint performance requirements. However, due to the vague definition of these performance levels for the various pipe materials, verification of joint performance in the field has been difficult. The purpose of this practice is to standardize the definitions of the performance levels of joining systems for all pipe materials and the means by which that specified performance level is verified.

9.3. More consistent specification of pipe joints will result when all parties involved understand the process of selecting the correct pipe joint for each particular application, and the criteria that must be met as a result of the definition of that particular type of joint. This practice establishes accepted definitions and performance criteria for the joints of buried pipe.

APPENDIX

(Nonmandatory Information)

X1. JOINT TESTING CRITERIA

X1.1. To assist the designers' knowledge regarding various joint testing criteria established by existing ASTM standards or employed by other departments within AASHTO, this listing and testing protocols are provided. These Department Of Transportation test methods are for informational purposes and are not necessarily the recommended specifications of the Subcommittee on Materials.

X2. STANDARD LEAKAGE TEST METHODS

Note X1—This section could include any other testing standard or information not previously discussed within the body of this practice.

X2.1. *Departments of Transportation Test Methods and Requirements*:

X2.1.1. *Washington State Department of Transportation*:

7-04.3(4) Cleaning and Testing

7-04.3(4)A General

Storm sewers and appurtenances, where required in the Plans, shall be cleaned and tested after backfilling by either the exfiltration or low-pressure air method at the option of the Contractor, except where the ground water table is such that the Engineer may require the infiltration test.

All work involved in cleaning and testing sewer lines between manholes or rodding inlets as required shall be completed within 15 working days after backfill of sewer lines and structures. Any further delay will require the written consent of the Engineer. The Contractor shall furnish all labor, materials, tools, and equipment necessary to make the test and clean the lines. The Contractor shall perform the tests in the presence of the Engineer. Precautions shall be taken to prevent joints from drawing during tests, and any damage resulting from these tests shall be repaired by the Contractor at no expense to the Contracting Agency. The manner and time of testing shall be subject to approval by the Engineer.

All wyes, tees, and stubs shall be plugged with flexible jointed caps, or acceptable alternate, securely fastened to withstand the internal test pressure. Such plugs or caps shall be readily removable, and their removal shall provide a socket suitable for making a flexible jointed lateral connection or extension.

If the Contractor elects to test large-diameter pipe one joint at a time, leakage allowances shall be converted to per joint by calculating the allowable leakage as described in Section 7-04.3(4)B or 7-04.3(4)C and then dividing by the number of joints in the tested section. If leakage exceeds the allowable amount, corrective measures shall be taken and the line then retested to the satisfaction of the Engineer.

If any storm sewer installation fails to meet the requirements of the test method used, the Contractor shall determine the source or sources of leakage and shall repair or replace all defective materials and/or workmanship at no expense to the Contracting Agency. The complete pipe installation shall meet the requirements of the test method used before being considered acceptable.

7-04.3(4)B Exfiltration Test—Storm Sewers

Prior to making exfiltration leakage tests, the Contractor may fill the pipe with clear water to permit normal absorption into the pipe walls, provided the leakage test shall be completed within 24 hours after such filling.

Leakage shall be not more than 5 liters per hour per meter of diameter per meter of storm sewer pipe, with a minimum test pressure of 2 meters column above the crown at the upper end of the pipe or above the active ground water table, whichever is higher as determined by the Engineer. The length of pipe tested shall be limited so that the pressure on the invert of the lower end of the Section tested shall not exceed 5 meters of water column. For each increase in pressure of 0.5 meter above a basic 2 meters measured above the crown at the lower end of the test section, the allowable leakage shall be increased by 10 percent.

7-04.3(C) Infiltration Test—Storm Sewers

Whenever the ground water table is above the crown of the higher end of the pipe Section at the time of testing, an infiltration test may be performed in lieu of the exfiltration test upon written permission of the Engineer. The maximum allowable limit for infiltration shall be 4 liters per hour per meter of diameter per meter of length with no allowance for external hydrostatic head.

7-04.3(4) D Low Pressure Air Test—Storm Sewers

Low pressure air testing may be used for pipes 750 millimeters in diameter and smaller in accordance with the following:

The first Section of pipe not less than 100 meters in length installed by each crew shall be tested in order to qualify the crew and material. Successful tests for this Section shall be a prerequisite to further pipe installation by said crew.

Immediately following the pipe cleaning, the pipe installation shall be tested with low-pressure air. Air shall be slowly supplied to the plugged pipe installation until the internal air pressure reaches 28 kilopascals greater than the average backpressure of any ground water that may submerge the pipe. At least two minutes shall be allowed for temperature stabilization before proceeding further.

The pipeline shall be considered acceptable when tested at an average pressure of 21 kilopascals greater than the average backpressure of any ground water that may submerge the pipe. The allowable rate of air loss shall be 1.8 liters per minute per square meter of internal pipe surface, but the total calculated air loss shall not be less than 55 liters per minute nor more than 200 liters per minute.

The requirements of this specification shall be considered satisfied if the time required in seconds for the pressure to decrease from 24 to 17 kilopascals greater than the average back pressure of any ground water that may submerge the pipe is not less than that computed according to the Standard Plan.

7-04.3(4) F Other Test Allowances—Storm Sewers

All lateral or side storm sewer branches included in the test Section shall be taken into account in computing allowable leakage. An allowance of 2.5 liters per hour per meter of head above invert shall be made for each manhole included in a test section.

X2.1.2. *Michigan Department of Transportation Test Method (MTM 723)*

1. *Scope*:
    1.1 This test method describes the requirements for independent laboratory testing of culvert and sewer joints, up to 24 in. (600 mm) in diameter, to verify WATERTIGHTNESS. Laboratory test results will be considered valid for five years once they have been reviewed and accepted by MDOT. Retesting will be required during this five-year period whenever the joint configuration or materials are changed.

1.2 Testing may be conducted by the manufacturer when witnessed and certified by an authorized representative of an independent laboratory. This authorized representative must verify the design and calibration of the testing apparatus.

1.3 Two procedures are included in this MTM either of which may be used to verify the WATERTIGHTNESS of sewer and culvert joints. The rate of water leakage from the test section or the rate of air pressure drop in the test section may be measured.

2. *Referenced Documents*:

2.1 *ASTM Standards*:

- C 924M, Standard Practice for Testing Concrete Pipe Sewer Lines by Low-Pressure Air Test Method (Metric)
- C 969M, Standard Practice for Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines (Metric)
- C 1091, Standard Test Method for Hydrostatic Infiltration Testing of Vitrified Clay Pipe Lines
- F 1417, Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air

3. *Significance and Use*:

3.1 Culvert and sewer joints, 24 in. (600 mm) or less in diameter, tested and approved in accordance this MTM will be placed on the Qualified Products List.

4. *Apparatus*:

4.1 Testing may be carried out using either air pressure or hydrostatic pressure. Provide plugs capable of sealing the sewer or culvert test section for the appropriate test method.

4.2 The pressure gauge used, for either method, shall have a range of 0 to 10 psi (70 kPa). The gauge shall read to the nearest 0.07 psi (0.5 kPa) with an accuracy of +0.01 psi (0.1 kPa).

4.3 The pressure test apparatus must include a 6.0 psi (40 kPa) pressure relief device.

4.4 When testing plastic pipe, the pipe shall be deflected five percent (5 percent) during the entire testing period to represent the maximum allowable deflection at the time of field installation. The apparatus described in ASTM F 949 shall be used to deflect the plastic pipe.

5. *Test Section*:

5.1 The pipe section to be pressurized using the air or hydrostatic test procedure described in Section 6 shall consist of either two standard length pipe sections for the diameter being tested or two pipe segments each having a minimum length of ten feet, properly connected in accordance with the watertight joint design.

5.2 Jointing procedures used in the laboratory must be readily adaptable for use in the field to allow verification testing.

5.3 The test section shall be clean and free of debris at the time of testing.

6. *Test Procedure*:

6.1 The test procedures presented have been adapted from ASTM field installation acceptance methods for hydrostatic (ASTM C 969M, C 1091) and air pressure (ASTM C 924M, F 1417) testing.

6.2 *Hydrostatic Pressure Testing*

6.2.1 Plug the ends of the test section to provide a watertight seal and provide bracing to withstand the expected test pressure. Bracing shall not create longitudinal compressive forces within the test section. One of the plugs shall be fitted with an orifice through which water can be introduced into the test section. A water supply line shall be fitted with suitable control valves and a pressure gauge allowing continuous monitoring of the hydrostatic pressure at the top of the pipe.

6.2.2 Fill the test section completely with water.

6.2.3 For concrete and clay pipe, the water-filled test section is to stand for a minimum of four hours and a maximum of 72 hours to allow for water absorption by the pipe material. Refill the test section as necessary before continuing with testing.

6.2.4 Bring the hydrostatic pressure in the test section to 4.0 psi (28 kPa) and begin timing the test. Measure the leakage from the pipe joint while maintaining 4.0 psi (28 kPa) for 20 minutes.

6.3 *Air Pressure Testing*

6.3.1 Plug the ends of the test section to provide an airtight seal and provide bracing to withstand the expected test pressure. Bracing shall not create longitudinal compressive forces within the test section. One of the plugs shall be fitted with an orifice through which air can be introduced into the test section. An air supply line shall be fitted with suitable control valves and a pressure gauge allowing continuous monitoring of the air pressure.

6.3.2 Pressurize the pipe to 4.0 psi (28 kPa). Allow a minimum of two minutes for the air pressure to stabilize to between 3.5 psi (24 kPa) and 4.0 psi (28 kPa). If necessary, add air to the test section to maintain the pressure between 3.5 psi (24 kPa) and 4.0 psi (28 kPa).

6.3.3 After the air pressure has stabilized between 3.5 psi (24 kPa) and 4.0 psi (28 kPa), close the air supply valve so that no additional air may enter the test section.

6.3.4 Record the air pressure and begin timing the test. Record the time required for the air pressure to decrease 1.0 psi (7.0 kPa).

7. *Basis of Acceptance*:

7.1 *Hydrostatic Pressure Verification*

The method of jointing is considered acceptable when the leakage is less than or equal to 200 gallons per inch of inside diameter per mile per day (20 liters per millimeter of inside diameter per kilometer of pipe per day).

7.2 *Air Pressure Verification*

The method of jointing is considered acceptable when the time required for the air pressure to decrease 1.0 psi (7.0 kPa) exceeds the minimum times listed in Table 723-2.

8. *Report*:

8.1 Independent laboratory test reports must be submitted which document that a minimum of three passing tests (either three hydrostatic or three air pressures) have been performed for each type of pipe jointing system and each diameter of pipe being submitted for approval as a Qualified Product.

8.2 *Each report must include the following information*:

- pipe and joint component manufacturer’s name,
- specific product name(s),
- description of joint configuration,
- material,
- specification for each component,
- the diameter of pipe joint tested,
- standard pipe section length for pipe joint tested,
- joint assembly procedure used in laboratory testing,
- the date and location of testing,
- observed leakage rate (hydrostatic) or time for 7.0 kPa pressure drop (air),
- field assembly diagram sufficient to allow identification of all joint system components, and
- certification statement by authorized representative of independent laboratory if testing is conducted by manufacturer and independently witnessed.

Table 723-1

Maximum Leakage for Various Pipe Diameter and Standard Pipe Section Lengths for Twenty-Minute Test Interval

Pipe Diameter, in. (mm)	Length of Pipe Section, ft (mm)	Allowable Leakage, oz (L)
12 (300)	8 (2400)	6.8 (0.20)
	10 (3000)	8.5 (0.25)
	12 (3600)	10.0 (0.30)
	15 (4500)	12.8 (0.38)
	18 (5400)	15.2 (0.40)
15 (375)	8 (2400)	8.5 (0.25)
	10 (3000)	10.5 (0.31)
	12 (3600)	12.5 (0.37)
	15 (4500)	15.9 (0.47)
	18 (5400)	18.9 (0.56)
18 (450)	8 (2400)	10.1 (0.30)
	10 (3000)	12.8 (0.38)
	12 (3600)	15.2 (0.45)
	15 (4500)	19.3 (0.57)
	18 (5400)	23.0 (0.68)
24 (600)	8 (2400)	13.5 (0.40)
	10 (3000)	16.9 (0.50)
	12 (3600)	20.3 (0.60)
	15 (4500)	25.4 (0.75)
	18 (5400)	30.4 (0.90)

Table 723-2

Minimum Time for 1-psi (7.0-kPa) Air Pressure Decrease for Various Pipe Diameters

Pipe Diameter, in. (mm)	Thermoplastic Pipe,[a] elapsed time (min:sec)	All Other Materials,[b] elapsed time (min:sec)
4 (100)	3:46	0:18
6 (150)	5:40	0:42
8 (200)	7:34	1:12
10 (250)	9:26	1:30
12 (300)	11:20	1:48
15 (375)	14:10	2:06
18 (450)	17:00	3:00
21 (525)	19:50	3:36
24 (600)	22:40	3:36

[a] ASTM F 1417

[b] ASTM C 828 and ASTM C 924M

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[1] This provisional practice was adopted and first printed in 2009.

Standard Practice for

Match Curing of Concrete Test Specimens

AASHTO Designation: PP 54-06[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Match Curing of Concrete Test Specimens

AASHTO Designation: PP 54-06[1]

1. SCOPE

1.1. This recommended practice covers procedures for making and curing cylindrical concrete specimens at the same temperature as that measured in a concrete member.

1.2. The concrete sample used to make the specimens shall be taken from the concrete being placed in the same member where the temperature is to be measured.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 205M/M 205, Molds for Forming Concrete Test Cylinders Vertically
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

2.2. *ASTM Standards*:
- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 1064/C 1064M, Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete

3. TERMINOLOGY

3.1. For definitions of terms used in this practice, refer to ASTM C 125.

4. SIGNIFICANCE AND USE

4.1. This method provides a procedure for curing concrete cylinders at the same temperature as that monitored at a specific location in a concrete member. Consequently, the compressive strength of the cylinder more accurately represents the in-place concrete strength of the member. The method is particularly useful for determining the concrete compressive strength at early ages in the fabrication of precast concrete members or for determining the compressive strength of concrete at a critical location in a structural member.

5. APPARATUS

5.1. The apparatus shall consist of a monitoring and heating system capable of maintaining concrete cylinders at a temperature within ±2°C (±4°F) of the temperature of the concrete at a specific location in the member. A satisfactory system may include a temperature sensor in the member, a controller, special insulated cylinder molds with built-in heating systems, and a temperature sensor in the molds.

5.2. *Temperature Sensor in the Member*—Temperature sensors shall be placed at the most critical locations for strength development. The purchaser shall determine the critical locations for temperature sensors in each type of member and show the locations on the project drawings or the contractor shall submit drawings showing proposed locations to the purchaser for approval.

5.2.1. Temperature sensor wire shall be durable enough to withstand the wear associated with construction operations and shall have a size of 20 awg or larger in diameter (Note 1).

Note 1—In locations where electrical interference may affect the measured data, shielded wire should be used.

5.3. *Controller*—The controller shall be capable of monitoring the temperatures of the member and cylinders and controlling the heating system to maintain the cylinder temperature within ±2°C (±4°F) of the temperature measured in the member. Proper operation of the system shall be verified on a regular basis in accordance with the manufacturer's recommendations.

5.4. *Cylinder Molds*:

5.4.1. Cylinder molds shall conform to the requirements of M 205M/M 205 for reusable molds and shall be fitted with watertight lids to prevent moisture loss.

5.4.2. Cylinder molds shall have inside dimensions of 100 by 200 mm (4 by 8 in.) or 150 by 300 mm (6 by 12 in.)

5.4.3. When heated cylinder molds are used, they shall have built-in thermocouples that sense the temperature of the concrete specimens. Each cylinder mold shall have a heating element that surrounds the core of the mold, provides uniform heat to the concrete specimen, and is capable of maintaining a cylinder temperature that matches the temperature of the concrete member within the stated tolerance (Note 2).

Note 2—Because the match-curing system only provides heat to the cylinder and cannot cool it, the temperature of the cylinder may exceed that of the member if the temperature of the member decreases at a greater rate than that of the cylinder.

6. TEST SPECIMENS

6.1. Test specimens shall be cylinders of concrete cast and hardened in an upright position, with a length equal to twice the diameter. When the nominal maximum size of coarse aggregate does not exceed 50 mm (2 in.), the cylinder may be 150 by 300 mm (6 by 12 in.). When the nominal maximum size of coarse aggregate does not exceed 25 mm (1 in.), the cylinder may be 100 by 200 mm (4 by 8 in.).

6.2. A minimum of two 150 by 300 mm (6 by 12 in.) or three 100 by 200 mm (4 by 8 in.) cylinders shall be made for each strength test when the specified strength does not exceed 34 MPa (5000 psi). A minimum of three cylinders shall be made for each strength test when the specified strength exceeds 34 MPa (5000 psi).

7. PROCEDURE

7.1. *System Installation*—Prior to concrete placement, the temperature sensors in the member shall be securely fixed at the specified locations. The sensor tips shall be installed such that they do not have direct contact with steel reinforcement. Prior to concrete placement, proper operation of the match-curing system shall be verified in accordance with the manufacturer's recommendations.

7.2. *Sampling Concrete*—The samples used to fabricate test specimens under this standard shall be obtained in accordance with T 141 unless an alternative procedure has been approved. The concrete sample shall be taken from concrete placed as close as practical to the temperature sensor in the member.

7.3. *Slump, Air Content, and Temperature*:

7.3.1. *Slump*—Measure and record the slump of each batch of concrete from which specimens are made, immediately after remixing in the receptacle as required by T 119M/T 119.

7.3.2. *Air Content*—Determine and record the air content in accordance with either T 152 or T 196M/T 196. The concrete used in performing the air content test shall not be used in fabricating test specimens.

7.3.3. *Temperature*—Determine and record the concrete temperature in accordance with ASTM C 1064/C 1064M.

7.4. *Molding Specimens*—Test specimens shall be molded using the procedures of T 23.

7.5. *Match Curing*:

7.5.1. *Covering after Finishing*—Immediately after finishing, precautions shall be taken to prevent evaporation and loss of water from the specimens. Cover specimens with a nonabsorbent, nonreactive plate or a sheet of impervious plastic.

7.5.2. *Specimen Storage*—During match curing, molds and specimens shall be shielded from direct rays of the sun, other heating devices, rain, and wind. All molds controlled by the same controller shall be stored together (Note 3).

Note 3—Because the match-curing system only provides heat to the cylinders, better temperature control is obtained when the cylinders are stored in an environment that is cooler than the temperature of the concrete in the member.

7.5.3. Connect the molds to the controller and match cure for the specified length of time.

7.5.4. Following the match-curing period, the cylinders shall be removed from the molds and subsequently stored in a similar temperature and moisture environment as the member unless stated otherwise in the project specifications.

7.5.5. When match-cured cylinders are used to determine concrete release strengths, it is recommended that match curing be continued for as long as possible and until the cylinders are stripped for testing.

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[1] Approved in January 2006, this standard was first published in 2006.

Standard Practice for

Static Segregation of Hardened Self-Consolidating Concrete (SCC) Cylinders

AASHTO Designation: PP 58-08

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Static Segregation of Hardened Self-Consolidating Concrete (SCC) Cylinders

AASHTO Designation: PP 58-08

1. SCOPE

1.1. This method covers procedures for determining the static segregation resistance (stability) of self-consolidating concrete (SCC) using hardened test specimens.

1.2. The concrete used to make the molded specimens shall be sampled after all on-site adjustments have been made to the mixture proportions, including the addition of mix water and admixtures.

1.3. The text of this standard references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements for this standard.

1.4. The values stated in SI units are to be regarded as the standard.

1.5. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 205M/M 205, Molds for Forming Concrete Test Cylinders Vertically
- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 141, Sampling Freshly Mixed Concrete

3. SIGNIFICANCE AND USE

3.1. This method provides a visual assessment of static segregation resistance of SCC using a Hardened Visual Stability Index (HVSI) rating to evaluate molded or cored hardened concrete cylinders cut lengthwise in two.

3.2. If the specimens are made and cured as specified herein, the resulting static segregation test data are able to be used for the following purposes:

3.2.1. Acceptance testing for specified static segregation limits,

3.2.2. Checking the adequacy of mixture proportions to resist static segregation, and

3.2.3. Quality control.

4. APPARATUS

4.1. *Molds, Cylinder*—150 by 300 mm (6 by 12 in.) cylinder molds for casting concrete test specimens shall conform to the requirements of M 205M/M 205.

4.2. *Small Tools*—Hand-held wood or metal float or trowel.

4.3. *Saw*—The saw shall have a diamond or silicon-carbide cutting edge and shall be capable of cutting specimens without excessive heating or shock.

4.4. *Core Drill*—The core drill shall conform to the requirements of T 24M/T 24.

4.5. A suitable container for filling specimen molds with SCC.

Note 1—Experience has shown pails and plastic cylinder molds to be suitable containers.

5. SAMPLING CONCRETE

5.1. Samples of freshly mixed SCC used to fabricate test specimens under this standard shall be obtained in accordance with T 141.

5.2. Cored test specimens taken from hardened self-consolidating concrete under this standard shall be obtained in accordance with T 24M/T 24, except for the following:

5.2.1. Cored test specimens may be taken so that the axis is perpendicular or parallel to the concrete as it was originally placed, and

5.2.2. Cored test specimens shall have a minimum diameter of 50 mm (2 in.) and sufficient length to assess extent of static segregation resistance.

5.3. Record the identification of the test specimens with respect to the location of the concrete represented and the time of casting.

6. MOLDING AND CURING SPECIMENS OF FRESHLY MIXED SCC

6.1. *Making Specimens*:

6.1.1. A minimum of two fresh test specimens shall be molded as near as practicable to the place where they are to be stored. If it is not practicable to mold the specimens where they will be stored, move them to the place of storage immediately after strike off. Place molds on a rigid surface free from vibration and other disturbances. The supporting surface shall be level to within 20 mm/m (0.25 in./ft).

6.1.2. Specimen molds shall be filled in one lift, poured using a suitable container without vibration, rodding, or tapping.

6.1.3. Strike off the surface of the concrete level with the top of the mold using a float or trowel.

6.2. *Curing*:

6.2.1. Immediately after molding and finishing, the specimens shall be capped with a plastic cylinder lid and stored for a period up to 24 h at a minimum temperature of 16°C (60°F).

7. PROCEDURE

7.1. Before subjecting the specimens to sawing, they either shall have a minimum curing period of 24 h or shall attain a minimum compressive strength of 6200 kPa (900 psi) according to T 22.

7.2. Specimens shall be sawn lengthwise down the center. If a specimen cannot be satisfactorily sawed smooth for lack of curing, then the remaining specimen(s) shall remain undisturbed for an additional minimum curing period of 24 h before being subjected to sawing.

7.3. Make a visual assessment of the cut planes of the hardened concrete cylinder or core using the criteria in Table 1 and illustrated in Figures 1 through 8. The cut planes shall be wetted to facilitate visual inspection. For cores taken perpendicular to the concrete as it was originally placed, the "top" and "bottom" of the cut plane shall be oriented parallel to the direction of placement.

Table 1—Hardened Visual Stability Index (HVSI) Rating Criteria

Rating	Criteria
0, stable	No mortar layer at the top of the cut plane and no variance in size and percentage area of coarse aggregate distribution from top to bottom.
1, stable	No mortar layer at the top of the cut plane but slight variance in size and percentage area of coarse aggregate distribution from top to bottom.
2, unstable	Slight mortar layer, less than 25 mm (1 in.) tall, at the top of the cut plane and distinct variance in size and percentage area of coarse aggregate distribution from top to bottom.
3, unstable	Clearly segregated as evidenced by a mortar layer greater than 25 mm (1 in.) tall or considerable variance in size and percentage area of coarse aggregate distribution from top to bottom, or both.

8. REPORT

8.1. *Report the following information*:

8.1.1. Identification number,

8.1.2. Location of concrete represented,

8.1.3. Date and time of molding,

8.1.4. HVSI rating for each hardened specimen, and

8.1.5. Results of any other tests on the fresh concrete and any deviations from the standard test methods.

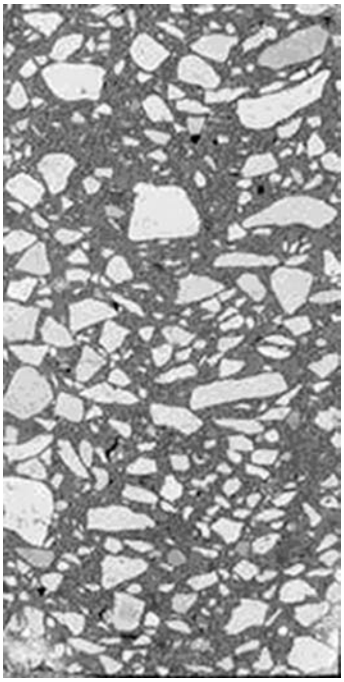


Figure 1—HVSI = 0, stable

Figure 2—HVSI = 0, stable

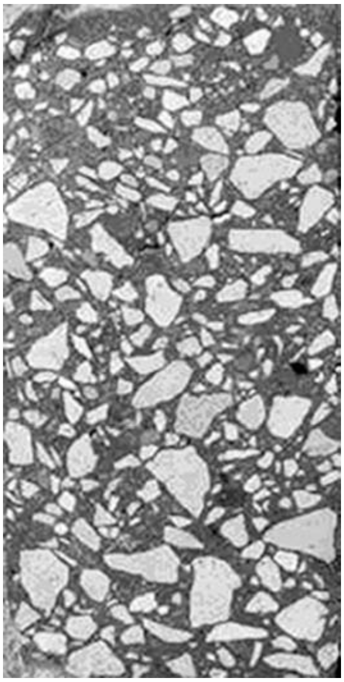


Figure 3—HVSI = 1, stable

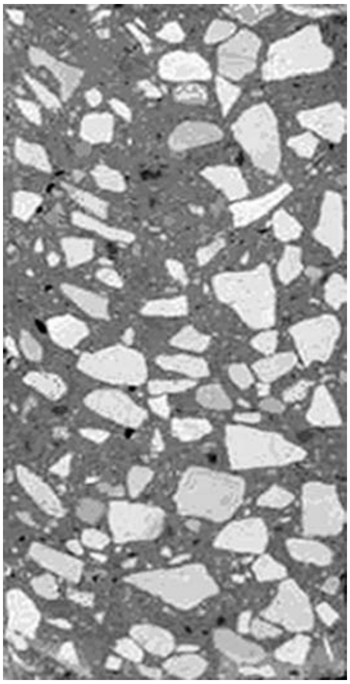


Figure 4—HVSI = 1, stable

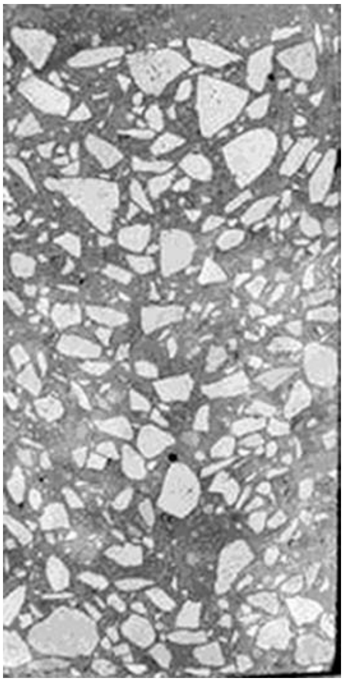


Figure 5—HVSI = 2, unstable

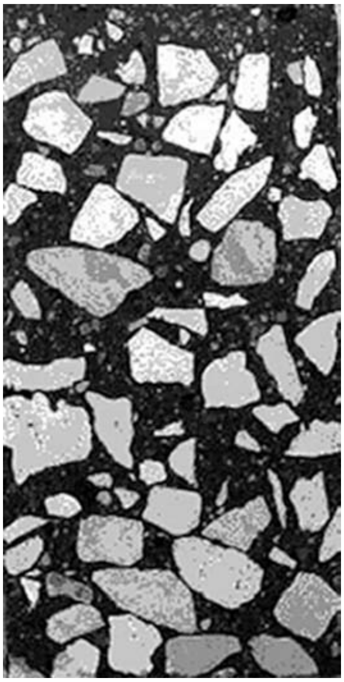


Figure 6—HVSI = 2, unstable

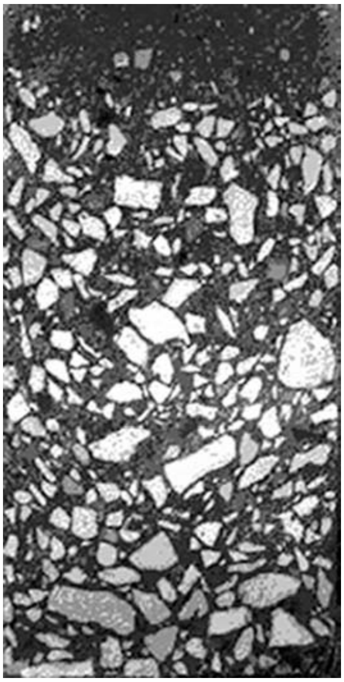


Figure 7—HVSI = 3, unstable

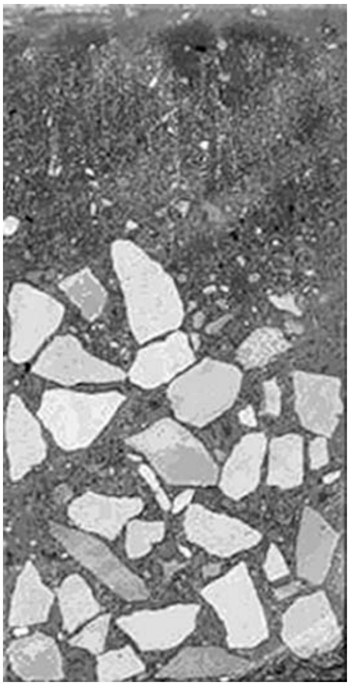


Figure 8—HVSI = 3, unstable

Standard Method of Test for

Determining Air Content of Hardened Portland Cement Concrete by High-Pressure Air Meter

AASHTO Designation: TP 59-00 (2007)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Determining Air Content of Hardened Portland Cement Concrete by High-Pressure Air Meter

AASHTO Designation: TP 59-00 (2007)[1]

1. SCOPE

1.1. This test method covers laboratory determination of the air content of hardened portland cement concrete with the use of the high-pressure air meter. This determination is made from the observation of change in linear piston movement with a specimen in the test chamber from that of the linear piston movement with no specimen in the test chamber. This change is due to a replacement of specific volume of compressible air by a specific volume of incompressible water.

1.2. *This procedure may involve hazardous materials, operations, and equipment. This procedure does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitation prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *linear piston movement* (LPM)—the travel of the hydraulic piston with a specimen in the test chamber.

3.1.2. *initial value* (INIT)—the stabilized travel of the hydraulic piston with no specimen in the test chamber.

3.1.3. *saturated surface dry* (SSD)—the saturated surface dry mass (weight) of the specimen.

4. SIGNIFICANCE AND USE

4.1. This test method covers determination of the air content of hardened concrete exclusive of any air that may be inside voids within aggregate particles. Therefore, determination of an aggregate correction factor, in accordance with the applicable requirements of T 152, is required.

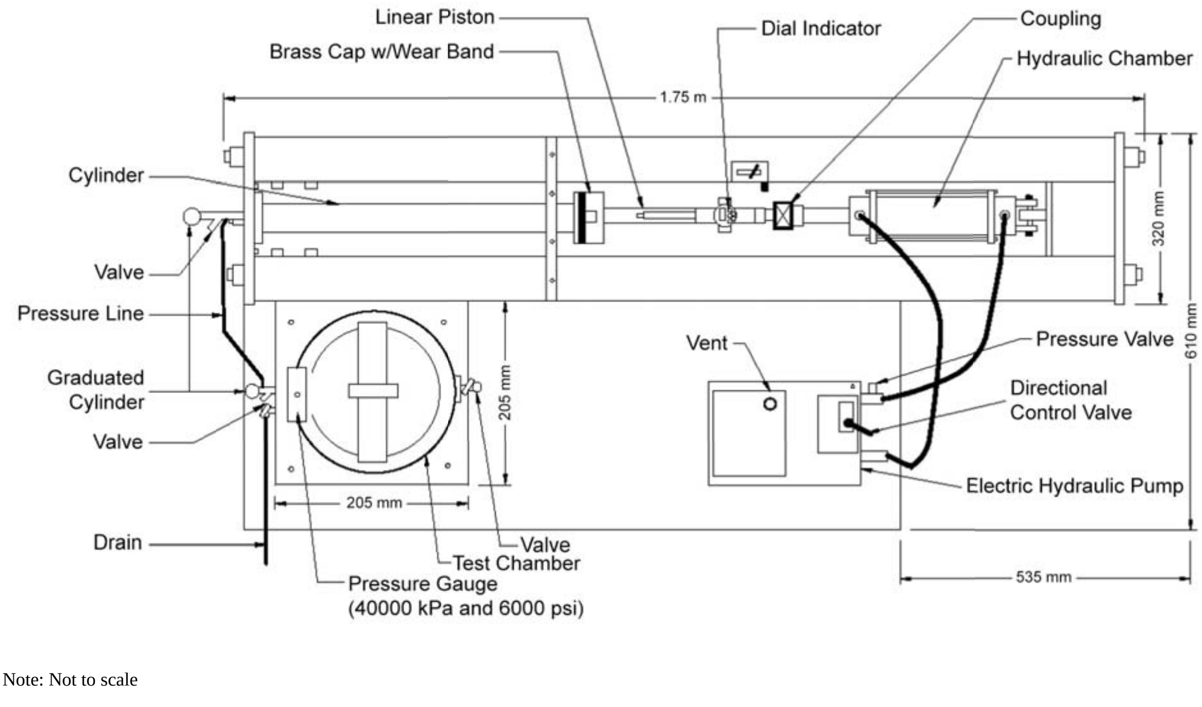
5. APPARATUS

5.1. *High-Pressure Air Meter* (see Figure 1):

5.1.1. *Hydraulic Pump and Hydraulic Cylinder*—A specially designed unit combining a hydraulic pump and a hydraulic cylinder employed to supply the 34470 kPa (5000 psi) load required to force water into a concrete specimen in the test chamber. The unit is supplied hydraulic pressure, which is converted to water pressure by movement of the hydraulic piston.

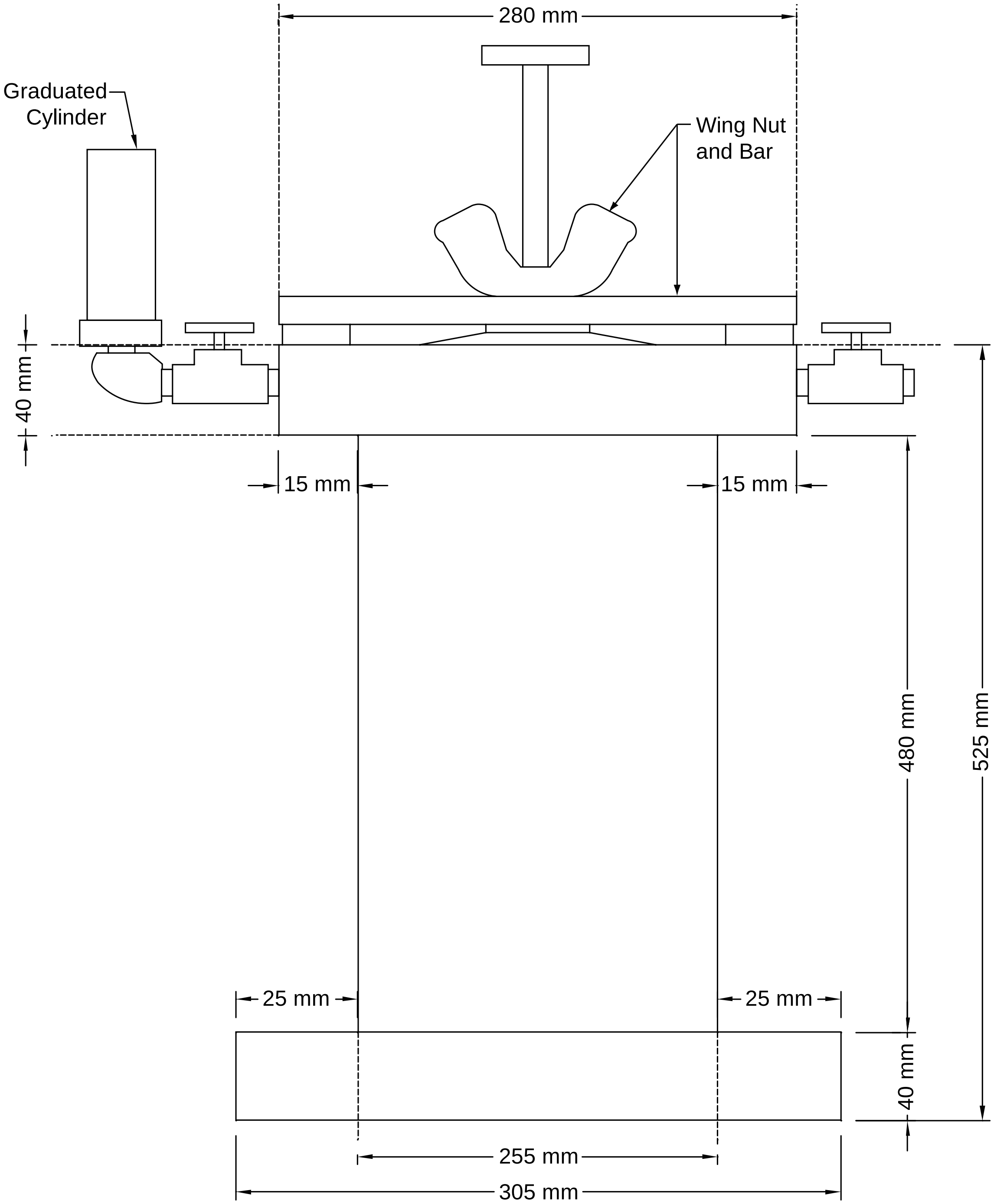
5.1.2. *Test Chamber* (Figures 2, 3, and 4)—A specially designed stainless steel seamless tube secured with a stainless steel plate at the bottom and a stainless steel lid at the top. This chamber is designed to contain water under pressure.

5.1.3. *The System*—The cylinder, of known volume, is attached to the test chamber, of known volume, that is completely filled with deionized water. This is done in order to enable load from the hydraulic pump to be applied to the test chamber. The system is equipped with a dial gauge accurate to 0.0254 mm (0.001 in.), in order to measure the movement of the hydraulic piston. Volume displacement is determined by the measured movement of the hydraulic piston.



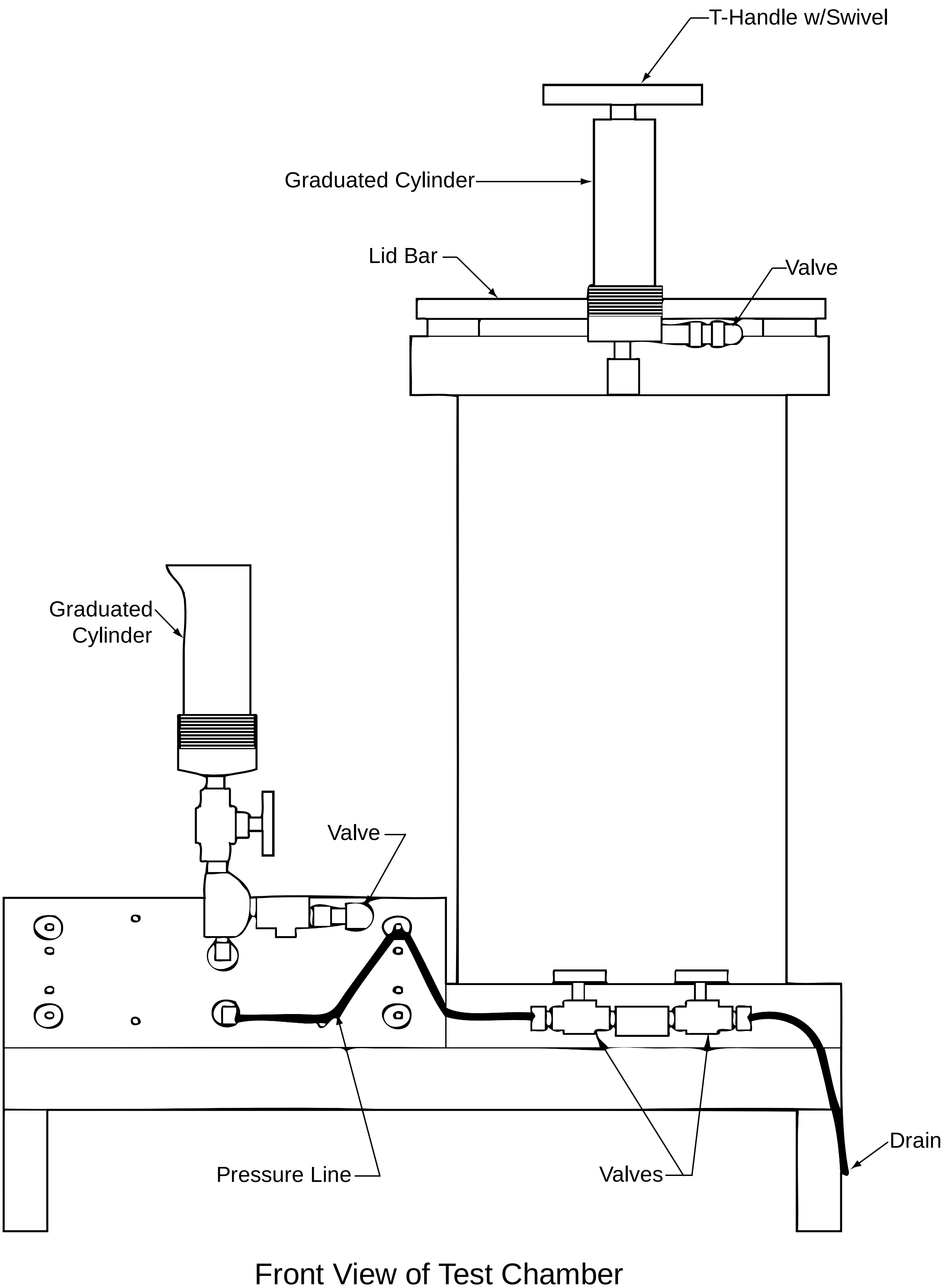
Note: Not to scale

Figure 1—High-Pressure Air Meter (Plan View)



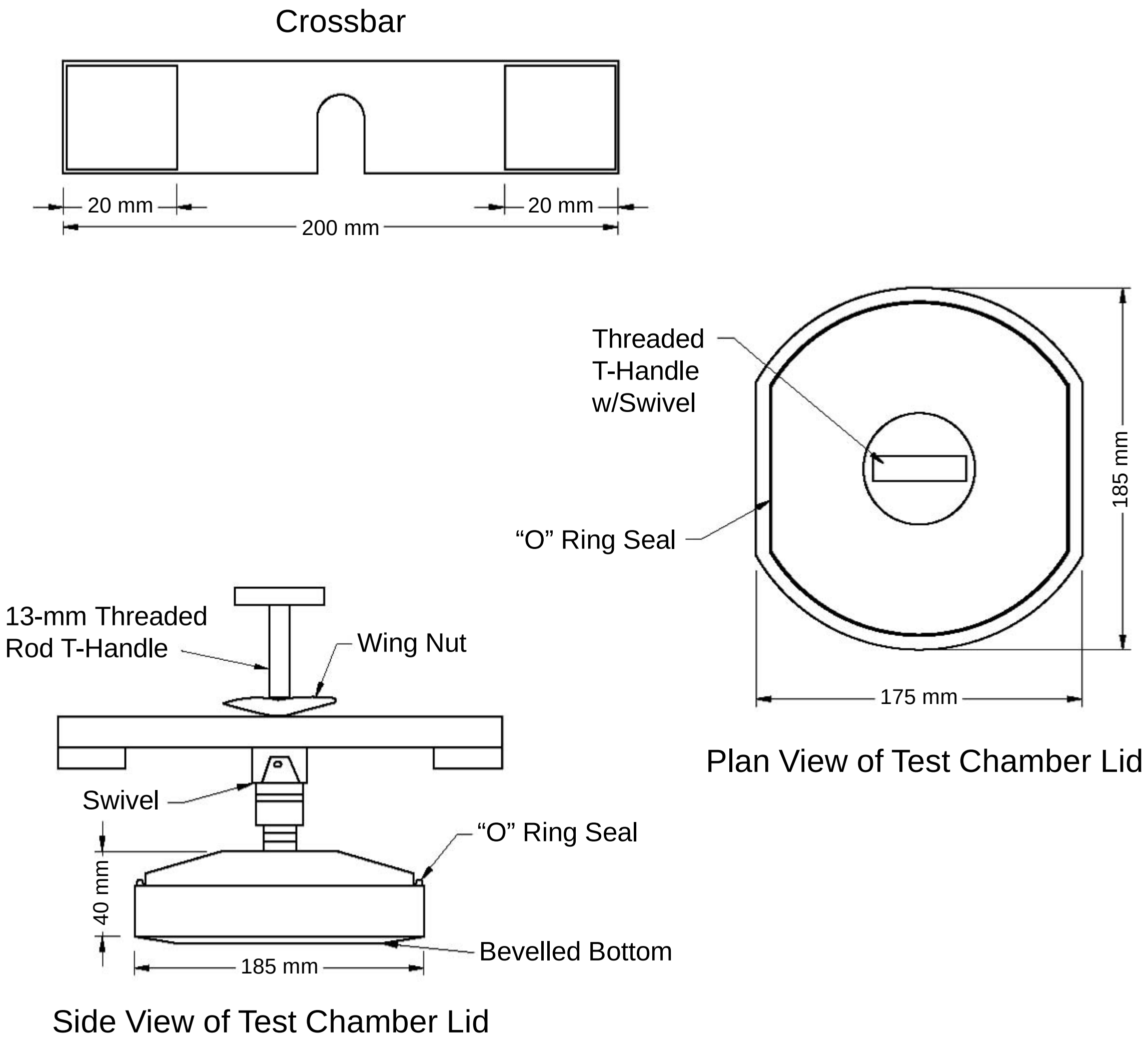
Note: Not to scale

Figure 2—Test Chamber



Note: Not to scale

Figure 3—Test Chamber (Front View)



Note: Not to scale

Figure 4—Test Chamber Lid

6. SAMPLING

6.1. Obtain a sound concrete sample free of steel reinforcement. The sample must be of suitable size to fit into the test chamber. The diameter of the stainless steel lid is 173 mm (6.8 in.) and the depth of the seamless tube is 480 mm (16.9 in.).

7. PREPARATION OF THE TEST SPECIMENS

7.1. *Oven Drying*—Oven dry the specimens for 72 hours at 138–149°C (280–300°F).

7.2. *Saturation*—After the specimens have been oven dried, saturate in 21 ± 6°C (70 ± 10°F) water for a period of 40 to 48 hours.

7.3. *Unit Mass (Weight)*—Determine the unit mass (weight) of the concrete sample in accordance with T 121M/T 121.

8. PREPARATION OF TEST EQUIPMENT

8.1. *Preconditioning the Water*:

8.1.1. Prior to opening the test chamber, close all valves except the valve positioned between the test chamber and the hydraulic cylinder. Remove the lid of the test chamber by loosening the wing nut at the top, thereby releasing the steel crossbar used to secure the lid. Tilt the lid and remove it from the chamber by aligning the flat sides of the lid with the flat sides of the test chamber.

8.1.2. Completely fill the test chamber with deionized water. Remove the pressure gauge and replace it with a plug capable of withstanding a 101 kPa (30 in Hg) vacuum. Apply Teflon® tape to the plug, prior to installation. Place the vacuum lid over the top of the test chamber. It may be necessary to apply vacuum grease to the O-ring of the vacuum lid to prevent leakage.

8.1.3. Engage the vacuum by turning on the power and opening the valves connecting the vacuum lid to the vacuum hose and the vacuum hose to the vacuum. The vacuum gauge should read approximately 91 kPa (27 in Hg). Apply the vacuum until air bubbles being pulled to the surface are no longer visible; this may be done overnight. The vacuum is applied to remove as much air as possible prior to the determination of an initial value.

8.1.4. Disengage the vacuum by closing the valves previously opened and turning off the power. The gauge should return to zero. Apply Teflon® tape to the pressure gauge and replace the plug with the pressure gauge. Replace the vacuum lid with the test chamber lid, do not secure the lid.

8.2. *Bleeding the System*—The system is bled to remove all entrapped air bubbles that may have developed throughout the workings of the high-pressure air meter. This is done by forcing water through the system.

8.2.1. Close the valve positioned between the test chamber and the hydraulic cylinder. Open the drainage valve positioned at the bottom of the test chamber. Allow water to freely flow from the drainage hose to ensure no entrapped air. Close drainage valve, and secure chamber lid by placing the crossbar over the top of the lid and tightening the wing nut.

8.2.2. Open the valve connected to the graduated cylinder located at the top of the test chamber. Fill the graduated cylinder with water. Open the valve opposite this valve and allow gravity to force water through the test chamber. Do not allow water to splatter onto the high-pressure air meter. Continue until no air bubbles are visible and the height of the water in the graduated cylinder reads 50 mL or below. Do not allow the water to completely drain. If this does occur, repeat Section 8.2.1. Close the valve opposite of the valve attached to the graduated cylinder.

8.2.3. Open the valve positioned between the test chamber and the hydraulic cylinder. Use the hydraulic pump, in the load position, to force water through the system. Water will be forced into the graduated cylinder, continue in the load position until the graduated cylinder is filled. Reverse hydraulic pump to release position and drain the graduated cylinder. Continue process until no air bubbles appear in the graduated cylinder. Close valve attached to the graduated cylinder. The valve positioned between the test chamber and the hydraulic cylinder must remain open.

9. PROCEDURE

9.1. *Determination of Initial Value*:

9.1.1. Place the hydraulic pump in the load position. Apply the load until the pressure in the test chamber is exactly 34470 kPa (5000 psi). Record the initial value read from the dial indicator attached to the hydraulic ram in Figure 5. Release the load very slowly, if the load is released quickly, the well holding the hydraulic fluid will overflow. Bleed the system as described in Section 8.2.2.

9.1.2. Repeat this process until the difference in subsequent movement is 0.0762 mm (0.003 in.) or less. This value is considered the INIT. Record all readings on the data sheet given in Figure 5.

Method of Test for
High-Pressure Air Content of Hardened Portland Cement Concrete
INIT DETERMINATION

OPERATOR ____________________
RECORDER ____________________
DATE ____________________
INIT ____________________

LPM	TIME	COMMENTS

Figure 5—Initial Value Determination (Data Record)

9.2. *Testing Hardened Concrete Specimen*:

9.2.1. Remove the lid of the test chamber. Open the drainage valve to release volume of water approximately equal to volume of the test specimen. Place test specimen in the test chamber using forceps; it is crucial that the water in the test chamber is disturbed as little as possible. This is to prevent introduction of air into water within the test chamber. Bleed the system as identified in Section 8.2, beginning at Section 8.2.2. Place the lid on the test chamber and secure it.

9.2.2. Check all valves, except the valve positioned between the test chamber and the hydraulic cylinder, to make certain that they are tightly closed. The valve positioned between the test chamber and the hydraulic cylinder must remain open. Apply load until pressure in the test chamber is exactly 34470 kPa (5000 psi).

9.2.3. Immediately record the value read from the dial indicator identifying the LPM. Record the time of the reading and hold the 34470 kPa (5000 psi) load. The LPM measured via the dial indicator must be recorded at 5-minute intervals. This value should only be read when the pressure in the test chamber is at 34470 kPa (5000 psi).

9.2.4. It will be necessary to reapply the pressure lost due to the compression of air, in the test specimen, within the first 5 minutes of testing. It may be necessary to reapply pressure at subsequent 5-minute time intervals to maintain the 34470 kPa (5000 psi) load. Maintain the 34470 (5000 psi) load until the movement of the piston remains the same for 15 minutes. Record this stabilized value on the data sheet given in Figure 6.

9.2.5. Record the INIT value obtained in Figure 5.

Method of Test for
High-Pressure Air Content of Hardened Portland Cement Concrete
AIR CONTENT DETERMINATION

OPERATOR ____________________
RECORDER ____________________
DATE ____________________
LAB # ____________________
INIT ____________________

LPM	TIME	COMMENTS

Figure 6—Air Content Determination (Data Record)

10. COMPLETION OF THE TEST PROCEDURE

10.1. Open the lid of the test chamber and remove the specimen from the test chamber.

10.1.1. If the testing is complete, replace the water removed from the test chamber and close the lid of the test chamber.

10.1.2. If additional testing is required, repeat the process beginning with Section 8.2.

11. CALCULATIONS

11.1. Compute volume of this test specimen to the nearest one decimal place according to the requirements of the data form given in Figure 7.

Method of Test for
COMPUTING VOLUME OF TEST SPECIMEN

Metric volume s	=		kg	/		kg/m^3 * (1000 mm/m)^3		
		SSD			Unit mass (weight)			
Volume s	=		mm^3					
English volume s	=		kg	/	0.4535924 kg/lb * (12 in./ft)^3]	/		pcf
		SSD					Unit mass (weight)	
Volume s	=		in.^{3}					

Figure 7—Volume of Test Specimen (Data Form)

11.2. Compute the hardened air content of the test specimen according to the procedure given in data form in Figure 8. The values are to be calculated to the nearest one decimal place.

Method of Test for
COMPUTING HARDENED AIR CONTENT OF TEST SPECIMEN

Metric air content	=	{[462121.65 *	(	–	)	]/	}	+ 1.46 –	
			LPM		INIT		Volume		Agg. correction
Air content	=		percent						
English air content	=	{[716.29 *	(	–	)	]/	}	+ 1.46 –	
			LPM		INIT		Volume		Agg. correction
Air content	=		percent						

Note: The coefficient 1.46 is a calibration factor based on Report No. 6-286, Corps of Engineers, U.S. Army Engineer Waterways Experiment Station.

Figure 8—Hardened Air Content of Test Specimen (Data Form)

11.3. *Calculate the plastic air content of the specimen as follows in Equation 1*:

$$\text{Plastic Air Content} = (\text{Hardened Air Content} - 1.53)/0.9 \qquad (1)$$

12. REPORT

12.1. Report the hardened concrete air content, nearest percent.

13. PRECISION AND BIAS

13.1. No precision or bias statements are available at this time.

14. KEYWORDS

14.1. Air content; hardened portland cement concrete.

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[1] Approved in January 1999, this provisional standard was first published in May 1999. Reconfirmed in 2002, 2005, 2006, and 2007.

Standard Method of Test for

Predicting Chloride Penetration of Hydraulic Cement Concrete by the Rapid Migration Procedure

AASHTO Designation: TP 64-03 (2007)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Predicting Chloride Penetration of Hydraulic Cement Concrete by the Rapid Migration Procedure

AASHTO Designation: TP 64-03 (2007)[1]

1. SCOPE

1.1. This procedure is for the rapid evaluation of chloride penetration resistance of concrete, from non-steady-state migration experiments.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24M/T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 277, Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

2.2. *ASTM Standard*:
- D 1193, Standard Specification for Reagent Water

3. DEFINITIONS

3.1. *Terminology*:

3.1.1. *chloride penetration depth*—the distance between the surface exposed to chloride solution and the chloride penetration front where the color changes from white to brown after spraying of 0.1 N silver nitrate solution.

3.1.2. *diffusion*—the movement of molecules or ions under a gradient of concentration, or more strictly speaking, chemical potential, from a high concentration zone to a low concentration zone.

3.1.3. *migration*—the movement of ions under the action of an external electrical field.

4. SUMMARY OF TEST METHOD

4.1. This test method uses electrical migration to accelerate the movement of chloride ions into a concrete specimen and a colorimetric indicator to measure the extent of chloride penetration. An external potential is applied axially across the specimen to force the chloride ions to migrate into the specimen. After a defined test duration, the specimen is axially split and a silver nitrate solution (colorimetric indicator for chloride) is sprayed on one of the fresh split surfaces. The chloride penetration depth is measured from the extent of the visible white silver chloride precipitate. From this penetration depth, the rate of chloride ion penetration is determined and used to rate the concrete.

5. SIGNIFICANCE AND USE

5.1. The results of this test can be used to rate concrete according to the relative ease with which chloride ions can penetrate into the concrete. This in turn gives an indication of the potential for corrosion of reinforcing steel due to chloride intrusion.

6. APPARATUS

6.1. Water-cooled diamond saw, capable of making cuts perpendicular to the axis of 100-mm diameter concrete cylinders or cores.

6.2. *Conditioning Equipment*:

6.2.1. *Vacuum desiccator*—250-mm diameter or larger (capable of containing at least three specimens), allowing two hose connections, each of which must be equipped with a stopcock.

6.2.2. *Vacuum pump*—capable of maintaining a pressure of less than 5 kPa (37 mm Hg) in the desiccator.

Note 1—Since vacuum will be drawn over water, the pump should be protected with a cold trap, or pump oil should be changed after each use.

6.2.3. *Vacuum gauge or manometer*—capable of reading vacuum levels as low as 1 kPa (5 mm Hg).

6.3. Migration apparatus shown schematically in Figure 1 (Note 1). Detailed drawings may be found in Annex A1.

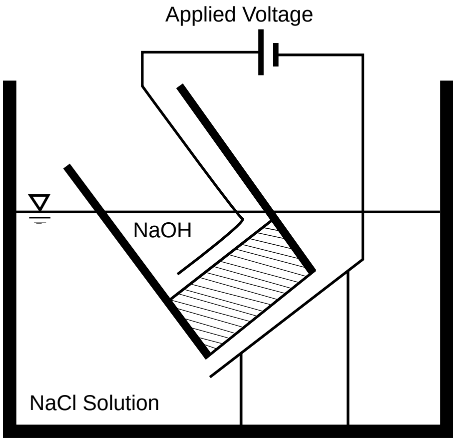


Figure 1—Schematic of Migration Apparatus

6.3.1. *Silicon rubber sleeve*, inner/outer diameter 100/115 mm, about 150 mm long.

6.3.2. *Two stainless steel clamps*, 20 mm wide with diameter range 105–115 mm. (See Figure 2.)

6.3.3. *Plastic container* (catholyte reservoir), 370 by 270 by 280 mm (L by W by H).

6.3.4. Plastic support with 0.5-mm thick stainless steel plate (cathode) attached. (See Figures A1.1–A1.5.)

6.3.5. *Stainless steel mesh or plate* (anode) with holes, about 0.5 mm thick. (See Figure A1.5.)

Note 2—Other designs are acceptable provided that temperatures of the specimen and solutions during the test can be maintained in the range of 20 to 25°C. Test cells for T 277 have been used successfully in this procedure. Use of T 277 cells requires test specimens to be coated as specified in T 277 before conditioning.

6.4. Power supply capable of supplying 0–60 V DC regulated voltage with the accuracy ±0.1 V.

6.5. *Ammeter,* capable of displaying current to ±1 mA.

6.6. *Thermometer or thermocouple,* with readout device capable of reading to ±1°C.

6.7. Any device suitable for splitting the specimen longitudinally, e.g., compression testing machine with split tensile test apparatus.

6.8. *Slide caliper,* with 0.1-mm resolution and ruler for measuring.

7. REAGENTS AND MATERIALS

7.1. *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available. Other grades may be used provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2. *Purity of Water*—Unless otherwise indicated, water shall be reagent quality water as defined by Type III of ASTM D 1193.

7.3. *Reagents*:

7.3.1. Sodium chloride solution, 10 percent by mass—dissolve 100 g sodium chloride (NaCl) in 900 g tap water.

7.3.2. Sodium hydroxide solution, 0.3 N—dissolve approximately 12 g sodium hydroxide in 1 L distilled or deionized water.

7.3.3. Silver nitrate ($AgNO_2$) solution, 0.1 M.

7.4. *Sealant*:

7.4.1. Five-minute epoxy or other suitable sealant for coating specimen sides, if required by the test apparatus. (See Note 2.)

8. SAMPLING, TEST SPECIMENS, AND TEST UNITS

8.1. The method requires cylindrical specimens with a diameter of 100 mm and a thickness of 50 mm, sliced from cast cylinders or drilled cores with a minimum original length of 100 mm. The cylinders or cores should meet the requirements described in R 39, T 23, or T 24M/T 24. Three specimens should be used in the test.

8.2. *Obtaining Test Specimens*:

8.2.1. If a drilled core is used, an outer (i.e., closest to the original surface) layer of the concrete (approximately 10~20 mm thick) should be cut off (Note 3), after which a 50 ± 2 mm thick slice should be cut from the remaining core length to be used as the test specimen. The end surface of the test specimen that was closest to the original surface (i.e., the end surface that was adjacent to the discarded outer layer) should be exposed to the chloride solution (catholyte).

8.2.2. If a cast cylinder is used, an outer (i.e., closest to the troweled surface) layer of the concrete approximately 25 mm thick should be cut off (Note 3), after which a 50 ± 2 mm thick slice should be cut from the remaining length of the cylinder to be used as the test specimen. The end surface closest to the original troweled surface should be exposed to the chloride solution (catholyte).

8.2.3. The thickness should be measured to the nearest 0.1 mm with a slide caliper at four locations equally spaced around the specimen. All four thickness measurements shall be 50 ± 2 mm.

Note 3—The term “cut” here means to saw perpendicularly to the axis of a core or cylinder by means of a water-cooled diamond saw.

9. CONDITIONING

9.1. Brush and wash away any burrs from the surfaces of the specimen. Wipe excess water from the surfaces of the specimens.

9.2. Coat specimen sides with 5-minute epoxy or other suitable sealant, if required. (See Note 2.)

9.3. *Preconditioning (Vacuum Saturation)*:

9.3.1. Place surface-dry specimens in the vacuum desiccator. Both end surfaces must be exposed.

9.3.2. Seal the desiccator and start the vacuum pump. The absolute pressure in the desiccator should decrease to a range of 1 to 5 kPa (7.5 to 37 mm Hg) within a few minutes. Maintain vacuum for 3 hours.

9.3.3. With the vacuum pump still running, open the water stopcock and fill the desiccator with de-aired tap water to cover the specimens. Close the water stopcock and maintain the vacuum for 1 additional hour.

9.3.4. Close the vacuum line stopcock and turn off the vacuum pump. Re-open the vacuum line stopcock to allow air to reenter the desiccator. Maintain the specimens in this condition for 18 ± 2 hours.

10. PROCEDURE

10.1. *Set Up (Note 4)*:

10.1.1. Measure the temperature of the NaOH and NaCl solutions. If the temperatures are not within the range 23 ± 2ºC, bring the temperatures of the NaOH and NaCl solutions to 23 ± 2ºC before starting the test.

10.1.2. Place the plastic support (cathode) in the catholyte reservoir and fill the reservoir with about 12 L of NaCl solution.

10.1.3. For each of the three test specimens, place a rubber sleeve around the specimen as shown in Figure 2 (Note 4). Place clamps as shown in the figure and tighten snugly.

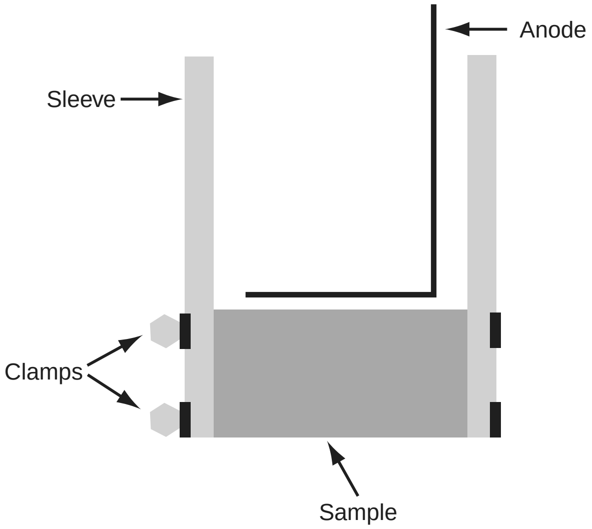


Figure 2—Assembly of Specimen in Rubber Sleeve and Placement of Anode

Note 4—If using an apparatus different than the one described here (e.g., T 277 cells), set up the apparatus in accordance with the applicable standard or the manufacturer's instructions.

10.1.4. Fill each sleeve with distilled water to check for leaks, and tighten clamps further if necessary (Note 5). Empty the water and place the specimens on the slanted plastic support (cathode) in the catholyte reservoir (Note 6).

Note 5—If the curved surface of the specimen is not smooth, or if there are significant defects (e.g., large voids or honeycombs) on the curved surface that may result in significant leakage, apply a strip of silicon sealant to improve the watertightness.

Note 6—If the concrete has been allowed to dry substantially after preconditioning, immerse it in tap water for a few minutes to re-saturate before placing it on the slanted plastic support (cathode) in the catholyte reservoir.

10.1.5. Fill the sleeve above the specimen with 300 ml of NaOH solution. Immerse the anode in the NaOH solution.

10.2. *Application of Voltage*:

10.2.1. Connect the cathode and anode to the negative and positive poles of the power supply, respectively. Turn on the power, set the power supply to a potential of 60.0 ± 0.1 VDC, and record the initial current (A) through each specimen to the nearest .001 A.

10.2.2. Check the current ranges in Table 1 and, if necessary, reset the potential according to the values in the table. If the potential is reset, record new values of initial current for each specimen. If the initial current is greater than 800 mA, do not continue with the test.

Table 1—Test Conditions

Initial Current at 60 V (mA)	Applied Voltage (V)	Test Duration (Hours)
<120	60	18
120–240	30	18
240–800	10	18
>800	Do Not Test	Do Not Test

10.2.3. For each specimen, measure and record the initial temperature in the anolyte solution using a thermometer or thermocouple.

10.2.4. After 18 hours, record the final current and temperature for each specimen, and record the temperature of the catholyte solution. Turn off the power supply.

10.2.5. Disassemble the test apparatus and remove test specimens.

10.3. *Measurement of Chloride Penetration*:

10.3.1. Rinse the specimens with distilled water. Wipe excess water from the surfaces of the specimen. Using a suitable device, split the specimen longitudinally into two pieces. Choose one piece for the penetration depth measurement.

10.3.2. Spray 0.1 M silver nitrate solution on the fresh-split surface. When the white silver chloride precipitate on the split surface is clearly visible (after about 15 minutes), use a ruler to measure the penetration depths at intervals of 10 mm, starting 10 mm from the edge, as shown in Figure 3 (Notes 7, 8, and 9). The depth should be read to the nearest millimeter. At least five valid depth measurements should be obtained.

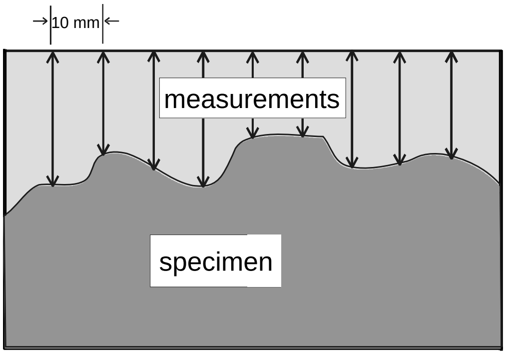


Figure 3—Measurement of Chloride Penetration Depth on Split Face of Specimen

Note 7—If the penetration front to be measured is obviously blocked by the aggregate, move the measurement to the nearest front where there is no significant blocking of aggregate, or alternatively, discard this depth if there are more than five valid depths.

Note 8—If the presence of a defect in the specimen (e.g., large void or honeycomb) results in a penetration front much larger than the average, measurement(s) should not be made at this location. Note such defects in the test report.

Note 9—To eliminate possible edge effects due to non-homogeneous degree of saturation or possible leakage during the test, no depth measurement should be made within 10 mm of the edge. (See Figure 3.)

11. CALCULATIONS

11.1. For each test specimen, the depth of penetration is determined by discarding the high and the low value and taking the mean of the remaining measurements.

11.2. The rate of penetration is calculated by dividing the depth of penetration (mm) by the product of the applied voltage (V) and the test duration (hr).

12. REPORT

12.1. *Report the following information*:

12.1.1. Name and address of the testing laboratory;

12.1.2. Date and identification number of the test report;

12.1.3. Name and address of the organization or person who ordered the test;

12.1.4. Name and address of the manufacturer or supplier of the tested object;

12.1.5. Date of arrival of the tested object;

12.1.6. Description of the tested object including sampling, composition, and curing age;

12.1.7. Purpose of the test;

12.1.8. Test method;

12.1.9. Any deviation from the test method;

12.1.10. Name and address of the person who performed the test;

12.1.11. Date of the test;

12.1.12. Test information including the specimen dimensions, applied potential, initial and final currents, and initial and final temperatures;

12.1.13. Average (for three specimens) penetration depth and rate of penetration as well as individual penetration depth measurements for each specimen;

12.1.14. Any unusual observations, such as significant defects in the specimens or a large penetration front due to a defect or leakage;

12.1.15. Inaccuracy or uncertainty of the test results; and

12.1.16. Date and signature.

13. PRECISION AND BIAS

13.1. *Precision*:

13.1.1. *Single-Operator Precision*—The single-operator coefficient of variation of a single test result (where a test result is, as defined in this test method, the average of three separate measurements) has been found to be 8.8 percent according to the results from the Nordic round-robin test between six laboratories.[2] Therefore, results of two properly conducted tests (each consisting of the average of three individual measurements) by the same operator on concrete samples from the same batch should not differ by more than 25 percent.

13.1.2. *Multilaboratory Precision*—The multilaboratory coefficient of variation of a single test result (where a test result is, as defined in this test method, the average of three separate measurements) has been found by Hooton et al.[3] to be 16 percent for plain portland cement concrete or concrete blended with silica fume, and by Tang and Sorenson to be 23.6 percent for concrete blended with slag. Therefore, results of two properly conducted tests (each consisting of the average of three individual measurements) should not differ by more than 45 percent for portland cement concrete or concrete blended with silica fume, or 67 percent for concrete blended with slag.

13.2. *Bias*—Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

14. KEYWORDS

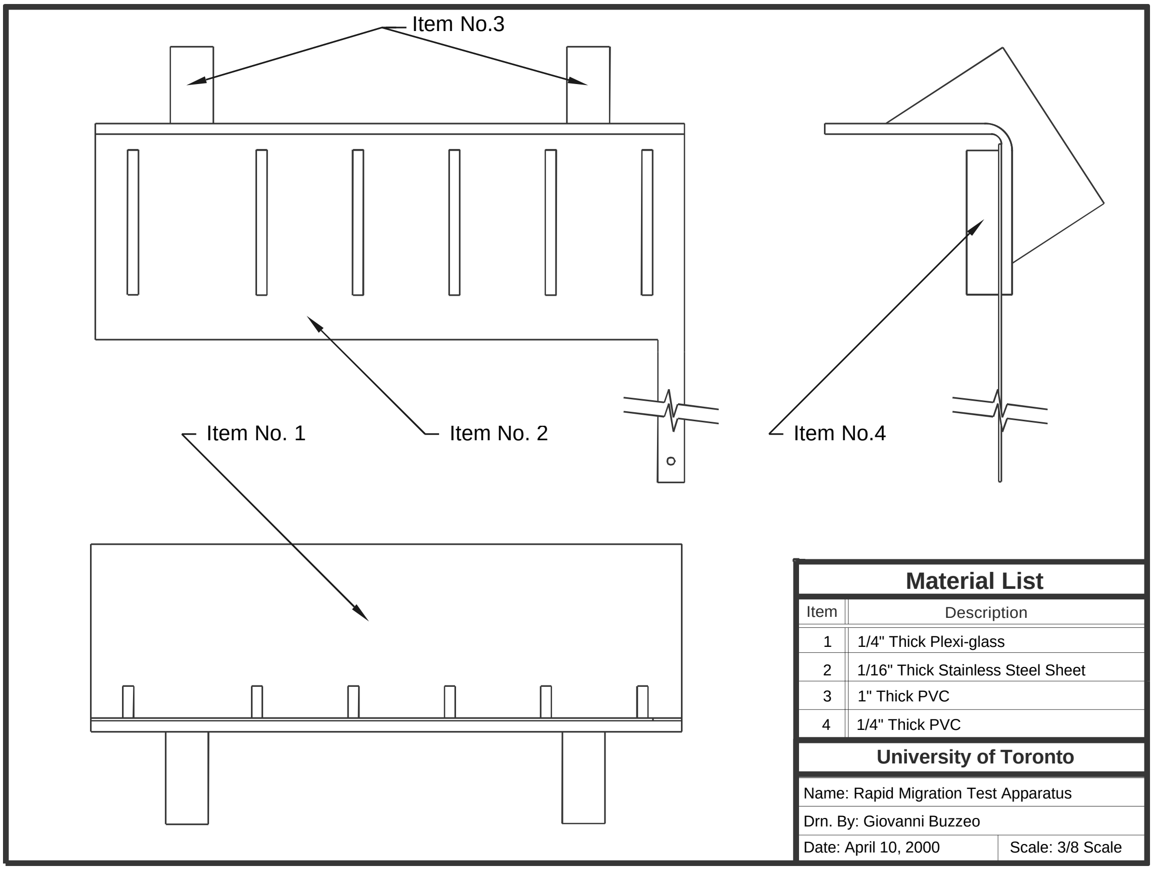
14.1. Concrete; corrosion; chloride penetration; electrical migration.

ANNEX

(Mandatory Information)

A1. APPARATUS DESCRIBED IN SECTION 6

A1.1. This Annex contains drawings for the apparatus as described in Section 6 of this standard.



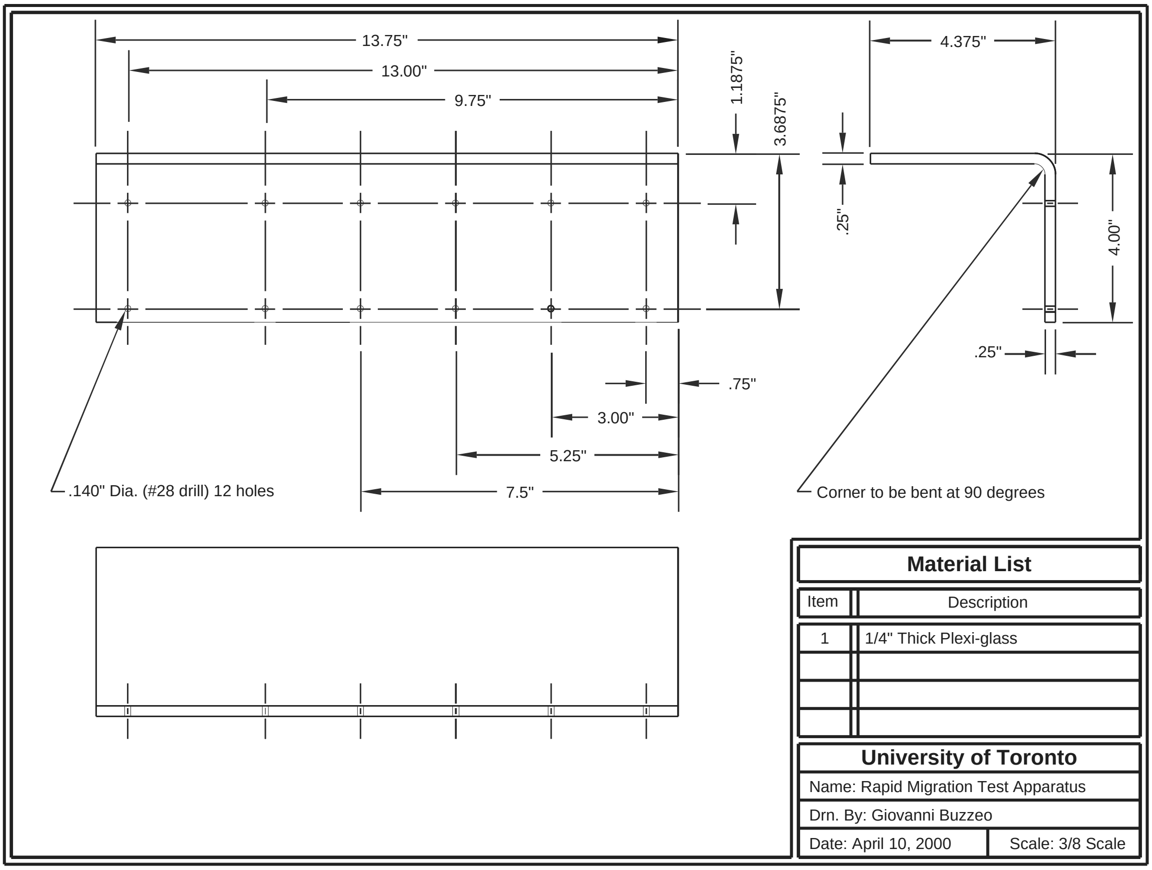
Material List

Item	Description
1	1/4" Thick Plexi-glass
2	1/16" Thick Stainless Steel Sheet
3	1" Thick PVC
4	1/4" Thick PVC

University of Toronto

Name: Rapid Migration Test Apparatus
Drn. By: Giovanni Buzzeo
Date: April 10, 2000 Scale: 3/8 Scale

Figure A1.1—Cathode Assembly



Material List

Item	Description
1	1/4" Thick Plexi-glass

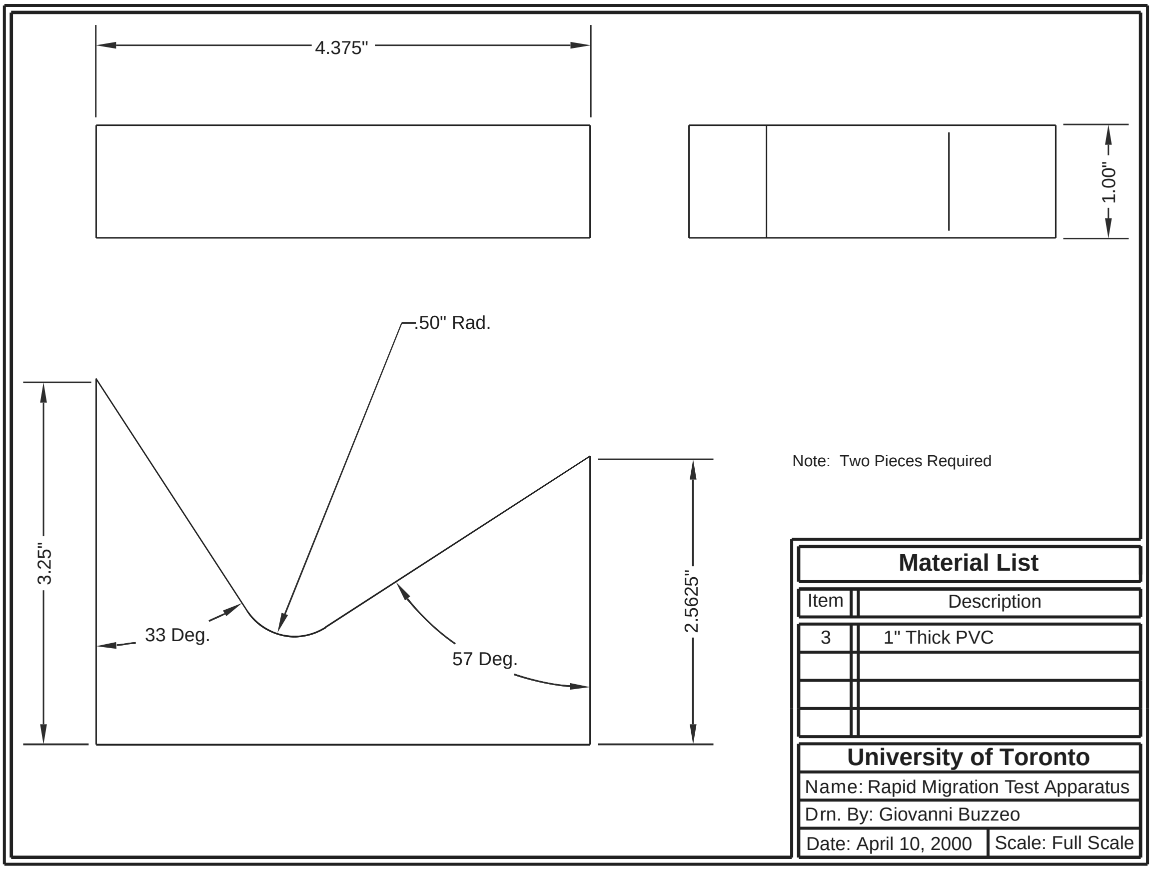
University of Toronto

Name: Rapid Migration Test Apparatus

Drn. By: Giovanni Buzzeo

Date: April 10, 2000 Scale: 3/8 Scale

Figure A1.2—Cathode: Detail of 3-in. Plexiglas™ Sheet



Note: Two Pieces Required

Material List

Item	Description
3	1" Thick PVC

University of Toronto

Name: Rapid Migration Test Apparatus

Drn. By: Giovanni Buzzeo

Date: April 10, 2000 Scale: Full Scale

Figure A1.3—Cathode: Detail of 1-in. PVC

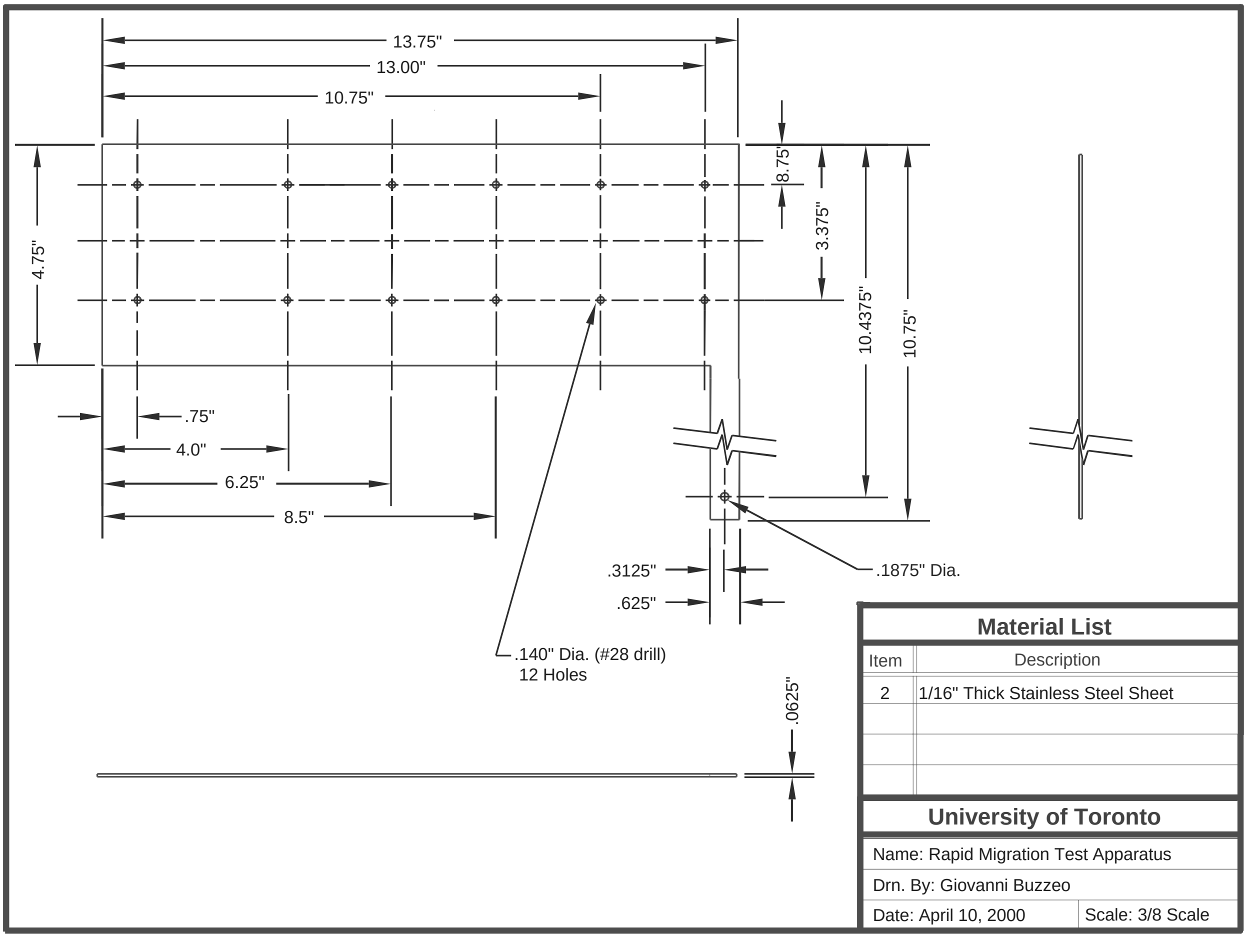


Figure A1.4—Cathode: Detail of Stainless Steel Sheet

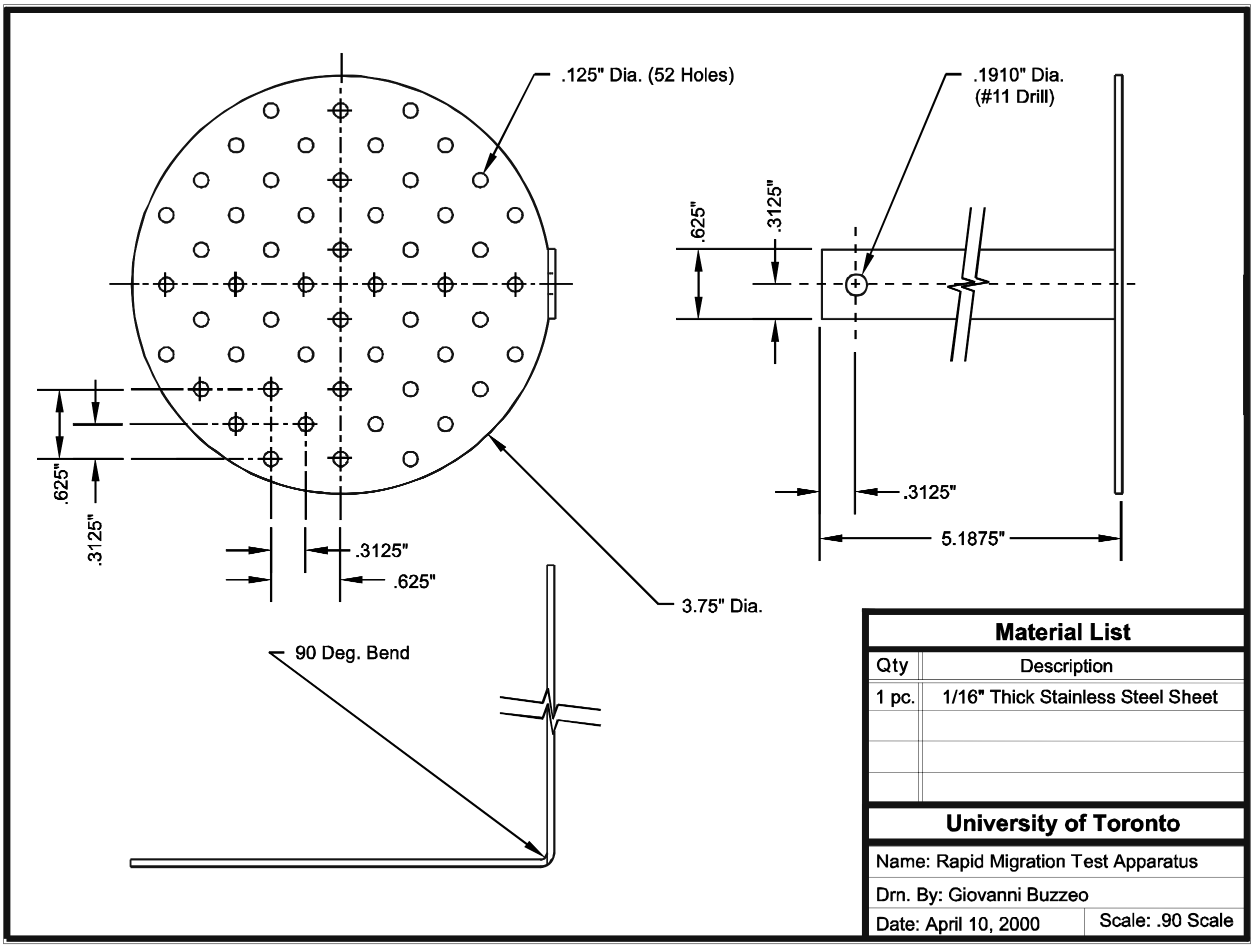


Figure A1.5—Anode

APPENDIX

(Nonmandatory Information)

X1. INTERPRETATION OF RESULTS

X1.1. Table X1.1 shows recommended ranges of the rate of penetration measured by this test method (mm/V-hr) corresponding to different grades of high-performance concrete (HPC) proposed by Goodspeed et al.[4] The recommended ranges for the rapid migration test are based on laboratory research by Hooton et al.[3] in which the rapid migration test was compared to the T 277 test. The rapid migration test result limits shown below correspond to ranges of charge passed in T 277 used to define HPC grades based on chloride penetration. Those ranges are: Grade 1—2000 to 3000 coulombs, Grade 2—800 to 2000 coulombs, and Grade 3—less than 800 coulombs.

Table X1.1—Recommendations for Chloride Penetration Rate Corresponding to FHWA HPC Performance Grades

	FHWA HPC Performance Grade		
	1	2	3
Rate of penetration (mm/V-hr)	$0.034 \geq x > 0.024$	$0.024 \geq x > 0.012$	$0.012 \geq x$

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[1] Approved in November 2002, this standard was first published in July 2003. A one-year extension was approved in 2006 with a two year extension approved in 2007.

[2] Tang, L. and H. E. Sorensen. *Evaluation of the Rapid Test Methods for Chloride Diffusion Concrete, NORDTEST Project No. 1388-98.* SP Report 1998: 42, SP Swedish National Testing and Research Institute. Bords, Sweden, 1998.

[3] Hooton, R. D., M. D. A. Thomas, and K. Stanish. *Prediction of Chloride Penetration in Concrete*, FHWA-RD-00-142. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2001.

[4] Goodspeed, C. H., S. Vanikar, and R. A. Cook. "High-Performance Concrete Defined for Highway Structures." *Concrete International*, Vol. 18, No. 2, February 1996, pp. 62–67.

Standard Method of Test for

Slump Flow of Self-Consolidating Concrete (SCC)

AASHTO Designation: TP 73-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Slump Flow of Self-Consolidating Concrete (SCC)

AASHTO Designation: TP 73-09[1]

1. SCOPE

1.1. This test method covers determination of slump flow of self-consolidating concrete (SCC), both in the laboratory and in the field. SCC is defined as a highly workable concrete that can flow through densely reinforced or complex structural elements under its own weight without vibration and adequately fill voids without experiencing segregation or excessive bleeding.

1.2. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 141, Sampling Freshly Mixed Concrete

3. SUMMARY OF TEST METHOD

3.1. A sample of freshly mixed SCC is placed in an inverted mold shaped as the frustum of a cone. The mold is raised, allowing the SCC to spread radially. After flow has ceased, the diameter of the SCC is measured in two perpendicular directions. The average of the two measured diameters is the slump flow.

4. SIGNIFICANCE AND USE

4.1. This test method is applicable to SCC, defined in Section 1.1.

4.2. This test method is intended to provide the user with a procedure to assess the horizontal free flow of SCC in the absence of obstructions. The test gives an assessment of filling ability and may give some indication of resistance to segregation, but it gives no indication of the ability of the SCC to pass between reinforcement without blocking.

4.3. This test method is applicable to SCC having coarse aggregate up to 25 mm [1 in.]. If the coarse aggregate is larger than 25 mm [1 in.], the test method is applicable when it is performed on the fraction of concrete passing a 25-mm [1-in.] sieve, with the larger aggregate being removed in accordance with Section 6 of T 141.

5. APPARATUS

5.1. *Mold*—The SCC shall be placed in an inverted slump cone mold conforming to the applicable requirements of T 119M/T 119.

5.2. *Base Plate*—The base plate shall be made of a stiff, nonabsorbing material, at least 820 mm [32 in.] square and marked with both a circle indicating the central location for the slump cone and a concentric circle with a diameter of 500 mm [20 in.].

5.3. Scoop.

5.4. Strike-off bar.

5.5. Tape measure containing increments of 6 mm [0.25 in.] or less.

5.6. Stopwatch.

6. SAMPLING

6.1. Approximately 6 L [0.2 ft^3] of SCC is needed to perform the slump flow test, sampled normally.

6.2. The sample of concrete shall be obtained in accordance with T 141.

7. PROCEDURE

7.1. Moisten the base plate and the inside of the slump cone.

7.2. Place the base plate on a level, stable surface and the inverted slump cone centrally on the base plate, and hold down firmly (Figure 1).

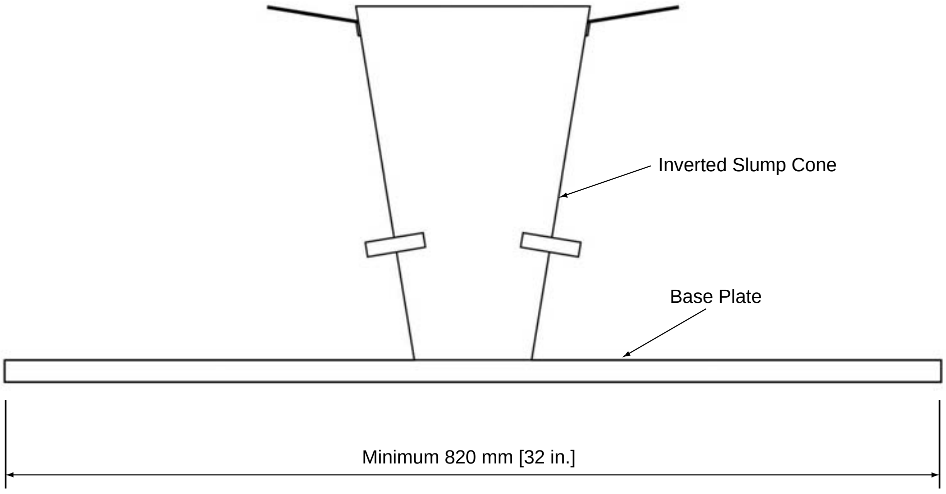

Figure 1—Mold and Base Plate for Slump Flow Test

7.3. From the sample of concrete obtained in accordance with Section 6, fill the entire mold continuously. The mold shall be held firmly in place during filling.

7.4. Do not rod or tamp the SCC. Do not tap or vibrate the cone.

7.5. Use the strike-off bar to strike off the SCC level with the top of the cone.

7.6. Remove any spilled or struck off SCC from around the base of the cone to preclude interference with the flowing SCC.

7.7. Raise the cone vertically 230 mm ± 75 mm [9 in. ± 3 in.] above the base plate with no lateral or torsional motion within a time period of 3 s ± 1 s, and allow the SCC to flow out freely from within. Complete procedures in Sections 7.3 through 7.7 within $2^1/_2$ min.

7.8. Simultaneous with the lifting of the cone, start the stopwatch. Record the time required for the first contact of the SCC slump flow patty with the 500-mm [20-in.] ring on the base plate. This is the T-50 time.

7.9. After the concrete flow has stopped, measure the final diameter of the SCC in two perpendicular directions to the nearest 6 mm [0.25 in.] (Note 1). The average of the two measured diameters is the slump flow in millimeters (inches). Any halo shall be included in the slump flow diameter.

Note 1—Measure the largest diameter of the slump flow as one diameter and the perpendicular diameter as the second to ensure consistency between tests. If the two values differ in diameter by more than 51 mm [2 in.], the test is considered invalid and must be repeated because it is likely that the cone was raised with lateral motion.

8. REPORT

8.1. Record the final diameter of the SCC in two perpendicular directions. The average of the two measured diameters is the slump flow in millimeters (inches) to the nearest 5 mm [0.25 in.].

8.2. Record the T-50 time, the time required for the slump flow patty to reach the 500-mm [20-in.] ring on the base plate.

9. PRECISION AND BIAS

9.1. No precision and bias statements are available at this time.

10. KEYWORDS

10.1. Cone; flowability; plasticity; SCC, self-consolidating concrete; slump; workability.

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[1] Approved in 2007, this standard was first published in 2008. Revised in 2009.

Standard Method of Test for

Passing Ability of Self-Consolidating Concrete (SCC) by J-Ring

AASHTO Designation: TP 74-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Passing Ability of Self-Consolidating Concrete (SCC) by J-Ring

AASHTO Designation: TP 74-09[1]

1. SCOPE

1.1. This test method covers determination of the passing ability (Note 1) of self-consolidating concrete (SCC) by the J-Ring method, both in the laboratory and in the field. SCC is defined as a highly workable concrete that can flow through densely reinforced or complex structural elements under its own weight without vibration and adequately fill voids without experiencing segregation or excessive bleeding.

Note 1—Passing ability is defined as the ability of SCC to flow through openings such as the spaces between reinforcing bars without segregation or without aggregate blocking. Blocking is defined as the condition in which pieces of coarse aggregate combine to form elements large enough to obstruct the flow of the SCC between reinforcing bars or other obstructions in the concrete formwork.

1.2. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 141, Sampling Freshly Mixed Concrete
- TP 73, Slump Flow of Self-Consolidating Concrete (SCC)

3. SUMMARY OF TEST METHOD

3.1. The J-Ring apparatus consists of a rigid ring connecting 4-in. vertical smooth bars. The ring is held to a base plate, and an inverted slump cone is placed in its center. A sample of freshly mixed SCC is allowed to flow from the inverted slump cone through the bars of the J-Ring apparatus. The final average diameter of the slump flow patty after flowing through the bars compared to the average slump flow measured without the J-Ring is a measure of the passing ability of the SCC, and the difference in height of the SCC inside and outside of the ring provides an indication of blocking.

4. SIGNIFICANCE AND USE

4.1. This test method is applicable to self-consolidating concrete (SCC), defined in Section 1.1.

4.2. This test method is intended to provide the user with a procedure to assess the passing ability without blocking of SCC. The test gives an indication of the ability of the SCC to flow around and between reinforcement without blocking.

4.3. This test method is applicable to SCC having coarse aggregate up to 25 mm [1 in.].

5. APPARATUS

5.1. *J-Ring Apparatus*—The J-Ring consists of a rigid ring connecting 4-in. vertical smooth bars. The J-Ring shall be of dimensions shown in Figure 1, with tolerances as shown in Table 1. The J-Ring shall be made of steel or some other rigid, non-absorbent material not readily attacked by the cement paste. The 16 vertical round bars shall be spaced as shown in Figure 1 and of diameter of 16 mm [$^{5}/_{8}$ in.]. Connections of the round bars to the ring may be of any type that provides sufficient rigidity to maintain consistent clear spacing between the bars. Threaded, welded, or interference fit connections may be suitable, but care should be taken that heat deformation during welding does not deform the ring and lead to out-of-plumb bars with incorrect clear spacing.

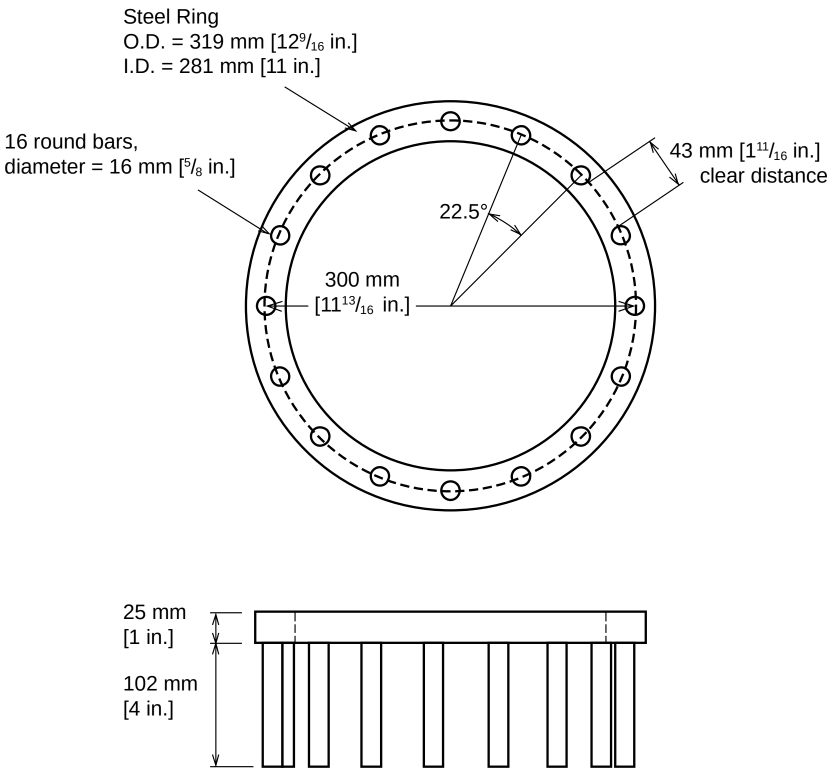

Figure 1—J-Ring Dimensions

Table 1—J-Ring Dimensions and Tolerances

Dimension	in.	mm
Ring diameter (centerline)	$11^{13}/_{16} \pm {}^{1}/_{8}$	300 ± 3.3
Ring width	$1^{9}/_{16} \pm {}^{1}/_{16}$	38 ± 1.5
Bar diameter	${}^{5}/_{8} \pm {}^{1}/_{32}$	16 ± 3.3
Bar spacing (clear distance)	$1^{11}/_{16} \pm {}^{1}/_{32}$	43 ± 1.0
Ring thickness	$1 \pm {}^{1}/_{16}$	25 ± 1.5
Bar length	$4 \pm {}^{1}/_{4}$	102 ± 6.0

5.2. *Slump Cone Mold*—The SCC shall be placed in an inverted slump cone mold conforming to the applicable requirements of T 119M/T 119.

5.3. *Base Plate*—The base plate shall be made of a stiff, nonabsorbing material, at least 820 mm [32 in.] square and marked with both a circle indicating the central location for the slump cone and a concentric circle with a diameter of 500 mm [20 in.].

5.4. Scoop.

5.5. Strike-off bar.

5.6. Tape measure containing increments of 6 mm [0.25 in.] or less.

6. SAMPLING, TEST SPECIMENS, AND TEST UNITS

6.1. Approximately 6 L [0.2 ft^3] of SCC is needed to perform the slump flow and J-Ring test, sampled normally.

6.2. The sample of concrete shall be obtained in accordance with T 141.

7. PROCEDURE

7.1. Moisten the base plate and the inside of the slump cone.

7.2. Place the base plate on a level, stable surface. Place the J-Ring centrally on the base plate and the inverted slump cone centrally inside it (Figure 2).

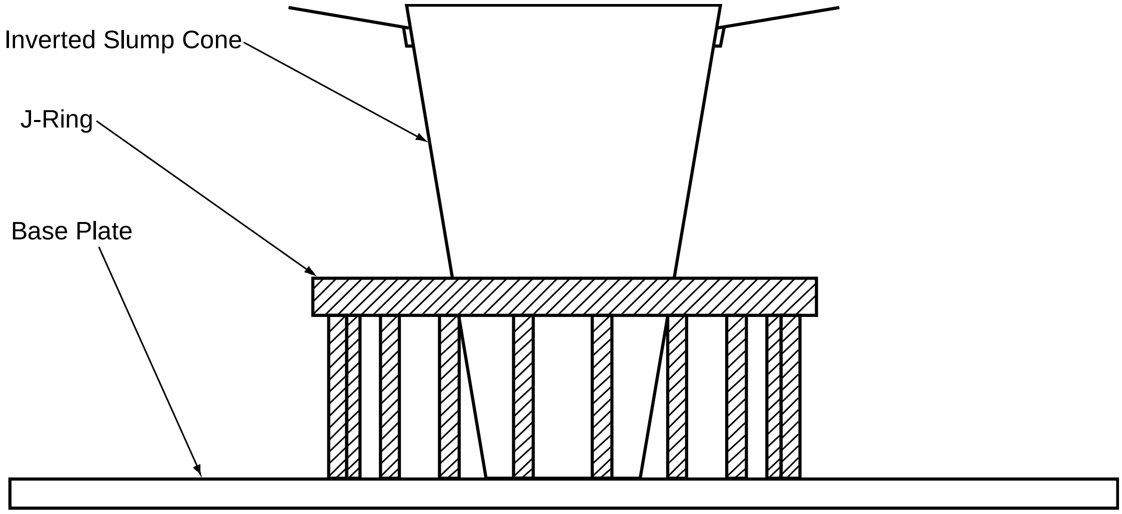

Figure 2—J-Ring Test Apparatus

7.3. From the sample of concrete obtained in accordance with Section 6, fill the entire mold continuously. The mold shall be held firmly in place during filling.

7.4. Do not rod or tamp the SCC. Do not tap or vibrate the cone.

7.5. Use the strike-off bar to strike off the SCC level with the top of the cone.

7.6. Remove any spilled or struck off SCC from around the base of the cone to preclude interference with the flowing SCC.

7.7. Raise the cone vertically 230 mm ± 75 mm [9 in. ± 3 in.] above the base plate with no lateral or torsional motion within a time period of 3 s ±1 s, and allow the SCC to flow out freely from within. Complete procedures in Sections 7.3 through 7.7 within $2^1/_2$ min.

7.8. After the concrete flow has stopped, measure the final diameter of the SCC in two perpendicular directions to the nearest 6 mm [0.25 in.] (Note 2). The average of the two measured diameters is the slump flow in millimeters (inches). Any border of mortar without coarse aggregate or a bleed water "halo" shall be included in the slump flow diameter.

Note 2—Measure the largest diameter of the slump flow as one diameter and the perpendicular diameter as the second to ensure consistency between tests. If the two values differ in diameter by more than 51 mm [2 in.], the test is considered invalid and must be repeated because it is likely that the cone was raised with lateral motion.

7.9. Measure the height of the SCC just inside the ring at four locations to an accuracy of 6 mm [0.25 in.] (heights are designated h_{a1} through h_{a4}). Measure the height of the SCC just outside the ring at four locations to an accuracy of 6 mm [0.25 in.] (heights are designated h_{b1} through h_{b4}). A flat bar or tamping rod placed horizontally across the top of the J-Ring apparatus may be used as a reference to determine the height of the SCC.

7.10. Measure the difference in height between the slump flow patty at the center of the ring (h_1) and just inside the ring at four locations to accuracy of 6 mm [0.25 in.]. A flat bar or tamping rod placed horizontally across the top of the J-Ring apparatus may be used as a reference to determine the height of the SCC.

7.11. Conduct the standard test, TP 73, using SCC from the same sample as used for this J-Ring test so that the results of the J-Ring test may be compared with the results from the slump flow test.

8. CALCULATION OF RESULTS

8.1. Calculate the average of the two measured diameters of the SCC patty after flowing through the J-Ring apparatus. This average value is the J-Ring flow. In general, greater J-Ring flow values indicate greater passing ability.

8.2. Calculate the average of the two measured diameters of the SCC after unrestricted flowing, without the J-Ring in place, by TP 73. This average value is the slump flow.

8.3. Calculate the difference between the J-Ring flow and the slump flow. This value is an indication of the passing ability of the SCC. A difference of less than 25 mm [1 in.] indicates good passing ability, and a difference greater than 51 mm [2 in.] indicates poor passing ability.

8.4. Calculate the average of the four measured heights inside the ring as ham and calculate the average of the four measured heights outside the ring as h_{bm}. Calculate the difference in mean heights between the inside and the outside of the J-Ring as $h_{ab} = (h_{am} - h_{bm})$.

8.5. Calculate the difference between the height of the SCC at the center of the ring and the mean height of the SCC inside the ring as $(h_1 - h_{am})$.

8.6. Calculate the J-Ring test value, J, as $2(h_{ab}) - (h_1 - h_{am})$. A J-Ring test value less than 15 mm [0.6 in.] indicates satisfactory passing ability without blockage.

9. REPORT

9.1. Record the J-Ring flow to the nearest 6 mm [0.25 in.].

9.2. Record the slump flow (without the J-Ring in place) measured by TP 73.

9.3. Record the difference between the J-Ring flow and the slump flow to the nearest 6 mm [0.25 in.].

9.4. Record $h_{ab} = (h_{am} - h_{bm})$, the difference in mean heights between the inside and the outside of the J-Ring, to the nearest 6 mm [0.25 in.].

9.5. Record $(h_1 - h_{am})$, the average of the four measured differences in height between the SCC at the center of the ring and the SCC just inside the bars, to the nearest 6 mm [0.25 in.].

9.6. Record the J-Ring test value, $2(h_{ab}) - (h_1 - h_{am})$, to the nearest 6 mm [0.25 in.].

10. PRECISION AND BIAS

10.1. No precision and bias statements are available at this time.

11. KEYWORDS

11.1. Flowability; passing ability; reinforcement; SCC; self-consolidating concrete; workability.

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[1] Approved in 2007, this standard was first published in 2008. Revised in 2009.

Standard Test Method for

Air-Void Characteristics of Freshly Mixed Concrete by Buoyancy Change

AASHTO Designation: TP 75-08[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Test Method for

Air-Void Characteristics of Freshly Mixed Concrete by Buoyancy Change

AASHTO Designation: TP 75-08[1]

1. SCOPE

1.1. This test method covers the determination of characteristics of the air-void system of fresh concrete using a sample of mortar. Spacing factor, specific surface, and entrained air content are determined by capturing air bubbles released from a mortar sample.

1.2. The sample will only be representative of the depth of the concrete within approximately 60 mm (2.5 in.) below the level at which the sampling is begun. This method is applicable to fresh concrete with a minimum slump of 10 mm (0.4 in.) and air content between 3.5 and 10 percent by volume. Only air voids less than 3 mm (0.1 in.) in diameter are measured by this method.[2] The test must be performed in sheltered, stable conditions.

1.3. The values stated in SI units are to be regarded as the standard.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 141, Sampling Freshly Mixed Concrete
- T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
- T 196M/T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method

2.2. *ASTM Standard*:

- C 457, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

3. SUMMARY OF TEST METHOD[3]

3.1. This method determines the air-void characteristics of fresh concrete by expelling all air bubbles present in a given mortar sample, collecting the air bubbles and recording their quantities, and calculating their size distribution. According to Stokes' law, larger bubbles rise faster than smaller ones. Thus, for bubbles rising a known distance, the size of the bubbles can be determined from the time of their arrival at the surface of the liquid. The air voids of a sample of fresh concrete mortar are released as bubbles by mixing the mortar with a viscous liquid. The bubbles then emerge from the viscous liquid, rise through an overlying column of water, and collect under a submerged dish. As the bubbles accumulate under the dish, the buoyancy of the dish changes. The change in buoyancy of the dish, as measured by a change in weight and recorded as a function of time, can be related to the number of bubbles of different sizes by an empirical correlation. Specific surface, spacing factor, and air content as specified by ASTM C 457 may be calculated from this data with the use of an algorithm.

4. SIGNIFICANCE AND USE

4.1. An adequate air-void system in hardened concrete protects the cement paste from damage during freezing and thawing cycles under moist conditions. This air-void system can be characterized by the volume of entrained air, spacing between air voids, specific surface, and void-size distribution.

4.2. This buoyancy change test method is capable of testing the air-void system of concrete *in situ*, reflecting the history of the concrete as it is in place, not as it is prepared in a sample for testing.

4.3. The primary function of the buoyancy change method is to provide air-void size and distribution information for concrete mixture designs. This test method could be used by the mix designer to evaluate various mix proportion options during prequalification. The effect of admixture combinations and admixture dosages on the air-void system can be evaluated. It can also be used by the approving agency as a quick laboratory check on mixes offered to them for approval.

4.4. During production, the adequacy of the air-void system can be verified for acceptance and feedback can be provided for manufacturing control. This method also allows rapid assessment of the effect of production changes in the mixture or equipment, or variations in placement conditions such as temperature, slump, and pumping on the air-void system. Characterization of the air-void system of the concrete shortly after production provides an assessment of the durability of the cement paste. Results are usually obtained within two hours, allowing adjustments in the subsequent production.

4.5. This method yields results that generally correlate well with the results of a linear traverse measurement on hardened concrete, as prescribed in ASTM C 457 for characteristics of the air-void system. Discrepancies between the results of this method and the results of ASTM C 457 may be due to coalescence of bubbles in the analysis liquid or due to errors in the ASTM C 457 test. The buoyancy change method does not give a total air content result that can be directly correlated with the results of T 152 and T 196M/T 196.

4.6. For further discussion of the significance of characteristics of the air-void system, see ASTM C 457, Section 5, Significance and Use.

5. APPARATUS[4]

5.1. *Analysis and Data Collection Apparatus*—This assembly, the sampling equipment and materials, are designed and built to function as an integrated system that has been demonstrated by the manufacturer to accurately measure and calculate air-void distribution in fresh air-entrained concrete.

5.1.1. *Riser Cylinder*—A clear plastic cylinder with a base and a collar approximately as shown in Figure 1. The base shall have an integral heating element capable of maintaining the analysis liquid at 23 ± 2°C (73 ± 4°F) and entry holes for the plastic rod and the sample syringe with gaskets to make a watertight seal.

5.1.2. *Magnetic Stirrer*—A magnetic stirrer capable of maintaining 300 rpm during mixing.

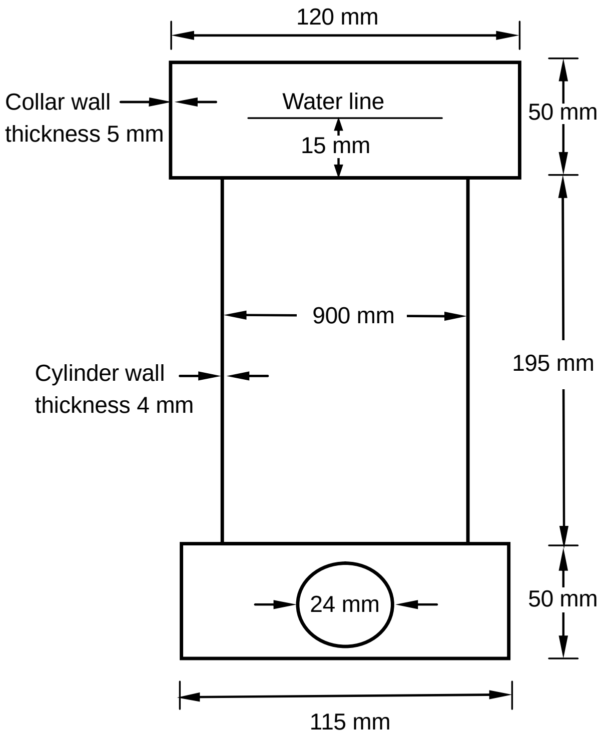

Figure 1—Riser Cylinder

5.1.3. *Balance*—The electronic balance shall meet the requirements of M 231, Class G1. The balance shall also have an integral arm from which the dish can be suspended.

5.1.4. *Cabinet*—The cabinet shall house the riser cylinder, magnetic stirrer, and balance as shown in Figure 2.

Figure 2—Typical Apparatus with Riser Cylinder, Cabinet, and Computer

5.1.5. *Stirrer Rod*—A ferromagnetic steel rod approximately 6 mm (0.25 in.) in diameter and 62 mm (2.5 in.) in length.

5.1.6. *Temperature Sensor*—The temperature sensor shall detect the temperature of the analysis liquid at the bottom of the cylinder. The temperature sensor shall be capable of measuring the temperature to within 0.5°C (1.0°F) in the range of 15 to 30°C (59 to 86°F) and of transmitting such measurements to the computer through an appropriate interface.

5.1.7. *Syringes*—20-ml plastic syringes, with the tapered end removed, calibrated and marked for collecting the specified sample volume as shown in Figure 3.

5.1.8. *Plastic Rod*—The cylindrical plastic rod shall be at least 35 mm (1.5 in.) longer than the width of the base. The outside diameter of the body of the rod is the same as the syringes used in the test. A 1-mm length at the end of the rod shall have a reduced diameter that fits tightly within the inside diameter of the syringe as shown in Figure 3.

5.1.9. *Dish*—The clear, shallow dish shall be large enough to cover the entire area of the cylinder, retain the rising bubbles, and fit within the collar. The dish shall have an opening on the side to allow entrapped air to be removed.

Note 1—An inverted Petri dish with an appropriate slot, as shown in Figure 3, can fulfill these requirements.

5.1.10. *Suspension Device*—A device to suspend the dish from a balance arm by a single wire as shown in Figure 3.

Figure 3—Petri Dish, 20 ml Syringe, and Temperature Sensor

5.1.11. *Control System*—A computer, software, and interface system capable of controlling the test, recording data, and displaying data at least once per minute during the test. It shall also calculate, display, and record the air content(s), air-void spacing factor, and specific surface of the air-void system.

5.2. *Sampling Equipment*:

5.2.1. *Sampling Assembly*—The sampling assembly shall hold the syringe and a wire cage and vibrate at approximately 50 Hz with an amplitude that allows the mortar to flow into the wire cage.

Note 2—A drill operating at 3000 rpm with an eccentrically weighted, forked assembly as shown in Figure 4 can fulfill these requirements. The hammering function of the drill can be used as needed in stiffer concrete mixes.

Figure 4—Wire Cage and Funnel

5.2.2. *Wire Cage*—The cage shall be of sufficient size to obtain a sample of fresh concrete mortar, similar to Figure 4. The cage wires shall have a clear spacing of 6 mm (0.24 in.).

5.2.3. *Plastic Plate*—A rigid, clear plastic plate approximately 250 by 250 by 3 mm (10 by 10 by $^1/_8$ in.) with a center hole of a diameter approximately 3 mm ($^1/_8$ in.) greater than that of the wire cage.

5.3. *Miscellaneous Tools*:

5.3.1. *Funnel*—A calibrated funnel marked for measuring a specified amount of analysis liquid similar to that shown in Figure 4. The funnel shall be capable of introducing the analysis liquid into the bottom of the water-filled riser cylinder with a minimum of mixing.

5.3.2. *Spatula*—A spatula to trim the mortar sample flush with the end of the syringe.

5.3.3. *Water Container*—A container with a 4-L (2-gal) minimum capacity.

Note 3—A 19-L (5-gal) portable insulated drinking water cooler is useful for repeated testing.

5.3.4. *Heating Element*—An immersible heating element capable of maintaining the water in the container at approximately 23 ± 2°C (73 ± 4°F).

5.3.5. *Thermometer*—A thermometer accurate to ±0.5°C (±1.0°F) over the range of 10 to 30°C (50 to 86°F).

5.3.6. *Brush*—A brush with an angled head and a handle longer than the riser cylinder is tall.

5.3.7. *Insulated box.*

Note 4—An insulated "cooler-type" lunchbox is useful.

5.3.8. *Sealable Plastic Bags*—Commercially available in pint and quart sizes.

6. MATERIALS

6.1. *Analysis Liquid*—The analysis liquid shall have physical and chemical properties such that the air-void bubbles remain discrete. The viscosity of the analysis liquid must remain constant over the range of temperatures found in the test and be compatible with the apparatus and the control system. The viscosity of the analysis liquid used shall provide a measurable separation in time between the arrivals of bubbles of different sizes at the top of the water column. The analysis liquid and its viscosity shall be specified by the equipment manufacturer.

Note 5—A commercially available solution of glycerol in water can fulfill these requirements. A mixture of 4 parts glycerol to 1 part distilled water has been known to work well.

6.2. *De-aerated Water*—The water shall be potable and shall have been maintained at atmospheric pressure and approximately 23 ± 2°C (73 ± 4°F) for a minimum of 12 hours before use.

Note 6—Properly de-aerated water is crucial to this test. The solubility of air in water increases as pressure increases and temperature decreases. The change in dissolved air content due to temperature occurs slowly; thus, the water must be maintained at constant temperature for a minimum of 12 hours before use. De-aerated water also reabsorbs air when cooled. If the water is not de-aerated correctly or if it is used shortly after reheating, air may be liberated in the riser cylinder. Air bubbles may form in the riser cylinder and on the dish, and may have a considerable effect on the specific surface and spacing factor results.

6.3. *Ice or Freezer Packs*—Ice as needed in cubes or chips or frozen re-freezable ice packs or cubes.

7. SAMPLING

7.1. Take samples as soon as possible after the concrete is in the desired state. The sampling location depends on the purpose of the test. Samples can be extracted from concrete *in situ* (pavements, structural members, decks, etc.), from concrete sampling containers such as unit weight buckets, beam molds, or cylinder molds, or from other locations.

7.2. Insert a syringe into the sampling assembly and mount the wire cage onto the sampling assembly. Fully collapse the syringe.

7.3. Place the plastic plate in good contact with the surface of the concrete to be sampled. Begin the vibration of the sampling assembly. Lower the wire cage through the hole in the plastic plate into the concrete. The vibration will cause the mortar fraction of the concrete to flow into the wire cage. Advance the wire cage into the concrete at a rate such that the concrete surface under the plate and the surface of the mortar within the cage remain at approximately the same level at all times. Avoid filling the cage with surface mortar by pressing the plastic plate against the fresh concrete. The pressure is adequate when the air bubbles under the plastic plate do not move towards the hole while sampling.

7.4. Advance the wire cage into the concrete until the end of the syringe plunger is in full contact with the surface of the mortar. While maintaining the vibration, push the syringe cylinder smoothly into the mortar at such a rate that the wire cage remains full of mortar until the syringe is fully extended. Stop the vibration and withdraw the wire cage and syringe from the concrete.

7.5. Remove the wire cage and the syringe from the sampling assembly saving the excess mortar from the wire cage. Pack this excess mortar around the end of the syringe to be used to displace any large air bubbles from the syringe.

7.6. Immediately place the sample in a plastic bag on ice or freezer packs in the insulated box to retard the onset of initial set. Testing must begin before the initial set of the concrete.

7.7. If large air bubbles are present at the base of the syringe, remove the plunger and pack enough excess mortar through the opposite end of the syringe to remove the air bubble. Replace the plunger to contact the mortar. Remove the excess mortar from the outside of the syringe and clean the outside of the syringe with a damp cloth. Advance the plunger to the mark corresponding to the specified sample volume and trim the mortar flush with the end of the syringe cylinder using the spatula. Retract the plunger approximately 1 mm (0.04 in.) to allow room for the recessed end of the plastic rod. This step may be performed at any time before step 9.9, seating the syringe on the plastic rod. If the air bubble is larger than 2 ml, discard and resample.

Note 7—2 ml is approximately the distance from the end of the plunger to the calibration mark when the plunger of the syringe is fully extended. The 2 ml of material is packed into the opposite end of the syringe. This material is then forced back out of the syringe when the plunger is advanced to the calibration mark.

8. PREPARATION OF APPARATUS

8.1. Bring the analysis liquid and at least 2 L (0.5 gal) of de-aerated water to a temperature of 23 ± 2°C (73 ± 4°F) without altering other characteristics of the liquids.

Note 8—Using ice in sealed plastic bags or freezer packs to cool the liquids is acceptable.

8.2. Select a test location protected from any wind, vibration, or movement that may affect the balance readings. Place the cabinet on a stable and level surface. Allow the balance to stabilize so that it does not drift more than 0.01 g in four minutes. If the balance has auto-zeroing capability, place a small load on the balance to obtain a non-zero reading in order to observe the variation of the reading.

8.3. Connect the control system.

Note 9—Place the control system so that if the plastic rod is accidentally removed from the base of the riser cylinder the contents of the riser cylinder will not spill onto the control system.

8.4. See Appendix X4 for additional hints on preparation of apparatus.

9. PROCEDURE

9.1. Enter all required data into the control system.

9.2. Place the stirrer rod flat on the bottom of the riser cylinder. Insert the plastic rod through the hole on the wider side of the base of the riser cylinder so the full diameter of the plastic rod protrudes though the hole on the opposite (narrower) side of the base.

Note 10—Using a light coat of waterproof grease on the rubber o-rings will improve the seal between the plastic rod and the base of the riser cylinder.

Note 11—When testing low-viscosity materials such as self-consolidating concrete, it is permissible to tilt the riser column to seat the syringe on the plastic rod before the liquids are added to the riser column.

9.3. Fill the riser cylinder with de-aerated water to about 15 mm (0.5 in.) above the bottom of the top collar. Use the brush to remove all bubbles from the stirrer rod, the plastic rod, and the riser cylinder.

Note 12—Rotating the plastic rod can be helpful in ensuring that all bubbles are removed.

9.4. Mount the riser cylinder in position on the cabinet. It is permissible to fill the riser cylinder with the water after positioning the riser cylinder on the cabinet.

9.5. Fill the funnel with the manufacturer's specified amount of the analysis liquid.

9.6. Insert the analysis liquid into the bottom of the riser cylinder using the funnel to minimize the mixing of the analysis liquid with the de-aerated water. Replace the stopper once the specified amount of analysis liquid has been discharged. Remove the funnel from the riser cylinder and discard any remaining liquid in the funnel.

9.7. Connect the integral heating element of the riser cylinder and the temperature sensor to the control system.

9.8. Insert the dish into the riser cylinder collar. Submerge the dish in the de-aerated water and tilt to allow all entrapped air to escape through the opening. Suspend the dish from the balance arm in such a way that it is approximately centered and does not touch the walls of the riser cylinder collar. Only a single wire of the suspension device may break the surface of the water. Add more de-aerated water if necessary.

9.9. Seat the syringe containing the sample on the reduced end of the plastic rod. Move the syringe and plastic rod together through the riser cylinder base until the junction of the syringe and plastic rod is at the nearest inside edge of the riser cylinder. Leaving the syringe in position, continue withdrawing the plastic rod until the reduced end is flush with the opposite inside edge of the riser cylinder.

Note 13—To make positioning the plastic rod and syringe with respect to the riser cylinder easier, mark the correct position on the plastic rod and note the position of the syringe before starting the test. If moving the plastic rod and syringe is difficult, use a small amount of waterproof grease or analysis fluid on the gaskets and use a twisting motion.

9.10. Remove enough of the air that may have risen during the separation of the syringe and the plastic rod from under the dish so the dish is neither touching nor close to the wall of the riser cylinder collar.

9.11. When the temperature of the analysis liquid as measured by the temperature sensor is 23 ± 2°C (73 ± 4°F), inject the mortar from the syringe into the riser cylinder. Immediately start the mixing and data collection.

9.12. If any of the recorded temperature readings are outside the range of 23 ± 2°C (73 ± 4°F), discard the test.

9.13. If unusual variations that may be due to vibration or disturbance are noted in the data, discard the test.

9.14. Analyze samples as soon as possible. However, samples may be used whenever they can be completely dispersed in the analysis liquid by the stirring action.

10. REPORT

10.1. *The report shall include the following information*:

10.1.1. Project identification;

10.1.2. Test identification number;

10.1.3. Date of test;

10.1.4. Sampling location;

10.1.5. Slump by T 119M/T 119 (if known);

10.1.6. Air content by T 152 or T 196M/T 196 (if known);

10.1.7. Unit weight by T 121M/T 121 (if known);

10.1.8. Mortar (material less than 6 mm) volume, percent, as calculated from the mix design;

10.1.9. Paste volume, percent, as calculated from the mix design;

10.1.10. Sample volume, ml;

10.1.11. Test temperature range, °C (°F);

10.1.12. Air content(s), percent;

10.1.13. Spacing factor, mm (in.); and

10.1.14. Specific surface, mm^2/mm^3 ($in.^2/in.^3$).

11. PRECISION AND BIAS

11.1. *Precision*—The existing data from this method are not sufficient to develop a precision statement. The necessary data could be generated by performing a “round robin” test using several devices at a single facility.

11.2. No bias statement has been developed. There is no accepted reference material suitable for determining bias from the true air-void characteristics of concrete.

12. KEYWORDS

12.1. Air content; air-void characteristics; air-void parameters; air-void system; fresh concrete; spacing factor; specific surface.

APPENDIXES

(Nonmandatory Information)

X1. VERIFICATION

X1.1. To correlate the air-void characteristics (spacing factor, entrained air content, or specific surface) as determined by the buoyancy change method from fresh concrete with those obtained by ASTM C 457 from hardened concrete, compare a minimum of five pairs of samples. Each pair of samples of the fresh and hardened concrete should be from the same batch of concrete, placed and consolidated uniformly, of comparable depth, and located as close together as possible without including any of the area disturbed during sampling the fresh concrete in the hardened sample. Calculate the percentage difference of the buoyancy test results from the ASTM C 457 results for each pair, and then average these percentage differences. The average of the percentage differences of the five pairs should be 20 percent or less for the results to be considered equivalent. Average percentage differences greater than 20 percent may arise from ASTM C 457 testing errors such as mistaking fly ash spheres or voids left by sand grains plucked from the polished surface of the specimen during sample preparation for air voids in the concrete paste. Sampling errors, testing errors in the buoyancy change method, admixtures that affect the viscosity or the miscibility of fresh concrete, or other factors may also cause some variation. The buoyancy change method is less likely than ASTM C 457 to overestimate the quantity and quality of the air voids in any given concrete. In the buoyancy change method, bubbles may coalesce after release into the fluid, and the portion of entrained air associated with the coarse aggregate is excluded from the sample. Thus, the buoyancy change method will tend to give a lower specific surface and higher spacing factor than ASTM C 457.

X2. EQUIPMENT HANDLING REQUIREMENTS

X2.1. The commercially available Germann Air Void Analyzer does not require special handling when it is packed securely in its metal carrying case. The Kansas Department of Transportation’s Air-Void Analyzer has been transported in its case and set up at remote locations at least twice a week for three construction seasons with few deleterious effects.

X3. REPEATABILITY

X3.1. Although each buoyancy test requires a unique sample and therefore cannot be duplicated exactly, researchers at the Kansas Department of Transportation have found that pairs of samples obtained within 0.5 m of each other in the field vary 10 percent from each other on average.

X4. SET UP HINTS

X4.1. Several steps can be taken to reduce the amount of time necessary to set up the buoyancy testing equipment.

X4.1.1. Preparing the de-aerated water and the bottle of analysis liquid in an insulated water container at least one day before testing occurs will save time. If the water container will be stored in an area that is cooler than the specified temperature, set the immersible heater to the correct temperature and put it into the covered water container. If the room temperature is slightly higher than the specified temperature, uncovering the container will allow the water to cool approximately 3°C (5°F). If the room temperature is much higher than the specified temperature, a sealed bag of ice or freezer packs placed in the covered water container the night before testing will generally result in the correct water and analysis fluid temperature.

X4.1.2. After the water has been brought to the proper temperature, care should be taken to keep the temperature as constant as possible. Protect the water container from temperature extremes, such as may be encountered in an enclosed vehicle.

X4.1.3. Obtaining a constant balance reading at the beginning of the test may take a significant amount of time if the equipment is set up in an unstable location. Mobile work trailers that are resting on their tires are generally not stable enough. Any movement by people in the trailer can move the trailer enough to disturb the apparatus and render the test unusable. Generally, only trailers that have been put up on blocks so they are not sitting on their tires are at all acceptable, and only as a last alternative.

X4.1.4. Isolating the test equipment from vibration will reduce the time necessary to obtain a constant balance reading at the beginning of the test. One or two anti-vibration pads may be used under each corner of the cabinet to attenuate shock and vibration.

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[1] Approved in 2007, this standard was first published in 2008.

[2] See "The Air Void Analyzer for Assessment of Quality of Air Void Structures in the Fresh, Still Plastic Concrete" by Dansk Beton Teknik A/S (2001) for more information.

[3] For additional information, see Appendix B of "Air Void Analyzer Evaluation," FHWA-SA-96-062.

[4] Suitable equipment is commercially available.

Standard Method of Test for

Visual Stability Index (VSI) of Self-Consolidating Concrete (SCC)

AASHTO Designation: TP 80-10[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Visual Stability Index (VSI) of Self-Consolidating Concrete (SCC)

AASHTO Designation: TP 80-10[1]

1. SCOPE

1.1. This test method covers determination of the visual stability index of self-consolidating concrete (SCC), both in the laboratory and in the field. SCC is defined as a highly workable concrete that can flow through densely reinforced or complex structural elements under its own weight without vibration and adequately fill voids without experiencing segregation or excessive bleeding.

1.2. The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3. *This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- T 119M/T 119, Slump of Hydraulic Cement Concrete
- T 141, Sampling Freshly Mixed Concrete
- TP 73, Slump Flow of Self-Consolidating Concrete (SCC)

3. SUMMARY OF TEST METHOD

3.1. The Visual Stability Index (VSI) is a visual rating of the resistance to segregation of an SCC mixture and may be determined when performing the Slump Flow Method of Test in TP 73. A sample of freshly mixed self-consolidating concrete is placed in a mold shaped as the inverted frustum of a cone. The mold is raised, allowing the SCC to spread radially. The stability of the mixture is then rated visually and assigned a Visual Stability Index based on the criteria in this document.

4. SIGNIFICANCE AND USE

4.1. This test method is applicable to self-consolidating concrete (SCC), defined in Section 1.1.

4.2. This test method is intended to provide the user with a procedure to assess the stability of SCC. The stability (or segregation resistance) of an SCC mixture is the ability of the mixture to remain homogeneous in composition during transport, during placement, and subsequent to placement. The VSI does not quantify a property of the concrete mixture, but is useful for quality control/consistency testing.

4.3. This test method is applicable to SCC having coarse aggregate up to 25 mm [1 in.].

5. APPARATUS

5.1. *Mold*—The SCC shall be placed in an inverted slump cone mold conforming to the applicable requirements of T 119M/T 119.

5.2. *Base Plate*—The base plate shall be made of a stiff nonabsorbing material, at least 820 mm [32 in.] square, marked with a circle indicating the central location for the slump cone, and a concentric circle with a diameter of 500 mm [20 in.].

5.3. *Scoop*—A scoop of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the mold

5.4. *Strike-Off Bar*—A flat straight bar of steel or other suitable metal at least $^1/_8$ in. (3 mm) thick and $^3/_4$ in. (20 mm) wide by 12 in. (300 mm) long.

5.5. Tape measure containing increments of 5 mm [0.25 in.] or less.

6. SAMPLE

6.1. Approximately 6 L [0.2 ft^3] of SCC is needed to perform the slump flow and VSI tests, sampled normally.

6.2. The sample of concrete shall be obtained in accordance with T 141.

7. PROCEDURE

7.1. Moisten the base plate and inside of the slump cone.

7.2. Place the base plate on a level stable surface and the inverted slump cone centrally on the base plate and hold down firmly (Figure 1).

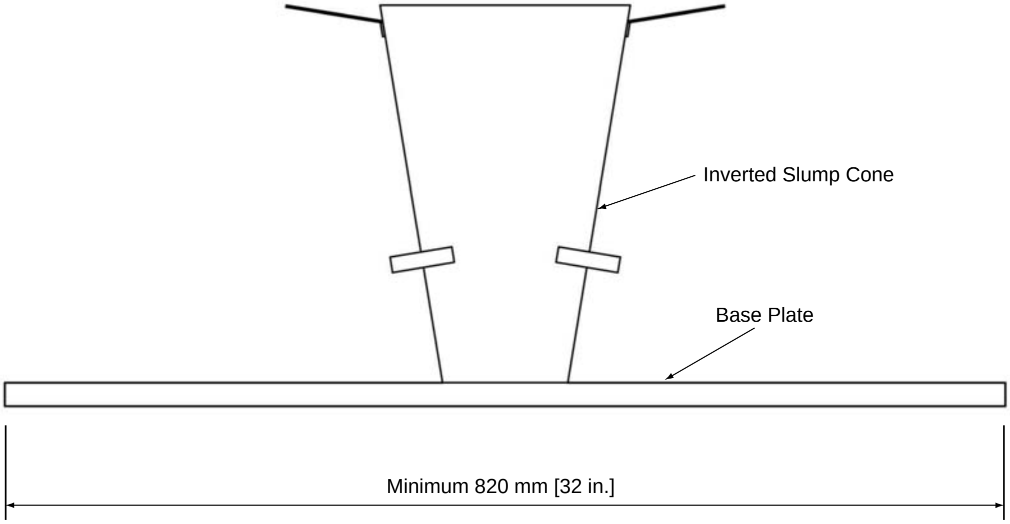

Figure 1—Mold and Base Plate for Slump Flow Test (Inverted Cone Orientation)

7.3. From the sample of concrete obtained in accordance with Section 6, fill the entire mold continuously. The mold shall be held firmly in place during filling.

7.4. Do not rod or tamp the SCC. Do not tap the sides of the cone or vibrate.

7.5. Use the strike-off bar to strike off the SCC level with the top of the cone.

7.6. Remove any spilled or struck off SCC from around the base of the cone to preclude interference with movement of the flowing SCC.

7.7. Immediately raise the cone vertically 230 ± 75 mm [9 ± 3 in.] above the base plate with no lateral or torsional motion within a time period of 3 ± 1 s, and allow the SCC to flow out freely from within. Complete the steps described in Sections 7.3 through 7.7 within $2^1/_2$ min.

7.8. If the Slump Flow test of TP 73 is being performed, diameters of the patty may be measured at this point.

7.9. Using the guidelines in Section 8, rate the stability of the mixture in 1.0 increments by visual examination of the SCC on the base plate and in the wheelbarrow or mixer.

8. INTERPRETATION OF RESULTS

8.1. In the case of severe segregation, most of the coarse aggregate may remain in the center of the slump flow patty of SCC. A border of mortar without coarse aggregate or a bleed water “halo” may occur at the edge of the slump flow patty of SCC.

8.2. Refer to Table 1 and Figures 2 through 8 for assignment of Visual Stability Index.

Table 1—Criteria for Visual Stability Index (VSI) of SCC

Rating	Criteria
0	No evidence of segregation in slump flow patty or in mixer drum or wheelbarrow.
1	No border of mortar without coarse aggregate in the slump flow patty, but some slight bleed or air popping on the surface of the concrete in the mixer drum or wheelbarrow.
2	A slight border of mortar without coarse aggregate (<10 mm [$^3/_8$ in.]) and/or aggregate pile in the slump flow patty and highly noticeable bleeding in the mixer drum and wheelbarrow.
3	Clearly segregating by evidence of a large border of mortar without coarse aggregate (>10 mm [$^3/_8$ in.]) and/or large aggregate pile in the center of the slump flow patty and a thick layer of paste on the surface of the resting concrete in the mixer drum or wheelbarrow.

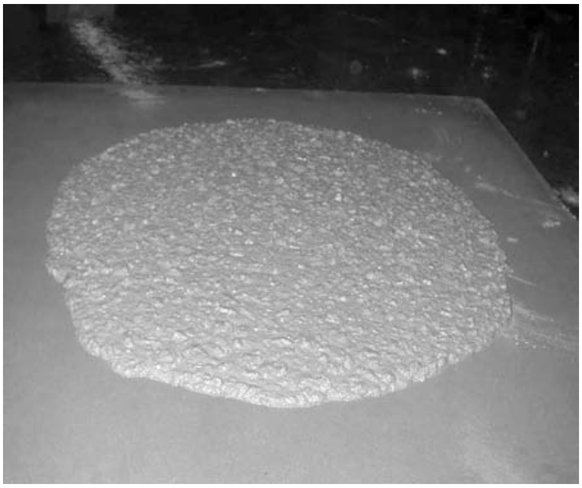

Figure 2—Visual Stability Index = 0

Figure 3—Visual Stability Index = 1

Figure 4—Visual Stability Index = 1

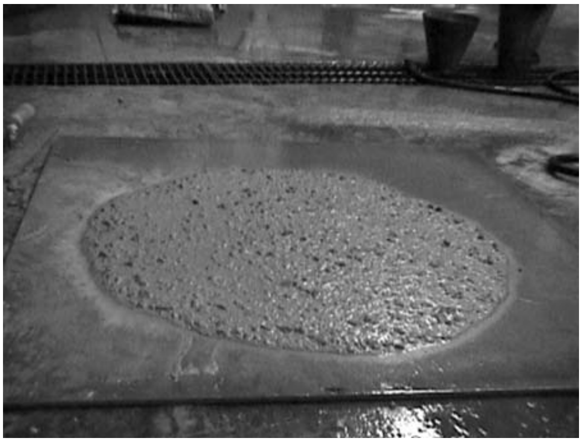

Figure 5—Visual Stability Index = 2

Figure 6—Visual Stability Index = 2

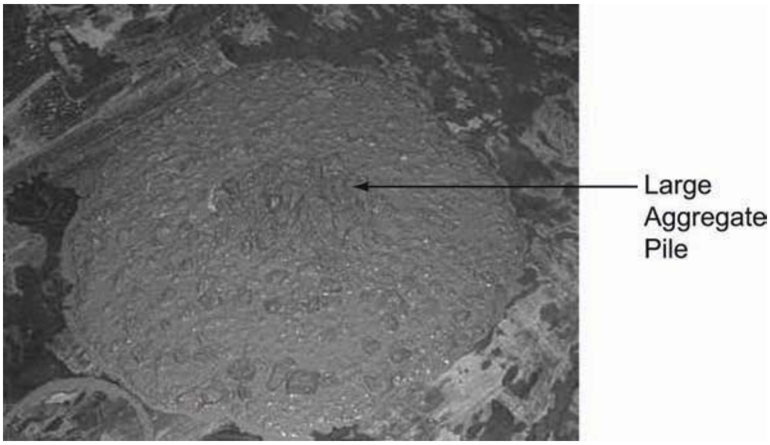

Figure 7—Visual Stability Index = 3

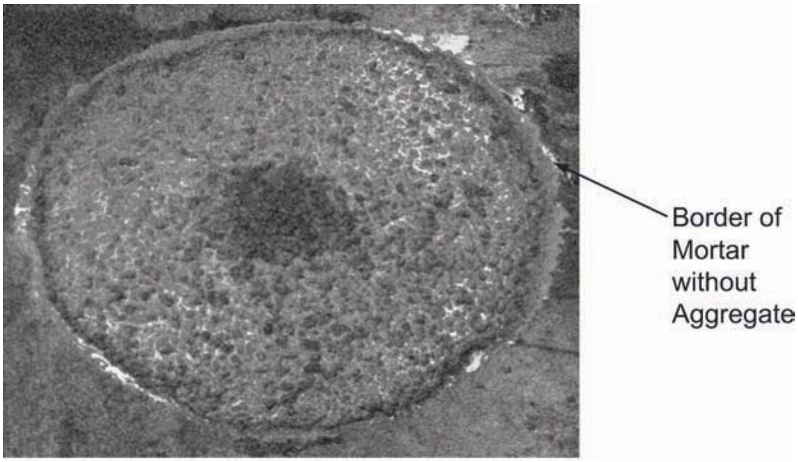

Figure 8—Visual Stability Index = 3

9. REPORT

9.1. Record the Visual Stability Index of the mixture.

10. PRECISION AND BIAS

10.1. No precision and bias statements are available at this time.

11. KEYWORDS

11.1. Halo; SCC; segregation; self-consolidating concrete; slump flow; stability; Visual Stability Index; VSI; workability.

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[1] This test method was adopted and first printed in 2009. Revised in 2010.

Standard Method of Test for

Sampling and Fabrication of 50-mm (2-in.) Cube Specimens Using Grout (Non-Shrink) or Mortar

AASHTO Designation: TP 83-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Sampling and Fabrication of 50-mm (2-in.) Cube Specimens Using Grout (Non-Shrink) or Mortar

AASHTO Designation: TP 83-10

1. SCOPE

1.1. This method covers field sampling and fabrication and initial curing of 2-in. (50-mm) cube specimens of non-shrink grout or mortar materials, or both.

1.2. The values stated in either inch-pound or SI units shall be regarded separately as standard. The inch-pound units are shown in parentheses. The values stated might not be exact equivalents; therefore, each system must be used independently of the other.

Note 1—Unit weight was the previous terminology used to describe the property determined by this test method, which is mass per unit volume.

1.3. The text of this test method references notes and footnotes that provide explanatory information. These notes and footnotes (excluding those in tables) shall not be considered as requirements of this test method.

1.4. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

Warning—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 106M/T 106, Compressive Strength of Hydraulic Cement Mortars (Using 50-mm or 2-in. Cube Specimens)
- T 141, Sampling Freshly Mixed Concrete

2.2. *ASTM Standards*:

- C 109/C 109M, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
- C 1107/C 1107M, Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink)

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard*:

3.1.1. *plastic mix*—material viscous enough that an indentation will be left in the surface of the grout after tamping.

3.1.2. *fluid mix*—material fluid enough that little or no indentation will be left in the surface after puddling.

4. APPARATUS

4.1. *Specimen Molds Including Cover Plate(s)*—The 2-in. (50-mm) cube specimen molds shall be tight-fitting and made of brass or other suitable material. This material shall not be susceptible to attack by the cement mortar. The mold portion shall have not more than three cube compartments and shall be separable into not more than two parts. The parts of the molds (mold halves and cover plate(s)), when assembled, shall be positively held together. The working surface of the cover plate(s) shall be plane and shall be positively attached to the side walls of the mold. The interior faces of the molds shall conform to the tolerances of Table 1.

Table 1—Permissible Variations of Specimen Molds

Parameter	2-in. Cube Molds		50-mm Cube Molds	
	New	In Use	New	In Use
Planeness of sides	<0.001 in.	<0.002 in.	<0.025 mm	<0.05 mm
Distance between opposite sides	2 in. ± 0.005 in.	2 in. ± 0.02 in.	50 mm ± 0.13 mm	50 mm ± 0.50 mm
Height of each compartment	2 in. + 0.01 in. to –0.005 in.	2 in. + 0.01 in. to –0.015 in.	50 mm + 0.25 mm to –0.13 mm	50 mm + 0.25 mm to –0.38 mm
Angle between adjacent faces[a]	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°

[a] Measured at points slightly removed from the intersection. Measured separately for each compartment between all the interior faces and the adjacent face and between interior faces and top and bottom planes of the mold.

4.2. *Tamper*—A nonabsorptive, nonabrasive, nonbrittle material such as a hard rubber compound having a Shore A durometer hardness of 80 ± 10. The tamper shall have a cross section of about $^1/_2$ in. by 1 in. (13 mm by 25 mm) and a length of 5 to 6 in. (125 to 150 mm). The tamping face shall be flat and at right angles to the length of the tamper.

4.3. *Trowel*—Steel bladed, 4 to 6 in. (100 to 150 mm) in length, with straight edges.

4.4. *Watertight Container*—A 6-in. by 12-in. (150-mm by 300-mm) concrete cylinder mold with lid.

4.5. *Other Equipment*—Rubber gloves, scoop, clamps to secure the cover plate, light release oil for oiling the molds, small brush or lint-free cloth for applying and removing excess release oil, and burlap or wrapping cloth capable of retaining moisture.

5. SAMPLING

5.1. Samples shall be obtained in accordance with T 141 when the batch equals or exceeds 1 yd^3 (1 m^3). When the batch is less than 1 yd^3 (1 m^3), sample from the batch after discharge. If remixing is required, sample after remixing. Begin molding the specimens within an elapsed time of not more than $2^1/_2$ minutes from completion of the mixing.

Note 2—This test is to be used only for grouts with 100 percent passing the $^{3}/_{8}$-in. (9.5-mm) sieve.

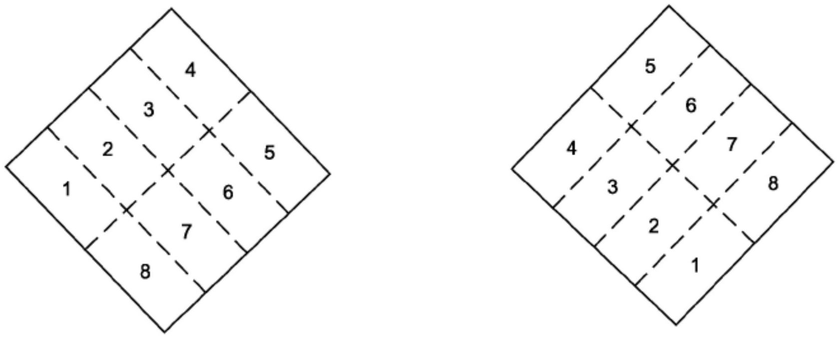
5.2. Obtain a representative sample of the mix. Samples shall be a minimum size of 4 lb (2000 g) for each set of three cubes to be fabricated.

6. PROCEDURE

6.1. Assemble both portions of the mold and the bottom cover plate. All joints shall be watertight. If not watertight, seal the surfaces where the halves of the mold join by applying a coating of light cup grease (non-water-soluble). The amount should be sufficient to extrude slightly when the halves are tightened together. Repeat this process for attaching the mold to the bottom cover plate. Remove any excess grease. Apply a thin coating of release agent to the interior faces of the mold and the bottom cover plate. Wipe the mold faces and base plate as necessary to remove any excess release agent and to achieve a thin, even coating on the interior surfaces. Adequate coating is that which is just sufficient to allow a distinct fingerprint to remain following light finger pressure.

6.2. Place a layer of grout about 1 in. (25 mm) (approximately one-half of the depth of the mold) in all of the cube compartments. Consolidate according to the consistency (plastic or fluid) of the mix.

6.2.1. For plastic mixes, tamp the lift in four rounds of 8 tamps for a total of 32 tamps with the rubber tamper in 10 seconds. See Figure 1 for tamping sequence of each round. Rounds 1 and 3 and Rounds 2 and 4 shall be the same.



Rounds 1 and 3

Rounds 2 and 4

Figure 1—Tamping Sequence

6.2.2. For fluid mixes, puddle the lift 5 times with a gloved finger. See Figure 2 for puddling sequence.

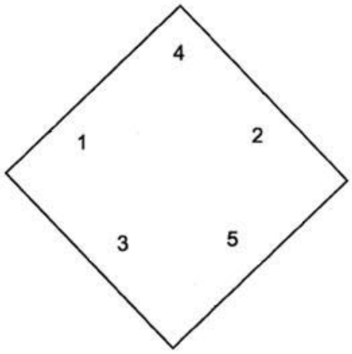


Figure 2—Puddling Sequence

6.3. Place the second lift in each of the cube compartments, slightly over-filling each compartment. Consolidate the material in the same fashion as the first lift with the additional requirement that, during consolidation of the second lift, any grout forced out onto the top of the mold after each round will be pushed back onto the compartment by means of the tamper or gloved fingers, or both, before the next consolidation round. When consolidation of the grout is completed, material should extend slightly above the top of the mold. After the last round, push any grout forced onto the top of the mold back into the compartment with the trowel.

6.4. Smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mold. Then, for the purpose of leveling the mortar and making the mortar that protrudes above the top of the mold of more uniform thickness, draw the flat trailing edge of the trowel (with leading edge slightly raised) once lightly along the length of the mold. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straightedge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the length of the mold. The material shall be flush with the top of the mold.

6.5. Immediately secure the top cover plate to the cube mold.

6.6. Place the molds in a secure location away from vibration and as close as possible to the structure for initial curing. Cover with wet burlap, towels, or rags; seal it in a plastic sack in a level location out of direct sunlight; and record the time. These samples shall remain undisturbed and protected from freezing or overheating for a period of 24 ± 4 hours.

6.7. At the end of the initial curing period as required by the agency, either:

6.7.1. Place the sealed plastic sack into a watertight container. Transport the cube samples immediately to the location of final curing. During transport, the cube samples shall be protected from jarring, freezing, and moisture loss; or

6.7.2. Disassemble the mold and carefully remove the cube samples. Using a permanent marker, identify the cube samples. Handling the cube samples very carefully, wrap them in wet burlap or wet towels and place them into a watertight container. Transport the cube samples immediately to the location of final curing. During transport, the cube samples shall be protected from jarring, freezing, and moisture loss.

6.8. Final curing shall consist of removing the samples from the transport container and immersing the cube samples in a lime-saturated water storage tank. They are to remain in the storage tank until time of test. (Curing cube samples of material other than hydraulic cement shall be in conformance with the manufacturer’s recommendations.) The storage tank shall be made of noncorroding materials.

Standard Specification for

Detectable Warning Surfaces

AASHTO Designation: MP 12-04

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Detectable Warning Surfaces

AASHTO Designation: MP 12-04

1. SCOPE

1.1. Detectable warnings provide a distinctive surface of truncated domes detectable by cane or underfoot to alert people with vision impairments of the transition to vehicular ways. These warnings compensate for the sloped surfaces of curb ramps that remove a tactile cue provided by curb faces.

1.2. It is not the intent of this specification to relieve the supplier from the final responsibility to provide an appropriate product for the intended function, nor is it intended to specify all the design details. The objective is to provide a sufficiently detailed specification that the function is clearly defined to provide a standard geometry of the detectable warning surface.

2. REFERENCED DOCUMENTS

2.1. The Access Board, *Accessibility, Guidelines and Standards,* "Draft Guidelines for Accessible Public Rights-of-Way," November 23, 2005, www.access-board.gov/prowac/draft.htm.

3. TERMINOLOGY

3.1. *detectable warning*—A surface feature built in or applied to walking surfaces or other elements to warn of hazards on a circulation path.

4. DETECTABLE WARNING SURFACES

4.1. *General*—Detectable warnings shall consist of a surface of truncated domes aligned in a square grid pattern and shall comply with the following requirements:

4.1.1. *Dome Size*—Truncated domes in a detectable warning surface shall have a base diameter of 0.9 in. (23 mm) minimum to 1.4 in. (36 mm) maximum, a top diameter of 50 percent of the base diameter minimum to 65 percent of the base diameter maximum, and a height of 0.2 in. (5 mm).

4.1.2. *Dome Spacing*—Truncated domes in a detectable warning surface shall have a center-to-center spacing of 1.6 in. (41 mm) minimum and 2.4 in. (61 mm) maximum, and a base-to-base spacing of 0.65 in. (16 mm) minimum, measured between the most adjacent domes on square grid.

4.1.3. *Contrast*—Detectable warning surfaces shall contrast visually with adjacent walking surfaces either light-on-dark or dark-on-light.

4.1.4. *Size*—Detectable warning surfaces shall extend 24 in. (610 mm) minimum in the direction of travel and the full width of the curb ramp, landing, or blended transition.

4.2. *Location*:

4.2.1. *Curb Ramps and Blended Transitions*—The detectable warning surface shall be located so that the edge nearest the curb line is 6 in. (150 mm) minimum and 8 in. (205 mm) maximum from the curb line.

4.2.2. *Rail Crossings*—The detectable warning surface shall be located so that the edge nearest the rail crossing is 6 in. (150 mm) minimum and 8 in. (205 mm) maximum from the vehicle dynamic envelope.

4.2.3. *Platform Edges*—Detectable warning surfaces at platform boarding edges shall be 24 in. (610 mm) wide and shall extend the full length of the platform.

Standard Specification for

Stainless Clad Deformed and Plain Round Steel Bars for Concrete Reinforcement

AASHTO Designation: MP 13M/MP 13-04 (2006)

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Stainless Clad Deformed and Plain Round Steel Bars for Concrete Reinforcement

AASHTO Designation: MP 13M/MP 13-04 (2006)

1. SCOPE

1.1 This specification covers the stainless steel clad concrete reinforcement bars in cut lengths or coils, deformed and plain round. The standard sizes and dimensions of deformed bars and their number designations shall be those listed in Table 1 [Table 2].

Note 1—For coils of deformed bars, the capacity of industrial equipment limits the maximum bar size that can be straightened.

1.2 Bars are of three minimum yield levels: namely, 300 MPa [40000 psi], 420 MPa [60000 psi], and 520 MPa [75000 psi], designated as Grade 300 [40], Grade 420 [60], and Grade 520 [75], respectively.

1.3 Hot-rolled plain rounds, in sizes up to and including 50.8 mm [2 in.] in diameter in coils or cut lengths, when specified for dowels, spirals, and structural ties or supports, shall be furnished under this specification in Grade 300 [40], Grade 420 [60], and Grade 520 [75] (Note 2).

For ductility properties (elongation and bending), test provisions of the nearest nominal diameter deformed bar size shall apply. Those requirements providing for deformations and marking shall not be applicable.

Note 2—The weight for plain rounds smaller than 9.5 mm [$^3/_8$ in.] in diameter shall be computed on the basis of the size in ASTM A 510.

1.4 Welding of the material in this specification should not be attempted since no experience has been demonstrated regarding weldability of this product. Mechanical coupling should be specified for bars requiring continuous longitudinal connection. Mechanical couplings must conform to ASTM A 276, UNS S31803.

1.5 This specification is applicable for orders in either SI units (MP 13M) or in inch-pound units (MP 13). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to MP 13.

Table 1—Deformed Bar Designation Numbers, Nominal Masses, Nominal Dimensions, and Deformation Requirements, SI Units

		Nominal Dimensions[a]			Deformation Requirements, mm		
Bar Designation No.[b]	Nominal Mass, kg/m	Diameter, mm	Cross-Sectional Area, mm^2	Perimeter, mm	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
10	0.560	9.5	71	29.9	6.7	0.38	3.6
13	0.994	12.7	129	39.9	8.9	0.51	4.9
16	1.552	15.9	199	49.9	11.1	0.71	6.1
19	2.235	19.1	284	59.8	13.3	0.97	7.3
22	3.042	22.2	387	69.8	15.5	1.12	8.5
25	3.973	25.4	510	79.8	17.8	1.27	9.7
29	5.060	28.7	645	90.0	20.1	1.42	10.9
32	6.404	32.3	819	101.3	22.6	1.63	12.4
36	7.907	35.8	1006	112.5	25.1	1.80	13.7
43	11.38	43.0	1452	135.1	30.1	2.16	16.5
57	20.24	57.3	2581	180.1	40.1	2.59	21.9

[a] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same mass per meter as the deformed bar.

[b] Bar designation numbers approximate the number of millimeters of the nominal diameter of the bar.

Table 2—Deformed Bar Designation Numbers, Nominal Weights, Nominal Dimensions, and Deformation Requirements, U.S. Customary Units

		Nominal Dimensions[a]			Deformation Requirements, in.		
Bar Designation No.[b]	Nominal Weight, lb/ft	Diameter, in.	Cross-Sectional Area, in.^{2}	Perimeter, in.	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
3	0.376	0.375	0.11	1.178	0.262	0.015	0.143
4	0.668	0.500	0.20	1.571	0.350	0.020	0.191
5	1.043	0.625	0.31	1.963	0.437	0.028	0.239
6	1.502	0.750	0.44	2.356	0.525	0.038	0.286
7	2.044	0.875	0.60	2.749	0.612	0.044	0.334
8	2.670	1.000	0.79	3.142	0.700	0.050	0.383
9	3.400	1.128	1.00	3.544	0.790	0.056	0.431
10	4.303	1.270	1.27	3.990	0.889	0.064	0.487
11	5.313	1.410	1.56	4.430	0.987	0.071	0.540
14	7.65	1.693	2.25	5.32	1.185	0.085	0.648
18	13.60	2.257	4.00	7.09	1.58	0.102	0.864

[a] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.

[b] Bar designation numbers are based on the number of eighths of an inch included in the nominal diameter of the bars.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- T 244, Mechanical Testing of Steel Products
- T 285, Bend Test for Bars for Concrete Reinforcement

2.2 *ASTM Standards*:

- A 6/A 6M, Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
- A 264, Standard Specification for Stainless Chromium-Nickel Steel-Clad Plate
- A 276, Standard Specification for Stainless Steel Bars and Shapes
- A 510, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel
- A 510M, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel (Metric)
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- A 959, Standard Guide for Specifying Harmonized Standard Grade Compositions for Wrought Stainless Steels
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 190, Standard Test Method for Guided Bend Test for Ductility of Welds
- G 12, Standard Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel

2.3 *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products Preparation for Shipment and Storage

2.4 *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)

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3. TERMINOLOGY

3.1 *Definition of Terms Specific to This Standard*:

3.1.1 *completed bar*—steel bar with stainless cladding and deformations (if deformed).

3.1.2 *deformed bar*—steel bar with protrusions; a bar that is intended for use as reinforcement in reinforced concrete construction.

3.1.2.1 *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protrusions conform to the provisions of this specification.

3.1.3 *deformations*—protrusions on a deformed bar.

3.1.4 *metallurgical bonding*—the joining of metals so as to form a permanent joint between the mating surfaces. The principal requirements of joining two metals to achieve a metallurgical bond are thoroughly clean surfaces, heat energy, and mechanical pressure.

3.1.5 *plain bar*—a round, square, or hexagonal steel bar without protrusions.

3.1.6 *rib*—longitudinal protrusion on a deformed bar.

3.1.7 *stainless clad bar*—steel bar with stainless cladding for corrosion protection.

3.1.7.1 *Discussion*—The stainless cladding on the surface of the bar is provided by means of metallurgical bonding with the base steel. The stainless cladding offers corrosion protection to the level provided by the thickness of the alloy furnished. The stainless steel cladded reinforcement shall conform to the provisions of this specification.

4. ORDERING INFORMATION

4.1 Orders for material under this specification should include the following information:

4.1.1 Quantity (mass) [weight],

4.1.2 Name of material (stainless clad deformed and plain round steel bars for concrete reinforcement),

4.1.3 Size,

4.1.4 Cut length or coils,

4.1.5 Deformed or plain round,

4.1.6 Grade,

4.1.7 Packaging (see Section 19),

4.1.8 AASHTO designation and year of issue,

4.1.9 Certified mill test reports (if desired), and

4.1.10 Country of origin, which identifies producer and where material was produced.

Note 3—A typical ordering description is as follows: 10 000 kg , stainless clad deformed and plain round steel bars for concrete reinforcement, No. 25, 18 m long, deformed, Grade 420, in secured lifts, to MP 13M/MP 13-__. Certified mill test reports are required. Metric: Bundles shall have tags identifying producer, heat/lot number, and where material was manufactured. [10 tons, stainless clad deformed and plain round steel bars for concrete reinforcement, No. 8, 60 ft 0 in. long, deformed, Grade 60, in secured lifts, to MP 13M/MP 13-__. Certified mill test reports are required.] Customary: Bundles shall have tags identifying producer, heat/lot number, and where material was manufactured.

5. MATERIALS AND MANUFACTURE

5.1 The bars shall be rolled from properly identified heats/lots of stainless clad and core steel billets.

6. CHEMICAL REQUIREMENTS OF BAR

6.1 The manufacturer shall make an analysis of each heat/lot of steel from test samples taken preferably on the finished product. The percentages of required elements identified in Table 3 shall be determined along with identification of stainless alloy cladding, and conformance of its analysis with ASTM A 276, Type 316 or Type 316L.

6.2 The purchaser may make an analysis from finished bars. The product analysis of the core steel of the finished bars may vary from the heat analysis requirements of Table 3 by the percentages listed for each element as per Table B of ASTM A 6/A 6M.

Table 3—Chemical Requirements of Core Steels

Element	% of Element by Weight
Carbon	0.45 max
Manganese	1.40 max
Phosphorus	0.040 max
Sulfur	0.050 max
Silicon	0.04–0.40
Chromium	—
Nickel	—
Copper	—
Molybdenum	—
Vanadium	—

Note: Where a dash appears, there is no requirement.

7. REQUIREMENTS FOR STAINLESS STEEL CLADDING

7.1 Stainless steel cladding shall meet the requirements of ASTM A 959 [A 276], UNS S31600, or UNS S31603. These are austenitic, nonmagnetic stainless steels and will allow for the use of magnetic thickness gauges in determining coating thickness.

7.2 Stainless steel cladding shall be applied prior to the rolling of the completed bar.

7.3 *Cladding Thickness*:

7.3.1 For acceptance purpose, at least 90 percent of all recorded thickness measurements of the cladding on the completed bar shall be a minimum of 175 μm [0.007 in.] on the completed bar. Thickness measurements below 125 μm [0.005 in.] shall be considered cause for rejection.

7.3.2 A single recorded thickness measurement is the average of three individual readings obtained between three consecutive deformations (or within a 50-mm [2-in.] section for smooth bar). A minimum of five recorded measurements evenly spaced along each side of the test bar (a minimum of ten recorded measurements per bar) shall be obtained.

7.3.3 The cladding thickness shall be measured on the body of a straight length of bar between the deformations (or within a 50-mm [2-in.] section for smooth bar).

7.3.4 Cladding thickness measurements shall be taken on the full section of the bar as rolled.

7.3.4.1 Measurements shall be made in accordance with ASTM G 12, following the instructions for calibration and use recommended by the thickness gauge manufacturer. Pull-off or fixed probe gauges shall be used. “Pencil-type” pull-off gauges that require instantaneous readings (i.e., do not record the reading) shall not be used.

7.3.4.2 If a specimen for cladding thickness fails to meet the specified requirements, two retests shall be permitted on two random specimens from the same heat/lot for each failed test. If the results of both test specimens meet the specified requirements, the heat/lot shall be accepted.

7.4 *Bond Strength*—The cladding/core shall have minimum bond strength of 20 ksi per ASTM A 264.

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8. REQUIREMENTS FOR DEFORMATIONS

8.1 Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

8.2 The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45 degrees. Where the line of deformations forms an included angle with the axis of the bar from 45 degrees to 70 degrees inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformation is greater than 70 degrees, a reversal in direction is not required.

8.3 The average spacing or distance between deformations on each side of the bar shall not exceed seven-tenths of the nominal diameter of the bar.

8.4 The overall length of deformations shall be such that the gap between the ends of the deformations on opposite sides of the bar shall not exceed 12.5 percent of the nominal perimeter of the bar. Where the ends terminate in a longitudinal rib, the width of the longitudinal rib shall be considered the gap. Where more than two longitudinal ribs are involved, the total width of all longitudinal ribs shall not exceed 25 percent of the nominal perimeter of the bar; furthermore, the summation of gaps shall not exceed 25 percent of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.14 times the nominal diameter.

8.5 The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1 [Table 2].

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9. MEASUREMENTS OF DEFORMATIONS

9.1 The average spacing of deformations shall be determined by measuring the length of a minimum of ten spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space. Spacing measurements shall not be made over a bar area containing bar-marking symbols involving letters or numbers.

9.2 The average height of deformations shall be determined from measurements made on not fewer than two typical deformations. Determinations shall be based on three measurements, per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

9.3 Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been established by determinations on each heat/lot tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 8. No rejection may be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

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10. TENSILE REQUIREMENTS

10.1 The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 4 [Table 5].

Table 4—Tensile Requirements, SI Units

	Grade 300[a]	Grade 420	Grade 520[b]
Tensile strength, min MPa	500	620	690
Yield strength, min MPa	300	420	520
Elongation in 203.2 mm, min %			
Bar Designation No.:			
10	11	9	—
13, 16	12	9	—
19	12	9	7
22, 25	—	8	7
29, 32, 38	—	7	6
43, 57	—	7	6

[a] Grade 300 bars are furnished only in sizes 10 through 19.

[b] Grade 520 bar are furnished only in sizes 19 through 57.

Table 5—Tensile Requirements, U.S. Customary Units

	Grade 40[a]	Grade 60	Grade 75[b]
Tensile strength, min psi	70000	90000	100000
Yield strength, min psi	40000	60000	75000
Elongation in 8 in., min %			
Bar Designation No.:			
3	11	9	—
4, 5, 6	12	9	—
7, 8	—	8	—
9, 10	—	7	—
11, 14, 18	—	7	6

[a] Grade 40 bars are furnished only in sizes 3 through 6.

[b] Grade 75 are furnished only in sizes 11, 14, and 18.

10.2 The yield point or yield strength shall be determined by one of the following methods:

10.2.1 The yield point shall be determined by arrest of the digital load readout, or marked change in the linearity of the elastic stress-strain line, or halt of the pointer, or drop of the beam, as described in Section 13.1.1 of T 244.

10.2.2 Where the steel tested does not exhibit a well-defined yield point, the yield point shall be determined at extension under load using an autographic diagram method or an extensometer as described in Sections 13.1.2 and 13.1.3 of T 244.

10.2.3 The extension under load shall be 0.005 mm/mm [0.005 in./in.] of gauge length (0.5 percent) for Grade 300 [40] and Grade 420 [60] and shall be 0.0035 mm/mm [0.0035 in./in.] of gauge length (0.35 percent) for Grade 520 [75]. When material is furnished in coils, the test sample must be straightened prior to placing it in the jaws of the tensile machine. Straightening shall be done carefully to avoid the formation of local sharp bends and to minimize cold work. Insufficient straightening before attaching the extensometer can result in lower-than-actual yield strength readings.

10.2.4 The percentage of elongation shall be as prescribed in Table 4 (Table 5) when tested in accordance with Section 13.4 of T 244.

10.2.5 Tension test specimens shall be the full section of the bar as rolled. The unit stress determinations on full-sized specimens shall be based on the nominal bar area. If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gauge length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

10.2.6 If the results of an original tension specimen fail to meet the specified minimum requirements and are within 14 MPa [2000 psi] of the required tensile strength, within 7 MPa [1000 psi] of the required yield point, or within two percentage units of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the heat/lot. If all results of these retest specimens meet the specified requirements, the heat/lot shall be accepted.

11. BENDING REQUIREMENTS

11.1 The bend-test specimen shall withstand being bent around a pin without cracking, wrinkling, or splitting of the cladding when tested in accordance with T 285. The requirements for angle of bending and sizes of pins are prescribed in Table 6 [Table 7]. When material is furnished in coils, the test sample must be straightened prior to placing it in the bend tester. The bend-test specimens shall be the full section of the bar as rolled.

11.2 The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus that provides:

11.2.1 Continuous and uniform application of force throughout the duration of the bending operation.

11.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate.

11.2.3 Close wrapping of the specimen around the pin during the bending operation.

11.3 Other acceptable methods of bend testing may be used, such as:

11.3.1 Placing the bar specimen into a lubricated guided bend fixture, as defined by ASTM E 190.

11.3.2 Placing the bar specimen across two pins free to rotate, and applying the bending force with a central rotating pin, and adhering to the size and clearance requirements of Figure 1 of ASTM E 190.

11.3.3 If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in Section 13.3.1, a retest shall be permitted on two random specimens from the same heat/lot. If the results of both test specimens meet the specified requirements, the heat/lot shall be accepted. The retest shall be performed on test specimens that are at air temperature, but not less than 16ºC [60ºF].

11.4 When failures occur under more severe methods, retests shall be permitted under the bend test method prescribed in Section 11.2.

Table 6—Bend-Test Requirements, SI Units

Bar Designation No.	Pin Diameter for Bend Test[a]		
	Grade 300	Grade 420	Grade 520
10, 13, 16	$3^1/_2$ *d*[b]	$3^1/_2$ *d*	—
19	5 *d*	5 *d*	5 *d*
22, 25	—	5 *d*	5 *d*
29, 32, 36	—	7 *d*	7 *d*
43, 57, (90°)	—	9 *d*	9 *d*

[a] Test bends 180° unless noted otherwise.

[b] *d* = nominal diameter of specimen.

Table 7—Bend-Test Requirements

Bar Designation No.	Pin Diameter for Bend Test[a]		
	Grade 40	Grade 60	Grade 75
3, 4, 5	$3^1/_2$ *d*[b]	$3^1/_2$ *d*	—
6	5 *d*[b]	5 *d*	—
7, 8	—	5 *d*	—
9, 10	—	7 *d*	—
11	—	7 *d*	7 *d*
14, 18, (90°)	—	9 *d*	9 *d*

[a] Test bends 180° unless noted otherwise.

[b] *d* = nominal diameter of specimen.

12. PERMISSIBLE VARIATION IN MASS [WEIGHT]

12.1 The permissible variation shall not exceed 6 percent under nominal mass [weight]; except for bars smaller than 9.5 mm [$^3/_8$ in.] plain round, the permissible variation in mass [weight] shall be computed upon the basis of the permissible variation in diameter in ASTM A 510M [ASTM A 510]. Reinforcing bars are evaluated on the basis of nominal mass [weights]. In no case shall the overmass [overweight] of any bar be the cause for rejection.

12.2 The specified limit of variation shall be evaluated in accordance with ASTM E 29 (rounding method).

13. FINISH

13.1 The bar shall be free of detrimental surface imperfections.

13.2 Seams, surface irregularities, or mill scale shall not be cause for rejection, provided they are not signs of improper cladding operations.

13.3 Weight, dimensions, cross-sectional area, and tensile properties of a hand wire-brushed test specimen shall not be less than the requirements of this specification (Note 4).

Note 4—Deformed bars destined to be mechanically spliced may require a certain degree of roundness in order for the splices to adequately achieve strength requirements.

13.3.1 Surface imperfections other than those specified in Section 13.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements. Examples include, but are not limited to, laps, seams, scabs, slivers, cooling or casting cracks, and mill or guide marks.

14. NUMBER OF TESTS

14.1 For bar sizes No. 10 to 57 [3 to 18], inclusive, one tension test and one bend test shall be made of each size rolled from each heat/lot.

14.2 Tests for cladding thickness shall be made on a minimum of three bars of each size from each heat/lot unless otherwise specified by the purchaser.

15. INSPECTION

15.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

15.2 *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein and may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification, where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

16. REJECTION

16.1 Unless otherwise specified, any rejection based on tests made in accordance with Section 6.2 shall be reported to the manufacturer within 20 working days from the day the samples were tested by the purchaser.

17. TEST REPORTS

17.1 When specified in the purchase order, report the following information, on a per heat/lot basis. Additional items may be reported as requested or desired.

17.2 Chemical analysis shall include the composition of the stainless alloy cladding, and the elements carbon, manganese, silicon, phosphorus, and sulfur for core steel.

17.3 Tensile properties.

17.4 Bend-test results.

17.5 Cladding thickness results.

17.6 Origin of materials and manufacturing processes for verification of “Domestic Origin” requirements.

18. MARKING

18.1 When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer’s heat/lot or test identification number.

18.2 Each producer shall identify the symbols of his marking system.

18.3 All bars produced to this specification, except plain round bars, which shall be tagged for grade, shall be identified by a distinguishing set of marks legibly rolled into the surface of one side of the bar to denote, in the following order:

18.3.1 *Point of Origin*—Letter or symbol established as the producer’s mill designation.

18.3.2 *Size Designation*—Arabic number corresponding to bar designation number of Table 1 [Table 2].

18.3.3 *Type of Steel*—Letter C indicates that the bar was produced to this specification.

18.3.4 *Minimum Yield Designation*—For Grade 420 [60] bars, either the number 4 [60] or a single continuous longitudinal line through at least five spaces offset from the center of the bar side. For Grade 520 [75] bars, either the number 5 [75] or two continuous longitudinal lines through at least five spaces offset each direction from the center of the bar. (No marking designation for Grade 300 [40] bars.)

19. PACKAGING

19.1 When specified in the purchase order, packaging shall be in accordance with the procedures in ASTM A 700.

19.2 The stainless steel clad bar shall be handled and shipped such that carbon steel bars, lifting straps, tiedown cables, or chains do not come in contact with clad bars.

19.3 *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

20. KEYWORDS

20.1 Concrete reinforcement; deformations (protrusions); steel bars.

ANNEX

(Mandatory Information)

A1. GUIDELINES FOR JOB-SITE PRACTICES

A1.1. When handling stainless steel clad bars, care shall be exercised to avoid damage to the bundles.

A1.2. Equipment for handling stainless steel clad bar shall have protected contact areas.

A1.3. Stainless steel clad bars shall be off-loaded as close as possible to their points of placement or under the crane so that the bars can be hoisted to the areas of placement to minimize rehandling.

A1.4. When handling stainless steel clad bars, care shall be exercised to avoid damage to the bundles.

A1.5. Stainless steel clad bar shall be stored off the ground on protective cribbing, and timbers placed between the bundles when stacking is necessary. Space supports sufficiently close to prevent sags in the bundles.

A1.6. Stainless steel clad bar shall be stored separately from regular steel.

A1.7. Long-term outside job-site storage shall be minimized or the material shall be stored indoors.

A1.8. Stainless steel clad bar shall not be flame cut.

A1.9. Placed stainless steel clad bars shall be inspected for damage prior to placing concrete. Damage to bars, which exhibit active corrosion (red-rust), shall be evaluated. Bars that have damage exceeding 2 percent of the surface area in any 0.3-m [1-ft] length shall be replaced.

A1.10. When placing stainless steel clad bar, all wire supports, spacers, and tying wire shall be plastic, plastic coated, or Type 316 stainless steel.

A1.11. Stainless steel clad bar in contact with black steel shall be minimized or eliminated where possible.

A1.12. Cut ends of stainless clad bars shall be epoxied and capped according to manufacturer’s recommendations with either stainless steel caps or plastic caps. Caps shall be sealed to prevent the intrusion of moisture.

Standard Specification for

Uncoated, Corrosion-Resistant, Deformed and Plain Alloy, Billet-Steel Bars for Concrete Reinforcement and Dowels

AASHTO Designation: MP 18M/MP 18-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Uncoated, Corrosion-Resistant, Deformed and Plain Alloy, Billet-Steel Bars for Concrete Reinforcement and Dowels

AASHTO Designation: MP 18M/MP 18-09[1]

1. SCOPE

1.1. This specification covers uncoated, corrosion-resistant, deformed and plain alloy, billet-steel concrete reinforcement and dowel bars in cut lengths or coils, where corrosion-resistant performance may be essential (Notes 1 and 2). The standard sizes and dimensions of deformed bars and their number designations shall be those listed in Table 2 [Table 3].

Note 1—For coils of deformed bars, the capacity of industrial equipment limits the maximum bar size that can be straightened.

Note 2—The degree of corrosion-resistance needed for a specific use is dependent on both the project's environmental conditions and its application.

Comparative corrosion performance data in accordance with Section 11 and Annex A shall apply only when specified by the purchaser.

1.2. Bars are of three minimum yield levels: 420 MPa [60000 psi], 520 MPa [75000 psi], and 690 MPa [100000 psi], designated as Grade 420 [60], Grade 520 [75], and Grade 690 [100], respectively.

1.3. Hot-rolled plain rounds, in sizes up to and including 50.8 mm [2 in.] in diameter in coils or cut lengths, when specified for dowels, spirals, and structural ties or supports, shall be furnished under this specification in Grade 420 [60], Grade 520 [75], and Grade 690 [100] (Note 3).

For ductility properties, test provisions of the nearest nominal diameter deformed bar size shall apply. Those requirements providing for deformations and marking shall not be applicable (Note 3).

Note 3—The weight for plain rounds smaller than 9.5 mm [$^3/_8$ in.] in diameter shall be computed on the basis of the size in ASTM A 510.

Note 4—Welding of the material in this specification should be approached with caution since no specific provisions have been included to enhance its weldability. When the steel is to be welded, a welding procedure suitable for the chemical composition and intended use or service should be used.

1.4. This specification is applicable for orders in either SI units (as Specification MP 18M) or in inch-pound units (as Specification MP 18). SI units and inch-pound units are not necessarily equivalent. Inch-pound units are shown in brackets in the text for clarity, but they are the applicable values when the material is ordered to MP 18.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- T 244, Mechanical Testing of Steel Products
- T 285, Bend Test for Bars for Concrete Reinforcement

2.2. *ASTM Standards*:

- A 484/A 484M, Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
- A 510, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel
- A 510M, Standard Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel (Metric)
- A 700, Standard Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment
- A 751, Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
- A 955/A 955M, Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement
- A 1035/A 1035M, Standard Specification for Deformed and Plain, Low-carbon, Chromium, Steel Bars for Concrete Reinforcement
- E 29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3. *Military Standards*:

- MIL-STD-129, Marking for Shipment and Storage
- MIL-STD-163, Steel Mill Products Preparation for Shipment and Storage

2.4. *Federal Standard*:

- Fed. Std. No. 123, Marking for Shipment (Civil Agencies)

3. TERMINOLOGY

3.1. *Description of Terms Specific to This Standard*:

3.1.1. *deformed bar*—steel bar with protrusions; a bar that is intended for use as reinforcement in reinforced concrete construction.

3.1.1.1. *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protrusions conform to the provisions of this specification.

3.1.2. *deformations*—protrusions on a deformed bar.

3.1.3. *plain bar*—steel bar without protrusions.

3.1.4. *rib*—longitudinal protrusion on a deformed bar.

3.1.5. *lot*—bars of one bar number and pattern of deformation contained in an individual shipping release or shipping order.

4. ORDERING INFORMATION

4.1. Orders for material under this specification should include the following information:

4.1.1. Quantity (Mass) [weight];

4.1.2. Name of material (uncoated, corrosion-resistant, deformed and plain alloy, billet-steel bars for concrete reinforcement and dowels);

4.1.3. Size;

4.1.4. Cut length or coils;

4.1.5. Deformed or plain;

4.1.6. Grade;

4.1.7. Packaging (see Section 22);

4.1.8. AASHTO designation and year of issue; and

4.1.9. Certified mill test reports (if desired).

Note 5—A typical ordering description is as follows: 10 Mg, uncoated, corrosion-resistant, deformed and plain alloy, billet-steel bars for concrete reinforcement and dowels, No. 25, 18-m long, deformed, Grade 520, in secured lifts, to MP 18M-__. Certified mill test reports are required. [10 tons, uncoated, corrosion-resistant, deformed and plain alloy, billet-steel bars for concrete reinforcement and dowels, No. 8, 60 ft 0 in. long, deformed, Grade 75 in secured lifts, to MP 18-__. Certified mill test reports are required.]

5. MATERIALS AND MANUFACTURE

5.1. The bars shall be rolled from properly identified heats of mold cast or strand cast steel.

6. CHEMICAL REQUIREMENTS

6.1. The chemical analysis of each heat shall be determined in accordance with ASTM A 751. The manufacturer shall make the analysis on test samples taken preferably during the pouring of the heat. The percentages of carbon, chromium, copper, manganese, molybdenum, nickel, nitrogen, phosphorus, silicon, sulfur, and vanadium shall be determined and reported as required in Section 20.

6.2. The analysis of the heat shall be made by the manufacturer and shall conform to the analysis tolerances specified in Table 1 of ASTM A 484/A 484M when compared to the chemistry reported in Annex A, Section A1.6.3.

6.2.1. A product check made by the purchaser shall conform to the analysis tolerances specified in Table 1 of ASTM A 484/A 484M when compared to the chemistry reported in Annex A, Section A1.6.3.

6.3. The chemical composition as shown by heat analysis shall be limited by Table 1.

Table 1—Maximum Chemical Constituents (Weight %) Except as Indicated

Element	Amount
Carbon	0.15%
Chromium	9.2% (Minimum)
Manganese	2.0%
Nitrogen	0.20%
Phosphorus	0.045%
Silicon	1.0%
Sulfur	0.030%

7. REQUIREMENTS FOR DEFORMATIONS

7.1. Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

7.2. The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45 degrees. Where the line of deformations forms an included angle with the axis of the bar from 45 to 70 degrees inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformation is greater than 70 degrees, a reversal in direction is not required.

7.3. The average spacing or distance between deformations on each side of the bar shall not exceed seven-tenths of the nominal diameter of the bar.

7.4. The overall length of deformations shall be such that the gap between the ends of the deformations on opposite sides of the bar shall not exceed 12.5 percent of the nominal perimeter of the bar. Where the ends terminate in a longitudinal rib, the width of the longitudinal rib shall be considered the gap. Where more than two longitudinal ribs are involved, the total width of all longitudinal ribs shall not exceed 25 percent of the nominal perimeter of the bar; furthermore, the summation of gaps shall not exceed 25 percent of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.14 times the nominal diameter.

7.5. The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 2 [Table 3].

Table 2—Deformed Bar Designation Numbers, Nominal Masses, Nominal Dimensions, and Deformation Requirements, SI Units

		Nominal Dimensions[b]			Deformation Requirements, mm		
Bar Designation No.[a]	Nominal Mass, kg/m	Diameter, mm	Cross-Sectional Area, mm^2	Perimeter, mm	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
10	0.560	9.5	71	29.9	6.7	0.38	3.6
13	0.994	12.7	129	39.9	8.9	0.51	4.9
16	1.552	15.9	199	49.9	11.1	0.71	6.1
19	2.235	19.1	284	59.8	13.3	0.97	7.3
22	3.042	22.2	387	69.8	15.5	1.12	8.5
25	3.973	25.4	510	79.8	17.8	1.27	9.7
29	5.060	28.7	645	90.0	20.1	1.42	10.9
32	6.404	32.3	819	101.3	22.6	1.63	12.4
36	7.907	35.8	1006	112.5	25.1	1.80	13.7
43	11.38	43.0	1452	135.1	30.1	2.16	16.5
57	20.24	57.3	2581	180.1	40.1	2.59	21.9

[a] Bar numbers approximate the number of millimeters of the nominal diameter of the bar.

[b] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same mass per meter as the deformed bar.

Table 3—Deformed Bar Designation Numbers, Nominal Weights, Nominal Dimensions, and Deformation Requirements, U.S. Customary Units

		Nominal Dimensions[b]			Deformation Requirements, in.		
Bar Designation No.[a]	Nominal Weight, lb/ft	Diameter, in.	Cross-Sectional Area, $in.^2$	Perimeter, in.	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5% of Nominal Perimeter)
3	0.376	0.375	0.11	1.178	0.262	0.015	0.143
4	0.668	0.500	0.20	1.571	0.350	0.020	0.191
5	1.043	0.625	0.31	1.963	0.437	0.028	0.239
6	1.502	0.750	0.44	2.356	0.525	0.038	0.286
7	2.044	0.875	0.60	2.749	0.612	0.044	0.334
8	2.670	1.000	0.79	3.142	0.700	0.050	0.383
9	3.400	1.128	1.00	3.544	0.790	0.056	0.431
10	4.303	1.270	1.27	3.990	0.889	0.064	0.487
11	5.313	1.410	1.56	4.430	0.987	0.071	0.540
14	7.65	1.693	2.25	5.32	1.185	0.085	0.648
18	13.60	2.257	4.00	7.09	1.58	0.102	0.864

[a] Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars.

[b] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.

8. MEASUREMENTS OF DEFORMATIONS

8.1. The average spacing of deformations shall be determined by measuring the length of a minimum of ten spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space. Spacing measurements shall not be made over a bar area containing bar marking symbols involving letters or numbers.

8.2. The average height of deformations shall be determined from measurements made on not fewer than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

8.3. Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 7. No rejection may be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

9. TENSILE REQUIREMENTS

9.1. The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 4 [Table 5].

9.2. The yield point or yield strength shall be determined by the offset method (0.2 percent offset), described in Section 13.2 of T 244. When material is furnished in coils, the test sample must be straightened prior to placing it in the jaws of the tensile machine. Straightening shall be done carefully to avoid the formation of local sharp bends and to minimize cold work. Insufficient straightening before attaching the extensometer can result in lower-than-actual yield strength readings.

9.3. The percentage of elongation shall be as prescribed in Table 4 [Table 5] when tested in accordance with Section 13.4 of T 244.

Table 4—Tensile Properties Requirements, SI Units

	Grade 420	Grade 520	Grade 690
	Tests of Full Bar Cross Section		
Tensile strength, min, MPa	620	690	1030
Yield strength, min, MPa	420	520	690
Elongation in 203.2 mm, min %:			
Bar Designation No.:			
10	9	7	7
13, 16	9	7	7
19	9	7	7
22, 25	8	7	7
29, 32, 36	7	7	7
43, 57	7	6	6

Table 5—Tensile Properties Requirements, U.S. Customary Units

	Grade 60	Grade 75	Grade 100
	Tests of Full Bar Cross Section		
Tensile strength, min, psi	90000	100000	150000
Yield strength, min, psi	60000	75000	100000
Elongation in 8 in., min %:			
Bar Designation No.:			
3	9	7	7
4, 5	9	7	7
6	9	7	7
7, 8	8	7	7
9, 10, 11	7	7	7
14, 18	7	6	6

10. BENDING REQUIREMENTS

10.1. The bend-test specimen shall withstand being bent around a pin without cracking on the outside of the bent portion when tested in accordance with T 285. The requirements for angle of bending and sizes of pins are prescribed in Table 6 [Table 7]. When material is furnished in coils, the test sample must be straightened prior to placing it in the bend tester.

Table 6—Bend-Test Requirements, SI Units

	Grade 420	Grade 520	Grade 690
Bar Designation No.	Pin Diameter for Bend Tests[a]		
10, 13, 16	3.5*d*[b]	3.5*d*	3.5*d*
19	5*d*	5*d*	5*d*
22, 25	5*d*	5*d*	5*d*
29, 32, 36	7*d*	7*d*	7*d*
43, 57 (90°)	9*d*	9*d*	*c*

[a] Test bends 180° unless otherwise agreed.

[b] *d* = nominal diameter of specimen

[c] These bars are only used in straight lengths.

Table 7—Bend-Test Requirements, U.S. Customary Units

	Grade 60	Grade 75	Grade 100
Bar Designation No.	Pin Diameter for Bend Tests[a]		
3, 4, 5	3.5*d*[b]	3.5*d*	3.5*d*
6	5*d*	5*d*	5*d*
7, 8	5*d*	5*d*	5*d*
9, 10, 11	7*d*	7*d*	7*d*
14, 18 (90°)	9*d*	9*d*	*c*

[a] Test bends 180° unless otherwise agreed.

[b] *d* = nominal diameter of specimen

[c] These bars are only used in straight lengths.

10.2. The bend test shall be made on specimens of sufficient length to ensure free bending and with an apparatus that provides:

10.2.1. Continuous and uniform application of force throughout the duration of the bending operation.

10.2.2. Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate.

10.2.3. Close wrapping of the specimen around the pin during the bending operation.

10.3. Other acceptable more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin, may be used. When failures occur under more severe methods, retests shall be permitted under the bend-test method prescribed in Section 10.2.

11. COMPARATIVE CORROSION RESISTANCE PERFORMANCE (PURCHASER SPECIFIED)

11.1. Comparative corrosion performance data for chromium containing steels (e.g., ASTM A 955/A 955M and ASTM A 1035/A 1035M) shall be furnished, based on mutual agreement between the manufacturer and the purchaser, as described in Annex A.

12. PERMISSIBLE VARIATION IN MASS [WEIGHT]

12.1. The permissible variation shall not exceed 6 percent under nominal mass [weight] except for bars smaller than 9.5 mm [$^3/_8$ in.] plain round. The permissible variation in mass [weight] shall be computed upon the basis of the permissible variation in diameter in ASTM A 510M [ASTM A 510]. Reinforcing bars are evaluated on the basis of nominal mass [weights]. In no case shall the overmass [overweight] of any bar be the cause for rejection.

12.2. The specified limit of variation shall be evaluated in accordance with ASTM E 29 (rounding method).

13. FINISH

13.1. The bar shall be free of detrimental surface imperfections.

13.2. Seams, surface irregularities, or mill scale oxidation shall not be cause for rejection, provided the weight, dimensions, cross-sectional area, and tensile properties are not less than the requirements of this specification.

13.3. Surface imperfections other than those specified in Section 13.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements. Examples include but are not limited to laps, seams, scabs, slivers, cooling or casting cracks, and mill or guide marks (Note 6).

Note 6—Deformed bars intended to be mechanically spliced or butt-welded may require a certain degree of roundness in order for the splices to adequately achieve strength requirements.

14. TEST SPECIMENS

14.1. Tension test specimens shall be the full section of the bar as rolled. The unit stress determinations on full-sized specimens shall be based on the nominal bar area.

14.2. The bend-test specimens shall be the full section of the bar as rolled.

15. NUMBER OF TESTS

15.1. For bar sizes No. 10 to 36 [No. 3 to 11], inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If, however, material from one heat differs by three or more designation numbers, one tension and one bend test shall be made from both the highest and lowest designation number of the deformed bars rolled.

15.2. For bar sizes No. 43 and No. 57 [No. 14 and No. 18] bars, one tension test and one bend test shall be made of each size from each heat.

16. RETESTS

16.1. If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gauge length, as indicated by scribe marks on the specimen before testing, a retest shall be allowed.

16.2. If the results of an original tension specimen fail to meet the specified minimum requirements and are within 14 MPa [2000 psi] of the required tensile strength, within 7 MPa [1000 psi] of the required yield point, or within two percentage units of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the lot. If all results of these retest specimens meet the specified requirements, the lot shall be accepted.

16.3. If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in Sections 16.4 and 16.7, retest shall be permitted on two random specimens from the same lot. If the results of both test specimens meet the specified requirements, the lot shall be accepted. The retest shall be performed on test specimens that are at air temperature but not less than 16°C [60°F].

16.4. If a mass [weight] test fails for reasons other than flaws in the specimen as described in Section 16.7, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

16.5. If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

16.6. If a corrosion resistance test fails for reasons other than flaws as described in Section 16.7, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

16.7. If any test specimen develops flaws, it may be discarded and another specimen of the same size bar from the same heat may be substituted.

17. INSPECTION

17.1. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer’s works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests (except product analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

17.2. *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein and may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification, where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

18. REJECTION

18.1. Unless otherwise specified, any rejection based on tests made in accordance with Section 6.3 shall be reported to the manufacturer within five working days from the receipt of samples by the purchaser.

18.2. Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

19. REHEARING

19.1. Samples tested in accordance with Section 6.2 that represent rejected material shall be preserved for 2 weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

20. TEST REPORTS

20.1. Test reports should include the following:

20.1.1. Chemical analysis, including percentages of carbon, chromium, copper, manganese, molybdenum, nickel, nitrogen, phosphorus, silicon, sulfur, and vanadium;

20.1.2. Tensile properties;

20.1.3. Bend test;

20.1.4. Comparative corrosion performance data (if appropriate); and

20.1.5. *Qualification test*—Annex A (Purchaser specified) with chemical analysis tolerances conforming to Section 6.2.

21. MARKING

21.1. When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

21.2. Each producer shall identify the symbols of his marking system.

21.3. All bars produced to this specification, except plain round bars, which shall be tagged for grade, shall be identified by a distinguishing set of marks legibly rolled into the surface of one side of the bar to denote, in the following order:

21.3.1. *Point of Origin*—Letter or symbol established as the producer's mill designation.

21.3.2. *Size Designation*—Arabic number corresponding to bar designation number of Table 2 [Table 3].

21.3.3. *Type of Steel*—Letters "CS" indicating that the bar was produced to this specification.

21.3.4. *Minimum Yield Designation*—For Grade 420 [60] bars, either the number 4 [60] or a single continuous longitudinal line through at least five spaces offset from the center of the bar side. For Grade 520 [75] bars, either the number 5 [75] or two continuous longitudinal lines through at least five spaces offset each direction from the center of the bar. For Grade 690 [100] bars, either the number 6 [100] or three continuous longitudinal lines through at least five spaces offset each direction from the center of the bar.

21.3.5. It shall be permissible to substitute a metric size bar of Grade 420 for the corresponding inch-pound size bar of Grade 60, a metric size bar of Grade 520 for the corresponding inch-pound size bar of Grade 75, and a metric size bar of Grade 690 for the corresponding inch-pound size bar of Grade 100.

22. PACKAGING

22.1. When specified in the purchase order, packaging shall be in accordance with the procedures in ASTM A 700.

22.2. *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. Government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

23. KEYWORDS

23.1. Alloy steel bars; concrete reinforcement; corrosion-resistant; deformations (protrusions); dowels.

ANNEX A

(Mandatory Information)

(The following shall apply only when specified in the purchase order.)

A1. TEST METHOD FOR COMPARATIVE QUALITATIVE CORROSION CHARACTERIZATION OF STEEL BARS USED IN CONCRETE REINFORCEMENT

Note A1—This test method aims to emphasize the key differences in the corrosion behavior of corrosion-resistant steels (CRS) as compared to carbon steel, namely the enhanced resistance to chlorides and lower pH environments. The test protocols apply only to solid uncoated monolithic bars and are divided into two main categories. Considering that chloride attack and carbonation are typically the most important causes of corrosion initiation in steel-reinforced concrete structures, two test types are included to evaluate the corrosion performance of the CRS alloy as a function of (1) pH of the environment and (2) concentration of chloride ions, in particular the $[Cl^-]/[OH^-]$ threshold ratio.

A1.1 *Scope*:

A1.1.1 This test method describes procedures to evaluate the comparative qualitative corrosion performance of CRS alloy steel bars to those of M 31M/M 31, utilizing electrochemical polarization resistance and potentiodynamic polarization measurements in various test solutions.

A1.1.2 Bars tested in accordance with these test procedures shall be characterized as corrosion-resistant when both:

A1.1.2.1 The ratio of the polarization resistance (R_p) measured at pH = 10 to the polarization resistance measured at pH = 13 is greater than or equal to (≥) 0.5; i.e.,

$[R_p \text{ at } (\text{pH} = 10)]/[R_p \text{ at } (\text{pH} = 13)] \geq 0.5$, and

A1.1.2.2 The measured pitting potential is greater than or equal to (≥) 250 mV vs. Ag/Ag Cl reference electrode at a $[Cl^-]/[OH^-]$ ratio equal to 2.

A1.2 *Referenced Documents*:

A1.2.1 *AASHTO standards*:

- M 31M/M 31, Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

A1.2.2 *ASTM standards*:

- G 3, Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing
- G 59, Standard Test Method for Conducting Potentiodynamic Polarization Resistance Measurements
- G 102, Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements

A1.3 *Test Equipment and Materials*:

A1.3.1 *Containers*—500-mL capacity polypropylene (PP) beaker, or equivalent. The solutions used are characterized by a high pH value, hence, glass containers shall not be used.

A1.3.2 *Voltmeter*—High impedance voltmeter (at least one Mohm), measuring to 0.001 mV.

A1.3.3 *Potentiostat*—Potentiostat with 20 V compliance voltage (e.g., Gamry Instruments series G 750).

A1.3.4 *Reference Electrode* (i.e., Ag/AgCl reference electrode or Accumet #13-620-52 Calomel Reference Electrode).

A1.3.5 *Wire*—16-gauge [1.5-mm^2] insulated copper wire is used to make the electrical connections to the bars.

A1.3.6 *Test Solution*—Test solution, compatible with material under test (see Section A1.5.4 for solution preparation).

A1.4 *Test Method*:

A1.4.1 *Description of Tests*—Two well-established types of corrosion tests are included: Linear Polarization Resistance and Potentiodynamic Polarization curves. This section presents a brief overview of each test, similar to test procedures and measurements described in ASTM G 3, G 59, and G 102.

A1.4.1.1 *Linear Polarization Resistance*—The linear polarization resistance technique, or simply polarization resistance, involves measuring the change in the open-circuit potential of the electrolytic cell when an external current is applied to it. For a small perturbation about the open-circuit potential (OCP), there is a linear relationship between the change in applied voltage (ΔE) and the change in the measured current per unit area of electrode (Δi). The ratio $\Delta E/\Delta i$ gives the polarization resistance (R_p) term, which is inversely related to the corrosion performance of the alloy.

A1.4.1.2 *Potentiodynamic Polarization*—In this test, the potential is made to change at a constant rate over a wide range, typically from a very cathodic to a very anodic potential, while the corrosion current density is measured. The test indicates the potential regions where there is electrode activity, and provides a variety of information about the corrosion behavior of the sample. Active, passive, and transpassive regions, for instance, can be readily identified. When chlorides are present, the test can be used to identify the concentration in which pitting corrosion is initiated.

A1.5 *Experimental Procedure*:

A1.5.1 *Steel Sample Preparation*—Test samples of approximately 1-in. length and $^5/_{16}$-in. diameter must be machined from the rebar to be tested, taking care not to overheat or unintentionally induce microstructural changes to the alloy. A screw thread is drilled and tapped (e.g., 6-32 by $^3/_{16}$ in.) into one end of the specimen, to enable electrical contact to be made. The surface of the test specimen shall be polished with SiC paper down to 1000 grit. Electrical contact shall be made to the specimen with a threaded rod long enough to extend outside of the electrochemical cell.

A1.5.2 *Electrochemical Cell*—A standard three-electrode electrochemical cell shall be used. The body of the cell must be made of plastic in order to avoid glass etching due to the elevated pH of the test solutions (a 500-ml PP beaker can be used, for instance).

A1.5.3 *Electrochemical Cell and Sample Assembly*—The specimen shall be covered with adhesive-lined dual-wall heat-shrink tubing in such a way that only approximately $^1/_2$ in. in length of the specimen is left exposed; the remaining length of the specimen as well as the contacting rod must be covered with heat-shrink tubing. The electrical insulation shall be applied with care to provide a crevice-free seal. The exposed surface area shall be measured and recorded. Before testing, after the equipment is set up and the electrochemical cell is ready to receive the test specimen, the exposed area of the specimen shall be repolished, degreased with acetone, and cleaned with methanol and deionized water.

A1.5.4 *Test Solution Preparation*—Test solution shall be prepared with deionized water and certified reagent chemicals. Ideally, the experiments should be controlled by an automated potentiostat and corresponding software, such as a Gamry Instruments series G 750 potentiostat or another equivalent model.

A1.5.4.1 *Polarization Resistance*—Before performing the polarization resistance experiment, the test specimen as prepared according to the procedure in Section A1.5.1 shall be placed in the electrochemical cell and exposed to the aqueous solution for 30 minutes. The OCP shall be measured. A potential variation of –15 mV to +15 mV over OCP shall be applied at a scan rate of 0.125 mV/sec, and the corresponding changes in the current density (in $\mu A/cm^2$) shall be recorded. The polarization resistance term R_p is then calculated based on this data. In order to properly evaluate the corrosion behavior of the corrosion-resistant steel (CRS), and particularly to demonstrate the fundamental difference between the CRS and carbon steels, the polarization resistance tests shall be performed for two different pH levels (e.g., pH = 13 and pH = 10), while maintaining the ionic strength (I_S) of the solutions constant. Naturally aerated aqueous solutions shall be prepared immediately before the test.

Note A2—Carbon steel typically loses its passive film at pH values between 11 and 10, while CRS is expected to maintain its corrosion resistance at lower pH levels.

Note A3—A lower pH solution (i.e., pH = 9) can be used; however, the buffering capacity for such a solution is low. During testing, the pH value shall be monitored to assure that no significant drop in pH occurs.

Note A4—Ionic strength (I_S) is defined as one-half the summation of the product of the concentration of each ion and its charge squared, as shown in the equation $I_S = {}^1/_2 \Sigma c_i z_i^2$ (Lehmann et al., 1996).[2]

Table A1.1 illustrates the composition of aqueous test solutions.

Table A1.1—Polarization Resistance Aqueous Test Solutions

pH	NaOH (mol/l)	I_S	NaOH (g/l)	K_2SO_4 (mol/l)	K_2SO_4 (g/l)
13	0.1	0.1	4	—	—
10	0.0001	0.1	0.004	0.0333	5.8042

A1.5.4.2 *Potentiodynamic Polarization*—After preparing the test sample as described in Section A1.5.1, the specimen shall be immediately placed in the electrochemical cell and conditioned at –1200 mV (vs. Ag/AgCl reference electrode) for 2 minutes in order to reduce any possible air-formed oxide film. Then the potential shall be gradually increased from –1200 mV at a scan rate of 1 mV/s. If a cyclic scan is desired, the potential shall be taken to the beginning of the transpassive region (about +550 mV vs. Ag/AgCl when no chlorides are present) and reversed back to the starting potential.

In the presence of chlorides, the onset of pitting corrosion is detected by a shift of the transpassive region to lower potential values during the forward (anodic) scan. This new potential value is referred to as the pitting potential (for a particular chloride concentration). Pitting corrosion is initiated when a chloride threshold value (as represented by the ratio between Cl^- and OH^- ions prepared in solution) is exceeded. A simulated concrete pore solution with a constant $[OH^-]$ (0.55M KOH + 0.16M NaOH, as described by Taylor, 1997)[3] shall be prepared. The concentration of Cl^- ions shall be changed to a desired level by adding NaCl salt (see Table A1.2 for examples). In order to verify and demonstrate the enhanced corrosion performance of CRS in highly aggressive environments, it is recommended that potentiodynamic polarization curves be measured in at least two environments: (1) simulated concrete pore solution with no chlorides, and (2) the same aqueous solution with a high concentration of chlorides (e.g., ratio $[Cl^-]/[OH^-] = 2$ or higher).

Note A5—Carbon steel rebar typically presents chloride threshold ratios between 0.2 and 0.85, with 0.6 being the most commonly referenced value.

Table A1.2 below illustrates the chemical composition of simulated concrete pore test solutions.

Table A1.2—Simulated Concrete Pore Solutions for Potentiodynamic Polarization Tests

$[Cl^-/OH^-]$	[KOH] (mol/l)	KOH (g/l)	[NaOH] (mol/l)	NaOH (g/l)	$[OH^-]$ (mol/l)	$[Cl^-]$ (mol/l)	[NaCl] (mol/l)	NaCl (g/l)
0	0.55	30.86	0.16	6.40	0.71	0.00	0.00	0.00
1	0.55	30.86	0.16	6.40	0.71	0.71	0.71	41.49
2	0.55	30.86	0.16	6.40	0.71	1.42	1.42	82.98
3	0.55	30.86	0.16	6.40	0.71	2.13	2.13	124.48

Note A6—The two sets of tests described above can clearly demonstrate the corrosion behavior of a selected CRS and show how it compares to regular carbon steel rebar when test parameters, such as pH values and $[Cl^-]$ levels (both considered excessively aggressive in the case of carbon steels), are controlled.

A1.6 *Report*:

A1.6.1 *Polarization resistance*—Report the polarization resistance R_p at pH = 10 and R_p at pH = 13 for test solutions prepared in accordance with Table A1.1 for the comparison bar material (M 31M/M 31) and the uncoated CRS test bar material. Evaluate the ratio of $R_p(\text{pH} = 10)/R_p(\text{pH} = 13)$.

A1.6.2 *Potentiodynamic Polarization*—Report the pitting potential in mV (vs. standard hydrogen electrode and vs. the reference electrode used in the test) at $[Cl^-]/OH^-] = 0$ and $[Cl^-]/OH^-] = 2$ for test solutions prepared in accordance with Table A1.2 for the comparison bar material (M 31M/M 31) and the uncoated CRS test bar material.

A1.6.3 *Chemical Constituents*—Report chemical analysis percentages for the following elements: carbon, chromium, copper, manganese, molybdenum, nickel, nitrogen, phosphorus, silicon, sulfur, and vanadium.

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[1] Approved in January 2009. First published in June 2009.

[2] Lehmann, H. P., X. Fuentes-Arderiu, and L. F. Bertello. “Glossary of Terms in Quantities and Units in Clinical Chemistry.” *Pure and Applied Chemistry*, V. 68, No. 4, 1996, pp. 957–1000.

[3] Taylor, H. F. W. *Cement Chemistry*, Second Edition. London: T. Telford, 1997, xviii, p. 459.

Standard Practice for

Overcoating Field Test Program for Evaluating Protective Coatings on Existing Bridges or Salvaged Beams

AASHTO Designation: PP 55-06 (2009)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Overcoating Field Test Program for Evaluating Protective Coatings on Existing Bridges or Salvaged Beams

AASHTO Designation: PP 55-06 (2009)[1]

1. SCOPE

1.1. This field testing program has been established to provide the end user with test results which can be used to make performance judgments on one-, two-, or three-coat systems for maintenance overcoating previously painted steel structures.

1.2. This field testing program is intended to apply to maintenance overcoating, herein defined as the practice of cleaning and painting over an existing coating which is largely intact but has areas of corrosion or peeling paint in need of repair. This practice usually includes the spot preparation of rusted or degraded areas, feathering edges of existing paint, power washing the entire structure, priming bare or repaired areas, applying an intermediate coat over the repaired areas or entire structure, and the optional step of applying a full topcoat over the entire structure, or a similar variation of these procedures.

1.3. This field testing program evaluates the performance of protective coatings applied to existing painted steel surfaces with various degrees of surface preparation and condition, including surfaces hand tool cleaned (SSPC SP 2), surfaces cleaned by conventional power tools (SSPC SP 3), surfaces power tool cleaned to bare metal (SSPC SP 15), and industrial blast (SSPC SP 14).

1.4. The coating materials in the field testing program are applied to previously painted steel surfaces of existing bridges or salvaged bridge beams after proper surface preparations, as described herein, and thereafter evaluated annually, unless otherwise agreed, for a period of 3 years.

1.5. All of the elements of this field testing program shall be performed in accordance with applicable local, state, and national regulations governing environmental and worker protection. Specific references to material, environmental, and worker protection requirements are not necessarily made in this document since these regulations are widely known and compliance with these regulations is standard practice in the bridge painting industry.

1.6. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 337, Non-Instrumental Determination of Metallic Zinc in Zinc-Rich Primers
- *Guide for Painting Steel Structures*, 1997

2.2. *ASTM Standards*:

- D 562, Standard Test Method for Consistency of Paints Measuring Krebs Unit (KU) Viscosity Using a Stormer-Type Viscometer
- D 610, Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
- D 660, Standard Test Method for Evaluating Degree of Checking of Exterior Paints
- D 714, Standard Test Method for Evaluating Degree of Blistering of Paints
- D 1475, Standard Test Method For Density of Liquid Coatings, Inks, and Related Products
- D 2196, Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield type) Viscometer
- D 2369, Standard Test Method for Volatile Content of Coatings
- D 2371, Standard Test Method for Pigment Content of Solvent-Reducible Paints
- D 2697, Standard Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings
- D 2698, Standard Test Method for Determination of the Pigment Content of Solvent-Reducible Paints by High-Speed Centrifuging
- D 3335, Standard Test Method for Low Concentrations of Lead, Cadmium, and Cobalt in Paint by Atomic Absorption Spectroscopy
- D 3359, Standard Test Methods for Measuring Adhesion by Tape Test
- D 3718, Standard Test Method for Low Concentrations of Chromium in Paint by Atomic Absorption Spectroscopy
- D 3960, Standard Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings
- D 4138, Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means
- D 4214, Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films
- D 4400, Standard Test Method for Sag Resistance of Paints Using a Multinotch Applicator
- D 4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D 5043, Standard Practice for Field Identification of Coatings
- D 5064, Standard Practice for Conducting a Patch Test to Assess Coating Compatibility
- D 5895, Standard Test Methods for Evaluating Drying or Curing During Film Formation of Organic Coatings Using Mechanical Recorders
- D 6580, Standard Test Method for The Determination of Metallic Zinc Content in Both Zinc Dust Pigment and in Cured Films of Zinc-Rich Coatings
- D 7091, Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
- E 11, Standard Specification for Woven Wire Test Sieve Cloth Standard Test Sieves

2.3. *FHWA*:

- RD-91-011, Effect of Surface Contaminants on Coating Life

2.4. *The Society of Protective Coatings (SSPC)*:

- PA 1, Shop, Field, and Maintenance Painting of Steel
- PA 2, Measurement of Dry Coating Thickness with Magnetic Gages
- SP 1, Solvent Cleaning
- SP 2, Hand Tool Cleaning
- SP 3, Power Tool Cleaning
- SP 14, Industrial Blast Cleaning
- SP 15, Commercial Grade Power Tool Cleaning
- SP COM, Surface Preparation Commentary for Steel and Concrete Substrates
- Vis-1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning
- Vis-3, Guide and Reference Photographs for Steel Surfaces Prepared by Hand and Power Tool Cleaning
- PA Guide 5, Guide to Maintenance Coating of Steel Structures in Atmospheric Service
- Guide 6, Guide for Containing Debris Generated During Paint Removal Operations
- Guide 7, Guide for the Disposal of Lead-Contaminated Surface Preparation Debris
- TU 3, Technology Update No. 3, Overcoating, 2004

2.5. *Federal Standards*:

- Fed. Std. No. 40, CFR 51.100(s), Volatile Organic Compound Definition
- Fed. Std. No. 40, CFR 59.406(a), Volatile Organic Compound Compliance Provisions
- Fed. Std. No. 40, CFR Part 59, Subpart D, Section 59.400 through 59.413 National Volatile Organic Compound Emission Standards for Architectural Coatings
- Fed. Std. No. 40, CFR 261.24, Table 1—Maximum Concentration of Contaminants for the Toxicity Characteristic
- Fed. Std. No. 595, Colors Used in Government Procurement
- EPA SW-846, Method 1311, Toxicity Characteristic Leaching Procedure (TCLP)
- OSHA 1926.62, Lead Exposure in Construction; Interim Final Rule

3. DISCUSSION

3.1. The purpose of this program is to provide a basis for comparing the performance of coating systems applied with existing painted structures under similar conditions of weathering exposures. There are a number of variables, issues, and risks involved with overcoating an existing painted structure. The intent of this test is not to address all of these issues, but rather to create test conditions under which coating systems can be applied and evaluated to provide a basis for evaluating coating performance.

3.2. To provide comparability of field testing and results, all test sites shall use the same testing methods described herein and all field testing and evaluation shall be administered by a qualified representative of the specifying agency selected by and reporting to the agency.

3.3. Recommended reference for additional guidance can be found in ASTM D 5064, Standard Practice for Conducting a Patch Test to Assess Coating Compatibility; the SSPC TU 3, Technology Update on Overcoating; and the AASHTO *Guide for Painting Steel Structures*.

4. CANDIDATE TEST SITES FOR FIELD TESTING

4.1. The candidate test sites (existing bridges or salvaged steel bridge beams) should be in a condition requiring maintenance overcoat painting and not total repainting. If bridges are used, they should permit access for field testing and evaluation with a minimum of rigging and traffic control requirements.

4.2. The field test program, if possible, shall include a total of four test sites that are representative of the conditions in the agency's jurisdiction.

4.3. The candidate test sites should have existing paint(s) representative of paints commonly used in the past, such as lead-pigmented oil alkyds, etc.

4.4. The owner of a candidate test site may provide basic support services to the representative of the specifying agency as determined by site conditions and by the requirements of the agreement, such as traffic control and access. Support services are voluntary and on an as-available basis. Test bridges shall be exempted from maintenance painting activities of the host state during the length of the test. See Section 9.6.

4.5. The candidate structural steel shall preferably be rolled beams or welded girders offering uniform and continuous areas for dividing into test areas.

5. PRETEST STRUCTURE INSPECTION

5.1. Prior to surface preparation and paint application, each test area (as described in Section 7) will be characterized in terms of the following properties to provide a basis of comparison among test sites and for proper evaluation of new coating performance.

Note 1—Chloride testing shall also be performed after surface preparation. See Section 8.4.5.

5.1.1. History of existing coating and photographs of test areas.

5.1.2. Visible rusting in accordance with ASTM D 610.

5.1.3. Visible blistering in accordance with ASTM D 714.

5.1.4. Coating degradation estimated percent.

5.1.5. Chalking of topcoat in accordance with ASTM D 4214.

5.1.6. Checking of topcoat in accordance with ASTM D 660.

5.1.7. Coating thickness using magnetic thickness gauge in accordance with ASTM D 7091.

5.1.8. Number of coats in accordance with ASTM D 4138 (Test Method A).

5.1.9. Adhesion in accordance with ASTM D 3359 Method A cross cut.

5.1.10. Adhesion in accordance with ASTM D 4541, Pull-off adhesion, Annex A.2, Pneumatic Adhesion Test Instrument.

5.1.11. Character of substrate, i.e., mill scale, blasted, corroded, etc.

5.1.12. Chloride contamination (see FHWA RD-91-011, Appendix F).

5.1.13. Environmental Exposure Climatic Region: hot/dry; cold/dry; hot/wet; cold/wet; compass orientation of test areas; and exposure to UV: high, moderate, or low.

5.2. It is advisable to select candidate bridge or salvaged beam test sites for overcoat field testing that have existing coating characteristics that yield an "OK" or "Low Risk" recommendation from Table 1, Risk of Salvaging Existing Coating Based on Adhesion/Thickness Characteristics, of the SSPC TU 3 (overcoating). However, if the specifying agency and the coating manufacturer agree a lower rating is acceptable for application of the coatings for test, criteria other than adhesion and thickness of coating may be considered and documented.

6. MATERIALS REQUIREMENTS

6.1. An analysis of the coating system properties required in Sections 6.2, 6.3, 6.4, and 6.7 shall be performed by a contracted independent testing lab and submitted to the agency within six months of the start of field testing.

6.2. The Volatile Organic Compound (VOC) level of overcoat paint systems shall be stated by the manufacturer on the product data sheets and shall be classified according to the maximum recommended VOC after thinning of the coating as applied. This level shall be stated for each coat in the system and shall meet the requirement of the agency.

6.3. Each coating (primer, intermediate, and top coat) submitted for field testing shall be tested to determine its total lead content. The total lead content shall be determined using a dry film sample in accordance with ASTM D 3335. The percentage of total lead in each coating shall not exceed 0.01 percent (100 ppm).

6.4. The properties of each coating (as determined in a mixed condition) shall be stated on the certified Product Data Sheet, including the following:

6.4.1. Total solids, percentage by mass in accordance with ASTM D 2369.

6.4.2. Pigment, percentage by mass in accordance with ASTM D 2371.

6.4.3. Metallic zinc content, percentage by mass in primer shall be determined in accordance with ASTM D 6580. An optional test method is T 337.

6.4.4. Total solids, percentage by volume in accordance with ASTM D 2697.

6.4.5. Mass per volume (grams per liter) in accordance with ASTM D 1475.

6.4.6. Viscosity (Stormer at 25°C) KU in accordance with ASTM D 562 (not suitable for viscosities above 143 KU).

6.4.7. Viscosity (Brookfield at 25°C) cP in accordance with ASTM D 2196. The spindle size and revolutions per minute shall be reported.

6.4.8. Pot life in hours, at specified temperature and specified humidity.

6.4.9. Sag resistance (Lenata) in micrometers wet film thickness, in accordance with ASTM D 4400.

6.4.10. Recommended minimum and maximum dry film thickness in micrometers.

6.4.11. Theoretical coverage (e.g., m^2/liter for 25 micrometers dry film thickness or micrometer/m^2/liter, whichever is appropriate for the particular coating).

6.4.12. Minimum drying time set to touch, dry hard, tack free time, and dry through (and maximum when applicable) in accordance with ASTM D 5895 at 25°C and 50 percent relative humidity.

6.4.13. Mixing ratio for multi-component coatings by volume, mass, or a combination of mass and volume. This is not required for a pre-mixed (all in one) zinc primer.

6.4.14. Mixing ratio for multi-component coatings, by mass.

6.4.15. Shelf life of each component stored at 25°C.

6.4.16. Infrared analysis by using Fourier transform infrared (FTIR) spectroscopy, as specified in Section 6.7.

6.4.17. Heavy metals testing for mixed coatings in accordance with ASTM D 3335 and D 3718. Heavy metals to be tested will include lead, chromium, and cadmium.

6.4.18. Dry film analysis for leachable heavy metals shall include arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver for each coating. The dried film shall be removed from a non-metallic glass test panel and pulverized to pass through a 250-μm (No. 60) sieve. The pulverized film passing the 250-μm (No. 60) sieve shall be extracted in accordance with the TCLP, Method 1311 of EPA SW-846. The extract shall then be analyzed for heavy metals using the appropriate EPA SW-846 test method for each metal.

6.4.19. The manufacturer shall supply chemical test results that will define the character and nature of the coating system being submitted. Actual results shall be verified by the qualifying laboratory and shall be part of the qualifying laboratory's written report. The type of information provided by the coating manufacturer should include, but not necessarily be limited to, the following: epoxide values (for the epoxy component of two component epoxy coatings), amine values (for that component of epoxy coatings which contains amine or amidoamine cross-linkers), isocyanate group content (for that component of a polyurethane coating that contains the isocyanate component), and identification of hindered amine light stabilizers (for any topcoat that contains such additives). Note that for epoxy coatings cross-linked with polyamide resin, there is currently no standardized test method for determining amide content.

Note 2—If a manufacturer's standard Product Data Sheet does not contain all of the above required information, a supplemental sheet and/or an MSDS with the additional information shall be provided.

6.5. For testing purposes the color of the final topcoat shall be designated by the specifying agency. If used, the color of the intermediate coat shall be a contrasting color.

6.6. *Application Requirements*—The following information shall be supplied by the coatings manufacturer:

6.6.1. The minimum and maximum surface profile requirements (height in micrometers);

6.6.2. Application requirements for ambient temperature, surface temperatures, material temperature, and humidity;

6.6.3. Requirements for application by spray, brush, or roller.

6.7. *Coating Identification Tests*:

6.7.1. An analysis of vehicle solids by FTIR spectroscopy consisting of 16 scans minimum per sample shall be performed as follows:

6.7.1.1. For zinc primer solvent-based coats, infrared spectrum (2.5 to 15 micrometers) of each liquid vehicle component via the potassium bromide sandwich technique.

6.7.1.2. For two component solvent-based topcoats, infrared spectrum (2.5 to 15 micrometers) of each single component via the potassium bromide sandwich technique and of the mixed and dried components in appropriate mixing ratios (dried film) via the potassium bromide pellet technique, or alternatively by the IR card sampling technique, which is called the PTFE technique.

6.7.1.3. For zinc primer water-based coats, infrared spectrum (2.5 to 15 micrometers) of the liquid vehicle component after drying and applying the potassium bromide pellet technique, or alternatively by using the IR card sampling technique, which is called the PTFE technique.

6.7.1.4. For two component water-based coats, infrared spectrum (2.5 to 15 micrometers) of each single component after drying and applying the potassium bromide single-pellet technique, or alternatively by the IR card sampling technique, which is called the PTFE technique; and also of the mixed and dried components in appropriate mixing ratios (dried film) via the single-pellet technique, or alternatively by using IR card sampling technique, which is called the PTFE technique.

6.7.2. The VOC shall be determined in accordance with ASTM D 3960 for primer and topcoats. If exempted solvents are part of the formulation, the manufacturer is responsible for listing those solvents and the percentage of the volatile material in the mixed coating that they represent. The manufacturer may specify an alternative induction time as permitted by U.S. EPA Reference Method 24 when the coating is submitted by test. If the manufacturer does not specify an induction time, the test will be conducted with an induction period of 1 hour.

7. TEST AREAS

7.1. Each test coating will be applied on four test areas at each test site. Each test area will be a minimum of four linear feet of beam. The test areas for all coatings in the testing program will be randomly distributed about the entire testing site. The test area on a steel beam will include both sides of the web and “wrap around” the bottom flange. Two of the four areas shall be covered with a simulated deck. The test areas should be different, if the candidate structure allows, such as interior beam vs. sun-exposed fascia, expansion area vs. midspan, etc. When practicable, salvaged steel beams at test sites should be oriented to achieve different exposures. Each candidate test site will have two control test areas. For the control coating system, the same number of coats and film thickness will be used at all test sites. The control coating system should be selected by the agency. Base this selection on field performance that has been documented in the state where the testing is performed. If the candidate structure allows, the two application sites selected for the control coatings system should be different.

8. SURFACE PREPARATION

8.1. All test areas shall be power washed with potable water using 4500–5000 psi pressure with a zero-degree rotary nozzle placed no more than 8 in. from the surface and held perpendicular to it to remove residual dirt, debris, and contaminants. It may be necessary to catch water used for this purpose using filtering screens or tarps to collect any paint debris removed during cleaning. The structure will be allowed to dry prior to any mechanical surface preparation.

8.2. All non-adherent paint and rust will be removed, collected, and properly disposed of.

8.3. Test areas shall be spaced with an approximate 3-in. clear gap between adjacent test areas.

8.4. The following description is a suggested division of each test area into sub-areas for evaluation of various surface preparation methods. The specifying agency may elect to evaluate other methods of surface preparation and develop a specific matrix of these methods to suit proposed methods in its state.

8.4.1. One half (approximately) of each test area will be cleaned in accordance with SSPC SP 2, Hand Tool Cleaning, using a wire brush and dull putty knife. Edges of intact paint will be worked with a dull putty knife with reasonable effort.

8.4.2. The other half (approximately) of each test area will be cleaned in accordance with SSPC SP 3, Power Tool Cleaning, using needle guns, rotary peening tools, and disc sanders fitted with non-woven abrasive pads. All power tools used will be fitted with shrouding devices and vacuum attachments and used in conjunction with a suitably powered HEPA vacuum to collect dust and debris generated during cleaning. Edges of intact paint will be “feathered” using the disc tool. Care shall be taken not to burnish bare metal surfaces.

8.4.3. A continuous “strip” of bare metal (approximately 4–5 in. wide) shall be placed through the length of the sub-areas described in Sections 8.4.1 and 8.4.2 and prepared to SSPC SP 15 cleanliness using a rotopeen tool.

8.4.4. A continuous “strip” of bare metal (approximately 4–5 in. wide) shall be placed through the length of the sub-areas described in Sections 8.4.1 and 8.4.2 and prepared to SSPC SP 14 cleanliness.

8.4.5. Perform chloride testing before and after surface preparation using the same chloride detection methodology and in the same locations. Surface chloride measurements shall be below 7 $\mu g/cm^2$ prior to the application of the coating.

9. PAINT APPLICATION

9.1. Paint application shall conform to the requirements of SSPC PA 1, except as amended herein or as recommended by the paint manufacturer.

9.2. Prior to painting, the appropriate atmospheric conditions will be documented, including air and surface temperature and relative humidity.

9.3. Paint may be applied by brush, roll, or spray, as determined by the agency. All reasonable attempts will be made to achieve specified film builds.

9.4. Application, dry time, time-to-recoat, and environmental conditions for painting shall comply with the manufacturer's recommendations. All application procedures outlined in Section 6.6.3, including wet film thickness, shall be documented for each coat by the representative of the specifying agency.

9.5. Within two days after the paint has been applied and cured, each test area shall have two vertical scribes cut to bare metal in each test area. The scribes shall be placed approximately three to four inches from the edge of each sub-area described in Sections 8.4.1 and 8.4.2. The scribe shall extend through the strips described in Sections 8.4.3 and 8.4.4. The total length of a vertical scribe shall extend for most of the height of the test area. The scribes shall conform to the cutting requirements of ASTM D 3359. (See Figure 1.)

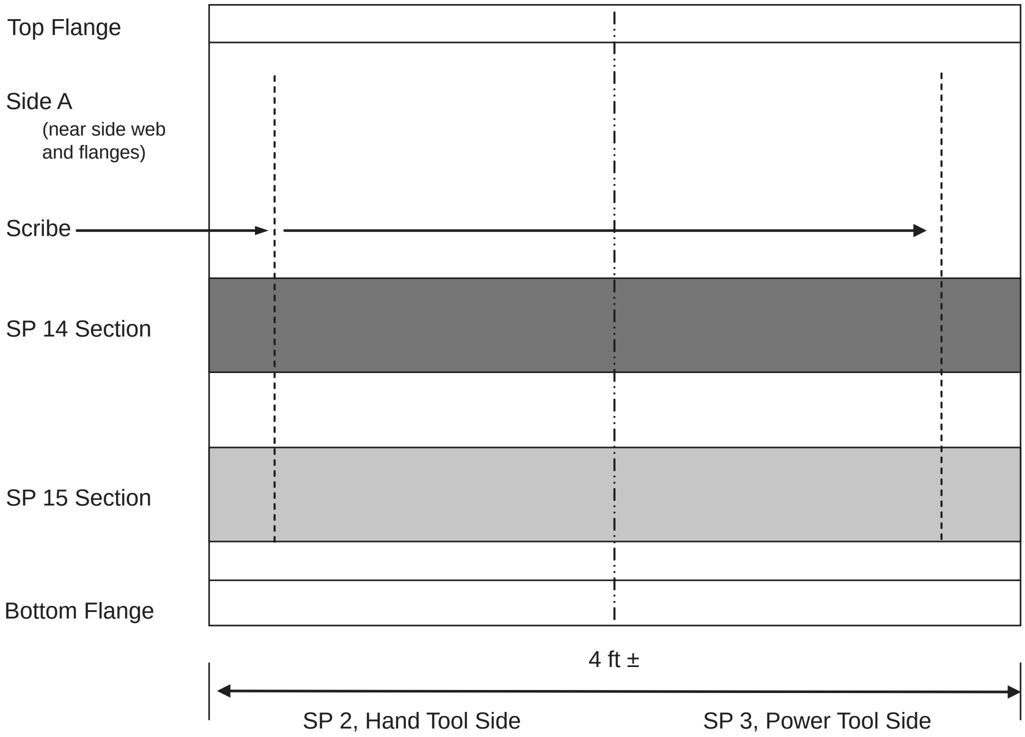

Figure 1—Sketch of Test Patches

9.6. If and when the host state agrees to perform this task, the corrosion process shall be accelerated by applying a dilute solution of salt water by spray to each test area bi-weekly for the winter months or at some other agreed-upon frequency. Application(s) of the salt water solution shall be documented and summarized in the final report. The percentage of sodium chloride in the dilute solution shall be as agreed between the agency and the host state.

10. EVALUATION

10.1. All test areas shall be evaluated annually (unless otherwise specified) and documented by the representative of the specifying agency.

10.2. Each of the sub-areas of surface preparation in each test area (i.e., SSPC SP 2, SSPC SP 3, SSPC SP 14, SSPC SP 15, and scribe) shall be evaluated and rated separately. All areas shall be evaluated visually for rust, coating adhesion, and overall appearance and condition. Evaluation criteria shall include, but not be limited to, the following for each system applied:

10.2.1. Percentage of visible rust for each type of surface preparation for each test area, averages of same for each test site, and averages of same for all sites in accordance with ASTM D 610.

10.2.2. Visible blistering in accordance with ASTM D 714 for each type of surface preparation for each test area, averages of same for each test site, and averages of same for all sites.

10.2.3. Assessment of chalking of topcoat in accordance with ASTM D 4214 at the end of 3 years.

10.2.4. Checking of topcoat in accordance with ASTM D 660.

10.2.5. Adhesion in accordance with ASTM D 3359, Method A Cross Cut, three tests at the end of 3 years for each type of surface preparation for each test area, averages of same for each test site, and averages of same for all sites.

10.2.6. Adhesion in accordance with ASTM D 4541, Annex A.2, Pneumatic Adhesion Test Instrument, three tests at the end of 3 years for each type of surface preparation for each test area, averages of same for each test site, and averages of same for all sites.

10.2.7. Scribe undercut average measurement for each test area with an average for all test sites at the end of 3 years. At the conclusion of the test period, scrape the scribes and measure and report cutback.

10.2.8. Written assessment of the overall performance of each coating at the end of 3 years, noting the limitations and benefits of each system.

10.3. The representative of the specifying agency shall issue a report of the testing. The report shall document the environmental exposure of the test areas and include the coating properties, pre-test conditions, application procedures, annual and final evaluations, and photographs after cleaning and after each evaluation. The representative of the specifying agency will evaluate coating performance by an appropriate rating system and compare and rank all coatings involved in testing accordingly, including the control. Suitable consideration shall be given for differing conditions between test sites. The evaluation information shall be summarized for all systems in a spreadsheet format that is easily understood and approved by the agency.

10.4. The coating testing and performance ratings will be reviewed by the agency for acceptance.

11. ENVIRONMENTAL AND WORKER PROTECTION

11.1. Personnel preparing the field testing shall use appropriate respirators, eye protection, hearing protection, protective clothing, and hygiene necessary to meet the requirements of OSHA and the governing agency.

11.2. Vacuum-assisted power tools and appropriate tools and equipment shall be used as necessary to collect paint debris and protect the ground and water surfaces in the vicinity of the test sites.

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[1] This practice was adopted in 2005 and first published in 2006. Reconfirmed in early 2009.

Standard Method of Test for

Evaluation of Adhesive Anchors in Concrete Under Sustained Loading Conditions

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AASHTO Designation: TP 84-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Evaluation of Adhesive Anchors in Concrete Under Sustained Loading Conditions

AASHTO Designation: TP 84-10

INTRODUCTION

Adhesive anchor systems have widespread use in transportation structures such as bridge widening, concrete repair and rehabilitation, barrier retrofitting, utility installation on existing structures, and tunneling. These systems are used to anchor threaded rod and reinforcing bars in concrete. This test method determines an adhesive anchor's ability to withstand sustained tensile loads under normal conditions.

1. SCOPE

1.1. This test method applies to structures used in AASHTO applications and is applicable to adhesive anchor systems with steel anchors in predrilled holes in concrete.

1.2. This test method determines the time to failure for adhesive anchors in concrete at various levels of sustained loading.

1.3. The static load test is developed from ASTM E 488 and the sustained load (creep) test is modified from ASTM E 1512 and ICC-ES AC308.

1.4. This test method only addresses the effect of sustained loads on adhesive anchors. Numerous other factors affect the load capacity of adhesive anchors and a complete battery of tests is essential to evaluate an adhesive anchor. Refer to ICC-ES AC308 for a listing of some of the many factors and related test methods that apply to adhesive anchors.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- A 193/A 193M, Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications
- C 31/C 31M, Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C 39/C 39M, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
- C 42/C 42M, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- D 907, Standard Terminology of Adhesives
- D 2990, Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

- E 488, Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements
- E 1512, Standard Test Methods for Testing Bond Performance of Bonded Anchors

2.2. *International Code Council Standards*:

- ICC-ES AC308, Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements

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3. TERMINOLOGY

3.1. Refer to ASTM D 907 for a complete listing of terminology related to adhesives.

3.2. *Definitions of Terms Specific to This Standard*:

3.2.1. *adhesive anchor*—a post-installed anchor that transfers load to concrete through an adhesive compound embedded in a hole in hardened concrete. The adhesive materials used include epoxy, cementitious material, polyester resin, and others.

3.2.2. *Adhesive anchor system*—for the purposes of this standard, the adhesive anchor system is composed of the following components: adhesive anchor; proprietary adhesive compounds in combination with a mixing and delivery system; accessories for cleaning the drilled hole, such as wire brushes, air nozzles, etc.; and printed instructions for the adhesive anchor installation, including hole preparation, injection, and cure.

3.2.3. *creep*—the deformation or displacement of an adhesive over time due to stress.

3.2.4. *embedment depth*—distance from the surface of the structural member to the end of the installed anchor.

3.2.5. *linear variable differential transformer (LVDT)*—an electronic instrumentation device used for measuring displacement.

3.2.6. *static load test*—a test in which a load is slowly applied at a specified rate for one cycle until failure.

3.2.7. *sustained load (creep) test*—a test in which a constant load is continuously applied until failure due to creep.

3.2.8. *test specimen*—the structural member, anchor rod, and adhesive.

3.2.9. *Symbols*:

- d = nominal anchor diameter, in. (mm)
- d_o = nominal diameter of drilled hole in concrete, in. (mm)
- f'_c = specified compressive strength of concrete, psi (MPa)
- h_{ef} = effective depth of embedment of an anchor, in. (mm)

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4. SIGNIFICANCE AND USE

4.1. *This test method provides a means of*:

4.1.1. Determining the mean static load of an adhesive anchor,

4.1.2. Determining acceptable loads to apply to an adhesive anchor based on the lifetime of the structure, and

4.1.3. Determining an adhesive anchor's ability to endure sustained loads.

4.2. The stress versus time-to-failure graph is useful to the practicing engineer in selecting and designing adhesive anchors.

4.3. A stress versus time-to-failure graph can give an indication of the reduction in capacity of an adhesive anchor due to sustained load at a given design lifetime.

4.4. This test method provides a means for comparing adhesive anchor products for sustained loading applications.

4.5. The test methods in this standard should be followed in order to ensure reproducibility of test results.

5. TEST APPARATUS

5.1. *Instrumentation and Data Collection*:

5.1.1. All laboratory instrumentation (electronic load, displacement, temperature, and humidity sensors, etc.) must be calibrated with certified equipment.

5.1.2. A load cell or other load-measuring device must be able to measure forces to within ±1 percent of the anticipated peak load.

5.1.3. As an alternative, a load cell is not required for monitoring the sustained load (creep) test if the test apparatus has a stiffness that is sufficiently low to ensure accuracy of 1 percent of the applied sustained load at the maximum anchor creep displacement and if a stiffness-displacement relationship can be established to determine the load applied with reasonable confidence.

5.1.4. Displacements should be measured continuously by LVDTs, linear potentiometers, or an equivalent device with an accuracy of at least 0.001 in. (0.025 mm).

5.1.5. The instrumentation must be placed in a way that does not interfere with the anchor or testing apparatus. The instrumentation should measure the vertical displacement and load on the anchor relative to the test specimen. The instrumentation should be placed in such a way that it will remain parallel to the axis of the anchor and will not be affected by the deflection or failure, or both, of the anchor or test specimen.

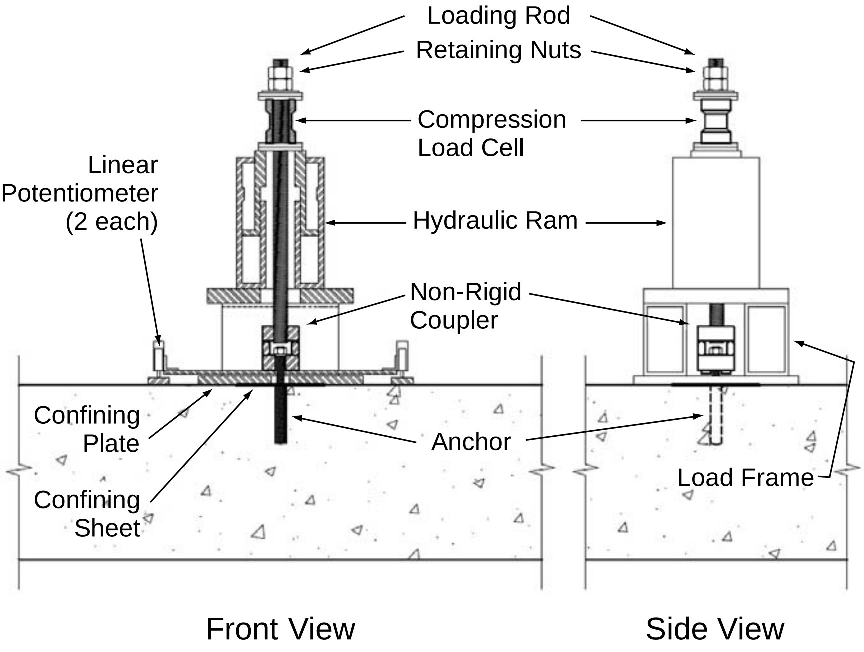
5.1.6. Two displacement measuring devices shall be placed equidistant and sufficiently far away from the anchor to not be within the potential failure surface. The two displacement values shall be averaged to obtain the actual displacement. One displacement measuring device may be used if it is placed centered on the anchor's axis and can be shown to produce acceptable confidence.

5.1.7. *Static Load Test*—The measuring devices and the data collection system must be able to gather data points at least twice per second for the static load test.

5.1.8. *Sustained Load (Creep) Test*—The measuring devices and the data collection system must be able to gather data points according to a progressively reducing frequency as discussed in Section 9.4.6.2 and Note 4.

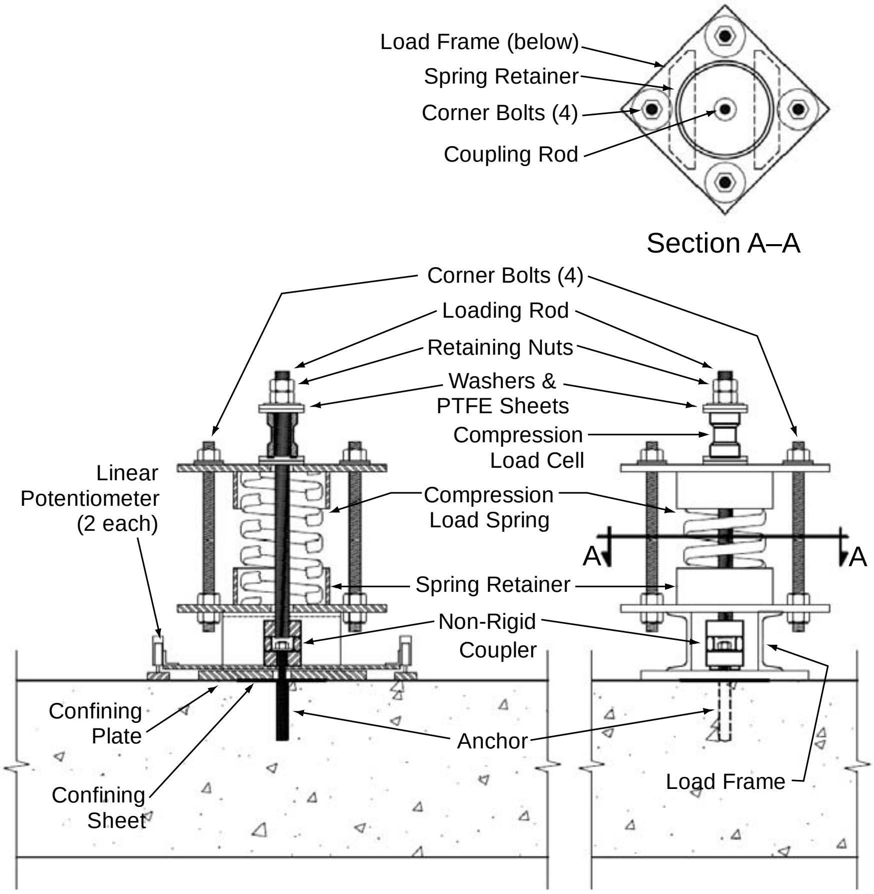
5.2. *Test Apparatus*:

5.2.1. Examples of suitable test apparatus for static and sustained load (creep) tests are shown in Figures 1 and 2, respectively.



Source: Modified from Cook et al. [14.2]

Figure 1—Static Load Test Apparatus



Source: Modified from Cook et al. [14.2]

Figure 2—Sustained Load (Creep) Test Apparatus

5.2.2. The test apparatus must be of sufficient capacity so as to not yield during testing.

5.2.3. *Coupler*—A coupler shall be used between the anchor and the test loading rod, providing a nonrigid connection that does not transfer bending forces.

5.2.4. *Confining Plate*:

5.2.4.1. The thickness of the confining plate should be greater than or equal to the nominal anchor diameter $\pm{}^{1}/_{16}$ in. (±1.5 mm).

5.2.4.2. In order to account for surface irregularities, a sheet of tetrafluoroethylene, polytetrafluoroethylene, fluorinated ethylene propylene, or perfluoroalkoxy of up to 0.06 in. (0.15 mm) of the same shape and dimensions of the confining plate shall be placed between the confining plate and the surface of the concrete.

5.2.4.3. The confining plate and the confining sheet shall be large enough to ensure that the pressure on the concrete underneath the plate does not exceed $0.40\,f'_c$.

5.2.4.4. The hole in the confining plate and the confining sheet shall be 1.5 d_o to 2.0 d_o. The shape of the hole shall match the anchor's cross-section. The size and shape of the hole shall be maintained in all tests.

6. TEST SPECIMEN

6.1. *Anchorage System*—The anchorage system used in the tests should be representative of that used in the field.

6.2. *Anchor Placement*—Spacing of anchors to be tested should be sufficient to permit placement of the test apparatus without interference from adjacent anchors.

6.3. *Structural Member*:

6.3.1. The structural member shall have sufficient dimensions to permit placement of test anchors at least $2h_{ef}$ from any edge and to avoid splitting failure during testing.

6.3.2. Reinforcing steel can be used, but only what is necessary for handling, and shall not interfere with the anchor. Reinforcing cannot be located within an imaginary cone projecting from the end of the embedded anchor to the loaded face of the structural member with an internal vertex angle of 120 degrees.

6.3.3. The depth of the structural member should be at least $1.5h_{ef}$.

6.3.4. The length and width of the structural member shall be large enough to ensure proper placement of the anchors in accordance with minimum spacing and edge distances.

6.3.5. The surface of the structural member shall be formwork or steel-trowel finish.

6.3.6. The concrete compressive strength at time of testing shall be from 2500 psi to 4000 psi (17 MPa to 28 MPa), unless otherwise specified. The aggregate should be of river gravel or crushed rock with a maximum aggregate size of $^3/_4$ or 1 in. (19 or 24 mm). The concrete mixture shall not include any materials such as blast furnace slag, fly ash, silica fume, limestone powder, or admixtures, unless otherwise specified.

6.3.7. Cure the concrete for a minimum of 28 days, ensuring proper moisture for hydration.

6.3.8. Concrete cylinders shall be made in accordance with ASTM C 31 and cured in similar conditions as the structural member. Cylinders shall be de-molded at the same time as form removal.

6.3.9. Test concrete compressive strength in accordance with ASTM C 39 for concrete cylinders or ASTM C 42 for concrete cores if insufficient cylinders were cast. Concrete strength at any point can be determined from a concrete strength-age relationship curve constructed from a sufficient number of compression tests conducted at regular intervals. It is also permitted to linearly interpolate concrete strength from compression tests conducted at the beginning and end of a test series.

7. ADHESIVE AND ANCHOR INSTALLATION AND CURING

7.1. Prior to anchor installation, condition the test specimen to 75 ± 10ºF (24 ± 5ºC) and 50 ± 10 percent relative humidity.

7.2. *Hole*:

7.2.1. Drill holes in accordance with the manufacturer's specifications and document any deviations. Drilled holes must be perpendicular (±6 degrees) to the face of the concrete test specimen.

7.2.2. In order to more easily compare data, the embedment depth, h_{ef}, should be 4.5 ± 0.1 in. (115 ± 2.5 mm) unless otherwise specified. A shallower embedment depth may be used if it is determined that a steel failure would occur prior to bond failure.

7.2.3. For anchors with a diameter, d, the minimum embedment depth, h_{ef}, shall conform to Table 1.

Table 1—Minimum Embedment Depth

d	$h_{ef,\ \mathrm{min}}$
$^1/_2$ in.	$2^3/_4$ in.
$^5/_8$ in.	$3^1/_8$ in.
$^3/_4$ in.	$3^1/_2$ in.
≥ 1 in.	4 d

7.2.4. Clean the holes in accordance with the manufacturer's specifications and document any deviations.

7.3. *Adhesive*:

7.3.1. Prepare and install the adhesive in accordance with the manufacturer's specifications and document any deviations.

7.3.2. Cure the adhesive according to the manufacturer's specifications and document any deviations.

7.4. *Anchor*:

7.4.1. Install the anchor in accordance with the manufacturer's specifications and document any deviations.

7.4.2. To ensure bond failure, use a high-strength steel (minimum strength equivalent to ASTM A 193 Grade B7).

7.4.3. In order to more easily compare data, anchors shall be $^5/_8$ in.—11 UNC (16 mm) threaded rod unless otherwise specified.

8. SPECIMEN CONDITIONING

8.1. Begin conditioning of the test slabs to their final environmental condition upon completion of the manufacturer's specified curing time for the adhesive and initiate testing and within 7 ± 5 days.

8.2. Do not begin tests until the temperature and humidity of the test specimens have stabilized for at least 24 hours.

Note 1—Depending on the size of the structural member, it might take several days to raise and stabilize the concrete temperature to the final elevated temperature.

9. TEST PROCEDURE

9.1. The test procedure consists of two types of tests [static load test and sustained load (creep) test]. Static load tests are conducted initially to determine the mean static load. Subsequently, several sustained load (creep) tests are conducted at various percentages of the mean static load.

9.2. *General Requirements*:

9.2.1. All tests will be confined tests as shown in Figures 1 and 2.

9.2.2. The tests will be conducted at specified temperature and humidity. The temperature shall be monitored via thermocouples or temperature sensors placed in the concrete test specimen. The thermocouples or temperature sensors can be either cast-in-place or installed in a maximum $^1/_2$-in. (12-mm) diameter hole and sealed to ensure accurate concrete temperature readings. The thermocouples or temperature sensors ideally should be placed at the mid-depth of the anchor, but not deeper than $4^1/_2$ in. (114 mm).

9.2.3. The use of thermocouples is not required if it can be experimentally demonstrated that the test procedure will consistently produce test member temperatures in accordance with the target temperatures.

9.3. *Static Load Test*:

9.3.1. *Environmental Conditions*—Conduct the static load tests at a minimum temperature of 110 + 10ºF/– 0ºF (43 + 5ºC/– 0ºC) and below 40 percent relative humidity. Following the required adhesive curing time, raise the temperature to the minimum elevated temperature of 110ºF (43ºC). Do not begin testing until the temperature and humidity of the test specimen have stabilized for at least 24 hours.

9.3.2. *Number of Test Specimens*—A minimum of five anchors shall be tested and their results averaged.

9.3.3. *Test Setup*:

9.3.3.1. Ensure that the test apparatus and instrumentation comply with the requirements of Section 5.

9.3.3.2. Ensure that the test apparatus is centered over the anchor and that the force applied is acting through the center of the anchor and perpendicular to the structural member.

9.3.3.3. Place the confining sheet around the anchor as discussed in Section 5.2.4.2.

9.3.3.4. Place the confining plate over the confining sheet, assuring that there is full bearing with the structural member around the anchor.

9.3.3.5. Connect the loading rod to the anchor by means of a non-rigid connecting coupler (one that does not transfer bending moments from the loading rod to the anchor) and ensure that it is acting in-line with the anchor.

9.3.3.6. The amount of pre-tensioning to the apparatus during test setup shall be uniform for all samples.

9.3.4. *Loading*:

9.3.4.1. *Initial Load*—Apply an initial load not exceeding 5 percent of the estimated ultimate load capacity of the anchor system in order to bring all members of the test apparatus into bearing. Zero the displacement readings.

9.3.4.2. *Rate of Loading*—Two loading rates are allowed by ASTM E 488, the Continuous Load Rate and the Incremental Load Rate. The continuous load rate is the only load rate allowed in this test method for the calculation of mean static load and for inclusion in the stress versus time-to-failure graph. Apply a uniform load rate such that failure ideally will occur at 2 minutes. Failure shall not occur in less than 1 minute or greater than 3 minutes.

Note 2—The incremental load rate can be used in optional additional tests as a method to (1) provide an indication of an adhesive's displacement sensitivity to load at the higher stress levels, and (2) determine appropriate stress levels to test at for the sustained load (creep) tests. This method is discussed in further detail in Appendix X1.

9.3.5. *Data Collection*—Collect load and displacement readings according to Section 5.1.7.

9.3.6. *Determination of Failure*—See Appendix X2 for a description of the various failure modes and methods to determine static load strength.

9.3.7. *Calculations*—Determine and record the mean static load by averaging the individual static load strengths from each test series.

9.4. *Sustained Load (Creep) Test*:

9.4.1. *Environmental Conditions*—Conduct the sustained load (creep) tests at a minimum elevated temperature of 110 + 10ºF/– 0ºF (43 + 5ºC/– 0ºC) and below 40 percent relative humidity. Following the required curing time, raise the temperature to the minimum elevated temperature of 110ºF (43ºC). Do not begin the test until the temperature and humidity of the test specimen has stabilized for at least 24 hours.

9.4.2. *Test Series*—Conduct a minimum of two series of sustained load (creep) tests within two load ranges (PL1 and PL2) based on the *mean static load* from the static load test:

9.4.2.1. Percent load level range 1 (PL1) is suggested to be between 70 percent and 80 percent of *mean static load*.

9.4.2.2. Percent load level range 2 (PL2) is suggested to be between 60 percent and 70 percent of *mean static load*.

9.4.2.3. It is not necessary that all test specimens be tested at the same percent load level, but that they lie within the ranges and the averages of the two test series should vary by at least 10 percent of mean static load.

9.4.3. *Number of Test Specimens*—A minimum of five anchors per series shall be tested.

9.4.4. *Test Setup*:

9.4.4.1. Ensure that the test apparatus and instrumentation comply with the requirements of Section 5.

9.4.4.2. Ensure that the test apparatus is centered over the anchor and the force applied is acting through the center of the anchor and perpendicular to the structural member.

9.4.4.3. Place the confining sheet around the anchor as discussed in Section 5.2.4.2.

9.4.4.4. Place the confining plate over the confining sheet, assuring that there is full bearing with the structural member around the anchor.

9.4.4.5. Connect the loading rod to the anchor by means of a nonrigid connecting coupler and ensure that it is acting in-line with the anchor.

9.4.4.6. The amount of pre-tensioning to the apparatus during test setup shall be uniform for all samples.

9.4.5. *Loading*—Apply an initial load not exceeding 5 percent of *mean static load* in order to bring all members of the test apparatus into bearing. Zero the displacement readings. Apply the remainder of the sustained load within 2 minutes ± 1 minute in as smooth a manner as possible.

Note 3—A suggested modification to the sustained load (creep) test apparatus shown in Figure 2 is presented in Appendix X4 to provide for smooth load transfer.

9.4.6. *Data Collection*:

9.4.6.1. *Temperature*—Record the concrete specimen temperature at a maximum 1-hour interval. Alternatively, the concrete specimen temperature can be recorded at 24-hour intervals if the test chamber temperature is recorded at 1-hour intervals.

9.4.6.2. *Displacement*—The frequency of displacement readings can be reduced over time.

Note 4—The following schedule is a suggestion: every 3 seconds during loading, every minute for the first hour following loading, every 10 minutes for the next 9 hours, and every hour thereafter.

9.4.7. *Determination of Failure*—Failure for the sustained load (creep) test will be determined as the onset of tertiary creep. A discussion of tertiary creep and a method to determine its onset can be found in Appendix X3.

9.4.8. *Calculations*—Determine and record the time to failure and load level at failure for each specimen.

10. CALCULATIONS AND INTERPRETATION OF RESULTS

10.1. Determine the five individual static load strengths from each static load test. Methods to determine the static load strength can be found in Appendix X2.

10.2. Determine the *mean static load* by averaging the individual values from the static load tests.

10.3. Determine the time to failure for each sustained load (creep) test series as the initiation of tertiary creep. A procedure to locate the onset of tertiary creep can be found in Appendix X3.

10.4. Determine the failure load level for each sustained load (creep) test series at the initiation of tertiary creep.

10.5. Normalize the load levels for the sustained load (creep) test to a percent of the *mean static load* from the static load tests.

10.6. Plot the normalized values from the static load test and the sustained load (creep) test on a stress versus log of time-to-failure graph.

10.7. Extend a linear trendline through the 15 points plotted.

10.8. A stress versus time-to-failure graph can give an indication of the reduction in capacity of an adhesive anchor due to sustained load at a given design lifetime.

11. REPORT

11.1. *Data Collection*—Report the type of test (static load or sustained load) and the following applicable information:

11.1.1. Date of test and date of report.

11.1.2. Test sponsor and test agency.

11.1.3. *Anchor Information*—manufacturer, model, type, material, finish, shape, dimensions, and other relevant information.

11.1.4. *Adhesive Information*—manufacturer, model, type, lot, material, application method, and other relevant information.

11.1.5. *Structural Member Information*—description, dimensions, reinforcing, mix design of concrete, aggregate type, curing method, concrete strength at time of test, age of concrete at time of test.

11.1.6. *Installation Information*—description of the procedure, tools, and methods used to install the adhesive anchor. Include the drilling and cleaning of the holes as well as the installation of the adhesive and anchor. Document any deviations from the manufacturer's specifications.

11.1.7. *Adhesive Curing Information*—temperature and humidity conditions, duration of cure, time when conditioning of test specimen began.

11.1.8. Temperature and humidity conditions at time of installation and during adhesive cure, conditioning, and final testing.

11.1.9. Embedment depth and diameter of hole of installed anchors.

11.1.10. *Test Information*—description of test method, amount of initial load, and actual rate of loading.

11.1.11. Number of samples tested per series.

11.1.12. *Static Load Test Data*:

11.1.12.1. Individual and average load values per anchor and coefficient of variation.

11.1.12.2. Individual and average displacement values at maximum load.

11.1.12.3. Load versus displacement curves per anchor.

11.1.12.4. Load versus time curves per anchor.

11.1.13. *Sustained Load (Creep) Test Data*:

11.1.13.1. Individual time-to-failure values per anchor.

11.1.13.2. Individual load values and percent mean static load values at failure per anchor.

11.1.13.3. Individual displacement values at failure per anchor.

11.1.13.4. Load versus displacement curves per anchor.

11.1.13.5. Displacement versus time curves per anchor.

11.1.13.6. Load versus time curves per anchor.

11.1.13.7. Stress versus time-to-failure curve.

11.1.14. Photographs, sketches and descriptions of failure modes observed.

11.1.15. Summary of findings.

11.1.16. Listing of observers of tests and signatures of responsible persons.

12. PRECISION AND BIAS

12.1. *Precision*—No precision has been established for this test method.

12.2. *Bias*—No bias can be established because no reference material is available for this test.

13. KEYWORDS

13.1. Adhesive anchors; anchors; bonded anchors; creep test; concrete; post-installed anchors; static load test; sustained load test; test methods; time-to-failure test.

14. REFERENCES

14.1. Cook, R. A., and R. C. Konz. Factors Influencing Bond Strength of Adhesive Anchors. *ACI Structural Journal*, Vol. 98, No. 1. American Concrete Institute, Farmington Hills, MI, 2001, *pp.* 76–86.

14.2. Cook, R. A., R. C. Konz, and D. S. Richardson. *Specifications for Adhesive-Bonded Anchors and Dowels.* Report No. 96-3. University of Florida, Gainesville, FL, 1996.

APPENDIXES

(Nonmandatory Information)

X1. INCREMENTAL LOAD RATE

X1.1. The incremental load rate is a method that applies the load in several load steps, holds the load for 2 minutes, and then increases to the next load level. Apply the load in steps with the first increment not greater than 50 percent of the estimated ultimate load and each increment thereafter not exceeding 15 percent of the estimated ultimate load. Maintain each load increment within a tolerance of ±2 percent for 2 minutes.

X1.2. This method can provide an indication of an adhesive's sensitivity to sustained loading at higher load levels.

X1.3. Figure X1.1 shows a load-versus-displacement curve and a time-versus-displacement curve for an anchor under incremental loading.

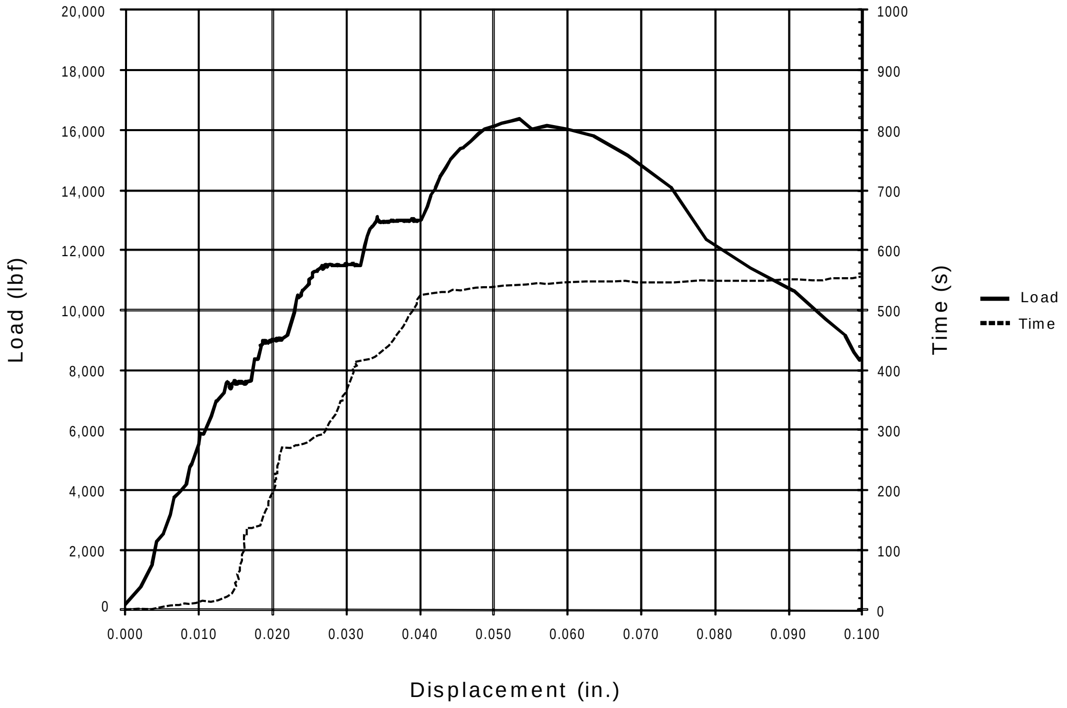


Figure X1.1—Load-Displacement and Time-Displacement Curves with Incremental Loading

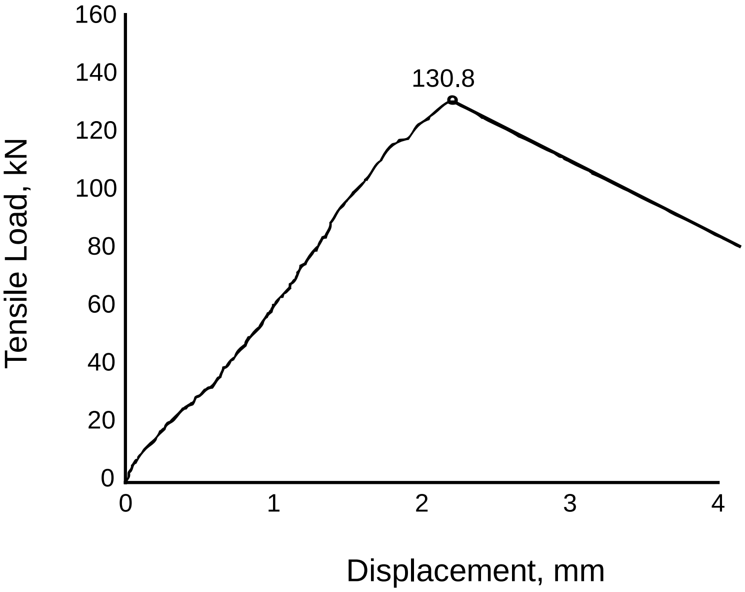
X1.4. As shown in Figure X1.1, as the load is held constant, the anchor in this graph displays more displacement at the higher load steps.

X1.5. Figure X1.1 also shows that, at the lower load levels, the displacement tends to stabilize. Additionally, at the higher load levels, the anchor continues to displace. This is indicated by the slope of the time-displacement curve.

X2. DETERMINING STATIC LOAD STRENGTH

X2.1. Cook and Konz [14.1] classify three types of load-displacement response (strength-controlled, stiffness-controlled, and displacement-controlled) for adhesive anchor systems. These three types of responses and methods of their analysis are summarized below:

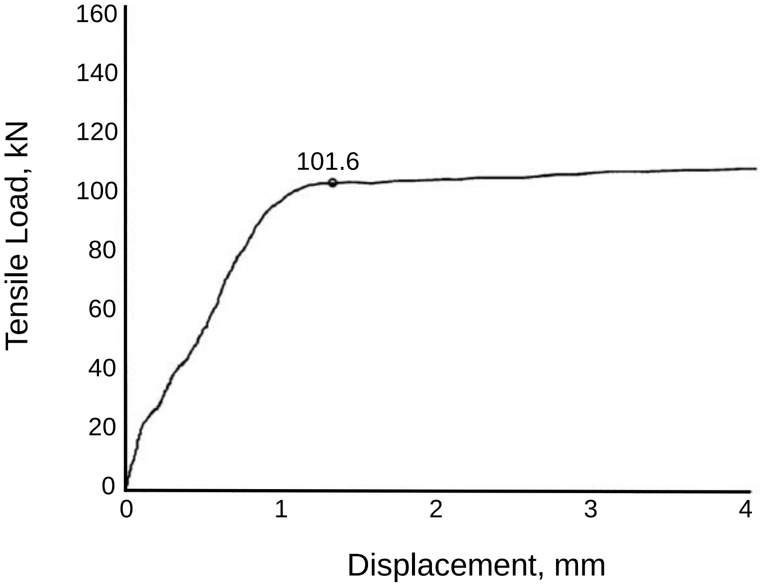
X2.1.1. *Strength-controlled*—This failure mode is defined by a very sharp peak in the load-displacement curve. There is a drastic reduction in the stiffness of the adhesive anchor beyond the peak. The static load strength is determined to be at the peak on the load-displacement graph. Figure X2.1 shows a typical curve of a strength-controlled failure.



Source: Cook and Konz [14.1], Reprinted with permission of ACI

Figure X2.1—Typical Strength-Controlled Failure

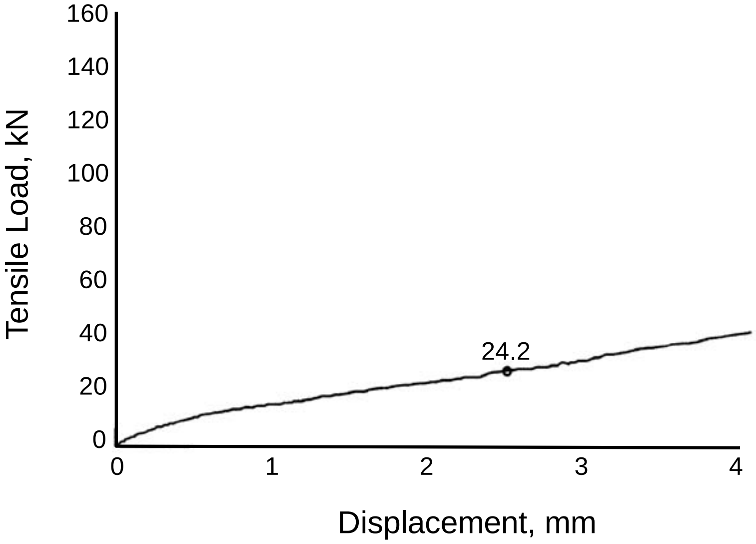
X2.1.2. *Stiffness-controlled*—This failure mode is defined by a large initial stiffness and a drastic change in stiffness that does not decrease, but rather continues to increase at a lower slope. Due to the lack of “peak” in the curve, the static load strength is determined by finding the point at a tangent stiffness of 30 kip/in. (5 kN/mm). The tangent stiffness (slope) at a given data point can be approximated by calculating the slope between a point five data points after and five data points before. Figure X2.2 shows a typical curve of a stiffness-controlled failure.



Source: Cook and Konz [14.1], Reprinted with permission of ACI

Figure X2.2—Typical Stiffness-Controlled Failure

X2.1.3. *Displacement-controlled*—This failure mode has a load-displacement curve with a relatively constant stiffness above the stiffness-controlled threshold of 30 kip/in. The maximum load occurs at very high, and impractical, displacements. In this case, the static load strength is set at a point with a displacement of 0.1 in. (2.5 mm). Figure X2.3 shows a typical curve of a displacement-controlled failure.

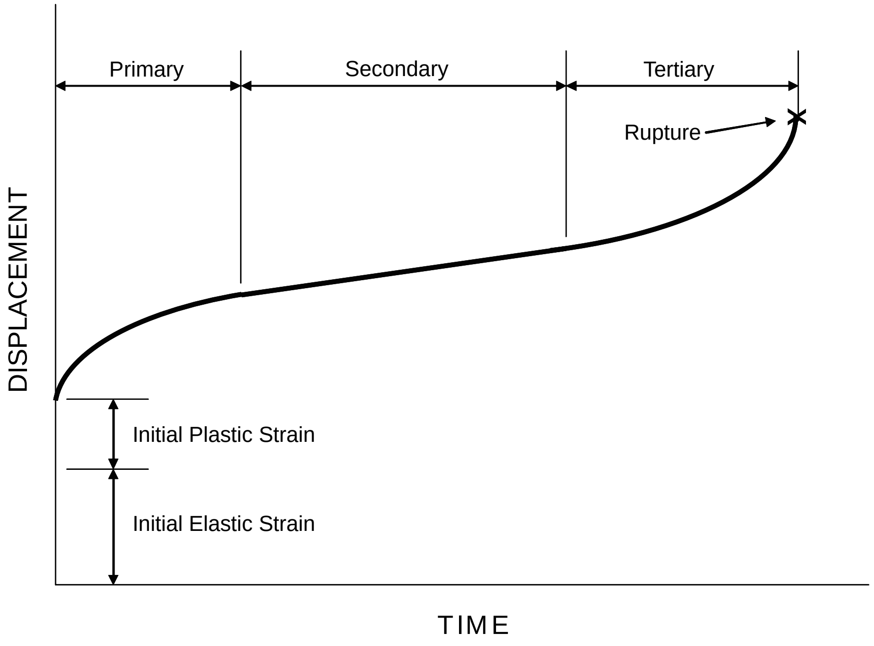


Source: Cook and Konz [14.1], Reprinted with permission of ACI

Figure X2.3—Typical Displacement-Controlled Failure

X3. DETERMINING ONSET OF TERTIARY CREEP

X3.1. As discussed in the appendix of ASTM D 2990, the displacement-versus-time curve will display three regions. Region 1 is the primary creep region and is characterized by an initial rapid decrease in the creep rate. Region 2 is the secondary creep region and is characterized by a relatively steady slope. Region 3 is the tertiary creep region and is characterized by a rapid increase in creep, ending in rupture. Figure X3.1 shows these three regions for a hypothetical sample.



Adapted from ASTM D 2990-01

Figure X3.1—Regions on the Creep Curve

X3.2. The onset of tertiary creep is found by analyzing the change in the slope of the creep curve:

X3.2.1. This method calculates the slope at a given point as the slope between itself and the prior data point.

X3.2.2. The change in slopes between the given point and the following data point is plotted and examined over the region just prior to rupture. It is suggested that this examination be conducted on a normal graph (not log time). The rupture point is easily identified on the displacement-versus-time graph. A suggested range for examining the change in slope is from 80 to 100 percent of time to rupture. Due to minor fluctuations in the displacement readings, the slope might change from positive to negative several times over this range.

X3.2.3. Tertiary creep is defined as the time the change in slope becomes positive for the last time prior to rupture. Figure X3.2 shows a sample graph for determining the initiation of tertiary creep.

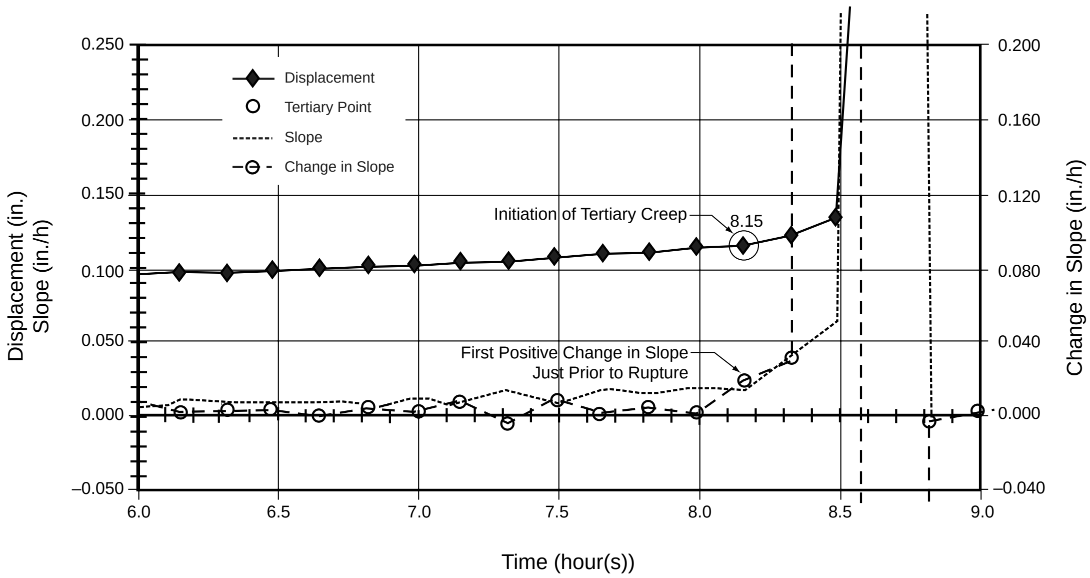


Figure X3.2—Sample Graph Showing Initiation of Tertiary Creep

X3.3. Failure for the sustained load is defined as the initiation of tertiary creep. The failure point for each sustained load test is plotted on the stress versus time-to-failure graph. Figure X3.3 shows a sample stress versus time-to-failure graph.

X3.4. A stress versus time-to-failure graph can give an indication of the reduction in capacity of an adhesive anchor due to sustained load at a given design lifetime.

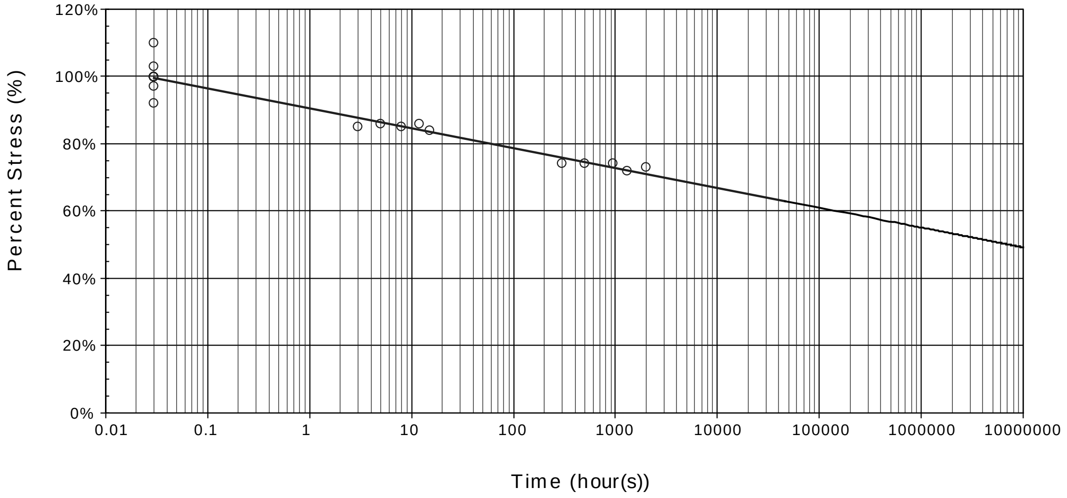
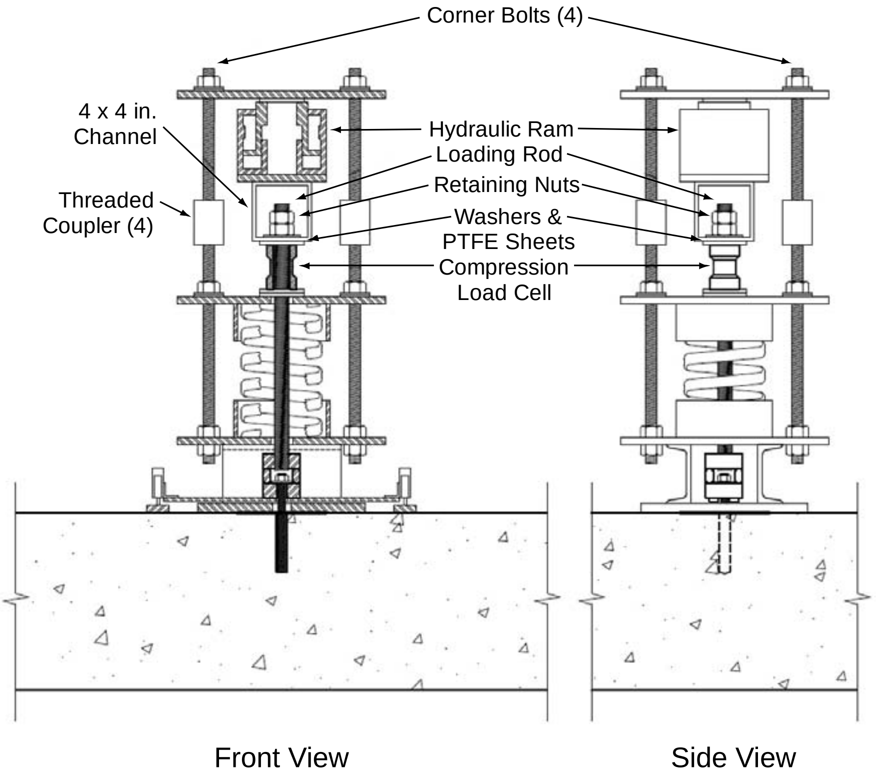


Figure X3.3—Sample Stress vs. Time-to-Failure Graph

X4. SUGGESTED SUSTAINED LOAD (CREEP) TEST APPARATUS FOR SMOOTH LOAD TRANSFER

X4.1. It is important that the load to the anchor be applied in a smooth manner. This can be accomplished with a hydraulic ram.

X4.2. Figure X4.1 shows a modified test apparatus for the sustained load (creep) test incorporating a hydraulic ram that reacts against a plate connected to the existing test apparatus by means of four threaded couplers. The ram and the upper plate can be removed following tightening of the loading rod nut.



Source: Modified from Cook et al. [14.2]

Figure X4.1—Suggested Load Transfer for Sustained Load (Creep) Tests

Standard Specification for

Smoothness of Pavement in Weigh-in-Motion (WIM) Systems

AASHTO Designation: MP 14-08[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Smoothness of Pavement in Weigh-in-Motion (WIM) Systems

AASHTO Designation: MP 14-08[1]

1. SCOPE

1.1. Weigh-in-motion (WIM) is the process of measuring the dynamic forces of moving vehicle tires on pavements and estimating the corresponding tire loads of the static vehicle. The dynamic forces of moving vehicles include the effects of road surface roughness and are modified by vehicle characteristics such as spring and un-spring mass, tire inflation pressures, out-of-round or dynamically unbalanced wheels and tires, suspension damping, and the vehicles' aerodynamic characteristics. The smoothness of the pavement surface in WIM systems directly affects the scale's ability to accurately estimate static loads from measured dynamic forces. Lack of smoothness creates difficulties in calibrating WIM equipment and may cause poor results from subsequent vehicle weight data collection efforts.

1.2. WIM system pavement smoothness is characterized by the output of a Class I profiler collecting data at 25-mm [1-in.] intervals. The data produced by such a profiler will approximate the actual perpendicular deviation of the pavement surface from an established horizontal reference parallel to the lane direction in the wheel tracks.

1.3. The specification requires field collection of pavement profile information of a WIM system or of a candidate WIM site. Computer software is then used to calculate indices of long- and short-range pavement surface roughness that have been correlated to distributions of tandem axle and gross vehicle weight error levels through extensive simulations of truck dynamic loading over measured profiles. Acceptable index levels are based on ensuring to a 95 percent level of confidence that the WIM system roughness will not produce errors that exceed the tolerance level limits recommended by ASTM.

1.4. The profiler test vehicle, as well as all attachments to it, shall comply with all applicable state and federal laws. Necessary precautions imposed by laws and regulations, as well as vehicle manufacturers, shall be taken to ensure the safety of operating personnel and other traffic.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 328, Inertial Profiler
- R 57, Operating Inertial Profiling Systems

2.2. *ASTM Standards*:

- E 867, Standard Terminology Relating to Vehicle-Pavement Systems
- E 950, Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference
- E 1170, Standard Practices for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces
- E 1318, Standard Specification for Highway Weigh-In-Motion (WIM) Systems with User Requirements and Test Methods
- E 1364, Standard Test Method for Measuring Road Roughness by Static Level Method

2.3. *Other Documents and References*:

- FHWA. *Traffic Monitoring Guide*, Fourth Edition. U.S. Department of Transportation, Federal Highway Administration, Office of Highway Information Management, Washington, DC, January 2001.
- FHWA. *Pavement Smoothness Specifications for LTPP WIM Locations*, Draft. Federal Highway Administration, Office of Infrastructure Research, Development, and Technology, McLean, VA, January 2002.
- FHWA. *A Program Guide to WIM Smoothness Index Software*. Federal Highway Administration, Office of Infrastructure Research, Development, and Technology, McLean, VA, 2005.
- Karamihas, Steven M. and Thomas D. Gillespie. *Smoothness Criteria for WIM Scale Approaches*. University of Michigan Transportation Research Institute, Ann Arbor, MI, September 2002.
- Karamihas, Steven M. and Thomas D. Gillespie. *Advancement of Smoothness Criteria for WIM Scale Approaches—Final Report*. University of Michigan Transportation Research Institute, Ann Arbor, MI, April 2004.

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *dynamic axle load (kg or lb), n*—the component of the time-varying forces applied perpendicularly to the road surface by the tires of any one axle of a moving vehicle.

3.1.2. *index, n*—a number or formula expressing some property, form, ratio, etc. of the relation or proportion of one amount or dimension to another.

3.1.3. *roughness, n*—vertical deviation of a pavement surface from a horizontal reference along a wheel track with characteristics that effect vehicle dynamics, including dynamic axle loads.

3.1.4. *profile record, n*—a data record of the surface elevation or slope along one or both wheel tracks of the road surface.

3.1.5. *weigh-in-motion (WIM), n*—the process of estimating a moving vehicle's gross weight and the portion of that weight that is carried by each wheel, axle, or axle group, or combination thereof, by measurement and analysis of dynamic vehicle tire forces. (See Terminology, ASTM E 867.)

3.2. *Definitions of Terms Specific to This Standard*:

3.2.1. *short-range roughness, n*—vertical deviations of the pavement surface from a horizontal reference within a range of pavement from 2.8 m [9.2 ft] preceding a WIM scale to 0.5 m [1.6 ft] beyond it.

3.2.2. *long-range roughness, n*—vertical deviations of the pavement surface from a horizontal reference within a range of pavement from 25.8 m [84.6 ft] preceding a WIM scale to 3.2 m [10.5 ft] beyond it.

4. TEST METHOD TO EVALUATE THE SMOOTHNESS OF PAVEMENT IN A WIM SYSTEM

4.1. *Performance Requirements*:

4.1.1. Functional performance requirements for Types I and II WIM systems were established and tabulated within ASTM E 1318. Table 1 summarizes the tolerance limits for 95 percent probability of conformity to WIM accuracy standards for axle loads, axle-group loads, and gross vehicle weights. Karamihas and Gillespie have developed short- and long-range profile-based indices that can predict the potential WIM error level due to roughness of the pavement. The development and use of these are documented within Annex A1.

4.1.2. Each Type I WIM scale location shall be chosen so that the short- and long-range roughness indices calculated from the pavement profile record of the WIM system do not exceed 0.5 m/km [31.7 in./mi] for either of the wheel tracks. Each Type II WIM scale location shall be chosen so that the short- and long-range roughness indices calculated from the pavement profile record of the WIM system do not exceed 1.25 m/km [79.2 in./mi] and 0.9 m/km [57.0 in./mi], respectively, for either of the wheel tracks. The achievement of these values is needed to ensure that a WIM site is likely to produce load estimates that meet the requirements of ASTM E 1318. When location requirements dictate scale placement in rough pavement, the existing pavement can be modified (overlaid, ground, etc.) or replaced to meet these smoothness requirements.

4.1.3. The very presence of a WIM scale will often create localized roughness within the pavement in its vicinity. If this localized roughness is just outside the range of the Short-Range Index (SRI) (2.8 m [9.2 ft] preceding a WIM scale to 0.5 m [1.6 ft] beyond it), then it will elevate the WIM error levels without any affect on the SRI value. To correct this, a Peak SRI value shall be calculated. This value is defined as the maximum value of SRI for all locations from 2.45 m [8.0 ft] ahead of the scale to 1.5 m [4.9 ft] beyond the scale. For Peak SRI, 0.75 m/km [47.5 in./mi] should be used as the acceptable threshold for Type I WIM and 1.6 m/km [101.4 in./mi] should be used for Type II WIM. Values below these figures are needed for both wheel tracks to ensure that a WIM site is likely to produce load estimates that meet the requirements of ASTM E 1318.

Table 1—Functional Performance Requirements for Types I and II WIM Systems

Function	Tolerance for 95% Probability of Conformance	
	Type I	Type II
Wheel Load	±25%	—
Axle Load	±20%	±30%
Axle-Group Load	±15%	±20%
Gross Vehicle Weight	±10%	±15%

4.1.4. In addition to the initial calculations of short- and long-range roughness indices for WIM scale location acceptance, the pavement smoothness of each existing WIM scale shall be verified annually. Profile records shall be collected and indices recalculated each year to ensure that the scale remains likely to produce load estimates that meet the functional performance requirements of ASTM E 1318.

4.1.5. In specifying a location for a WIM scale with more than one sensor on a single wheel track (typical with piezoelectric WIM equipment), the position of the scale shall be defined as the point midway between the sensors. SRIs and long-range indexes (LRIs) are to be referenced to this midway point.

4.1.6. Under certain conditions, jointed concrete pavement surfaces may exhibit significant changes in roughness due to variations in the temperatures of the pavement. Profile records of these pavements shall be taken at least twice, at times that correspond to approximate extremes of temperatures that are likely to be experienced at the candidate location. The location for a WIM scale shall be chosen so that the short- and long-range roughness indexes calculated from either of these profile records do not exceed the limits.

4.2. *Summary of Practice*—Test methods for evaluating the smoothness of pavement in an existing WIM system are presented herein. These procedures are applicable for determining whether either short-range or long-range roughness levels are at levels that would indicate a WIM scale is likely to produce acceptable levels of weighing error as defined in Table 1. The smoothness tests require the collection of longitudinal profile data with a sampling rate of 25 mm [1 in.] (Class I) according to the procedures in ASTM E 950. Computer analysis of these profiles serves to create indices of short- and long-range roughness that will be compared to acceptable threshold values.

4.3. *Significance and Use*—Karamihas and Gillespie conducted a correlation of calculated SRI and LRI values to WIM scale error for a large-scale study of pitch-plane simulations of 3S2 vehicles. Karamihas and Gillespie further verified this study of simulations of WIM scale errors associated with three-axle single-unit trucks. This correlation allows the indexes to be used to determine whether the WIM system pavement smoothness is sufficient to achieve weight measurements of 3S2 trucks (five-axle tractor-semi-trailers) and three-axle single-unit trucks that fall within ASTM error tolerance levels. The calculation of short- and long-range roughness indexes that fall within those that correlate to the scale measurement tolerances specified in Table 1 means that the scale is very likely to produce an acceptable level of weighing error.

4.4. *Procedure*:

4.4.1. *Profile Records*—Obtain profile records of both left and right wheel paths according to the procedures outlined in ASTM E 950 for Class I profilers using a 25-mm [1-in.] longitudinal sampling interval. These records should begin at least 122 m [400 ft] prior to the WIM scale sensor and extend to 30 m [100 ft] after the scale sensor. For WIM scales that are comprised of two or more sensors, the location of the scale will be defined as the longitudinal midpoint of the locations of the two outermost sensors. Record the WIM scale location as an Intermediate Feature Location Marker within the profile record as per Section 6.3.4 of ASTM E 950. Obtain a total of three records, compare the outputs for each, and evaluate each for equipment-related spikes. Continue collecting profile records until the operator is satisfied that at least one error-free record has been obtained.

4.4.2. *Calculation of Indexes*—A complete description of the procedure to calculate short- and long-range smoothness indices is described in Annex A1—Computation of Profile-Based Short- and Long-Range Indices. The procedure has been coded within the WIM Smoothness Index software available from FHWA's Long-Term Pavement Performance (LTPP) Program Product Delivery Team. This nonproprietary software performs the computations from Annex A1 with either R 57 or ERD text file versions of the profile records from any longitudinal profiler as inputs. Source code is available from FHWA's LTPP Product Delivery Team. Perform 'Site Evaluation' analysis of the WIM system pavement with the WIM Smoothness Index software. SRI, LRI, as well as peak SRI, values will be calculated for both left and right wheel paths of the WIM system.

4.4.3. Although including pavement features located more than 26 m [85 ft] ahead of a WIM scale does not improve its predictive ability, the LRI criterion might fail to screen out WIM sites with a major disturbance just beyond this range if the rest of the pavement is smooth. Although this is unlikely to occur in practice, a useful way to protect against very rough pavement features that are not captured by the LRI value at the scale location is to inspect the value of LRI for 30 m [100 ft] upstream of the scale to ensure that it does not exceed the lower threshold over this range.

4.5. *Interpretation of Results*—Lower threshold values of long-range, short-range, and peak short-range indexes are those below which a WIM system is very likely to produce an acceptable level of weighing error. Upper threshold values of these indexes are those above which a WIM system is very likely to produce an unacceptable level of weighing error. Threshold values for each of these three indexes for Types I and II WIM scales are tabulated in Table 2 and Table 3, respectively. An acceptable LRI value is required for a minimum of 30 m (100 ft) prior to the chosen location.

Table 2—Roughness Index Thresholds for Type I WIM

Index	Lower Threshold, m/km [in./mi]	Upper Threshold, m/km [in./mi]
Long Range	0.5 [31.7]	2.1 [133.1]
Short Range	0.5 [31.7]	2.1 [133.1]
Peak Short Range	0.75 [47.5]	2.9 [183.7]

Table 3—Roughness Index Thresholds for Type II WIM

Index	Lower Threshold, m/km [in./mi]	Upper Threshold, m/km [in./mi]
Long Range	0.9 [57.0]	3.8 [240.8]
Short Range	1.25 [79.2]	5.7 [361.2]
Peak Short Range	1.6 [101.4]	6.6 [418.2]

4.6. *Precision and Bias*—This is a test method that produces pass or fail results. The precision of the test is related to the degree of correlation between calculated index values and errors in measured values of tandem axle and cross vehicle weights. Since these relationships exhibited some scatter in a simulation study, conservative values for index cut-off values were chosen such that there was 95 percent confidence that a scale that met the index criteria would produce levels of weighing error that meet the ASTM E 1318 standards in the study.

5. TEST METHOD TO EVALUATE THE SMOOTHNESS OF PAVEMENT TO DETERMINE THE OPTIMAL WIM SYSTEM LOCATION

5.1. *Summary of Test Method*—A test method for determining the optimal position for a WIM scale within a limited site is presented herein. The procedures are applicable for determining a precise placement of a WIM scale within the linear distance covered by a profiler record that will result in minimum short-range and long-range roughness levels. The smoothness tests require the collection of longitudinal profile data with a sampling rate of 25 mm [1 in.] (Class I) according to the procedures in ASTM E 950. Computer analysis of these profiles at varying longitudinal scale placements serves to place the WIM scale in a location that will minimize short- and long-range roughness. Comparison of these values with acceptable threshold values will indicate whether the site is suitable. To protect against very rough pavement features that are not captured by the LRI value at the scale location, inspect the value of LRI for 30 m (100 ft) upstream of the scale to ensure that it does not exceed the lower threshold over this range.

5.2. *Significance and Use*—A correlation of calculated SRI and LRI values to WIM scale error was conducted for a large-scale study of pitch-plane simulations of 3S2 vehicles. This correlation allows the indexes to be used to determine whether the WIM system pavement smoothness is sufficient to achieve weight measurements of 3S2 trucks (five-axle tractor-semi-trailers) and three-axle single-unit trucks that fall within ASTM error tolerance levels. The calculation of short- and long-range roughness indexes for each candidate scale location within a profile record may be used to determine the correct positioning of a scale to maximize its likelihood of producing acceptable levels of weighing error as outlined in Table 1.

5.3. *Test Methods*:

5.3.1. *Profile Records*—Obtain profile records of both left and right wheel paths according to the procedures outlined in ASTM E 950 Class I profilers using a 25-mm [1-in.] longitudinal sampling interval. These records shall meet the minimum requirements for vertical measurement resolution outlined in ASTM E 950 for Class I profilers and should cover the entire longitudinal extent of roadway to be considered for the WIM scale placement. Obtain a total of three records, compare the outputs for each and evaluate each for equipment-related spikes. Continue collecting profile records until the operator is satisfied that at least one error-free record has been obtained.

5.3.2. *Calculation of Indexes*—A complete description of the procedure to calculate short- and long-range smoothness indices is described in Annex A1—Computation of Profile-Based Short- and Long-Range Indexes. The procedure has been coded within the WIM Smoothness Index software available from FHWA's LTPP Product Delivery Team. This nonproprietary software performs the computations from Annex A1 with ERD text file versions of the profile records from any longitudinal profiler as inputs. Perform 'Location Selection' analysis of the WIM system pavement with the WIM Smoothness Index software. Short- and long-range as well as peak SRI values for both left and right wheel paths will be calculated and graphed for each potential WIM scale location within the record.

5.4. *Interpretation of Results*—Lower threshold values of long-range and short-range indexes are those below which a WIM site is very likely to produce an acceptable level of weighing error. Upper threshold values of these indices are those above which a WIM site is very likely to produce an unacceptable level of weighing error. Threshold values for the long- and short-range indexes for Types I and II WIM scales are tabulated in Table 2 and Table 3, respectively. A location shall be chosen that will result in acceptable index values. An acceptable LRI value is required for a minimum of 30 m [100 ft] prior to the chosen location.

5.5. *Precision and Bias*—See Section 4.6.

ANNEXES

(Mandatory Information)

A1. COMPUTATION OF PROFILE-BASED SHORT- AND LONG-RANGE INDEXES

A1.1. *Four-Pole Butterworth Filter*:

A1.1.1. A pre-filter shall be applied. An elevation profile for each wheel track is replaced with a slope profile, obtained point-by-point by subtracting adjacent elevation values and dividing by the sample interval.

A1.1.2. An ideal band-pass filter passes some range of frequencies without distortion and suppresses all other frequencies. A Butterworth filter fulfills these needs. The exclusion of very short and very long wavelengths minimizes the effects of high amplitude, short wavelength change in the profile at the edges of the spatial weighting function. It also prevents absolute elevation or grade from influencing index values by filtering very long wavelength signals. The transfer function for the frequency response for this filter can be written as:

$$P\left(s^2\Omega_h^2\right) = F\left(\left(s^2 + 2\zeta\Omega_l s + \Omega_l^2\right)\left(s^2 + 2\zeta\Omega_h s + \Omega_h^2\right)\right) \qquad (A1.1)$$

where:

$P(x)$ = input function and $F(x)$ is the filtered profile,

Ω_h = high spatial cutoff expressed as a wavelength,

Ω_l = low spatial cutoff expressed as a wavelength, and

ζ = dimensionless damping ratio, set at 0.707 for a Butterworth filter.

Replacing *s* in the theoretical transfer function with the derivative operation $sy = \frac{\partial y}{\partial x}$, the frequency response can be expressed as an equation:

$$b_2 \frac{\partial^2 P}{\partial x^2} = \frac{\partial^4 F}{\partial x^4} + a_1 \frac{\partial^3 F}{\partial x^3} + a_2 \frac{\partial^2 F}{\partial x^2} + a_3 \frac{\partial F}{\partial x} + a_4 F \qquad (A1.2)$$

where:

$$b_2 = \Omega_h^2$$

$$a_1 = 2\zeta\left(\Omega_l + \Omega_h\right)$$

$$a_2 = \Omega_l^2 + 4\zeta\Omega_l\Omega_h + \Omega_h^2$$

$$a_3 = 2\zeta\Omega_l\Omega_h\left(\Omega_l + \Omega_h\right)$$

$$a_4 = \Omega_l^2\Omega_h^2$$

or in matrix form:

$$\frac{\partial F(x)}{\partial x} = AF(x) + BP(x) \qquad (A1.3)$$

where:

$$F(x) = \begin{bmatrix} F(x) \\ \dfrac{\partial F(x)}{\partial x} \\ \dfrac{\partial^2 F(x)}{\partial x^2} \\ \dfrac{\partial^3 F(x)}{\partial x^3} \end{bmatrix}, \quad A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -a_4 & -a_3 & -a_2 & -a_1 \end{bmatrix}, \text{ and } \quad B = \begin{bmatrix} 0 \\ b_2 \\ -a_1 b_2 \\ (a_1^2 - a_2)b_2 \end{bmatrix}$$

The $F(x)$ matrix is analogous to the array of state variables of the quarter car filter that completely describes the state of the simulated system. A state transition matrix, describing the response of the system over the interval between points i–1 and I, can be used to solve the differential equations for the Butterworth filter. The response is:

$$F_i = SF_{i-1} + PP_i \qquad (A1.4)$$

S and P can be calculated:

$$S = e^{At} \qquad (A1.5)$$

and $P = A^{-1}(S - I)B$ *(A1.6)*

where:

t = time interval between profile samples,

I = 4 by 4 identity matrix.

The calculation of S requires taking e to a matrix power. This may be done through a Taylor series expansion:

$$e^{At} = I + \sum_{i=1}^{N} \frac{A^i t^i}{i!} \qquad (A1.7)$$

where:

N = number large enough to obtain the required accuracy.

To solve differential equations such as Equation A1.3, it is necessary to estimate the values of the state variables at a starting time. To initialize the Butterworth filter, the elements of the F array for I = 1 shall be set as:

$$F_1 = \left[0,\ 0,\ -\Omega_h^2 (p_{L_0/\Delta} - p_1) / L_0,\ 2\zeta\Omega_h^2 (\Omega_h + \Omega_l)(p_{L_0/\Delta} - p_1) / L_0 \right] \qquad (A1.8)$$

where:

$p_{L_0/\Delta}$ = the elevation point that appears at the initialization length,

L_0 = the initialization length,

Δ = the interval between profile samples, and

p_1 = the first profile elevation point.

A2. SPATIAL WEIGHTING OF THE FILTERED SIGNALS

A2.1. A ‘box’ spatial weighting function is applied to the band-pass filter output. Such a function has a value of unity within its boundaries and zero outside of them. The boundaries of this function will be set at the values tabulated in Table A2.1. This weighting function shall be applied after the filter, meaning that the filter response rather than the profile is weighted. The result is that profile features outside the weighting function window can influence the index.

Table A2.1—Weighting Function Boundaries

	Preceding Scale Location	Beyond Scale Location
Short-Range Index	3.0 m [10 ft]	0.3 m [1 ft]
Long-Range Index	25.0 m [82.0 ft]	3.0 m [10 ft]

A3. AVERAGE-RECTIFIED INDEX ACCUMULATION

A3.1. Following the application of a weighting function, individual SRI and LRI values are to be calculated by accumulating over the range of weighting function boundaries.

$$\text{Index} = \left[\frac{1}{N_2 - N_1 + 1} \sum_{i=N_1}^{N_2} abs(F_i \bullet W_i)^P \right]^{1/P} \qquad (A3.1)$$

where:

F = filtered profile,

N_1 = sample number of the first spatial weighting function boundary,

N_2 = sample number of the second spatial weighting function boundary,

W = weighting function, and

P = accumulator exponent (set to 1 for average-rectified accumulation).

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[1] Provisional standard first published in 2005. Revised in 2008.

Standard Practice for

Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods

AASHTO Designation: PP 67-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods

AASHTO Designation: PP 67-10

1. SCOPE

1.1 This practice outlines the procedures for quantifying cracking distress at the network level in asphalt pavement surfaces utilizing automated methods. Detailed specifications are not included for equipment, instruments, or the associated software used to process the images. According to these specifications, any equipment that can be adequately validated to meet the functionality stipulated herein is considered acceptable. The goal is to achieve a significant level of standardization, which will contribute to the production of consistent pavement condition estimates while not unduly limiting innovation.

1.2 The automation level covered by this standard involves minimal human intervention in the process. It is understood that the current level of technology requires significant human review of the automation process to provide Quality Control/Quality Assurance (QC/QA) of the results and to detect and correct outliers. It is anticipated that the required level of human intervention will decline over the next few years.

1.3 Collect the images to be processed according to PP 68.

1.4 Sampling of images from the data collection standard process is acceptable before proceeding with the analysis process in this standard. The data sample is to be large enough to provide the confidence level required by the agency. Sample size and spacing will depend on construction practices and numerous other factors that impact pavement continuity. A 100 percent sample is recommended until a sampling method can be supported by statistical analysis.

1.5 *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*:

- PP 68, Collecting Images of Pavement Surfaces for Distress Detection
- PP 70, Collecting the Transverse Pavement Profile

2.2 *ASTM Standard*:

- E 1656, Standard Guide for Classification of Automated Pavement Condition Survey Equipment

2.3 *Other Standard*:

- *Distress Identification Manual for the Long-Term Pavement Performance Program*, FHWA Report RD-03-031

3. TERMINOLOGY

3.1 *crack*—a fissure of the pavement material at the surface with minimum dimensions of 1-mm (0.04-in.) width and 25-mm (1-in.) length.

3.2 *crack length*—the length is measured between crack termini. If a terminus was created due to reaching the maximum length, a new crack begins at the terminus.

3.3 *crack orientation*—the angular measurement in degrees between the direction of travel and a line drawn between the ends of the crack as measured within the measurement zone of interest.

3.4 *crack position*—the coordinates of the midpoint of the crack measured perpendicular to the shoulder edge of the pavement and the longitudinal location relative to the starting collection point.

3.5 *crack terminus*—the point at which the crack width goes below and remains less than 1 mm (0.04 in.) for a 10-mm (0.4-in.) length, or the intersection with another crack, or when the maximum of 3.67 m (12 ft), is reached or the end of a summary section is reached.

3.6 *crack width*—the average gap in mm between the two edges of a crack measured at points along the gap with a minimum spacing of 3 mm (0.12 in.).

3.7 *inside wheelpath*—a longitudinal strip of pavement 0.75 m (30 in.) wide and centered 0.875 m (34 in.) from the centerline of the lane toward the adjacent lane.

3.8 *longitudinal crack*—a crack at least 0.3 m (12 in.) long and with a crack orientation between +10 and –10 degrees.

3.9 *measurement zone*—one of the five strips of pavement created by the wheelpaths and the areas between and outside the wheelpaths.

3.10 *outside wheelpath*—a longitudinal strip of pavement 0.75 m (30 in.) wide and centered 0.875 m (34 in.) from the centerline of the lane toward the shoulder.

3.11 *pattern crack*—a crack that is part of a network of cracks that form an identifiable grouping of shapes. For this practice, this includes all cracks that are not defined as transverse or longitudinal.

3.12 *summary section*—a portion of a pavement lane over which the data are summarized.

3.13 *transverse crack*—a crack at least 0.3 m (12 in.) long and with a crack orientation between 80 and 100 degrees.

4. SIGNIFICANCE AND USE

4.1 This practice outlines the procedures for quantifying cracking distress at the network level in asphalt pavement surfaces utilizing automated methods.

4.2 The level of development of the current technology requires that the collection and analysis processes be linked together. It is hoped that in the future, a standard set of images may be created by the collection equipment from a “standard pavement distress simulation package” yet to be developed and used to evaluate and control the performance of this method.

5. DATA COLLECTION

5.1 Data are collected according to PP 68.

6. DATA REDUCTION—CRACK DETECTION

6.1 The system that detects the presence of a pavement anomaly that is commonly considered a crack typically involves one or more image analysis software routines.

6.2 It is anticipated that future detection processes may involve the analysis of images of multiple characteristics to improve the reliability of the detection process.

6.3 The detection process is clearly dependent on the quality of the images to be analyzed. Currently, there is no reliable method to independently measure the performance of the collection and analysis processes. The criteria listed herein therefore represent the requirements of the total collection and analysis system. It is anticipated that a reliable method will be developed to independently establish the image quality so that, in the future, each process can be evaluated separately.

6.4 *An acceptable result of this process is a crack map in which at least*:

6.4.1 Thirty percent of the cracks less than 3 mm (0.12 in.) and 50 percent of cracks from 3 mm (0.12 in.) to less than 5 mm (0.2 in.) wide are mapped (see Note 1).

6.4.2 Eighty-five percent of the cracks 5 mm (0.2 in.) or wider are mapped (see Note 1).

6.4.3 A crack is considered mapped if at least 85 percent of its length is detected (see Note 1).

6.4.4 Utilizing images clear of distresses and without discontinuities, or pavement markings, the system should report less than 3 m (10 ft) of total false cracking length in 50 m^2 (540 ft^2) of pavement (see Note 1). The determination of this capability will be made utilizing five 0.1-km (0.06-mi) samples of various pavement types that meet the criteria.

Note 1—These values are the estimates of a panel of experts. Ongoing research and equipment developments will better define these values over the next few years. As capabilities are better defined, separate levels of performance may be established for two or three classes of equipment and software.

7. DATA ANALYSIS—CRACK CLASSIFICATION AND VALUATION

7.1 The summary section distance for cracking data is 0.1 km (0.06 mi).

7.2 Detected pattern cracks (neither longitudinal nor transverse) are separated into five measurement zones across the pavement.

7.2.1 Zone 1 is between the inside wheelpath and the lane edge at the adjacent lane.

7.2.2 Zone 2 is the inside wheelpath.

7.2.3 Zone 3 is the space between the wheelpaths.

7.2.4 Zone 4 is the outside wheelpath.

7.2.5 Zone 5 is between the outside wheelpath and the lane edge at the shoulder.

7.3 *Pattern Cracks Will Be Summarized by*:

7.3.1 The sum of the lengths in meters (feet) of all pattern cracks in the summary section shall be the extent of pattern cracking for each zone within the section.

7.3.2 The average width in millimeters (inches) of all pattern cracks in the summary section shall be the severity of pattern cracking for each zone within the section.

7.4 *Longitudinal Cracks Will Be Summarized by*:

7.4.1 The sum of the lengths in meters (feet) of all longitudinal cracks in the summary section shall be the extent of longitudinal cracking for each zone within the section.

7.4.2 The average width in millimeters (inches) of all longitudinal cracks within the summary section shall be the severity of longitudinal cracking for each zone within the section.

7.5 *Transverse Cracks Will Be Summarized by*:

7.5.1 The sum of the lengths in meters (feet) of all the transverse cracks in the summary section shall be the extent of transverse cracking in each zone within the section.

7.5.2 The average width in millimeters (inches) of all transverse cracks within the summary section shall be the severity of transverse cracking in each zone within the section.

7.6 Detected cracks greater than 25 mm (1 in.) wide may reflect that a narrower crack is present and was sealed. Since current technology cannot separate these conditions, it is recommended that the system flag these occurrences for technician analysis. This analysis can be supported by input from the data collection operator by flagging when crack sealing is present.

8. DATA REPORTING

8.1 The calculated extent of each crack category (Zones 1–5 pattern, Zones 1–5 transverse, and Zones 1–5 longitudinal) in meters (feet) shall be the reported extent value for each category.

8.2 The calculated severity of each category in millimeters (inches) shall be the reported severity value for that category.

Note 2—Therefore, each summary section will have 30 values that characterize the cracking contained therein.

8.3 Each of these values may be first normalized to a scale of 0 to 10 with 10 being the most severe. Those with a value equal to or exceeding the average value of the worst (highest extent and severity values) 10 percent of the historical, agency-wide population for the past 10 years would get a 10 and the remainder values linearly transferred to the normalized scale. The normalized values may then be combined in various ways to provide a reduced data set for reporting (a) more general cracking index(es) for each section at the agency's discretion.

Note 3—In this proposed normalization method, the resulting normalized values would get more sensitive to the amount of distress as the worst 10 percent of the pavements have improved values. An effective distribution is thus maintained over the entire scale but at the expense of sacrificing absolute comparison capability. Since a 10-year average is used and system changes tend to be very slow, the shifting effect will be extremely slow and thus should not affect short-term comparisons. Also, since each system will be normalizing to itself, any attempted comparison between systems would be erroneous.

9. DATA INTERPRETATION

9.1 The agency is free to utilize the reported data as best fits its pavement management needs.

9.2 Any increase in the extent and severity of cracking in Zones 2 and 4 above that in Zone 3 is expected to typically reflect the impact of traffic loading.

9.3 Agencies are alerted that dividing the scalar extent and severity values into level categories or bins can result in erratic results. When values are near the bin limits, natural variation in the data will cause dramatic shifts in results. Such converting can be useful, however, for general comparison to previously collected data in which bin limits were used.

10. SYSTEM VALIDATION

10.1 The process of calibrating and checking the performance of the crack detection and analysis process is left to the agency. Generally, the agency should follow the manufacturer's recommendations for calibrating and verifying the performance of the process. The following considerations should be included in any program.

10.2 The interrelationship between the supplied images and the performance of the processing system is evident.

10.3 A standard set of images from the collection equipment should be created that challenge the processes with the full range of crack types, extents, and severity. The ground truth for these images is to be determined by manually surveying 100 percent of the pavement sections themselves (not their images). Manual examination of the images should only be used as a diagnostic if unsatisfactory results are obtained. These standard images can be used repeatedly until the collection process is modified, necessitating the collection of a new set.

10.4 The standard images created according to Section 10.3 should be used to verify performance of the detection and analysis processes on a routine basis. The frequency depends on the system's past performance and the risk associated with having to reprocess all data since the last check, should a failure occur.

10.5 Generally, performance can be divided into two sections: the ability to create an acceptable crack map, and the ability to properly analyze the created map.

10.6 The ability to create an acceptable map is considered the most challenging and therefore should be checked most frequently. The results of the analysis portion should correlate with trained observers reviewing the images better than 95 percent.

11. VALIDATION/ACCEPTANCE REPORT

11.1 The detection performance report should present, in tabular form, the ground truth values and the values that the automated detection process derived for each severity category listed in Section 6.4 with the percent of success. It should also report the length of false cracks detected per each 50 m^2 (540 ft^2) of pavement.

11.2 The analysis performance report should compare the values in each crack reporting category with the values derived by trained observers utilizing the crack map generated by the automated detection process. The test sections should be the same ones used for the verification of the analysis process.

12. CHECKING THE PERFORMANCE

12.1 A recommended check of the performance of the entire crack collection, detection, and analysis process is to routinely process the data from one or more validation sites. The validation sites should represent most of the data collection variables that the system is expected to encounter during routine data collection. Results are then compared for reasonableness with previous runs. A typical implementation of this process would involve 5 km (3 mi) of collected data and be performed monthly.

13. KEYWORDS

13.1 Asphalt pavement surface; automated data collection; pavement cracking distress; pavement images; pavement management.

Standard Practice for

Collecting Images of Pavement Surfaces for Distress Detection

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Standard Practice for

Collecting Images of Pavement Surfaces for Distress Detection

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1. SCOPE

1.1 This practice outlines the procedures for collecting images of pavement surfaces utilizing automated methods for the purpose of distress detection for both network- and project-level analysis. Detailed specifications are not included for equipment or instruments used to collect the images. According to this standard, any equipment that can be adequately validated to meet the functionality stipulated herein is considered acceptable. The goal is to achieve a significant level of standardization that will contribute to the production of consistent pavement condition estimates while not unduly limiting innovation.

1.2 The images are to be collected utilizing a platform traveling at or near the prevailing highway speed.

1.3 The data collected should cover the entire driven lane in the travel direction.

1.4 *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- PP 67, Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods

2.2 *ASTM Standard*:

- E 1656, Standard Guide for Classification of Automated Pavement Condition Survey Equipment

2.3 *Other Standard*:

- *Distress Identification Manual for the Long-Term Pavement Performance Program*, FHWA Report RD-03-031

3. TERMINOLOGY

3.1 *crack*—a fissure of the pavement material at the surface with minimum dimensions of 1 mm (0.04 in.) width and 25 mm (1 in.) length.

3.2 *crack width*—the average gap in millimeters (inches) between the two edges of a crack measured at points along the gap with a minimum spacing between the measurement points of 4 mm (0.16 in.).

3.3 *pavement distress*—external indications of pavement defects or deterioration.

3.4 *pavement image*—a presentation of the pavement that describes a characteristic (gray scale, color, temperature, elevation, etc.) of a matrix of points (pixels) on the pavement.

4. SIGNIFICANCE AND USE

4.1 This practice outlines the procedures for collecting images of pavement surfaces utilizing automated methods for the purpose of distress detection. Its purpose is to produce consistent data collection.

4.2 It is recognized that the requirements for the collected image(s) listed below are linked to the capability of the associated distress detection system. This linkage is seen as necessary due to the current immaturity of the technology. It is hoped that future developments will provide for a more objective method of measuring performance that is independent of the detection system and easier to implement. There are methods to determine certain limited aspects of the collection processes such as the ability to collect images of 1-, 2-, 4-, 7-, and 10-mm (0.04-, 0.08-, 0.16-, 0.28-, and 0.4-in.) diameter rods placed on the pavement at various angles and positions. These processes can be particularly helpful in determining whether there have been any major changes in equipment performance.

5. DATA COLLECTION

5.1 *General Guidelines*—Each agency shall designate the lane(s) and direction(s) of travel to be surveyed or rated based on sound engineering principles and management needs within the agency. The following guidelines are recommended as minimums to provide a necessary database and for long-term uniformity.

5.2 *Survey*:

5.2.1 Reported images at least 4.0 m (13 ft) wide. Preferably, the images should be 4.25 m (14 ft) wide to include an additional 250 mm (10 in.) on the shoulder side so that pavement edge distress beyond the marking can be captured. Typically, vehicle wander requires that images at least 300 mm (12 in.) wider than the required image width be collected in order to report full width data. Data beyond the required image width may be discarded.

5.2.2 Image length in the travel direction shall be not greater than 100 m (325 ft).

5.2.3 The lanes for which the data are collected will depend on final use. Typically, network data are collected in the outside travel lane, and project-level collection covers all lanes.

5.2.4 For network data collection, it is desirable to collect the data in the same travel direction on each cycle.

5.3 *Pavement Image*:

5.3.1 The images must provide sufficient difference among data points representing distressed and nondistressed areas that subsequent distress detection techniques can delineate a minimum of 30 percent of all cracks under 3 mm (0.12 in.), 50 percent of all cracks present from 3 mm (0.12 in.) and under 5 mm (0.2 in.) wide and 85 percent of all cracks 5 mm (0.2 in.) wide or wider regardless of orientation or type (see Note 1). The determination of this capability will be made utilizing five 0.1 km (0.06 mi) samples containing an average of at least ten such cracks per sample.

5.3.2 The images should be sufficiently clear of erroneous differences in data points that a section of pavement without distress, discontinuities, or pavement markings that less than 3 m (10 ft) of total false cracking length is detected in 50 m^2 (540 ft^2) of pavement (see Note 1). The determination of this capability will be made utilizing five 0.1 km (0.06 mi) samples of various types that meet the criteria.

Note 1—These values are the estimates of a panel of experts. Ongoing research and equipment developments will better define these values over the next few years. As capabilities are better defined, separate levels of performance may be established for two or three classes of equipment.

5.3.3 Detected average crack width for each crack detected in Section 5.3.2 must be within 20 percent or 1 mm (0.04 in.), whichever is larger, of the actual width with at least 85 percent confidence.

5.3.4 Pavement images may be visible or infrared video that is either illuminated or passive. It may also be a dimensional map, or any combination of technologies that achieves sufficient distress detection reliability stated in Section 5.3.

6. DATA REPORTING

6.1 The location (latitude and longitude) of the first shoulder side data point of each image should be reported as a minimum, along with a unique image identifier.

6.2 The image scale should be equal in both directions and the value reported.

6.3 Other useful comment data that can affect image analysis, such as the presence of crack seal, railroad tracks, or excessive pavement marking, should be reported with the image.

7. SYSTEM VALIDATION

7.1 The process of calibrating and checking the performance of the measurement equipment is left to the agency. Generally, the agency should follow the manufacturer's recommendations for calibrating and verifying the performance of the equipment. The following considerations should be included in any program.

7.1.1 Location accuracy:

7.1.1.1 Distance measuring instrument accuracy;

7.1.1.2 Latitude–longitude accuracy.

7.1.2 Crack width and length in all orientations.

7.1.3 Crack delineation (sensitivity to the characteristic(s) that define(s) a fissure).

7.1.4 Minimum resolution vs. delineation level.

7.1.5 Minimum resolution vs. crack angle.

7.1.6 System platform stability and environmental impacts (moisture/wind/temperature):

7.1.6.1 Performance at various sun angles and intensities;

7.1.6.2 Performance at various speeds;

7.1.6.3 Performance at various vehicle attitudes and distances relative to the pavement;

7.1.6.4 Performance at various humidity and temperature levels;

7.1.6.5 Performance at different wind conditions;

7.1.6.6 Performance under various lighting conditions;

7.1.6.7 Resolution versus position of cracks due to optical distortion.

7.2 Ground truth for system calibration and verification shall be the close physical examination of the pavement surface by trained technicians with measurement instruments during a lane closure.

7.3 *Validation/Acceptance Report*:

7.3.1 The ground truth report is a crack map depicting each crack in the section and its unique identifier. Included with the map is a table listing the crack identifiers along with the location, length, and average width of each crack in each summary section.

7.3.2 The validation report will tabulate the cracks from the ground truth report into severity categories based on average width and present a comparison to those detected by the automated system in each category. It will also present the length of false cracking reported by the automated system.

7.4 The operator and driver (optional) are critical components of the total measurement system. They must be trained in equipment operation, including instrument failure detection and system management. Smooth, precise operation of the instrument platform is necessary for optimum results.

7.5 *Quality Control/Quality Assurance (QC/QA)*:

7.5.1 The formal calibration and performance verification program may be supplemented with a validation program in which the equipment traverses defined portion(s) of pavement on a regular basis. The validation site should represent most of the data collection variables that the system is expected to encounter during routine data collection. Results are then compared for reasonableness with previous runs. A typical implementation of this process would involve 5 km (3 mi) of data collection and be performed monthly.

8. KEYWORDS

8.1 Asphalt pavement surface; automated data collection; pavement distress; pavement images; pavement management.

Standard Practice for

Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles

AASHTO Designation: PP 69-10

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Standard Practice for

Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles

AASHTO Designation: PP 69-10

1. SCOPE

1.1 This practice outlines a method for deriving pavement deformation parameters such as rut depth and cross-slope in pavement surfaces utilizing a transverse profile. Detailed specifications are not included for equipment or software used to make the calculations. According to this standard, any approach that can be adequately validated to meet the functionality stipulated herein is considered acceptable. The goal is to achieve a significant level of standardization that will contribute to the production of consistent pavement condition estimates without unduly restricting innovative methods.

1.2 The data will typically be processed utilizing a collection of algorithms in a computer.

1.3 *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCE DOCUMENTS

2.1 *AASHTO Standard*:

- PP 70, Collecting the Transverse Pavement Profile

2.2 *ASTM Standard*:

- E 1656, Standard Guide for Classification of Automated Pavement Condition Survey Equipment

2.3 *Other Standard*:

- *Distress Identification Manual for the Long-Term Pavement Performance Program*, FHWA Report RD-03-031

3. TERMINOLOGY

3.1 *Cross-slope*—the average transverse slope of the pavement surface expressed in percent.

3.2 *inside wheelpath*—a longitudinal strip of pavement 0.75 m (30 in.) wide and centered 0.875 m (35 in.) from the centerline of the lane toward the adjacent lane.

3.3 *lane*—the traveled surface between the inside edges of the pavement markings or, in the absence of markings, an equivalent portion of the pavement surface.

3.4 *outside wheelpath*—a longitudinal strip of pavement 0.75 m (30 in.) wide and centered 0.875 m (35 in.) from the centerline of the lane toward the shoulder.

3.5 *percent deformation*—the difference between the straight-line length and the profile length of a section of pavement divided by the straight-line length multiplied by 100.

3.6 *rut*—a broad longitudinal depression in the wheelpath of the pavement surface with a depth of at least 2 mm (0.080 in.), a width of at least 0.3 m (1.0 ft), and with a longitudinal length of at least 30 m (100 ft).

3.7 *summary section*—a longitudinal length of a pavement lane over which the data are summarized.

3.8 *transverse profile*—the vertical deviations of the pavement surface from a horizontal reference perpendicular to the lane direction.

3.9 *lane center*—a location halfway between the inside edges of the pavement edge markings. If no markings are present, a location 20 percent of the total pavement width from the pavement middle on two-lane roads and a location at the middle of the road on one-lane roads.

4. SIGNIFICANCE AND USE

4.1 The method outlines a set of procedures to calculate several measures of pavement deformation related to the transverse profile. The adoption of these procedures will help produce consistent data for pavement analysis.

4.2 This method reflects a balance between extreme calculation complexity and resultant accuracy. It is not expected to give the correct values for each individual deformation condition but to provide data that, taken in aggregate, will provide an accurate picture of the deformation involved. Likewise, there will be unusual transverse contours that will not calculate correctly. It is expected, however, that their occurrence will be minimal.

5. DATA COLLECTION

5.1 Typically, the transverse profile is to be collected according to PP 70. Other collection protocols may be followed if the data requirements of PP 70 are met or exceeded.

6. DATA REDUCTION

6.1 All calculations are made for each transverse profile reported. For network-level data, the processed profiles should not be more than 3 m (10 ft) apart and for project level, no farther apart than 0.5 m (1.5 ft).

6.2 The raw transverse profile data should be processed to first remove outlier values, and then to smooth the data. An example of smoothing involves the application of an approximately 50-mm (2-in.) moving average filter. The resultant profile is used for all subsequent calculations.

6.3 A system should be established to determine the lane location and width within each profile and correlate this information with the profile data.

6.4 *Establish the Cross-Slope*:

6.4.1 Utilizing the lane width and location from Section 6.3, determine the middle of the lane and locate the associated middle data point in the profile.

6.4.2 Determine the average elevation for each half lane.

6.4.3 The percent cross-slope is the difference in the average elevations divided by one-half the lane width multiplied by 100.

6.5 *Calculate Percent Deformations*:

6.5.1 Establish edge-points for the portion of the profile under consideration (see Section 3.3) by averaging the three closest elevation points and calculate the straight-line distance between them.

6.5.2 Add the section length of all the segments between the two edge points to approximate the profile length.

6.5.3 Subtract the straight-line length from the profile length and divide the result by the straight-line length and multiply by 100.

6.5.4 Potentially useful deformation portions for reporting would be: total lane, inside half, outside half, and middle third.

6.5.5 Deformation criteria can be used to select profiles for more detailed analysis, such as water entrapment or cross-sectional area.

6.6 *Determine Five Key Data Zones in the Lane*:

6.6.1 Define the lane edge utilizing lane pavement marks, construction history, or other means, if not already defined during collection.

6.6.2 Locate and determine values at five spots across the lane.

6.6.2.1 *Spot 1 is the lane center elevation*—Its elevation is the average of the elevation data points measured in the center 75 mm (3 in.) of the pavement lane. Its location is the center of the lane.

6.6.2.2 *Spot 2 is the inside wheelpath elevation*—Its elevation is the average of the elevation data points in the lowest 10 percent of the inside wheelpath. Its location is the midpoint of the selected points.

6.6.2.3 *Spot 3 is the inside edge elevation*—Its elevation is the average of the elevation data points within 100 mm (4 in.) of the inside pavement edge. Its location is 50 mm (2 in.) from the inside lane edge.

6.6.2.4 *Spot 4 is the outside wheelpath elevation*—Its elevation is the average of the elevation data points in the lowest 10 percent of the wheelpath. Its location is the midpoint of the selected points.

6.6.2.5 *Spot 5 is the shoulder elevation*—Its elevation is the average of the elevation data points within 100 mm (4 in.) of the outside pavement edge. Its location is 50 mm (2 in.) from the outside pavement edge.

6.7 *Calculate Rut Depth*:

6.7.1 Convert the percent cross-slope to an angle.

6.7.2 Rotate the profile about spot 3 by the angle above, thus leveling the profile.

6.7.3 Shift the profile so that the value of spot 3 is zero.

6.7.4 Proceed to center depression rut depth calculation if the value of spot 1 is more than 5 mm (0.2 in.) below the average of spots 2 and 4.

6.7.5 Normal rut depth calculation:

6.7.5.1 Rotate the profile about spot 3 until spot 1 is 0. The revised absolute value of spot 2 is the depth of the inside rut.

6.7.5.2 Rotate the lane half between spots 1 and 5 about spot 1 until spot 5 is zero. The revised absolute value of spot 4 is the depth of the outside rut.

6.7.6 Center depression rut depth calculation:

6.7.6.1 Rotate the profile about spot 3 until spot 5 is zero. The revised absolute value of spot 1 is the depth of the center depression.

6.8 *Calculate Rut Cross-Sectional Area*:

6.8.1 After completing the step in Section 6.7.5.1, scan the profile in both directions from spot 2 until three values equal to or greater than zero are reached, and record the location of the first one encountered in each direction. These locations are the rut edges.

6.8.2 The area can be approximated by adding all the elevation values between the edges and multiplying the sum by the data point interval.

6.8.3 Repeat the same process around spot 4 after completing the step in Section 6.7.5.2.

6.8.4 For center depressed pavements, the same process can be applied around spot 1.

6.9 *Calculate Water Entrapment Depth*:

6.9.1 Further smooth the profile with a 200-mm (8-in.) moving average filter.

6.9.2 For positive cross-slope (spot 5 filtered elevation less than spot 3) and zero cross slopes, scan the profile from spot 3 toward spot 5 for locations in which a filtered elevation is not equal to or at a lower filtered elevation than any previous filtered elevation plus 2 mm (0.08 in.).

6.9.3 Should such a point be encountered, continue scanning until three sequential filtered elevations that are lower than their predecessor are encountered. Take the filtered elevation at the highest point of the three (the lip) and subtract the lowest filtered elevation previously encountered. The difference is the water entrapment depth of the discovered depression. The location of the lowest point should also be recorded.

6.9.4 Beginning at the lip found in Section 6.9.3, continue scanning until the profile is completed. (It is quite likely to have multiple water entrapment depths encountered.) They can be sorted by location to determine their relationship to the wheelpaths.

6.9.5 For negative cross slopes (spot 3 filtered elevation less than spot 5), the profiles are scanned from spot 5 toward spot 3 in a similar fashion.

7. DATA REPORTING

7.1 *For network collection, each summary section shall be 10 m (33 ft) and have reported*:

7.1.1 The average cross-slope percentage;

7.1.2 The average rut depth for each wheelpath (normal or center) in millimeters (inches);

7.1.3 The maximum rut depth for each wheelpath in millimeters (inches).

7.2 For project level activity, each summary section shall be 2 m (7 ft) and have reported:

7.2.1 The items in Section 7.1 over the shorter summary section of the project level collection;

7.2.2 The water entrapment depth for each third of the lane width averaged over the profiles in the section; and

7.2.3 Average rut cross sectional area in square meters (square feet).

8. DATA INTERPRETATION

8.1 The agency is free to utilize the reported data as best fits its pavement management needs.

8.2 Agencies are alerted that dividing the scalar depth and percentage indexes into level categories or bins can result in erratic results. When values are near the bin limits, natural variation in the data will cause dramatic shifts in results. Such converting can be useful, however, for general comparison to previously collected data in which bin limits were used.

9. SYSTEM VALIDATION

9.1 The process of checking the performance of the analysis process is left to the agency. Generally, the agency should follow the manufacturer's recommendations for verifying its performance. The following considerations should be included in any program.

9.1.1 Multiple transverse profiles that reflect the conditions encountered in the real data collection world. These should include the profiles collected as part of the equipment verification process.

9.1.2 It is planned that a standard set of profiles will eventually be developed to verify the performance and highlight the limitations of the processing method.

10. KEYWORDS

10.1 Asphalt pavement surface; automated data collection; cross-slope; pavement management; rut.

Standard Practice for

Collecting the Transverse Pavement Profile

AASHTO Designation: PP 70-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Collecting the Transverse Pavement Profile

AASHTO Designation: PP 70-10

1. SCOPE

1.1 This practice outlines a method for collecting pavement transverse profile, including its relationship to a level horizontal reference in pavement surfaces utilizing automated measurement devices. The profile can subsequently be used to quantify cross-slope and pavement distresses such as transverse deformation, rut characteristics, water entrapment, or edge drop-off. Detailed specifications are not included for equipment or instruments used to make the measurements. Equipment that can be adequately validated to meet the functionality stipulated herein is considered acceptable. The goal is to achieve a standardized data set that supports a wide variety of interpretation methods to characterize pavement transverse profile characteristics to capture properties of engineering significance, without unduly restricting innovative methods.

1.2 This standard addresses data collection utilizing a measurement device traveling at or near the posted speed limit.

1.3 *This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standard*:

- PP 69, Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles

2.2 *ASTM Standard*:

- E 1656, Standard Guide for Classification of Automated Pavement Condition Survey Equipment

2.3 *Other Standard*:

- *Distress Identification Manual for the Long-Term Pavement Performance Program*, FHWA Report RD-03-031

3. TERMINOLOGY

3.1 *report interval*—the travel distance between the reported data.

3.2 *transverse profile*—vertical deviations of the pavement surface from a level horizontal reference perpendicular to the lane direction of travel.

3.3 *transverse measurement width*—distance between the first and last measurement point in the transverse profile.

3.4 *vertical measurement resolution*—the smallest distance of measurement in the vertical axis stored by the measure device.

3.5 *vertical measurement accuracy*—the difference between the vertical distance reported by the measuring device and a standard reference measurement.

4. SIGNIFICANCE AND USE

4.1 This standard provides guidelines for collecting transverse pavement profile for the subsequent extraction of selected pavement characteristics such as rut, cross-slope, deformation, and edge drop-off.

4.2 Two data reporting intervals are to be selected based on the level of detail required in the subsequent analysis. The longer interval is typical of network data collection while the shorter is more often related to project-level data acquisition.

5. DATA COLLECTION

5.1 *General Guidelines*—Each agency shall designate the lane(s) and direction(s) of travel to be surveyed or rated based on sound engineering principles and management needs within the agency. The following guidelines are recommended as minimums to provide a necessary database and for long-term uniformity.

5.2 The report interval between collected transverse profiles should not exceed 3.0 m (10 ft) for network-level collection and 0.5 m (1.5 ft) for project-level collection.

5.3 For network-level collection, at least one direction should be surveyed on undivided roads and both directions on divided highways. On undivided roads, measurements on the side carrying the heaviest truck loads are desired, when this knowledge is available in advance of the survey.

5.4 It is desirable to survey the same direction of travel and the same lane during subsequent survey cycles.

5.5 The transverse profile shall have a minimum width of 4.0 m (13 ft) for detecting distresses in the lane (between the longitudinal lane markings, when present) and 4.3 m (14 ft) if interpretation of edge drop-off is desired. The extra width should be on the shoulder side of the lane, beyond the edge marking. These widths include 400 mm (16 in.) beyond the normal requirements to account for vehicle wander. Data measured outside the location of interest may be discarded before reporting if a lane identification algorithm is employed at the collection stage.

6. DATA REQUIREMENTS

6.1 The transverse profile shall have data points with separation of less than or equal to 10 mm (0.4 in.).

6.2 Vertical measurement resolution shall be less than or equal to 1 mm (0.04 in.).

6.3 *Vertical measurement accuracy shall be less than or equal to*:

6.3.1 3 mm (0.12 in.) relative to the average elevation of that same profile;

6.3.2 5 mm (0.20 in.) relative to true level horizontal reference.

6.4 The profile shall be measured along a transverse line that deviates less than 10 degrees perpendicular to the lane centerline.

7. SYSTEM VALIDATION

7.1 The process of calibrating and checking the performance of the measurement equipment is the responsibility of the agency. Agencies should evaluate and confirm the manufacturer's recommendations for calibrating and verifying the performance of the equipment relative to their intended data use.

7.2 *Measurement System Elements to Be Validated*—The following elements of the measurement system should be validated:

7.2.1 Distance measuring instrument accuracy.

7.2.2 Data point spacing.

7.2.3 Transverse measurement width.

7.2.4 Vertical measurement resolution and accuracy relative to the vehicle.

7.2.5 Vertical measurement accuracy relative to a level horizontal reference.

7.2.6 Effect of operational and environmental variables, including:

7.2.6.1 Sun angle, intensities, shadows, temperature, and precipitation on the pavement surface; and

7.2.6.2 Measurement speed variability.

7.2.7 Pavement cross-slope, vertical grade, roughness, and horizontal curvature.

7.3 Validation reference for certification is manual measurements of surveyed lane sections made by trained technicians on suitable test sections designated by the agency. Multiple 3-m (10-ft) long test sample interval sections should be employed. One manual reference transverse profile measurement is performed in each test sample interval. The manual transverse measurement interval should not exceed 25 mm (1 in.). The test sample sections should be as uniform as possible along their length to reduce differences in exact measurement location. The longitudinal measurement interval of the manual reference transverse profiles should not be more than 150 mm (6 in.). Artificially manufactured artifacts with known dimensions, such as steel plates or wires, placed through the length of the test sections, may be used to assess system resolution and accuracy. All validation reference values must be measured to a true level reference. The variability in the reference measurement process needs to be assessed. When possible, at least three repeat manual reference transverse profile measurements should be performed on at least three test sections.

7.4 *Validation/Acceptance Report*:

7.4.1 The validation reference report will include assessments from multiple transverse elevation profiles.

7.4.2 The acceptance report should tabulate the data from at least five equipment runs and the validation reference values. It should also include the results from the resolution tests performed in at least four locations across the pavement.

7.4.3 The effects of operational and environmental variables investigated in the validation.

7.5 The operator and driver are critical components of the total measurement system. They must be trained in equipment operation including instrument failure detection and system management. Smooth, precise operation of the instrument platform is necessary for optimum results.

7.6 The formal validation and performance measurements should be supplemented with a routine operational check program in which the equipment measures a standard set of test sections on a regular basis. The check sites should be representative of the pavement system being measured. Time series analyses are used to check for changes in the measurement system not caused by changes in the road being measured. A typical implementation of this system check process would involve monthly measurements on a defined set of sections where the agency has knowledge of maintenance, construction, or other activities that could change the transverse profile of the test sections.

8. KEYWORDS

8.1 Automated pavement data collection; pavement cross-slope; pavement distress; pavement edge drop-off; pavement evaluation; pavement management; pavement monitoring; pavement surface; pavement transverse profile; rut; rutting.

Standard Method of Test for

Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method

AASHTO Designation: TP 76-10

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Method of Test for

Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method

AASHTO Designation: TP 76-10

1. SCOPE

1.1. This test method describes the procedures for measuring tire/pavement noise using the on-board sound intensity (OBSI) method and the procedures for verification of the measurement system. The test method provides an objective measure of the acoustic power per unit area at points near the tire/pavement interface.

1.2. The OBSI measurement method described herein permits the tire/pavement sound intensity to be measured directly and allows various pavements and textures to be directly compared.

1.3. This method is expected to be subject to revision as experience increases and research results are implemented.

1.4. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *ASTM Standards*:

- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- F 2493, Standard Specification for P225/60R16 97S Radial Standard Reference Test Tire

2.2. *ANSI Standards*:

- S1.9, Instruments for the Measurement of Sound Intensity
- S1.11, Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters
- S1.40, American National Standard Specifications and Verification Procedures for Sound Calibrators
- S1.42, American National Standard Design Response of Weighting Networks for Acoustical Measurements

2.3. *IEC Standards*:

- IEC 60942, Electroacoustics—Sound Calibrators
- IEC 61043, Electroacoustics—Instruments for the Measurement of Sound Intensity—Measurement with Pairs of Pressure Sensing Microphones
- IEC 61260, Electroacoustics—Octave-Band and Fractional-Octave-Band Filters
- IEC 61672, Electroacoustics—Sound Level Meters

3. TERMINOLOGY

3.1. *on-board sound intensity (OBSI) method*—a measurement procedure to evaluate the tire/pavement noise component resulting from the interaction of an ASTM F 2493 Standard Reference Test Tire (SRTT) on a pavement surface. Sound intensity measurements are taken at defined locations near the tire/pavement interface.

3.2. *overall sound intensity level*—the A-weighted level corresponding to the sum of broadband sound intensity within the one-third octave band ranges from 400 to 5000 Hz in dB(A) with a reference value of 1×10^{-12} W/m^2. A-weighting shall conform to ANSI S1.42.

3.3. *power train noise*—the noise from the power train, including the vehicle engine, exhaust system, air intake, fans, transmission, differential, and axles.

3.4. *pressure-intensity index (PI index)*—defined by the arithmetic average of the sound pressure levels (SPL) of both microphones on the probe minus the sound intensity level, as given by the following equation:

$$PI = SPL_{\mathrm{Avg}} - SIL$$

3.5. *run*—a single measurement traverse of a test section.

3.6. *sound intensity*—the acoustic energy flowing through a unit area in a sound field in W/m^2. As such, it is a vector quantity with an associated direction of propagation.

3.7. *sound intensity level (SIL)*—the logarithmic time average of the sound intensity in dB with a reference sound intensity of 1×10^{-12} W/m^2.

3.8. *sound pressure level (SPL)*—the logarithmic time average of the sound intensity in dB with a reference sound pressure of 20 µPa.

3.9. *standard reference test tire (SRTT)*—as defined in ASTM F 2493.

3.10. *system*—for this standard, refers to the entire system used to measure the sound intensity using the on-board method. This equipment includes the matched microphone pairs, preamplifiers, cables, sound analyzers, probe holders, and associated items mounted on the test vehicle or test trailer.

3.11. *test section*—a given length of pavement over which a sound intensity measurement is made.

3.12. *tire/pavement noise*—the sound generated by the interaction of the tire with the pavement surface as it traverses a specific length of pavement.

3.13. *traffic noise*—the overall noise emitted by the vehicles running over the road being evaluated.

3.14. *vehicle noise*—the total noise from a vehicle, including a combination of noise generated by tire/road interaction (tire/pavement noise), air turbulence, and the power train.

4. SIGNIFICANCE AND USE

4.1. This test method provides an objective measure for on-board determination of sound intensity at defined points near the tire/pavement interface to quantify the noise generated at the tire/pavement interface and the acoustical performance of pavements.

4.2. This test method should not be used to replace the pass-by (wayside) method for determination of vehicle noise.

4.3. The frequency analysis of the measured sound intensity is performed using one-third octave band resolution. During measurements, the frequency range of 200 to 10 000 Hz (center frequencies of one-third octave bands) is typically included. One-third octave bands with center frequencies of 400 to 5000 Hz consistently provide repeatable results. The one-third octave band filters should conform to ANSI S1.11. Directly measured or derived A-weighted values shall be described in the report.

5. GENERAL REQUIREMENTS

5.1. This test method measures the sound intensity emitted in close proximity to the SRTT. A-weighted SILs are reported in one-third octave frequency bands along with the overall SIL.

5.2. One-third octave band levels shall be measured and reported for standardized speeds depending upon the facility type. Equipment that is used for these measurements is described in Annex A4.

6. SELECTION OF TEST SECTION

6.1. A test section shall have the same nominal material and surfacing for its length. During testing, the test tire must be positioned such that it travels entirely on the test surface. The test section shall be dry and free of debris to the extent practical.

6.2. The test section should be a tangent (straight) section of the roadway. Horizontal curves should be avoided when possible. Roadway geometry and approximate grade shall be noted.

6.3. The condition of the road should be documented and pictures included of the typical surface when possible. It is recommended that historical data of the roadway surface, if available, be provided.

6.4. Test sections should be located away from large roadside objects within 2 ft (0.6 m) of the edge of pavement. If measurements must be made with an object(s) nearby, the location of the object(s) should be documented.

7. MEASURING PROCEDURE

7.1. *Measurement Locations*—Measurements shall be made alongside the leading edge and trailing edge of the SRTT contact patch on the passenger (right-side) wheel path (see Annex A5 and Figure A5.1). Figure A5.1 includes the specified locations for the microphone probes during measurement. If measurements are taken at both the leading and trailing edge locations in the same test run, care should be taken to reduce turbulence wake effects from causing a measurable bias in the data.

7.2. *Verification*—At the beginning of the test, and following all warm-up procedures specified by the manufacturer, the overall accuracy of the sound level measurement system (including the microphones) shall be checked and recorded using an acoustic calibrator or piston phone.

7.2.1. At a minimum, verification shall be conducted no more than 1 hour before and no more than 1 hour after the measurement period. Additional verification shall be conducted during the course of the measurements so that the maximum period between verification checks does not exceed 4 hours.

7.2.2. The measurement system shall be adjusted for accuracy according to the manufacturer's instructions. The results of all measurement system accuracy checks shall be recorded in the test report. If the results of any two subsequent verification checks during the measurement period differ by more than 0.5 dB, the testing between those checks shall be considered invalid.

7.2.3. The sound calibration device shall meet Class 1 requirements of ANSI S1.40. (Note that some calibrators require correction for environmental conditions. The manufacturer's specifications should be consulted.) The microphones and calibrator shall be calibrated in accordance with the manufacturer's specifications and ANSI S1.9 and S1.40, respectively.

7.3. *Measurement Period and Averaging*—The measurement defining a test section shall be an energy average over 440 ± 10 ft (134 ± 3 m) of pavement surface. Based on the nominal test speed, the following are the test durations that shall be used to approximately correspond to this distance:

■	60 mph (96 km/h)	5.0 ± 0.1 s
■	45 mph (72 km/h)	6.7 ± 0.1 s
■	35 mph (56 km/h)	8.6 ± 0.2 s
■	25 mph (40 km/h)	12.0 ± 0.2 s

The signals shall be A-weighted prior to digitization in order to prevent overload of the recording system. If a single probe is used, SILs from multiple runs shall be arithmetically averaged for the leading and trailing edges separately. The leading and trailing edge averages shall then be averaged on an energy basis. If dual probes are used, the SILs of two probes shall be energy averaged for each run. The averages for all runs shall then be averaged together arithmetically.

7.4. *Number of Runs*—At a minimum, two runs shall be performed per probe position. If any criterion below is not satisfied with the first two runs, additional runs are required until the criterion is satisfied.

7.4.1. The standard deviation of the overall SILs between the first two runs shall be no greater than 0.6 dB(A). If needed, additional runs shall be conducted until the standard deviation of the overall SIL is no more than 0.6 dB(A).

7.4.2. The standard deviation of the SIL between the first two runs within any one-third octave band with a center frequency between 400 and 5000 Hz shall be no greater than 1.2 dB(A). If needed, additional runs shall be conducted until the standard deviation of the SIL within each one-third octave band level with a center frequency between 400 and 5000 Hz is no more than 1.2 dB(A).

7.4.3. The PI index shall be less than 5 dB in each one-third octave band with a center frequency between 400 and 5000 Hz. Any run in which this criterion is not satisfied shall be rejected and not used in any averages of the runs.

7.4.4. The direction of the sound intensity vector (sound power flow per unit area) must be positive (sound energy propagating away from the tire) for each one-third octave band with a center frequency between 400 and 5000 Hz. Any run in which this criterion is not satisfied shall be rejected and not used in any averages of the runs.

7.4.5. The coherence of sound pressure between the two microphones of the sound intensity probe shall be equal to or greater than 0.8 for each one-third octave band with a center frequency between 400 and 4000 Hz. Any run in which this criterion is not satisfied shall be rejected and not used in any averages of the runs.

7.5. *Recording Data*—The sound should be recorded for later analysis. Recording instrumentation shall meet Class 1 requirements of ANSI S1.9.

7.6. *Compromised Data*—Data from measurements that are obviously influenced by any other source or that were recorded improperly shall be discarded.

7.7. *Air Density Parameter*—Measures shall be taken to accommodate the actual air density during measurement as part of the fundamental sound intensity calculation. Ideally, the manufacturer's documentation should be consulted for how to include this parameter. Alternatively, the sound intensity values can be measured with an assumed/programmed air density of 0.0755 lb/ft^3 (1.21 kg/m^3). A manual correction can then subsequently be made to the levels as follows:

$$\text{SIL Corrected (dB)} = \text{SIL Measured (dB)} + 10 \times [\text{Log}_{10}\,(0.0755\ \text{lb/ ft}^3) - \text{Log}_{10}\,(\text{actual air density during measurement in lb/ft}^3)]$$

$$(\text{SIL Corrected (dB)} = \text{SIL Measured (dB)} + 10 \times [\text{Log}_{10}\,(1.21\ \text{kg/m}^3) - \text{Log}_{10}\,(\text{actual air density during measurement in kg/m}^3)])$$

If not measured directly, air density can be estimated using measurements of ambient air temperature and barometric pressure.

7.8. *Reporting Results*—Measured SILs shall be reported to the nearest 0.1 dB(A).

7.9. *Frequency Spectrum Measurement*—Reporting shall be done in one-third octave band frequency spectra according to ANSI S1.11.

7.10. *Test Vehicle Operating Conditions*:

7.10.1. *Test Speed Variation*—During the test, the vehicle shall travel with constant speed [±1 mph (±1.6 km/h)] over the test section in an appropriate gear setting.

7.10.2. *Standard Speed*—60 mph (96 km/h) shall be used unless conditions do not permit. If a speed other than 60 mph (96 km/h) is used, it shall be clearly designated in the reporting of all SILs. Acceptable alternative measurement speeds include 45, 35, and 25 mph (72, 56, and 40 km/h, respectively).

7.10.3. *Tested Speed*—For each test, the speed shall be measured with any instrument that provides the required accuracy of ±1 mph (±1.6 km/h).

7.10.4. *Tire Inflation*—Cold tires should be inflated to 30 ± 2 psi (207 ± 14 kPa).

7.10.5. *Tire Mounting*—The SRTT shall be used with rotation in the same direction for each test for the life of the tire.

7.10.6. *Tire Inspection*—Remove small stones from the tread grooves prior to test runs. A tire with uneven wear and damage that may affect the noise measurement shall not be used.

7.11. *Temperature Measurement*—Limitations on temperature are equipment specific, and manufacturer specifications should be followed. The temperature of the ambient air and the surface of the pavement test section should be measured at 60-minute intervals.

7.12. *Check of Moisture in Porous Surfaces*—Water in porous surfaces is known to affect measurements. For porous surfaces, procedures should be applied to verify that the pores are dry.

7.13. *Barometric Pressure*—The barometric pressure during the course of the measurements shall be recorded.

7.14. *Tire Hardness*—The hardness of the tire rubber shall be evaluated within a month of the test run using a durometer per ASTM D 2240 and ASTM F 2493.

8. REPORTED DATA

8.1. *The test report shall include the following data*:

8.1.1. Time and date of measurement;

8.1.2. Organization and operators responsible for the measurement;

8.1.3. Pavement lane in which the tests are taken;

8.1.4. Vehicle speeds tested;

8.1.5. Components of the measurement system, including serial numbers, if applicable;

8.1.6. Instrumentation used to collect speed and meteorological data;

8.1.7. Date of last equipment calibration; and

8.1.8. Location of object(s) greater than 6 in. (150 mm) in height above the pavement that are within 2 ft (0.6 m) of the edge of pavement; and

8.1.9. Most recent measurement result of tire hardness and the date it was measured.

8.2. *The following acoustical measurement information shall be reported*:

8.2.1. Measured overall SILs for each good run and the average of the good runs;

8.2.2. Measured SILs by one-third octave bands with center frequencies between 400 and 5000 Hz for each good run and the average of the good runs;

8.2.3. Verification (calibration) results from all instances before, during, and after the measurement period;

8.2.4. Run-to-run differences of levels or standard deviations, or both, for the overall SIL and one-third octave bands with center frequencies between 400 and 5000 Hz;

8.2.5. PI index, sound intensity vector direction, and coherence check results; and

8.2.6. The air density input to the analyzer, temperature, and barometric pressure inputs to the analyzer to estimate air density, and the values of temperature and barometric pressure, or both, used in the subsequent estimation of air density.

8.3. *The test report should include the following data, if recorded*:

8.3.1. Representative photo(s) or video of the surface with a texture dimension reference (e.g., coin or scale);

8.3.2. Air temperatures during the measurement period and their average;

8.3.3. Road temperatures during the measurement period and their average;

8.3.4. Observations of roadway geometry, grade, and cross-slope; and

8.3.5. Observations of roadway condition.

9. PRECISION AND BIAS

9.1. *Precision*—Repeatability of measured results. Precision means obtaining the same answer for the same conditions but does not necessarily indicate accuracy. (Not available at this time.)

9.2. *Bias*—An error trend in the data caused by procedures, equipment, or local characteristics. (Not available at this time.)

10. KEYWORDS

10.1. Close proximity; noise measurement; on-board sound intensity; pavement noise; sound intensity; tire/pavement noise.

ANNEXES

(Mandatory Information)

A1. SCOPE

A1.1 The objective of this Annex is to define the required attributes of equipment to measure tire/pavement noise using the OBSI method. This equipment uses amplitude and phase matched microphones, mounted near a test tire to measure this isolated tire/pavement noise.

A1.2 It is not the intent of this Annex to relieve the supplier from the final responsibility to provide an appropriate product for the intended function nor is it intended to specify all the design details. The objective is to provide a sufficiently detailed specification such that the function is clearly defined. It is intended to be sufficiently detailed such that the data collected from multiple systems will be substantially identical.

A2. REFERENCED DOCUMENTS

A2.1 *The following references were used or referred to in the preparation of this text*:

A2.1.1 *ASTM Standards*:

- D 2240, Standard Test Method for Rubber Property—Durometer Hardness
- F 2493, Standard Specification for P225/60R16 97S Radial Standard Reference Test Tire

A2.1.2 *ANSI Standards*:

- S1.9, Instruments for the Measurement of Sound Intensity
- S1.11, Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters
- S1.40, American National Standard Specifications and Verification Procedures for Sound Calibrators
- S1.42, American National Standard Design Response of Weighting Networks for Acoustical Measurements

A2.1.3 *IEC Standards*:

- IEC 60942, Electroacoustics—Sound Calibrators
- IEC 61043, Electroacoustics—Instruments for the Measurement of Sound Intensity—Measurement with Pairs of Pressure Sensing Microphones
- IEC 61260, Electroacoustics—Octave-Band and Fractional-Octave-Band Filters
- IEC 61672, Electroacoustics—Sound Level Meters

A. GENERAL SYSTEM REQUIREMENTS

A3.1 *General Design*—The test vehicle may be a passenger vehicle (automobile). It is desirable that the wheel well for the test wheel be open (tire not covered on the outboard side) or an absorptive treatment be used to avoid reflections and conflict in calculating the sound intensity using the OBSI method. Trailers with test tire loading (similar to that of a passenger vehicle [850 ± 100 lb (385 ± 45 kg)]) are also possible for use but are not directly described in this methodology. If a trailer is used, the requirements noted herein must be observed. There shall be one appropriately instrumented SRTT for each test run. Pictures of typical setups are shown in Figures A5.2 through A5.5. The test tire shall be mounted on a non-driven, non-steering wheel (i.e., a wheel not directly driven by the power train or steering assembly).

A3.2 *Special Considerations*—The use of wind screens on the probes is necessary to minimize wind noise contamination in the lower frequency ranges. Wind screens shall be open-cell-structure foam, spherical, and 3.3 to 3.6 in. (84 to 91 mm) in diameter.

A3.3 *Recording Instrumentation*—A recording device is recommended but not required. If used, the quality must meet Class 1 requirements of ANSI S1.9. Methods that result in undistorted playback of recorded data are required. Digital Audio Tape (DAT) recorders that have been manufactured to meet recording industry standards are preferred because of the standardization that has occurred. Other digital recording methods may also be used if the overall sound recording characteristics are equivalent or better than those attainable with a conventional DAT recorder. (There is no standardization for other digital recording methods, and they should, therefore, be used with caution. Methods that utilize lossy data compression (e.g., MP3) must not be used.) Documentation on the recording equipment should accompany report or, alternatively, be available upon request.

A3.4 *Verification of the Test Vehicle and Measurement System*—The test vehicle and measurement system shall be checked for proper performance. This evaluation should determine if unwanted noise is occurring from the following sources:

- improperly operating vehicle,
- bearing or brake noise,
- microphone wind screen flutter, or
- equipment mount vibrations.

A3.5 *Quality Checks*—The spectral content of data collected from multiple tire/pavement combinations should be reviewed to determine if any frequency band does not appear to vary. Constant frequency band data is an indication that noise other than tire/pavement noise is present. The audio track should be carefully examined to determine if any unusual noise is present.

A4. EQUIPMENT

A4.1 *Sound Intensity Measurement System—for the OBSI method shall consist of the following*:

A4.1.1 For each sound intensity probe, two microphones shall be selected such that they comply with the Class 1 requirements of ANSI S1.9. If measurements at the leading and trailing edge are made concurrently, two probes shall be used that meet these requirements. Upon installation of the probes alongside the test tire, care must be taken to avoid unwanted turbulence and effects on the trailing set of microphones.

A4.1.2 Preamplifiers affixed to each individual microphone are required for signal amplification.

A4.1.3 Windscreens on each probe shall be used to control wind noise. The use of wind noise control devices, such as nose cones, is not necessary.

A4.1.4 A two-channel analyzer (minimum) that meets the Class 1 requirements of ANSI S1.9 shall be used.

A4.1.5 An acoustic calibrator or piston phone that meets the Class 1 requirements of ANSI S1.40 shall be used.

A4.1.6 A sound intensity calibrator or methodology as supplied by the equipment manufacturer for specific equipment should be used.

A4.1.7 Headphones should be used during measurement.

A4.1.8 Associated cabling and power supplies shall be used as necessary.

A4.1.9 *Vehicle Speed Measurement Instrumentation*—Any equipment with accuracy of ±1 mph (±1.6 km/h) may be used. Vehicle speedometers cannot be used to meet this requirement unless a verification of the accuracy is made prior to testing.

A4.1.10 *Temperature Measurement Instrumentation*—The temperature-measuring instruments for both the ambient and pavement temperatures shall have an overall accuracy of at least ±2.0°F (±1.2°C).

A4.1.11 *Frequency Analysis Instrumentation*—Equipment used must provide measurement of individual one-third octave frequency bands. The instrumentation used should meet the Class 1 requirements of ANSI S1.9.

A4.1.12 *Barometric Pressure*—The barometric pressure measuring instrument shall have an accuracy of ±0.75 in.Hg (±25 hPa).

A5. MOUNTING AND INSTALLATION REQUIREMENTS

A5.1 *Probe Position*—The sound intensity probes should be positioned as defined herein and illustrated in Figure A5.1. The point located between the two microphone diaphragms on a given probe shall have a fixed position relative to the tire, such that the horizontal distance from the plane of the nearest tire sidewall is 4.0 in. (102 mm). Exact orientation of the microphones should be as shown in Figure A5.1 at a height above ground level of 3 in. (76 mm). The spacing between the probes shall be 8.25 in. (209.6 mm), centered about the hub (4.125 in. (104.8 mm) on each side of hub). All of these positions shall have a tolerance of ±0.25 in. (±6.3 mm). Figures A5.2 through A5.5 show typical arrangements.

A5.2 *Microphone Spacing*—The pair of microphones on any sound intensity probe shall be separated in such a way that the center-to-center spacing between the two diaphragms is 0.63 ± 0.04 in. (16 ± 1 mm).

A5.3 *Positions Checks*—The microphones must be mounted in the same position for each test. All wiring associated with a probe should not be changed. The microphones on any given probe shall be parallel to each other and to the sidewall of the tire. This position can be checked at the time of installation.

A5.4 *Tire Balance and Alignment*—Proper balance and alignment of the SRTT should be verified. The camber angle and toe-in must comply with the vehicle specifications and be verified by a qualified mechanic for the specific vehicle type. During this same process, all mechanical parts such as brakes and shocks should be inspected for deterioration, improper operation, and any condition that could cause unwanted sound or vibration.

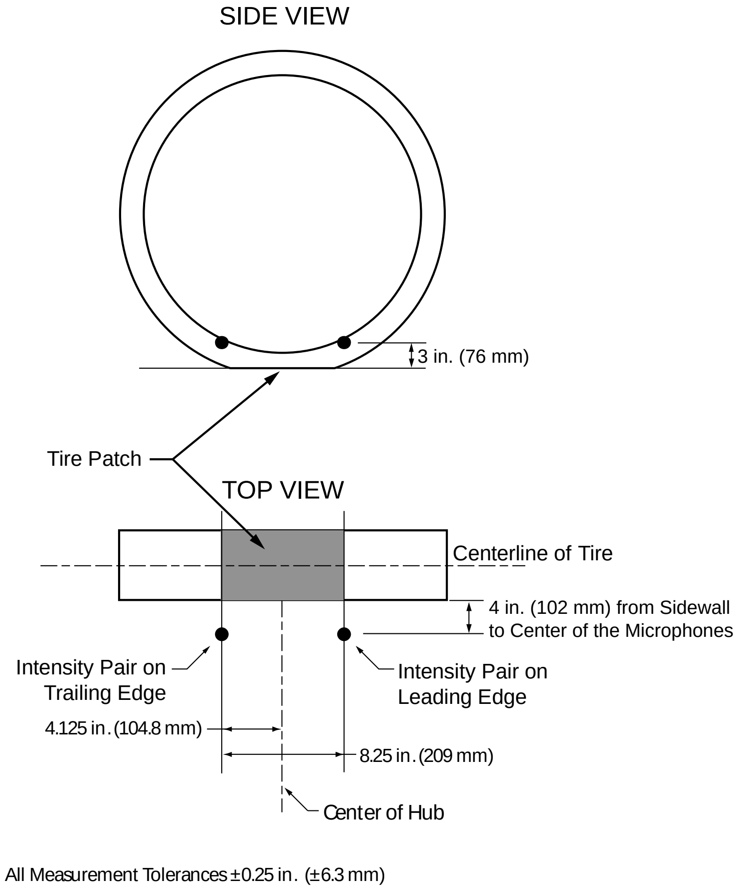

Figure A5.1—Microphone Positions: Leading/Trailing Edge Measurements (Courtesy of General Motors)

Figure A5.2—Dual-Probe Vertical OBSI Setup

Figure A5.3—Dual-Probe Vertical OBSI Setup (shown without required windscreens)

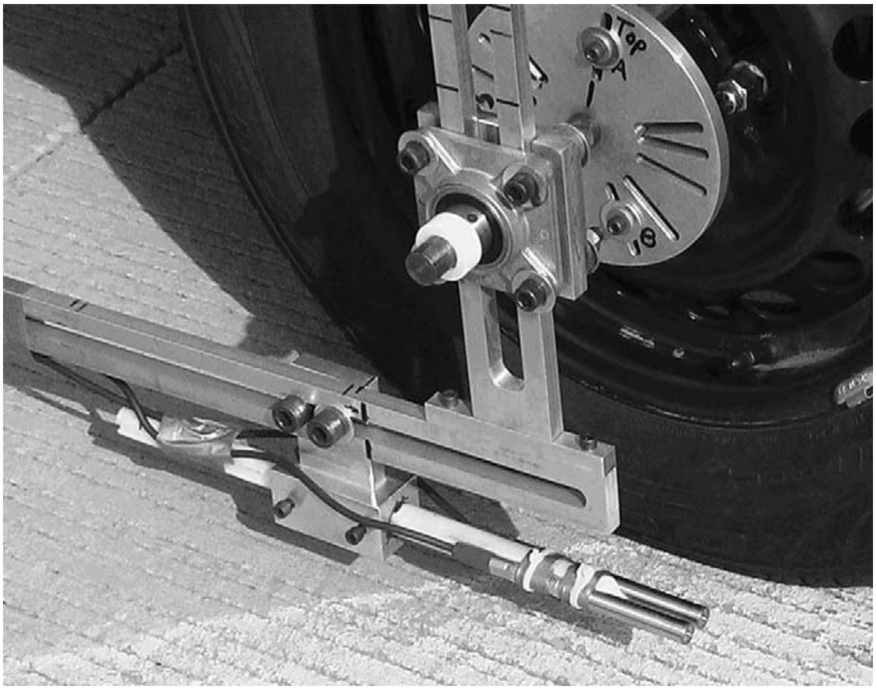

Figure A5.4—Single-Probe Horizontal OBSI Setup, Leading Edge (shown without required windscreens)

Figure A5.5—Dual-Probe Horizontal OBSI Setup (shown without required windscreens)

Standard Practice for

Evaluating the Engineering and Environmental Suitability of Recycled Materials

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AASHTO Designation: PP 56-06 (2008)[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Evaluating the Engineering and Environmental Suitability of Recycled Materials

AASHTO Designation: PP 56-06 (2008)[1]

1. SCOPE

1.1. This practice is to provide a general evaluation framework for assessing the feasibility to use recycled materials in the highway environment.

1.2. This document was developed using the *Framework for Evaluating Use of Recycled Materials in the Highway Environment*.

2. GENERAL PROVISIONS

2.1. It is recommended that the *User Guidelines for Waste and Byproduct Materials in Pavement Construction* be referred to before using this practice, as many common recycled materials for highway uses have already been evaluated with this method and are documented in the User Guidelines.

2.2. AASHTO resolution PR-14-01, Use of Recycled Materials, encourages the use of recycled materials in transportation applications where engineering, economic, and environmental conditions warrant their use.

3. SUMMARY OF THE PRACTICE

3.1. The evaluation framework is illustrated in a flowchart format as shown in Figure 1. There are five steps in the framework and three screening stages. The framework provides for combining or skipping steps if it is clear that such action is appropriate. The framework also provides, as part of the stepwise evaluation process, the means to modify or beneficiate materials that do not meet criteria so that there is an opportunity to revise the application based on new data obtained during the evaluation process.

3.2. *Framework Limitations*—This document is an attempt to provide an overall comprehensive evaluation framework that decision makers can use in evaluating recycled material use in highway applications. Although much progress has been made in the development of these procedures, the complexity associated with defining evaluation procedures and criteria demands that the evaluator select the best test methods and criteria subject to local conditions and that the criteria and test methods presented be continually updated as new information is made available. The multi-disciplinary engineering and environmental efforts involved in implementing the steps outlined in the framework will require that state engineering and environmental agencies forge cooperative efforts, pooling the necessary resources to undertake the evaluation effort. Only through such cooperative efforts can the complex issues that need to be addressed receive proper attention and ensure the appropriate use of recycled materials in the highway environment.

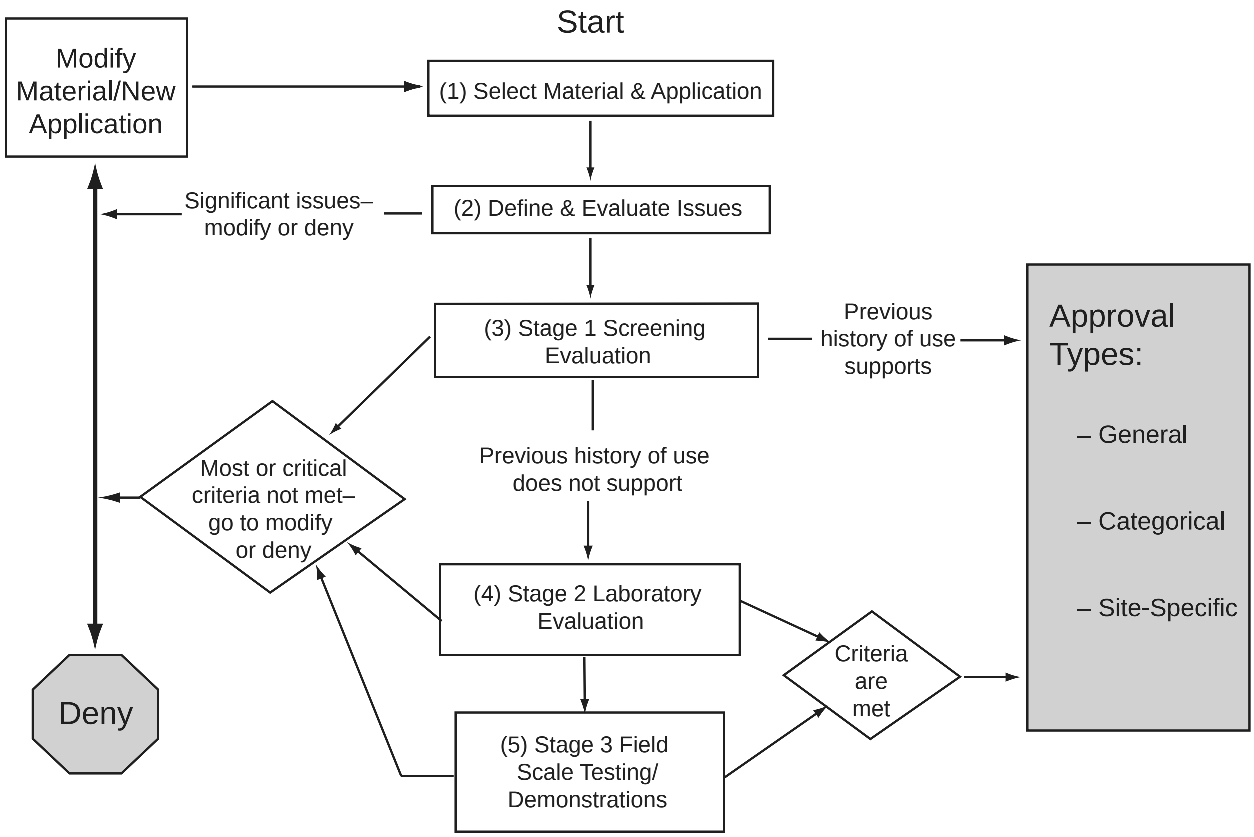

Figure 1—Evaluation Framework Flow Process

4. PROCEDURE

4.1. *Step 1—Select Material and Application*—The first step in the framework process is to select a material and a specific application (e.g., use blast furnace slag in embankment construction) that will be evaluated.

4.2. *Step 2—Define and Evaluate Issues*—The second step is to collect all relevant information that can provide input into the decision-making process. This includes, for the material and its proposed application; all related historical data; engineering and material property data; environmental, health, and safety data; implementation constraints; recycling issues; and economic issues.

The purpose of this step is to define all issues that may warrant more detailed examination and, in particular, those issues that may be problematic insofar as approval of the material for use may be concerned. A flowchart that can be used to identify the key issues in any material-application proposal is presented in Figure 2. Recommended checklists to ensure that the proper information is collected for such an evaluation are provided in Tables 1 through 6.

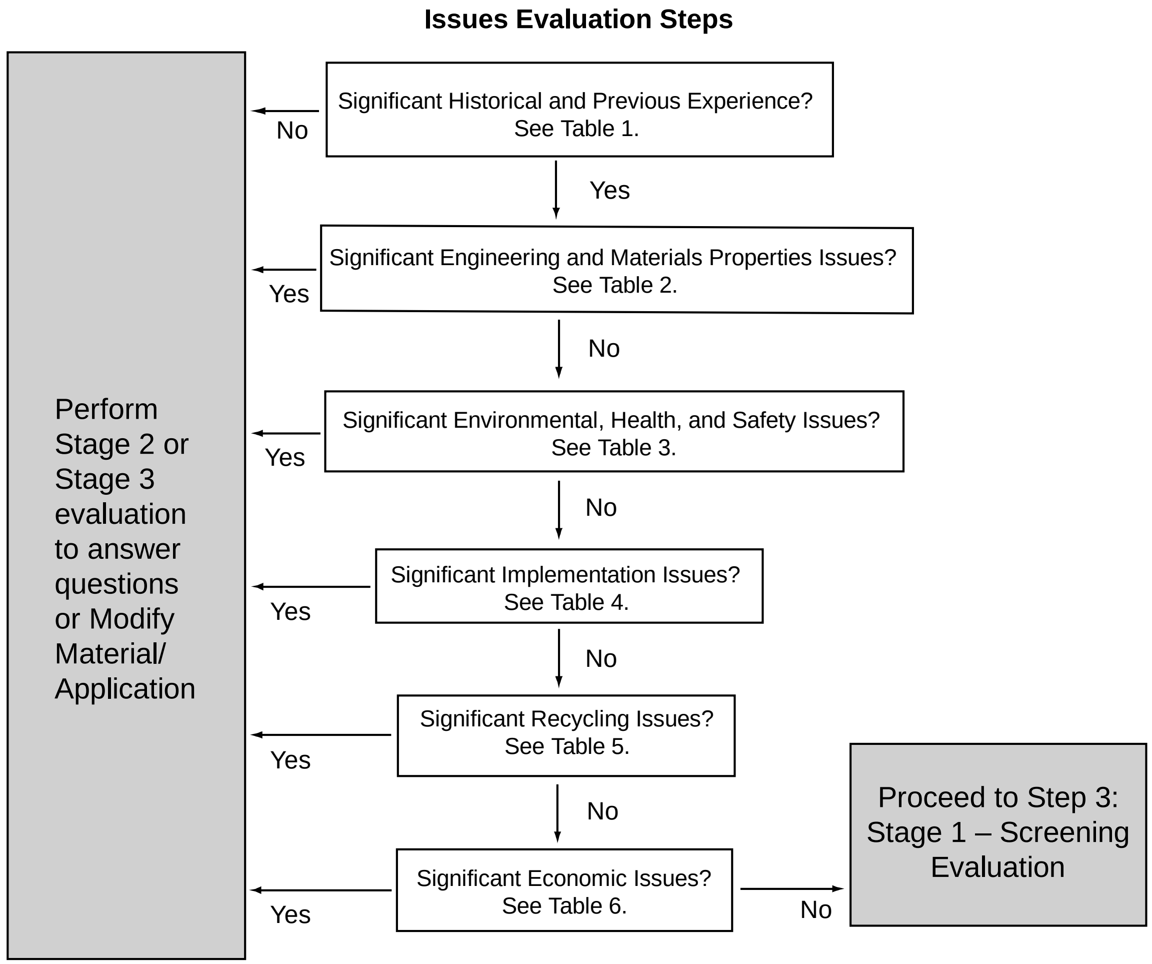

Figure 2—Issues Flowchart

Table 1—History and Previous Experience Questions

General Area	General Questions[a]		
History	1. Has the recycled material been used anywhere? If so, identify uses.	Y	N
	2. Is information available about the source of the recycled material? If so, collect it.	Y	N
	3. Has this recycled material been previously used for transportation applications? If so, identify applications.	Y	N
	4. Has this recycled material been used in geographically diverse locations? If so, identify locations.	Y	N
	5. Has this recycled material been used previously in a similar application? If so, identify location.	Y	N
	6. Has this recycled material been used in other agencies? If so, identify these agencies.	Y	N
	7. Have other agencies approved for this use? If so, identify these agencies.	Y	N
Previous Experience	1. Is information available about important prior experiences (previous use, prior objections, and similarity with other materials)? If so, collect the information.	Y	N
	2. Are there experts available to discuss prior experiences? This can include regulators, scientists, practitioners, waste generators, and associations. If so, contact the experts.	Y	N
	3. Is there any published literature about prior experiences? If so, obtain the information.	Y	N

[a] Y = Yes, N = No

Table 2—Engineering and Material Properties Questions

General Area	General Questions[a]		
Engineering	1. Is information available about the engineering properties of the recycled material? This could include information about gradation, bulk density, durability, and compaction data. If so, collect the pertinent information.	Y	N
	2. Is the recycled material appropriately characterized with respect to time-dependent engineering properties? This could include time-dependent variation in gradation, bulk density, durability, and compaction. If so, collect the pertinent information.	Y	N
	3. For the proposed application, are there appropriate engineering criteria for the product? This could include durability, grain size, and compaction requirements. If so, collect the pertinent criteria.	Y	N
	4. Is engineering information available about important prior experiences (previous use, prior performance criteria, and similarity with other materials)? If so, assemble the pertinent information.	Y	N
Material Properties	1. Is information available about the material properties of the recycled material? This could include information about loss on ignition, mineralogy, and pozzolanic activity of the waste material. If so, summarize the data.	Y	N
	2. Is the recycled material appropriately characterized with respect to time-dependent materials properties? If so, summarize the data.	Y	N
	3. For the proposed application, are there appropriate material properties criteria for the product? If so, identify the criteria.	Y	N

[a] Y = Yes, N = No

Table 3—Environmental, Health, and Safety (EHS) Properties Questions

General Area	General Questions[a]		
Environmental	1. Is information available about the environmental properties of the recycled material? This could include information about total elemental composition, total available elemental composition, and volatile and semi-volatile organics composition data. If so, collect the pertinent information.	Y	N
	2. Is the recycled material appropriately characterized with respect to time-dependent environmental properties? This could include time-dependent variation in total elemental composition, total available elemental composition, and volatile and semi-volatile organic composition. If so, collect the pertinent information.	Y	N
	3. For the proposed application, are there appropriate environmental criteria for the product? This could include leaching data, total content data, particle size, etc. If so, collect the pertinent criteria.	Y	N
	4. Is environmental information available about important prior experiences (previous use, prior performance criteria, and similarity with other materials)? If so, assemble the pertinent information.	Y	N
	5. Have there been any environmental assessments undertaken relative to the use of the proposed material? If so, summarize the information.	Y	N
Public Health	1. Are there any Materials Safety Data Sheets (MSDS) for the recycled materials? If so, collect the sheets.	Y	N
	2. Have there been health risk assessments (HRA) undertaken relative to the proposed use of the material? If so, summarize the information.	Y	N
Safety	1. Have there been prior Occupational Safety and Health Administration (OSHA) issues for generation, processing, storage, and use in previous efforts? If so, summarize the information.	Y	N

[a] Y = Yes, N = No

Table 4—Implementation Issue Questions

General Area	General Questions[a]			
Implementation	1. Are there any apparent political constraints? If so, describe them.	Y	N	U
	2. Are there any apparent regulatory constraints? If so, describe them.	Y	N	U
	3. Are there any apparent public acceptability constraints? If so, describe them.	Y	N	U

[a] Y = Yes, N = No, U = Unknown

Table 5—Recycling Issue Questions

General Area	General Questions[a]			
Recycling	1. Are there likely recycling or life-cycle issues? If so, identify them.	Y	N	U
	2. Has the recycled material or its application been reused within other areas of the highway environment? If so, identify them.	Y	N	U

[a] Y = Yes, N = No, U = Unknown

Table 6—Economic Issue Question

General Area	General Question[a]			
Economic	1. Are there any apparent economic constraints? If so, identify them.	Y	N	U

[a] Y = Yes, N = No, U = Unknown

4.3. *Step 3—Stage 1 Screening Evaluation*—The third step in the process is a Stage 1 screen. The purpose of a Stage 1 screen is to determine whether the data collected in Step 2 are sufficient to approve (or reject) the proposed application without additional study. A Stage 1 approval means that the evaluator has a high degree of certainty that there is sufficient information to justify acceptance of the proposed material and application. This typically involves demonstrating that the proposed material is sufficiently similar to reference materials, which have been used successfully, to warrant approval. A Stage 1 screen should include an assessment of all existing data pertaining to engineering data, environmental, health, and safety data, recycling issues, implementation concerns, political issues, and economic issues to ensure that the data are sufficient to permit a responsible decision. Recommended screening checklists with evaluation criteria are presented in Tables 7 through 11.

Table 7—Stage 1 Engineering Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]			
Material Source	Determine whether the proposed material is generated from similar source materials and the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y	N	U
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to those of the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y	N	U
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y	N	U
Engineering Properties	Assess whether there are sufficient data to compare the engineering properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate engineering property data available for both the proposed and reference materials, and are the data reliable?	Y	N	U
		2. Can it be determined that the proposed and reference materials have statistically similar engineering properties that are in conformance with the specifications of the proposed application, and are they comparable?	Y	N	U
Field Performance	Determine whether the reported historical data for the reference material provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	Y	N	U
		2. Are there experienced personnel available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	Y	N	U
		3. Is the historical performance data of the material sufficient to warrant a Stage 1 approval?	Y	N	U

[a] Y = Yes, N = No, U = Unknown

Table 8—Stage 1 Environmental, Health, and Safety Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]			
Material Source	Determine whether the proposed material is generated from similar source materials and the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y	N	U
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to those of the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y	N	U
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y	N	U
Environmental Properties	Assess whether there are sufficient data to compare the environmental properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate environmental property data available for both the proposed and reference materials, and are the data reliable?	Y	N	U
		2. Can it be determined that the proposed and reference materials have statistically similar environmental properties that are in conformance with the specifications of the proposed application, and are they comparable?	Y	N	U
Field Performance	Determine whether the reported historical data provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	Y	N	U
		2. Are there personal contacts (regulators or scientists with experience) available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	Y	N	U
		3. Were there any specific problems or difficulties reported, and were the reported problems satisfactorily addressed in previous investigations to warrant a Stage 1 approval?	Y	N	U

[a] Y = Yes, N = No, U = Unknown

Table 9—Stage 1 Recycling Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Engineering Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the engineering quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the production process during a post-service life application?	Y N U
		2. Could the proposed material properties be altered during either its service life or post-service life processing to such an extent that it could significantly impact the properties of the secondary material?	Y N U
Environmental Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the environmental quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the environment (air, water, or soil quality) during post-service life processing if introduced into a secondary application?	Y N U
		2. Could the proposed material adversely impact the environment (air, water, or soil quality) during its post-service life use if introduced into a secondary application?	Y N U
		3. Could the proposed material adversely impact the environment (air, water, or soil quality) if disposed of as construction and demolition debris after its initial service life?	Y N U
Worker Health and Safety Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the worker health and safety properties of the product if used in a secondary application at the completion of its useful service life?	1. Could harmful fugitive dust or volatile gaseous emissions resulting from the use of the proposed material impact worker health or safety during post-service life processing or construction activities?	Y N U
		2. Could the use of the proposed material create a hazard to the physical safety of workers during post-service life processing or construction activities?	Y N U

[a] Y = Yes, N = No, U = Unknown

Table 10—Stage 1 Implementation Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Institutional Acceptability	Consider the probability that the regulatory community will approve and the technical community will accept and utilize the material in the proposed application.	1. Rate the degree of difficulty that can be anticipated in obtaining approval to incorporate the material-application match into existing construction specifications.	H M L
		2. Rate the degree of difficulty that can be anticipated prior to the receipt of environmental approvals from regulatory agencies.	H M L
		3. Rate the degree of reluctance that engineers might have in specifying the material in the proposed application.	H M L
		4. Rate the degree of reluctance that contractors might have in utilizing the material in the proposed application.	H M L
Political Acceptability	Consider the degree to which public officials will support or impede the proposed application.	1. Rate the degree to which political opposition could impede the application.	H M L
Public Acceptability	Assess the degree to which the public will accept the proposed material-application strategy.	1. Rate the degree to which the public opposition due to perceived environmental, health, safety, or economic impacts could impede the application.	H M L

[a] H = High, M = Medium, L = Low

Table 11—Stage 1 Economic Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]		
Material Cost	$C_{DP} = P_{RM} + C_{PR} + C_{ST} + C_{LD} + C_{TR} + P$ (*1*) where: C_{DP} = Delivered price of the proposed material, P_{RM} = Price of the raw proposed material (F.O.B.), C_{PR} = Cost of processing the material, C_{ST} = Cost of stockpiling the material, C_{LD} = Cost of loading the material, C_{TR} = Cost of transporting the material, and P = Profit.	Is $C_{DP} \leq C_{DC}$? where: C_{DC} = Delivered price of conventional material	Y	N
Installation Cost	$C_{IP} = C_{DR} + C_{DP} + C_C + T_{RP}$ (*2*) where: C_{IP} = Cost of installation using the proposed material, C_{DR} = Cost for design of application with the recovered material, C_{DP} = Delivered price of the proposed material (see Eq. 1), C_C = Cost for construction with the recovered material, and T_{RP} = Cost of testing and inspection for the proposed application.	Is $C_{IP} \leq C_{IC}$? where: C_{IC} = Cost of installation using conventional material	Y	N
Life-Cycle Cost	$A_{CP} = C_{IP} \times CRF(i,n) + C_{AM}$ (*3*) where: A_{CP} = Annual life-cycle cost using the proposed material, C_{IP} = Cost of installation using the proposed material (see Eq. 2), $CRF(i,n)$ = The capital recovery factor with an interest rate of *i* percent and an expected service life of *n* years, and C_{AM} = Annual maintenance cost.	Is $A_{CP} \leq A_{CC}$? where: A_{CC} = Annual cost using conventional material	Y	N

[a] Y = Yes, N = No

4.4. *Step 4—Stage 2 Laboratory Evaluation*:

4.4.1. A Stage 2 laboratory evaluation is recommended if a Stage 1 review determines that existing information is insufficient to either accept or reject the application.

4.4.2. The Stage 2 evaluation screen is intended to characterize (1) the engineering and materials properties and (2) the environmental, health, and safety properties of the proposed recycled material and its application product. These data can then be compared with established criteria or with the performance of reference materials using available laboratory and analytical engineering and environmental protocols.

4.4.2.1. In a Stage 2 engineering and materials properties evaluation, a laboratory testing program must be developed that will provide sufficient data to demonstrate that the proposed material is suitable for use in the proposed application. Inherent in the evaluation is that laboratory testing requires assessment of the engineering and materials performance of the proposed material as well as the engineering and materials performance of the product or the application it will be used in.

4.4.2.2. In a Stage 2 environmental, health, and safety laboratory evaluation, a laboratory testing program must be developed that will provide sufficient data to demonstrate that the proposed material is suitable for use in its intended application. Inherent in the evaluation is that laboratory testing requires assessment of the environmental performance of the proposed material as well as the environmental performance of the product.

4.4.2.3. It is important to consider engineering and materials performance and environmental performance in potential post-service life utilization scenarios. While these reuse scenarios cannot be precisely described, it is important to identify, to the extent possible, future engineering and environmental issues that may arise if the recycled material is reused.

4.4.3. To undertake a Stage 2 laboratory evaluation, it is recommended that (1) a test plan be prepared that delineates the samples to be tested and the tests to which the sample will be subjected, (2) acceptable specifications or performance criteria be identified that can be used as a means for evaluating the results of the test plan, and (3) the data be statistically evaluated to determine whether specifications are met or performance is similar to appropriate reference materials.

4.4.4. The most critical steps in a Stage 2 evaluation are development of the test plan and establishment of performance criteria. The referenced *Framework for Evaluating Use of Recycled Materials in the Highway Environment* document provides a description of engineering and environmental parameters that will typically be of interest when evaluating the use of proposed materials in specific applications and provides detailed lists of applicable laboratory test methods that can be used in the evaluation.

4.5. *Step 5—Stage 3 Field Scale Testing/Demonstrations*:

4.5.1. The Stage 3 screen, the next step, is intended to provide field-scale data on (1) engineering and materials properties and (2) environmental, health, and safety properties of the proposed recycled material and its application product. These data can then be compared with established performance criteria, with reference materials (e.g., a control section), or with appropriate standards or regulatory limits.

4.5.2. The Stage 3 field testing stage is most applicable in situations where (1) the proposed recycled material has not been used historically so there is little or no field data, (2) there is little or incomplete historical data for the recycled material and more field data are needed, or (3) the proposed recycled material is being considered for new use in applications and there is no pertinent field data. Both short-term and long-term monitoring activities may be required.

4.5.2.1. Short-term monitoring activities are designed to evaluate how the new material might affect the application during the end-product production process, such as asphalt or portland cement concrete production, and during and/or immediately after construction.

4.5.2.2. Long-term monitoring activities are designed to evaluate how the proposed application performs during the post-construction period and can involve a time period ranging from several years up to the design life of the application.

4.5.3. To undertake a Stage 3 evaluation, it is recommended that (1) a demonstration test plan be prepared that delineates the field monitoring requirements, (2) acceptable specifications or performance criteria be identified to evaluate results of the field demonstration, and (3) the data be statistically evaluated to determine whether specifications are met or performance is similar to that of appropriate reference materials. Field monitoring activities will differ, depending on the type of application being proposed. Recommended engineering and environmental field monitoring activities are presented in the “Framework” document.

4.6. *Modify Material/New Application*:

4.6.1. *Modification Points in the Flowchart*—During each step in the evaluation process, the evaluator should be cognizant of conditions that suggest that the proposed material and its intended application have or are likely to encounter problems in gaining acceptance and that a reevaluation of the proposed strategy is in order. This reevaluation can result in the withdrawal or modification of the proposed recycled material and the proposed application. This reevaluation step is reflected in the Figure 1 flowchart, where at each node in the review process, the material and/or application may be modified.

4.6.2. *Beneficiation*:

4.6.2.1. Modifications can be made to improve the engineering suitability or the environmental suitability of the proposed recycled material in the selected application. This approach is termed *beneficiation*.

4.6.2.2. Engineering modifications could include such items as (1) modifying the proposed percentage of material to be used in the application, (2) requiring additional material processing, such as screening or crushing, to remove problematic fractions, or (3) requiring the introduction of additional reagents to mitigate any anticipated problem with the application. As a simple example, if an applicant proposes to introduce 30 percent foundry sand as an aggregate substitute material into a hot mix asphalt pavement, and such a mix design is unable to meet the aggregate gradation specification of the mix, then prior to rejecting the application, it would seem reasonable to request that the applicant modify the proposed mix design to comply with the gradation specification. As an additional example, suppose it is reasonable to introduce foundry sand at levels of approximately 25 percent, but during laboratory testing, stripping tests show that the pavement might be susceptible to water damage, then it would be reasonable to suggest that anti-stripping agents be incorporated into a foundry sand mix or that additional processing occur to reduce the stripping factor present in the spent foundry sand.

4.6.2.3. Environmental modifications could include such items as (1) adding moisture conditioning for dust control, (2) using chemical fixation or stabilization technologies to reduce the availability of contaminants of concern, (3) limiting the location of the proposed application, or (4) suggesting that removal of certain components of the proposed materials (e.g., fines) be undertaken prior to use. Environmental modifications can similarly be incorporated into a review process. For example, a proposal to use unconditioned (dry) coal fly ash as an embankment material might raise some concerns during a screening process because of the potential for fugitive dust emissions during transport and placement. Conditioning (moisture addition) to control these emissions would be a reasonable modification that could be incorporated into the process. If there is additional concern regarding erosion of the embankment, then a vegetative cover could be a reasonable modification.

4.6.3. *New Applications*—If an intended application does not meet certain criteria and if the recycled material cannot be modified, then another application may need to be explored. The evaluator can explore the use of the recycled material in an alternative application. For instance, if problems are expected with the percolation leaching of a mineral processing waste in an embankment, it may be more appropriate to consider its use as an aggregate substitute in an asphalt paving application where the asphaltic material produces a monolithic product with a reduced cumulative release of constituents from monolithic leaching.

4.7. *Approval Process*:

4.7.1. *Approval Points in Flowchart*—Approval can occur at Stages 1, 2, or 3 of the evaluation process. Approval or rejection will depend on the performance of the recycled material in the proposed application compared with criteria and specifications used by the decision maker. Much of the actual approval process will require, by use of common statistical measures, that the measured engineering and environmental properties of the recycled material or the product meet these criteria or specifications.

4.7.2. *General, Categorical, and Site-Specific Approvals*—When a proposal is submitted for consideration, an evaluation to completely accept or completely reject the proposed application is not required. A number of different types of approvals can be considered. These types are referred to in this document as general, categorical, and site-specific approvals.

4.7.2.1. *General*—General approvals are approvals in which minimal, if any, conditions are imposed on the applicant. Such approvals would be used where there is an overwhelming preponderance of data and history showing that the recycled material and application can be employed without adverse engineering or environmental consequences. General approvals would be appropriate for traditional highway materials in traditional applications, such as the recycling of asphaltic pavements or portland cement concrete pavements back into new pavement construction or pavement reconstruction. It may also be used for traditional recycled material in traditional applications, such as the use of coal fly ash or ground, granulated blast furnace slag as a supplementary cementitious material in portland cement concrete pavements. Finally, in some instances, it may be used for traditional recycled materials in new applications, such as the use of coal fly ash in a flowable fill mix for backfill applications.

4.7.2.2. *Categorical*—Categorical approvals impose more restrictive limits on where and how a material may be used than for general approvals. For example, such approvals might limit the use of a recycled material to a specific environment (e.g., a defined distance above the groundwater table), or a specific section of subapplication (e.g., base course as opposed to a wearing course pavement). For example, the use of blast furnace slag as a granular base below asphalt pavement in locations that are a minimum of 61 cm (2 ft) above high groundwater would be a categorical approval. Such approvals can be used where there is sufficient historical, laboratory, or possible field data showing that the recycled material and application can be employed without adverse engineering or environmental consequences in the specific environment. Categorical approvals are appropriate for traditional recycled materials in new applications, new materials in traditional applications, or new materials in new applications.

4.7.2.3. *Site-Specific*—Site-specific approvals are one-time approvals and require a new evaluation for the next project. These types of approvals normally require field monitoring to obtain additional information to assist the decision maker in assessing the suitability of the material. Site-specific approvals are normally associated with new material use in either traditional or new applications.

5. REFERENCES

5.1. *User Guidelines for Waste and Byproduct Materials in Pavement Construction*—This document provides information about the use of 19 waste and byproduct materials in six major highway applications. Each material is described (origin, current management options, market sources, and general uses). Detailed information is also given about their use in specific highway applications (performance records, processing, requirements, engineering properties, design considerations, construction procedures, and unresolved issues). The document also lays out conceptual evaluation guidance issues (framework, environmental, and costs) and describes the six major highway applications. Dr. Warren H. Chesner of Chesner Engineering, P.C., Robert J. Collins of Robert J. Collins and Associates, and Michael H. MacKay and John Emery of John Emery Geotechnical Engineering Ltd. are the authors. This work was funded through cooperative agreement DTFH61-95-C-00035 to Chesner Engineering, P.C. from FHWA. It is also available as publication number FHWA-RD-97-148 and can be seen online at http://tfhrc.gov/hnr20/recycle/waste/begin.htm.

5.2. *Waste and Recycled Materials in the Transportation Industry NCHRP 4-21 Database*—This database contains information on 21 waste and recycled materials. Information includes photographs of the materials, general information, production and use data, engineering properties data, environmental properties data, suitable highway applications, laboratory testing, field testing, references, and points of contact. The work was sponsored by AASHTO in cooperation with the FHWA and conducted under the auspices of the National Highway Cooperative Research Program, which is administered by the Transportation Research Board of the National Research Council. The authors are Dr. Warren H. Chesner, P.E., Christopher Stein, Robert J. Collins, and Lynette Van Helden of Chesner Engineering, P.C. Supporting technical information was provided by Michael H. MacKay, P.E., of John Emery Geotechnical Engineering Ltd. The work was conducted under NCHRP contract HR4-21 to Chesner Engineering.

5.3. *Framework for Evaluating Use of Recycled Materials in the Highway Environment*—This document, a follow-on to the User Guidelines and NCHRP 4-21 projects, provides a consensus framework for state transportation and environmental regulators to evaluate the prospective use of recycled materials in the highway environment. A logical framework is provided with issues identification, preliminary screening, laboratory testing, and field testing stages. A variety of approval and material modification steps are also offered. Extensive test methods and applicable standards or criteria (both materials and environmental) are given for the laboratory and field testing stages. An Expert Review Panel, consisting of experts from the highway community and state agency personnel, helped craft the approach. The document was authored by Dr. Taylor Eighmy of the University of New Hampshire (UNH) and Dr. Warren H. Chesner of Chesner Engineering, P.C. This work was funded by cooperative agreement DTFH61-97-X-00020 to UNH from the FHWA and can be seen online at http://www.rmrc.unh.edu.

APPENDIX

(Nonmandatory Information)

X1. FRAMEWORK EXAMPLE

X1.1. Appendix X1 presents an example of the evaluation process. It provides a step-by-step application of the framework process outlined in Figure 1 and the evaluation checklists introduced in this document. It is assumed in this example that an applicant submits an application to a State DOT and that the DOT initiates a joint review of the subject application with the State environmental agency. Together, the two agencies constitute the decision maker or evaluator. A State DOT could also initiate this review without an outside applicant request.

X1.2. *Step 1—Select Material and Application*—The applicant submits an application to the State DOT to use an industrial slag as an aggregate substitute in hot mix asphalt base courses.

X1.3. *Step 2—Define and Evaluate Issues*—The State DOT evaluator notifies the State environmental regulatory agency counterpart that an application has been submitted. A meeting is set up in which the applicant is requested to provide responses to the issues evaluation checklist questions:

- Historical experience (Table X1.1)
- Engineering properties (Table X1.2)
- Environmental properties (Table X1.3)
- Implementation issues (Table X1.4)
- Recycling issues (Table X1.5)
- Economic issues (Table X1.6)

The applicant submits the completed issues evaluation checklist tables, which (for example purposes) are presented in Tables X1.1 through X1.6.

Table X1.1—History and Previous Experience Questions

General Area	General Questions[a]	
History	1. Has the recycled material been used before? If so, identify uses.	N
	2. Is information available about the source of the recycled material? If so, collect it.	Y
	3. Has this recycled material been previously used? If so, identify applications.	N
	4. Has this recycled material been used in geographically diverse locations? If so, identify locations.	N
	5. Has this recycled material been used previously in a similar application? If so, identify location.	N
	6. Has this recycled material been used in other jurisdictions? If so, identify jurisdiction.	N
	7. Have other jurisdictions granted use? If so, identify jurisdictional province.	Y
Previous Experience	1. Is information available about important prior experiences (previous use, prior objections, and similarity with other materials)? If so, collect the information.	Y
	2. Are there experts available to discuss prior experiences? This can include regulators, scientists, practitioners, waste generators, and associations. If so, contact the experts.	N
	3. Is there any published literature about prior experiences? If so, obtain the information.	Y

[a] Y = Yes, N = No

Table X1.2—Engineering and Material Properties Questions

General Area	General Questions[a]	
Engineering	1. Is information available about the engineering properties of the recycled material? This could include information about gradation, bulk density, durability, and compaction data. If so, collect the pertinent information.	Y
	2. Is the recycled material appropriately characterized with respect to time-dependent engineering properties? This could include time-dependent variation in gradation, bulk density, durability, and compaction. If so, collect the pertinent information.	N
	3. For the proposed application, are there appropriate engineering criteria for the product? This could include durability, grain size, and compaction requirements. If so, collect the pertinent criteria.	N
	4. Is engineering information available about important prior experiences (previous use, prior performance criteria, and similarity with other materials)? If so, assemble the pertinent information.	N
Material Properties	1. Is information available about the material properties of the recycled material? This could include information about loss on ignition, mineralogy, and pozzolanic activity of the waste material. If so, summarize the data.	N
	2. Is the recycled material appropriately characterized with respect to time-dependent material properties? If so, summarize the data.	N
	3. For the proposed application, are there appropriate material properties criteria for the product? If so, identify the criteria.	Y

[a] Y = Yes, N = No

Table X1.3—Environmental, Health, and Safety (EHS) Properties Questions

General Area	General Questions[a]	
Environmental	1. Is information available about the environmental properties of the recycled material? This could include information about total elemental composition, total available elemental composition, and volatile and semi-volatile organics composition data. If so, collect the pertinent information.	Y
	2. Is the recycled material appropriately characterized with respect to time-dependent environmental properties? This could include time-dependent variation in total elemental composition, total available elemental composition, and volatile and semi-volatile organic composition. If so, collect the pertinent information.	N
	3. For the proposed application, are there appropriate environmental criteria for the product? This could include leaching data, total content data, particle size, etc. If so, collect the pertinent criteria.	Y
	4. Is environmental information available about important prior experiences (previous use, prior performance criteria, similarity with other materials)? If so, assemble the pertinent information.	Y
	5. Have there been any environmental assessments undertaken relative to the use of the proposed material? If so, summarize the information?	N
Public Health	1. Are there any Materials Safety Data Sheets (MSDS) for the recycled materials? If so, collect the sheets.	N
	2. Have there been health risk assessments (HRA) undertaken relative to the proposed use of the material? If so, summarize the information.	N
Safety	1. Have there been prior OSHA issues for generation, processing, storage, and use in previous efforts? If so, summarize the information.	N

[a] Y = Yes, N = No

Table X1.4—Implementation Issues Questions

General Area	General Questions[a]	
Implementation	1. Are there any apparent political constraints? If so, describe them.	U
	2. Are there any apparent regulatory constraints? If so, describe them.	U
	3. Are there any apparent public acceptability constraints? If so, describe them.	U

[a] Y= Yes, N= No, U = Unknown

Table X1.5—Recycling Issues Questions

General Area	General Questions[a]	
Recycling	1. Are there likely recycling or life-cycle issues? If so, identify them.	U
	2. Has the recycled material or its application been reused within other areas of the highway environment? If so, identify them.	N

[a] Y= Yes, N= No, U = Unknown

Table X1.6—Economic Issue Question

General Area	General Questions[a]	
Economic	1. Are there any apparent economic constraints? If so, identify them.	N

[a] Y= Yes, N= No, U = Unknown

X1.3.1. A summary of the results of the issues evaluation checklist analysis is presented in Table X1.7. The reviewing agencies determine whether any significant issues warrant modification or dismissal of the permit request; however, the absence of adequate environmental data means that, at a minimum, a Stage 2 environmental, and perhaps health and safety, step will be necessary. A Stage 1 screen is initiated.

Table X1.7—Industrial Slag as an Aggregate Substitute in an Asphalt Base Course Issues Evaluation

Area of Evaluation	Identified Issue
Historical Experience	The industrial slag from the applicant's facility has not been previously used in any application. Similar materials from other facilities have been used as an aggregate substitute material in asphalt pavements.
Engineering Properties	The applicant has gathered a significant amount of relevant engineering and material property data.
Environmental Properties	The applicant has inadequate environmental data.
Implementation Issues	No problematic issues were identified.
Recycling Issues	No problematic issues were identified.
Economic Issues	No problematic issues were identified.

X1.4. *Step 3—Stage 1 Screening Evaluation*—The Stage 1 screen is undertaken in accordance with the checklist outlined in Section 4.3 Step 3—Stage 1 Screening Evaluation:

- Engineering properties (Table X1.2)
- Environmental properties (Table X1.3)

X1.4.1. *Stage 1 Engineering Properties Screen*—The applicant is requested to provide data to demonstrate statistically that the engineering data submitted for the slag material will be consistent with time and that the engineering properties of the slag are statistically similar to reference materials (similar material that the applicant claimed has been successfully used in the past). Table X1.8 outlines the Stage 1 engineering evaluation.

Table X1.8—Stage 1 Engineering Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Material Production	Determine whether the proposed material is generated from the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to that of the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y
Engineering Properties	Assess whether there are sufficient data to compare the engineering properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate engineering property data available for both the proposed and reference materials, and are the data reliable?	Y
		2. Can it be determined that the proposed and reference materials have statistically similar engineering properties that are in conformance with the specifications of the proposed application, and are they comparable?	Y
Field Performance	Determine whether the reported historical data for the reference material provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	Y
		2. Are there personal contacts (engineers with experience) available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	Y
		3. Is the historical performance data of the material sufficient to warrant a Stage 1 approval?	Y

[a] Y = Yes, N = No, U = Unknown

X1.4.1.1. Based on the information provided, the decision maker determines that the engineering properties of the slag will be consistent throughout the year and that the properties of the slag are statistically similar to that of the reference material.

X1.4.2. *Stage 1 Environmental, Health, and Safety Screen*—The applicant has inadequate environmental data for the industrial slag. Table X1.9 outlines the Stage 1 environmental evaluation. A Stage 2 laboratory analysis will be required.

Table X1.9—Stage 1 Environmental, Health, and Safety Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Material Source	Determine whether the proposed material is generated from the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	U
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to that of the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	U
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	U
Environmental Properties	Assess whether there are sufficient data to compare the environmental properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate environmental property data available for both the proposed and reference materials, and are the data reliable?	N
		2. Can it be determined that the proposed and reference materials have statistically similar environmental properties that are in conformance with the specifications of the proposed application, and are they comparable?	N
Field Performance	Determine whether the reported historical data provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	N
		2. Are there personal contacts (regulators or scientists with experience) available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	N
		3. Were there any specific problems or difficulties reported, and were the reported problems satisfactorily addressed in previous investigations to warrant a Stage 1 approval?	N

[a] Y = Yes, N = No, U = Unknown

X1.4.2.1. The applicant submits supporting data to assist the evaluators in completing the remaining Stage 1 evaluation, which are shown in Tables X1.10 through X1.12.

X1.4.3. *Stage 1 Recycling Evaluation*—The decision maker and applicant define the likely reuses of the recycled base course that will contain the industrial slag. The potential engineering and environmental issues are evaluated for each reuse scenario. Table X1.10 outlines the Stage 1 recycling evaluation. Although no engineering issues were identified, the absence of adequate environmental data means that recycling from an environmental perspective could not be fully assessed.

Table X1.10—Stage 1 Recycling Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Engineering Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the engineering quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the production process during a post-service life application?	N
		2. Could the proposed material properties be altered during either its service life or post-service life processing to such an extent that it could significantly impact the properties of the secondary material?	N
Environmental Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the environmental quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the environment (air, water, or soil quality) during post-service life processing if introduced into a secondary application?	U
		2. Could the proposed material adversely impact the environment (air, water, or soil quality) during its post-service life use if introduced into a secondary application?	U
		3. Could the proposed material adversely impact the environment (air, water, or soil quality) if disposed of as construction and demolition debris after its initial service life?	U
Worker Health and Safety Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the worker health and safety properties of the product if used in a secondary application at the completion of its useful service life?	1. Could harmful fugitive dust or volatile gaseous emissions resulting from the use of the proposed material impact worker health or safety during post-service life processing or construction activities?	U
		2. Could the use of the proposed material create a hazard to the physical safety of workers during post-service life processing or construction activities?	U

[a] Y = Yes, N = No, U = Unknown

X1.4.4. *Stage 1 Implementation Evaluation*—The implementation screen defines potential institutional, political, and public issues that may arise from the proposed use of the industrial slag. Table X1.11 outlines the Stage 1 implementation evaluation. The absence of environmental data at the current stage of the evaluation limits the ability of the decision maker to adequately assess this issue.

Table X1.11—Stage 1 Implementation Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Institutional Acceptability	Consider the probability that the regulatory community will approve and the technical community will accept and utilize the material in the proposed application.	1. Rate the degree of difficulty that can be anticipated in obtaining approval to incorporate the material-application match into existing construction specifications.	H
		2. Rate the degree of difficulty that can be anticipated prior to the receipt of environmental approvals from regulatory agencies.	H
		3. Rate the degree of reluctance that engineers might have in specifying the material in the proposed application.	H
		4. Rate the degree of reluctance that contractors might have in utilizing the material in the proposed applications.	H
Political Acceptability	Consider the degree to which public officials will support or impede the proposed application.	1. Rate the degree to which political opposition could impede the application.	L
Public Acceptability	Assess the degree to which the public will accept the proposed material-application strategy.	1. Rate the degree to which the public opposition due to perceived environmental, health, safety, or economic impacts could impede the application.	L

[a] H = High, M = Medium, L = Low

X1.4.5. *Stage 1 Economic Evaluation*—The results of the economic screen, presented in Table X1.12, suggest that a significant economic incentive exists to utilize the material.

Table X1.12—Stage 1 Economic Screening Checklist

Parameter	Test Method	Evaluation Criteria[a]	
Material Cost	$C_{DP} = P_{RM} + C_{PR} + C_{ST} + C_{LD} + C_{TR} + P$ (*1*) where: C_{DP} = Delivered price of the proposed material, P_{RM} = Price of the raw proposed material (F.O.B.), C_{PR} = Cost of processing the material, C_{ST} = Cost of stockpiling the material, C_{LD} = Cost of loading the material, C_{TR} = Cost of transporting the material, and P = Profit.	Is $C_{DP} \leq C_{DC}$? where: C_{DC} = Delivered price of conventional material	Y
Installation Cost	$C_{IP} = C_{DR} + C_{DP} + C_C + T_{RP}$ (*2*) where: C_{IP} = Cost of installation using the proposed material, C_{DR} = Cost for design of application with the recovered material, C_{DP} = Delivered price of the proposed material (see Eq. 1), C_C = Cost for construction with the recovered material, and T_{RP} = Cost of testing and inspection for the proposed application.	Is $C_{IP} \leq C_{IC}$? where: C_{IC} = Cost of installation using conventional material	Y
Life-Cycle Cost	$A_{CP} = C_{IP} \times CRF(i,n) + C_{AM}$ (*3*) where: A_{CP} = Annual life-cycle cost using the proposed material, C_{IP} = Cost of installation using the proposed material (see Eq. 2), $CRF(i,n)$ = The capital recovery factor with an interest rate of i percent and an expected service life of n years, and C_{AM} = Annual maintenance cost.	Is $A_{CP} \leq A_{CC}$? where: A_{CC} = Annual cost using conventional material	Y

[a] Y = Yes, N = No

X1.4.6. A summary of the results of the Stage 1 screen is presented in Table X1.13. The reviewing agencies determine that the submitted engineering data are adequate.

Table X1.13—Stage 1 Screen Results

Evaluation Area	Evaluation Results
Engineering	The engineering evaluation did not identify any problematic issues. The industrial slag meets all required engineering criteria, and the production process meets required quality control criteria. No further engineering evaluation is required.
Environmental, Health, and Safety	Due to the lack of data, a Stage 1 evaluation could not be performed. A Stage 2 analysis is required.
Recycling	Due to the absence of environmental data, analysis of recycling issues could not be fully assessed.
Implementation	Due to the absence of environmental data, analysis of implementation issues could not be fully assessed.
Economic	It is economically practical to utilize the slag in the proposed application.

X1.5. *Step 4—Stage 2 Laboratory Testing*

X1.5.1. On the basis of the results of the Stage 1 screen, the decision maker prepares an environmental test plan and criteria for evaluation. Table X1.14 provides an outline of the Stage 2 environmental test plan, criteria, and results. The sequence of environmental tests presented in Table X1.14 is consistent with the environmental properties and tests outlined in Chapter 5, Table 5-2 of the "Framework" document for aggregate substitutes in bound applications.

Table X1.14—Stage 2 Environmental Testing Results

Environmental Property	Criteria	Results
Regulatory Testing of Aggregate Substitute	40 CFR, Part 261.21 40 CFR, Part 261.22 40 CFR, Part 261.23 40 CFR, Part 261.24	Nonignitable Noncorrosive Nonreactive Nontoxic
Inorganic Composition of Aggregate Substitute	Soil reference guidelines	The concentrations of arsenic and chromium were approximately one order of magnitude above the soil reference standards.
Organic Composition of Aggregate Substitute	—	Not required by decision maker since the material has undergone a high-temperature process.
Particle Size of Aggregate Substitute	—	Not required by decision maker since the material is a glassy substance and <1% of the material passes a No. 200 sieve. Fugitive dust emissions are not expected.
Mineralogical Composition of Aggregate Substitute	—	Not required by decision maker because the material has a low dusting potential and a low crystalline silica content.
Inorganic Leaching of Aggregate Substitute	U.S. EPA[a] drinking water standards	A distilled water leaching test was used to determine the inorganic leaching properties of the industrial slag. All leachate concentrations were below drinking water criteria but the upper 90% confidence limit for arsenic exceeds the criteria. A sample statistical calculation is presented in Table X1.15.
Organic Leaching of Aggregate Substitute	—	Not required by decision maker since material has undergone a high-temperature process.
Acid-Base Behavior of Aggregate Substitute	Soil reference guidelines	Results indicate increased leaching of arsenic under acidic conditions.
Product Inorganic Leaching	U.S. EPA[a] drinking water standards	Product inorganic leaching was determined using a distilled water leaching test and the TCLP[b] protocol on crushed product containing the industrial slag. All leachate concentrations were below drinking water criteria.
Product Organic Leaching	—	Not required by decision maker since the material has undergone a high-temperature process.
Product Abrasion	—	Not required by decision maker since material will be in binder course.
Product—Volatile Emissions	—	Not required by decision maker since the material has undergone a high-temperature process.

[a] United States Environmental Protection Agency

[b] Toxicity Characteristic Leaching Procedure

X1.5.2. The applicant is requested to undertake regulatory tests, inorganic composition tests, inorganic leaching tests, acid-base leach tests, and product inorganic leach tests.

X1.5.3. The results of these tests indicate that the slag is nonhazardous but contains concentrations of arsenic and chromium that were one order of magnitude higher than soil reference guidelines (cleanup guidelines). Leachate concentrations from distilled water leaching tests for inorganic constituents were all less than drinking water standards but the 90 percent confidence limit for arsenic exceeded the drinking water criterion as shown in Table X1.15. Acid-base leaching tests revealed higher arsenic concentrations in higher acid (low pH) solutions. Product testing was undertaken by preparing a design mix in which the slag was incorporated into the hot mix product. The product was subjected to a distilled water leach test and to TCLP testing protocols to assess the potential for leaching of the product in an aggressive leaching environment. All leachate concentrations were found to be below drinking water criteria.

Table X1.15—Stage 2 Environmental Testing Sample Statistical Calculation

Sample Arsenic Concentrations (µg/L): 38, 55, 51, 39, 42
Arsenic Drinking Water Criteria (µg/L): 50
Average Concentration (µg/L): 45
Standard Deviation: 7.58
N: 5
t: 2.132

The Upper Concentration Limit (UCL) can be calculated using a *t* statistic at = 0.05 for *n*–1 degrees of freedom (4) which is 2.132.

$UCL = 45 + 2.132\ (7.58/(5)^{1/2})$
$UCL = 52.2$

Here, the UCL of 52.2 exceeds the criteria of 50, and the material is deemed to exceed the criteria even though the average is 45.

X1.6. *Approval Process*—Upon review of the Stage 2 environmental test results, the decision maker determines that there is minimal potential risk to the environment if the slag is used in the proposed application. Nonetheless, to ensure environmental protection, the decision maker issues a categorical approval for the proposed application, which provides a number of test requirements and application limitations. The decision maker requires the following:

- The slag may be used in a hot mix base course at levels not to exceed 10 percent by weight of aggregate.
- A monitoring program is established to test for levels of arsenic and chromium in the slag product and a limiting level (one order of magnitude above the soil guidelines) is established. Any concentration above such levels would result in material rejection.

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[1] Approved in December 2005, this provisional standard was first published in July 2006. Reconfirmed in 2008.

Standard Practice for

Establishing Requirements for and Performing Equipment Calibrations, Standardizations, and Checks

AASHTO Designation: PP 57-06 (2009)[1]

**American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001**

Standard Practice for

Establishing Requirements for and Performing Equipment Calibrations, Standardizations, and Checks

AASHTO Designation: PP 57-06 (2009)[1]

1. SCOPE

1.1. This document contains general criteria and guidelines for establishing requirements for and performing equipment calibrations, verification of calibrations, standardizations, and checks.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 201, Kinematic Viscosity of Asphalts (Bitumens)
- T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

2.2. *International Standards*:

- *International Vocabulary of Basic and General Terms in Metrology* (VIM), second edition. International Organization for Standardization, Geneva, Switzerland, 1993.
- ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories
- *ISO Guide to the Expression of Uncertainty in Measurement* (GUM). International Organization for Standardization, Geneva, Switzerland, 1995. The U.S. edition of the GUM is entitled *American National Standard for Expressing Uncertainty—U.S. Guide to the Expression of Uncertainty in Measurement*, ANSI/NCSL Z540-2-1997.

3. TERMINOLOGY

3.1. *accuracy of measurement*—closeness of the agreement between the result of a measurement and a true value of the measurand (VIM, Section 3.5).

3.1.1. *Discussion*—Part 1 of the international standard ISO 5725-1 on the accuracy of measurement methods and results defines accuracy as the closeness of agreement between a test result and the accepted reference value. This definition is supplemented by a note which states that the term accuracy, when applied to a set of test results, involves a combination of random components and a common systematic error or bias component. Accuracy is thus viewed as a characteristic of a measurement process consisting of precision as well as bias components. A process is considered to be accurate only if it is precise as well as unbiased.

The expanded uncertainty of a measurement, discounting the bias, is equivalent to the accuracy of the measurement after a correction or correction factor is applied.

3.2. *calibration, n*—a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or between values represented by a material measure or a reference material, and the corresponding values realized by standards (VIM, Section 6.11).

3.2.1. *Example*—Balances (measurement instrument), Dynamic Shear Rheometer (measuring system), Pycnometer (material measure).

3.2.2. *Discussion*—The purpose of calibration is to ensure that measurements made by the laboratory are traceable to the International System of Units (SI). Where traceability of measurements to SI units is not possible or relevant, measurements must be traceable to certified reference materials, agreed methods, or consensus standards. Uncertainty estimates obtained during calibration are used to judge if an instrument is suitable for its intended purpose. There is a need to re-establish traceability or recalibrate only when instrument measurements drift out of control [as determined through verification of calibration (Section 3.10)].

3.3. *check, n*—a specific type of inspection and/or measurement performed on the physical properties of equipment and materials to determine compliance or otherwise with stated criteria.

3.4. *correction, n*—value added algebraically to the uncorrected result of a measurement to compensate for systematic error (VIM, Section 3.15).

3.4.1. *Discussion*—Since the systematic error cannot be known perfectly, the correction can only be an estimate.

3.5. *correction factor, n*—numerical factor by which the uncorrected result of a measurement is multiplied to compensate for systematic error (VIM, Section 3.16).

3.5.1. *Discussion*—Since the systematic error cannot be known perfectly, the correction factor can only be an estimate.

3.6. *standard, n*—material measure, measuring instrument, reference material, or measuring system intended to define, realize, conserve, or reproduce a unit of one or more values of a quantity to serve as a reference (VIM, Section 6.1).

3.7. *standardization, n*—a process that determines (1) the correction or correction factor to be applied to the result of a measuring instrument, measuring system, material measure, or reference material when its values are compared to the values realized by standards, (2) the adjustment to be applied to a piece of equipment when its performance is compared with that of an accepted standard or process.

3.7.1. *Discussion*—Standardization in case (1) is a simplified form of calibration that estimates systematic error but does not identify random error. Standardization, therefore, does not address all of the elements of uncertainty of measurement and does not lead to traceable measurements. An example of case (2) standardization is adjusting the number of blows of a mechanically operated hammer so it applies the energy equivalent to that of a manually operated hammer.

3.8. *traceability, n*—the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties (VIM, Section 6.10).

3.8.1. *Discussion*—There is a need for traceable measurements. Measurements, not the instrument, can be traceable. Measurement traceability is established through calibration. Measurement traceability is maintained through verification of calibration (a regular check of instrument output using a control standard).

3.9. *uncertainty of measurement, n*—parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (VIM, Section 3.10).

3.9.1. *Discussion*—The uncertainty of a measurement is required in order to establish its traceability. An evaluation of the uncertainty of measurement is conducted to determine if measurement equipment is fit for purpose.

The expanded uncertainty of a measurement, discounting the bias, is equivalent to the accuracy of the measurement after a correction or correction factor is applied.

3.9.2. The definitions of various uncertainty terms used in the GUM are:

- *Standard uncertainty*—uncertainty of the result of a measurement expressed as a standard deviation.
- *Combined standard uncertainty*—standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of the sum of the terms, the terms being the variances or covariance of these other quantities weighed according to how the measurement result varies with change in these quantities.
- *Expanded uncertainty*—quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurement.
- *Coverage factor*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty. The coverage factor *k* is typically in the range of 2 to 3.

3.10. *verification of calibration, n*—a process that establishes whether the results of a previously calibrated measurement instrument, measurement system, material measure, or reference material are in control.

3.10.1. *Discussion*—Verification of calibration is used to maintain the traceability of a measurement and to determine when to recalibrate. Control charts should be used to plot verification results and determine if instrument measurements have drifted out of control.

3.11. *verification of standardization, n*—a process that establishes whether the results of a previously standardized measurement instrument, measurement system, material measure, or reference material are in control.

3.11.1. *Discussion*—Verification of standardization is used to indicate when a shift in the population average occurs and when it is time to re-standardize. Control charts should be used to plot verification results and determine if instrument measurements have drifted out of control.

4. SIGNIFICANCE AND USE

4.1. Construction material test standards can be improved if equipment calibrations, standardizations, and checks are properly specified and if each activity and its requirements are understood.

4.2. The guidance in this document is intended to be used by standards developers in the selection of terms used in methods and in the establishment of appropriate requirements for equipment calibrations, standardizations, and checks.

4.3. The guidance in this document can also be used by laboratories for performing equipment calibrations, standardizations, and checks.

5. GUIDANCE FOR STANDARDS DEVELOPERS

5.1. *Calibration or Standardization versus Checking*—Most measuring instruments, measuring systems, and material measures should be either calibrated or standardized. Checking applies to test equipment that is not a measuring instrument, measuring system, or material measure such as an oven, straightedge, or specimen mold.

5.2. *Determining if Equipment Checks Are Necessary*—The primary consideration in deciding whether a piece of test equipment should be checked is the equipment's influence on the test result. If the physical properties of a piece of equipment could significantly influence the test result, then routine checks to determine compliance or otherwise with stated criteria are essential. However, if the physical properties of a piece of test equipment are not likely to affect the test result, routine equipment checks are not necessary.

5.3. *Calibration versus Standardization*—The two primary considerations for making the decision to calibrate or standardize a measuring instrument, measuring system, or material measure are (1) the measurement's influence on the test result and (2) the probability that the uncertainty of measurement could exceed the accuracy requirement of the measurement. Refer to Table 1 for guidance for determining whether to specify equipment calibration, standardization, or nothing.

Table 1—Guidance for Determining Whether Equipment Shall Be Calibrated, Standardized, or Neither

		Probability That the Uncertainty of Measurement Could Exceed the Accuracy Requirement of the Measurement		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Standardize	Calibrate	Calibrate
	Moderate	Standardize	Standardize	Calibrate
	Low	Nothing	Standardize	Standardize

5.4. *Selecting and Specifying Intervals for Equipment Calibrations, Standardizations, and Checks*—Equipment calibration, standardization, and check intervals shall be specified in the test methods (Notes 1 and 2). The two primary considerations for determining an acceptable interval are (1) the probability that time and/or usage will affect the instrument or device and (2) the measurement's or device's influence on the test result. Refer to Table 2 for guidance for determining intervals between calibrations, standardizations, and checks.

Note 1—When the risk associated with using inaccurate equipment or nonconforming equipment is high, equipment should be monitored frequently. When the risk is low, less frequent monitoring may suffice.

Note 2—Since the user may have verification of calibration data to support extending a calibration interval beyond the interval specified, the following wording is suggested for use when specifying calibration intervals: "In the absence of verification of calibration data to support the extension of the interval between calibrations, the interval between calibrations shall not exceed ______ months."

Table 2—Determining the Interval between Equipment Calibrations, Verification of Calibrations, Standardizations, and Checks

		Probability That Time or Usage Will Affect the Instrument/Device		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)	Frequent Monitoring (High Risk)
	Moderate	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)
	Low	Infrequent Monitoring (Low Risk)	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)

Note 3—Intervals for frequent monitoring should be between 1 month and 4 months; intervals for moderate monitoring should be between 4 and 12 months; intervals for infrequent monitoring should be between 12 and 24 months.

6. GUIDANCE FOR LABORATORIES THAT CHOOSE TO EXTEND CALIBRATION OR STANDARDIZATION INTERVALS BEYOND THE INTERVALS SPECIFIED IN STANDARDS

6.1. *General*—A laboratory may use the calibration and standardization intervals specified in a standard or may extend calibration and standardization intervals beyond the intervals specified in the standards. To extend calibration and standardization intervals beyond those specified, a laboratory must establish and implement a program for continual verification of equipment calibrations and standardizations.

6.2. Appendix X1 gives an example of an acceptable "verification of calibration" program. A "verification of standardization" program would be similar to the "verification of calibration" program.

7. REQUIREMENTS FOR LABORATORIES PERFORMING CALIBRATIONS, STANDARDIZATIONS, AND CHECKS

7.1. *General (the Risk)*—When the results of equipment calibrations, standardizations, or checks indicate that the equipment is out of conformance with specified requirements, the user shall evaluate the significance of the nonconforming work. The user shall review all test results reported since the previous calibration, verification of calibration, standardization, or check and notify clients if the validity of reported test results is in doubt.

7.2. *Calibrations*—Calibrations specified in a test method shall be performed by an accredited calibration service provider (see Note 4) or by a calibration service provider that has provided evidence that it conforms to the applicable requirements of ISO/IEC 17025.

Note 4—The National Voluntary Laboratory Accreditation Program (http://ts.nist.gov/standards/scopes/programs) and the American Association for Laboratory Accreditation (http://www.a2la.org) accredit calibration service providers.

7.2.1. Standards used to calibrate equipment shall be certified reference materials or standards calibrated by an accredited calibration laboratory (see Note 4).

Note 5—The expanded uncertainty of the standard used for equipment calibration purposes should be no greater than one half of the required accuracy of the equipment.

Note 6—Certificates that accompany standards used for calibrating equipment should include estimates of expanded uncertainty, the calibration conditions, and a reference to the calibration method.

7.2.2. The calibration process shall include an estimation of the uncertainty of measurement.

Note 7—Some of the factors that contribute to the uncertainty of measurement are the reference standard, the measurement method, repeatability of the instrument, resolution of the instrument, operator, and environmental conditions.

7.2.3. All calibrations shall be concluded with a comparison of the uncertainty of measurement with the required accuracy to determine whether the instrument is fit for purpose.

Note 8—Measurement uncertainty can be reduced by choosing a better reference standard and/or improving the calibration method.

7.2.4. The interval between equipment calibrations shall be no greater than the intervals specified in a method unless the laboratory has implemented a verification of calibration program. Where intervals are not specified, the interval between calibrations established by the laboratory shall be dictated by (1) equipment usage and the risks associated with making inaccurate measurements (see Table 2) or (2) the results of verification of calibration data (see Note 9) obtained at intervals chosen to minimize the risk of making inaccurate measurements.

Note 9—The interval between verification of equipment calibrations should also be dictated by equipment usage and the risks associated with making inaccurate measurements.

Note 10—Ideally, equipment should only be recalibrated when there is evidence to suggest that measurements are unstable.

7.3. *Standardizations*—Standards used to standardize equipment shall be reference materials or standards calibrated by an accredited calibration laboratory (see Note 4).

Note 11—The expanded uncertainty of the reference standard used for conducting standardization should be no greater than one half of the required accuracy of the equipment.

7.3.1. All standardizations shall be concluded with a comparison of the systematic error with the required accuracy to determine whether a correction or correction factor is necessary.

7.3.2. The interval between equipment standardizations shall be no greater than the interval specified in a method unless the laboratory has implemented a verification of standardization program. Where an interval is not specified, the interval between standardizations established by the laboratory shall be dictated by equipment usage and the risks associated with making inaccurate measurements (see Table 2).

7.4. *Checks*—The interval between equipment checks shall be no greater than the interval specified in the method unless such equipment is checked before each use or the laboratory has documented evidence to show that, for a specific level of usage, the conformance of the equipment to specification requirements would not be likely to change (see Note 12). Where an interval is not specified, the interval between equipment checks established by the laboratory shall be dictated by equipment usage and the risks associated with using nonconforming equipment.

Note 12—Measurement instruments used to make equipment checks should be calibrated and should have an expanded uncertainty of no greater than one half of the specified equipment tolerance.

Note 13—Equipment check intervals may be extended provided that equipment check data indicates that the equipment wear is predictable over time. Analysis of the equipment check data may indicate that the interval should be decreased to ensure that the equipment consistently meets the specification requirements or is removed from service when appropriate.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF A VERIFICATION OF CALIBRATION PROGRAM FOR LABORATORIES

X1.1. *General*—Laboratories interested in extending calibration intervals beyond the intervals specified in the standards and those interested in establishing a Laboratory Equipment Assurance Program should establish and implement a program for the continual verification of equipment calibrations.

X1.2. *Requirements*:

X1.2.1. *Artifact check standard*—A device for controlling the bias and long-term variability of the process once a baseline for these quantities has been established from historical data on the check standard. A stable artifact, such as a steel mass, might be an appropriate check standard for a verification of calibration program for balances.

X1.2.2. Graphing software, such as Microsoft Excel®.

X1.3. *Example*—A laboratory currently pays a calibration service to calibrate all of its balances every 12 months. The laboratory has decided to implement the following verification of calibration program for its balances in an effort to eliminate unnecessary recalibrations, reduce the cost of calibrations, and improve their mass measurements. The laboratory followed these steps:

- Establish artifact
- Take repeat measurements
- Collect readings in spreadsheet
- Calculate subgroup mean and subgroup range
- Draw average (x-bar) and range (R) charts
- Evaluate charts

Note X1—The process is in statistical control if the points in the control chart are distributed randomly and between the control limits. The WECO rules (Western Electric Company Rules) are a good indicator that the process may be out of control. [Visit the National Institute of Standards and Technology (NIST) website for more information: http://www.itl.nist.gov/div898/handbook/pmc/pmc.htm].

WECO Rules:

Any Point Above +3 Sigma
-- +3 σ LIMIT
2 Out of the Last 3 Points Above +2 Sigma
-- +2 σ LIMIT
4 Out of the Last 5 Points Above +1 Sigma
-- +1 σ LIMIT
8 Consecutive Points on This Side of Control Line
== CENTERLINE
8 Consecutive Points on This Side of Control Line
-- –1 σ LIMIT
4 Out of the Last 5 Points Below – 1 Sigma
-- –2 σ LIMIT
2 Out of the Last 3 Points Below –2 Sigma
-- –3 σ LIMIT
Any Point Below –3 Sigma

Trend Rules: 6 in a row trending up or down, 14 in a row alternating up and down.

Note X2—An out-of-control condition in the average (x-bar) chart indicates a shift in the population average and could be due to the measuring equipment going out of calibration or some problem with the check standard itself. An out-of-control condition in the range (R) chart indicates an increase in the dispersion of the repeat observations, which could be attributed to inadequate control of the environment or incompetence of the operator involved in the measurements.

X1.4. *Data*—A laboratory places a nominal 2000 g mass on a balance each morning and takes five readings. The measurements are recorded and then collected in a spreadsheet. Each set of five readings is considered a subgroup. Subgroup averages and ranges are calculated. The average of the subgroup averages and the average of the subgroup ranges are calculated after approximately twenty subgroups. See the example spreadsheet and control charts below. The interval between verifications could remain daily or be extended to weeks, months, or greater (see Note X3).

Note X3—The interval between verification of equipment calibrations should also be dictated by equipment usage and the risks associated with making inaccurate measurements.

Table X1.1—Verification of Calibration Data for Balance

Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Subgroup average	Max	Min	Subgroup range
2000.2	2000.4	2000.2	2000.2	2000.3	2000.3	2000.4	2000.2	0.2
2000.2	2000.2	2000.3	2000.3	2000.3	2000.3	2000.3	2000.2	0.1
2000.2	2000.4	2000.3	2000.3	2000.3	2000.3	2000.4	2000.2	0.2
2000.3	2000.5	2000.3	2000.3	2000.4	2000.4	2000.5	2000.3	0.2
2000.4	2000.4	2000.4	2000.3	2000.3	2000.4	2000.4	2000.3	0.1
2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	0.0
2000.4	2000.3	2000.4	2000.4	2000.4	2000.4	2000.4	2000.3	0.1
2000.3	2000.3	2000.3	2000.4	2000.4	2000.3	2000.4	2000.3	0.1
2000.4	2000.3	2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	0.1
2000.4	2000.4	2000.4	2000.4	2000.3	2000.4	2000.4	2000.3	0.1
2000.3	2000.3	2000.4	2000.4	2000.4	2000.4	2000.4	2000.3	0.1
2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	0.0
2000.4	2000.3	2000.3	2000.4	2000.4	2000.4	2000.4	2000.3	0.1
2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	2000.4	2000.3	0.1
2000.4	2000.3	2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	0.1
2000.3	2000.4	2000.4	2000.3	2000.3	2000.3	2000.4	2000.3	0.1
2000.3	2000.4	2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	0.1
2000.3	2000.4	2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	0.1
2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	0.0
2000.3	2000.3	2000.2	2000.3	2000.3	2000.3	2000.3	2000.2	0.1
2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	2000.3	0.0
2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	2000.4	2000.3	0.1
2000.4	2000.3	2000.3	2000.3	2000.3	2000.3	2000.4	2000.3	0.1
2000.4	2000.3	2000.5	2000.3	2000.3	2000.4	2000.5	2000.3	0.2
2000.3	2000.3	2000.3	2000.4	2000.3	2000.3	2000.4	2000.3	0.1
2000.3	2000.4	2000.4	2000.4	2000.4	2000.4	2000.4	2000.3	0.1
2000.1	2000.1	2000.1	2000.1	2000.0	2000.1	2000.1	2000.0	0.1
1999.7	1999.6	1999.7	1999.6	1999.5	1999.6	1999.7	1999.5	0.2
2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	2000.0	0.0
2000.0	2000.1	2000.0	2000.1	2000.1	2000.1	2000.1	2000.0	0.1
2000.0	2000.0	2000.0	1999.9	2000.0	2000.0	2000.0	1999.9	0.1
1999.9	2000.1	2000.0	2000.1	2000.0	2000.0	2000.1	1999.9	0.2
1999.9	1999.9	2000.0	2000.0	1999.9	1999.9	2000.0	1999.9	0.1
				Average:	2000.32			0.10

X1.5. *Control Charts*:

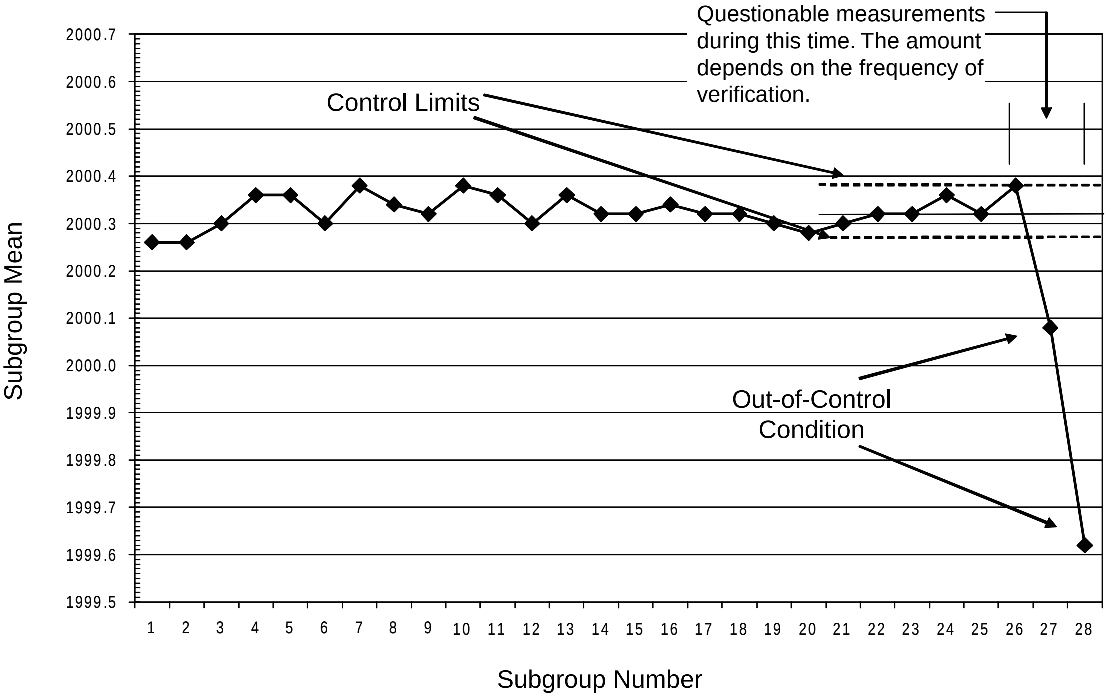

Figure X1.1—Average (X-bar) Chart for Verification of Balance Calibration

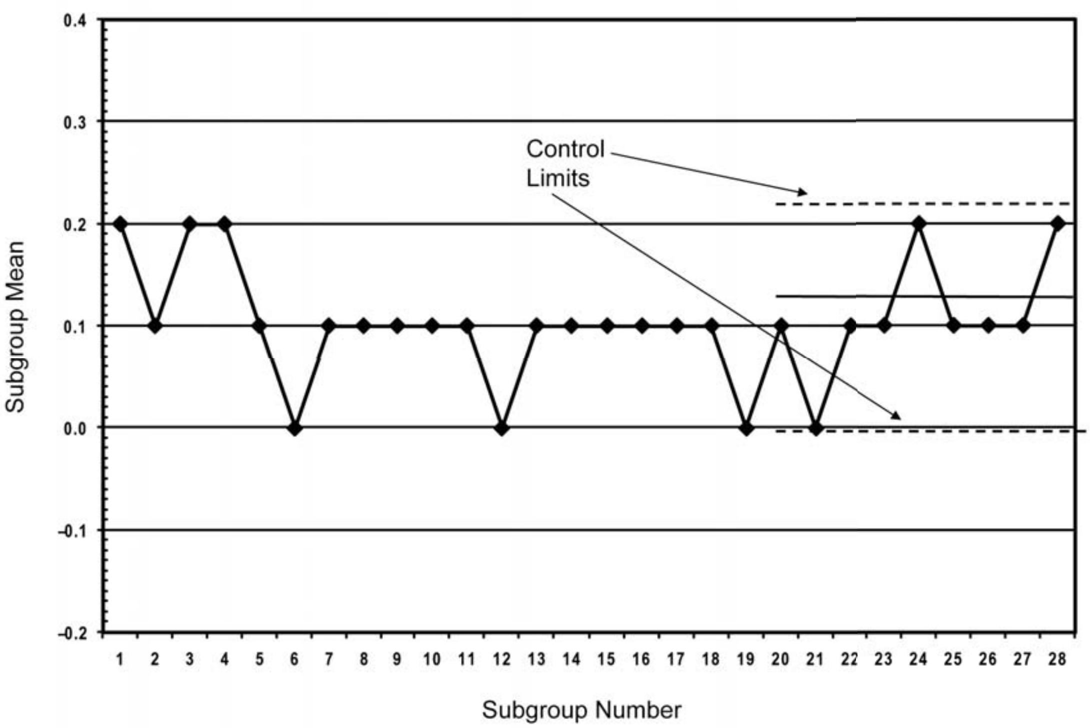

Figure X1.2—Range (R) Chart for Verification of Balance Calibration

X2. EXAMPLE OF A CALIBRATION REQUIREMENT FOR MEASURING EQUIPMENT

X2.1. *Decision to Calibrate the Equipment*—AASHTO T 201 (Kinematic Viscosity of Asphalts) states that a "…liquid-in-glass thermometers of an accuracy after correction of 0.02°C (0.04°F) can be used or any other thermometric device of equal accuracy."

This thermometer sits in a water or oil bath which holds the viscometer and the asphalt. The viscosity of asphalt is highly dependent on temperature. Additionally, since the accuracy requirement for the thermometer is small, the probability that the uncertainty of the temperature measurement could exceed the accuracy requirement for temperature is high. Therefore, the decision should be made to specify calibration for the thermometer.

		Probability That the Uncertainty of Measurement Could Exceed the Accuracy Requirement of the Measurement		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Standardize	Calibrate	Calibrate
	Moderate	Standardize	Standardize	Calibrate
	Low	Nothing	Standardize	Standardize

Figure X2.1—Guidance for Determining Whether Equipment Shall Be Calibrated, Standardized, or Neither

		Probability That Time or Usage Will Affect the Instrument/Device		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)	Frequent Monitoring (High Risk)
	Moderate	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)
	Low	Infrequent Monitoring (Low Risk)	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)

Figure X2.2—Determining the Interval between Equipment Calibrations, Verification of Calibrations, Standardizations, and Checks

X2.2. *Specifying Calibration*—"A liquid-in-glass thermometer or other thermometric device calibrated at the desired test temperatures shall be used. Each test temperature shall have an expanded uncertainty of measurement of 0.02°C (0.04°F) or less after applying any corrections."

X2.3. *Selecting the Calibration Interval (Standards Developer)*—As stated previously, the viscosity of asphalt is highly dependent on temperature. Additionally, most temperature measuring devices, especially liquid-in-glass thermometers, are susceptible to change with time and usage. Therefore, this instrument should be subjected to frequent monitoring.

X2.4. *Specifying the Calibration Interval*—"The thermometer used in this test shall be recalibrated at least every 4 months."

X2.5. *Selecting a Calibration Interval (Laboratory)*—A laboratory has two options in this case: accept the interval specified in the method (4 months) or implement process control through a verification of calibration program.

X2.5.1. Laboratory "A" performs many tests each day and chooses to implement a process control plan by comparing the test temperature of the working thermometer against that of a calibrated reference thermometer having an uncertainty of measurement of 0.01°C every month. Laboratory "A" records the difference in temperatures on a control chart and plans to recalibrate the working thermometer only if the plot of temperature differences indicates that the working thermometer has become unstable.

X2.5.2. Laboratory "B" performs a test once a week and plans to send their working thermometer to a local accredited calibration service provider for recalibration every 4 months.

X3. EXAMPLE OF A STANDARDIZATION REQUIREMENT FOR MEASURING EQUIPMENT

X3.1. *Decision to Standardize the Equipment*—AASHTO T 245 (Marshall Method) specifies thermometers for water baths that are sensitive to 0.2°C (0.4°F).

The water bath is used to heat the specimens to test temperature (60°C) before they are tested. The temperature of the specimens has a moderate effect on the test result. Additionally, there is a moderate probability that the uncertainty of the temperature measurement could exceed 0.2°C (0.4°F). Therefore, the decision should be made to specify standardization for the thermometer.

		Probability That the Uncertainty of Measurement Could Exceed the Accuracy Requirement of the Measurement		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Standardize	Calibrate	Calibrate
	Moderate	Standardize	Standardize	Calibrate
	Low	Nothing	Standardize	Standardize

Figure X3.1—Guidance for Determining Whether Equipment Shall Be Calibrated, Standardized, or Neither

X3.2. *Specifying Standardization*—"Thermometers for water baths shall be standardized at the test temperature. Corrections shall be applied to compensate for any systematic error."

X3.3. *Selecting the Standardization Interval (Standards Developer)*—Moderate to high risk exists as the temperature measurement has a moderate influence on the test result and there is a moderate to high probability that time or usage will affect the thermometer.

		Probability That Time or Usage Will Affect the Instrument/Device		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)	Frequent Monitoring (High Risk)
	Moderate	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)
	Low	Infrequent Monitoring (Low Risk)	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)

Figure X3.2—Determining the Interval between Equipment Calibrations, Verification of Calibrations, Standardizations, and Checks

X3.4. *Specifying the Standardization Interval*—"Thermometers for water baths shall be standardized at the test temperature at least every 6 months. Corrections shall be applied to compensate for any systematic error."

X4. EXAMPLE OF A "NOTHING" REQUIREMENT FOR MEASURING EQUIPMENT (NO CALIBRATION OR STANDARDIZATION)

X4.1. *Decision to Specify Nothing*—AASHTO T 176 (Sand Equivalent Test) specifies the use of a clock or watch (reading in minutes and seconds) for timing approximately 30 seconds for the hand-shaking method. This measurement has a very small influence on the test result, and there is no specified accuracy requirement. Even if one assumed an accuracy requirement of 1 second, the probability that the uncertainty of the time measurement could exceed 1 second is low. Therefore, the decision should be made to specify neither calibration nor standardization.

		Probability That the Uncertainty of Measurement Could Exceed the Accuracy Requirement of the Measurement		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Standardize	Calibrate	Calibrate
	Moderate	Standardize	Standardize	Calibrate
	Low	Nothing	Standardize	Standardize

Figure X4.1—Guidance for Determining Whether Equipment Shall Be Calibrated, Standardized, or Neither

X5. EXAMPLE OF AN EQUIPMENT CHECK REQUIREMENT

X5.1. *Decision to Check the Equipment*—AASHTO T 245 (Marshall Method) specifies that the internal diameter of the compaction mold shall be 3.995 in. to 4.005 in. This is not a requirement of the output of the device but rather is a requirement of its physical properties (dimensions). Therefore, a decision should be made to specify a check of the mold.

X5.2. *Specifying an Equipment Check*—"The internal diameter of mold cylinders shall be checked to determine whether they conform to the details shown in Figure 1 [of T 245]."

X5.3. *Selecting an Equipment Check Interval (Standards Developer)*—The mold's influence on the test results (stability and flow) is low. The probability that usage will affect the mold is moderate to high. Therefore, not checking the molds would lead to moderate risk.

		Probability That Time or Usage Will Affect the Instrument/Device		
		Low	Moderate	High
Measurement's Influence on the Test Result	High	Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)	Frequent Monitoring (High Risk)
	Moderate	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)	Frequent Monitoring (High Risk)
	Low	Infrequent Monitoring (Low Risk)	Infrequent Monitoring (Low Risk)	Moderate Monitoring (Moderate Risk)

Figure X5.1—Determining the Interval between Equipment Calibrations, Verification of Calibrations, Standardizations, and Checks

X5.4. *Specifying an Equipment Check Interval*—"The internal diameter of mold cylinders shall be checked at least every 12 months to determine whether they conform to the details shown in Figure 1 [of T 245]."

X5.5. *Selecting an Equipment Check Interval (Laboratory)*—A laboratory has two options, adopt the check interval specified in the method or establish a process control program that allows it to predict when the mold will cease to meet specification requirements.

X5.5.1. Laboratory "A" develops a process control plan by predicting the average life of each mold and extending the intervals for checking.

Date	Mold #1 (in.)	Mold #2 (in.)	Mold #3 (in.)
Dec. 1997	3.998	4.001	3.996
Dec. 1998	3.998	4.001	3.997
Dec. 1999	3.999	4.002	3.998
Dec. 2000	4.000	4.002	3.998
Dec. 2001	4.001	4.003	3.999
Wear Rate	0.0006/yr	0.0004/yr	0.0006/yr
Avg. wear rate = 0.0005 in./yr			

X5.5.2. Laboratory "B" performs only a few tests each month. The laboratory chooses to adopt a 12-month schedule for checking the internal diameter of their molds. In addition, they plan to record and analyze mold usage data and the results of the equipment checks and determine if it is feasible to extend the check interval beyond 12 months with minimal risk of using nonconforming equipment.

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[1] Approved in December 2005, this standard was first published in July 2006. Reconfirmed in 2007, 2008, and 2009.

Standard Practice for

Coal Combustion Fly Ash for Embankments

AASHTO Designation: PP 59-09[1]

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Coal Combustion Fly Ash for Embankments

AASHTO Designation: PP 59-09[1]

1. SCOPE

1.1. This practice covers the use of coal combustion fly ash (typically but not limited to non-self-hardening ash) as a fill material for the construction of embankments.

1.2. When properly processed, hauled, spread, and compacted on a prepared grade to appropriate density standards, coal combustion fly ash used alone, or blended with traditional soil aggregate or other approved aggregate materials, can be expected to provide a lighter-than-normal weight fill material (85 to 100 pcf, 1360 to 1600 kg/m^3) with adequate stability and load support for use as road or highway embankment.

1.3. The technique described in this practice uses containment berms, cover fill material, and sometimes a liner and leachate system to isolate the fly ash and any resulting effluent. This is a conservative approach to the environmental issues raised by the use of fly ash as fill, and may not be required for all fly ashes or for all regulatory requirements.

1.4. This practice recognizes that since fly ash is a by-product of the burning of coal in electricity- and steam-generating facilities, various state, county, and local environmental laws and regulations apply if fly ash is used as an alternative embankment material. Aspects of fly ash that are of environmental concern are identified. Therefore, this standard discusses elements such as impermeable layers and leachate collection, as they may be required according to the environmental regulations affecting the proposed installation.

1.5. More specific guidance for the detailed use of fly ash as embankment material may be found in ASTM E 2277.

1.6. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 146, Terms Relating to Subgrade, Soil-Aggregate, and Fill Materials
- M 295, Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 99, Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
- T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop

- T 272, Family of Curves—One-Point Method
- T 310, In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

2.2. *ASTM Standards*:

- C 295, Standard Guide for Petrographic Examination of Aggregates for Concrete
- C 311, Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
- D 5918, Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils
- E 2201, Standard Terminology for Coal Combustion Products
- E 2277, Standard Guide for Design and Construction of Coal Ash Structural Fills

2.3. *U.S. EPA Test Methods*:

- SW-846, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, 3rd Edition

3. GENERAL DESCRIPTION

3.1. Fly ash is the finely divided residue that results from the combustion of coal. Fly ash is the airborne residue that exits a coal combustion chamber with the flue gas and is removed from the flue gas by electrostatic precipitation, baghouses, or other particulate control devices prior to the introduction of scrubber reagents. It contains siliceous and aluminous materials.

3.2. For purposes of this practice, fly ash is divided into two types. One is self-hardening and the other is non-self-hardening. Both types contain siliceous or siliceous and aluminous materials, which in the presence of lime or portland cement and water react to form a cementitious material.

3.2.1. *Self-hardening fly ash (Class C)*—For the purpose of this practice shall mean fly ash that will form cementitious material in the presence of water alone.

3.2.2. *Non-self-hardening fly ash (Class F)*—For the purpose of this practice shall mean fly ash that requires the presence of lime or portland cement and water to form a cementitious material. It is likely that fly ash used in accordance with this practice will commonly be the non-self-hardening type, as it is less desirable for other uses.

3.3. Additional definitions relative to fly ash and other coal combustion by-products are provided in ASTM E 2201.

3.4. The very fine-grained nature of fly ash, similar to that of natural silt-sized materials, makes it susceptible to vertical capillary water migration. Capillary water migration in embankments could lead to embankment saturation and instability under loading or frost heaving due to the development of ice lenses. As such, this practice recommends that a layer of open-graded granular material be constructed at the base of the fly ash embankment, and a layer of cover material be constructed on top of the embankment to prevent frost penetration into the fly ash in frost-prone locations.

3.5. Aqueous solutions that percolate through fly ash or fly ash containing admixtures could exhibit pH values that fall outside the range of 5 to 9. The engineer is cautioned that aqueous solutions with pH values that fall outside this range could result in corrosive conditions detrimental to concrete or metal conduit structures.

3.6. For cases where applicable laws and regulations raise concern regarding the quality of the leachate from the fly ash embankment, this practice includes a liner and leachate collection system.

3.7. The definitions of fill material and other soil aggregate terms are provided in M 146.

4. FLY ASH ORDERING INFORMATION

4.1. *The purchaser or specifier of coal fly ash shall include the following information in the purchase order or contract documents*:

4.1.1. Reference to this standard, including year;

4.1.2. Reference to the requirements of state, local, or both, environmental protection agencies;

4.1.3. Requirements for grading, blending, or both;

4.1.4. Type or types of fly ash specified (self-hardening fly ash is commonly referred to as Class C ash and non-self-hardening fly ash is referred to as Class F); and

4.1.5. Exceptions or additions to this standard.

5. PHYSICAL AND CHEMICAL PARAMETERS

5.1. *Fly Ash*:

5.1.1. Fly ash shall meet the requirements set forth in the contract documents in regard to gradation, blending, and type of fly ash.

5.1.2. If not otherwise stated in the contract documents, fly ash supplied as an embankment material shall have 100 percent of the material pass the 12.7-mm ($^1/_2$-in.) sieve.

5.1.3. The loss on ignition (LOI) of the fly ash should not exceed 20.0 percent when tested in accordance with ASTM C 311. This guide limit on LOI has been established to allow fly ashes to be used for fill that have LOIs that are typically too high for use in concrete, without allowing such a high LOI that environmental impacts and buried energy issues become too large.

5.1.4. Fly ash may be combined with other approved embankment materials or admixtures as approved by the engineer. Mixing shall be accomplished by the use of mechanical interlock systems (pug mills), conveyor belt blending, or by other methods approved by the engineer. The supplier shall maintain actual production blending of fly ash and other approved embankment material within a tolerance of ±5 percent of the approved proportion.

5.1.5. Blends of fly ash and other approved embankment materials must be free of deleterious substances. Fly ash or blended products should be free of pyrites and other metal sulfides as determined by ASTM C 295. In particular, the presence of pyrites or other metal sulfides should be investigated when coal combustion bottom ash is added to a blended mix due to their potentially expansive nature. Other potentially expansive compounds, such as sulfur trioxide, could be present in certain coal combustion by-product sources. It is recommended that the engineer investigate the source material and blended product to ensure that excessive expansion will not be a problem.

5.1.6. If chemical stabilization of the fly ash is specified, the contractor should submit a mix design to the engineer for approval. The materials should be mixed in a mechanical interlock system (pug mill) or other approved method. The use of certain stabilizing agents may elevate pH values of aqueous solutions that may contact the stabilized fly ash. The engineer is reminded that aqueous solutions that percolate through fly ash or admixtures containing fly ash could exhibit pH values greater than 9 or less than 5, which could result in corrosive conditions detrimental to concrete or metal conduit structures.

5.2. *Containment Berms*:

5.2.1. Material used to construct the containment berms for the fly ash embankment shall meet the requirements of the specifying agency. Containment berm material should provide adequate strength to retain the fly ash fill during compaction.

5.3. *Cover for Fly Ash Embankment*:

5.3.1. Material used to construct the cover for the fly ash embankment shall meet the material requirements of the specifying agency. The cover material should be dense-graded so as to minimize infiltration of surface water and be placed of a thickness such that it will prevent freezing temperatures from reaching the fly ash fill. Fly ash materials, being very fine-grained, are naturally frost-susceptible and will likely heave if frozen. In some cases, it may even be desirable to specify a geomembrane over the top of the fill.

5.4. *Liner and Leachate Collection System*:

5.4.1. Where specified, material used to construct a liner beneath the fly ash embankment shall meet the material requirements of the specifying agency. In areas where a liner is not specified, consideration should be given to the installation of a capillary break such as recommended in Section 3.4 to prevent the rise of groundwater into the embankment.

5.4.2. Where specified, material for the components of a leachate collection system constructed beneath the fly ash embankment shall meet the material requirements of the specifying agency.

6. FIELD APPLICATIONS

6.1. *Site Preparation*:

6.1.1. Clear and grub the existing site in accordance with the applicable specification. All unsuitable material shall be removed. Compact the ground surface as per the agency’s specifications.

6.1.2. Place and compact a layer of open-graded granular material where necessary to meet lines and grades shown in the contract plans.

6.2. *Liner and Leachate Collection System*:

6.2.1. Where specified, construct the liner and leachate system in accordance with, and to the lines and grades shown in the contract plans.

6.3. *Containment Berms*:

6.3.1. Before construction of fly ash embankments begins, construct containment berms having a trapezoidal cross section and side slopes of 2:1 or less and a width of at least 1.8 m (6 ft) at the top of each containment berm segment. The first containment berm segments should be located on the outside limits of the embankment footprint. As the embankment is constructed upward, containment berms should be placed on the outside of each new tier before placing fly ash.

Note 1—For narrow embankments, such as ramps, the engineer may consider narrower containment berms because smaller equipment will be required.

6.3.2. The material used to construct containment berms should be placed in loose lifts having a maximum thickness of 200 mm (8 in.). Each lift should be compacted as required by the specifying agency.

6.4. *Fly Ash Placement*:

6.4.1. The delivery, placement, spreading, and compaction of fly ash should be planned so the work can proceed from one step to the next without delay.

6.4.2. Non-self-hardening fly ash should be conditioned for dust control and to reduce the potential for erosion by the addition of 10 to 15 percent water by weight at the source site prior to delivery, and subsequent storage (stockpiling) of the fly ash for a period of 24 hours or more until the water is evenly dispersed. If the supplier can demonstrate that water is evenly distributed throughout the fly ash, then stockpiling may not be required or the duration may be reduced. Self-hardening fly ash must be kept dry until placement to avoid hardening before compaction.

6.4.3. Delivery of fly ash must be in closed or covered trucks.

6.4.4. Large-scale storage of fly ash shall not be permitted at the project construction site. Small amounts of fly ash, such as a day’s supply for the project, may be stored for short periods of time to facilitate construction when stockpiling is done in accordance with the project sediment and erosion control plan.

6.4.5. Fly ash, delivered to the project site, should be unloaded directly inside the contained embankment area where it will be used.

6.4.6. Fly ash material should be spread into loose lifts approximately 200 mm (8 in.) thick. The engineer may consider thicker lift dimensions if it can be satisfactorily demonstrated with a test section that adequate compaction can be achieved over the full depth of the thicker lift.

6.4.7. If necessary for proper compaction, water should be added to the fly ash by the use of water distribution tank trucks. The water and fly ash should be mixed using a rototilling mixer or other approved method. At the time of compaction, the fly ash should have a moisture content that will result in an after-compaction dry density that complies with the requirements of the project specifications.

6.4.8. The fly ash embankment should be compacted as required by the specifying agency. This will normally be to a minimum density criteria. This material should be compacted much like a natural silt material.

Note 2—The first pass in the compaction process may be accomplished by the method known as tracking. This involves the use of a bulldozer track to accomplish initial compaction. The bulldozer is moved progressively across the fly ash embankment until the entire area is tracked. The fly ash embankment should then be compacted using pneumatic tired, vibratory, or other types of compaction equipment. Best results are often obtained when the equipment works from the edge of the embankment toward the center.

6.4.9. At the completion of each day's work, the surface of the fly ash embankment should be sealed. This is a preventative measure in which the compacted surface is crowned and graded for positive drainage so that rain would tend to flow off the embankment rather than penetrate into the embankment material.

6.4.10. The contractor should make available and use water, if necessary, to control the generation of dust due to drying of the fly ash.

6.4.11. Continue the placement and compaction of fly ash to the lines and grades shown in the contract plans.

6.5. *Finished Embankment*:

6.5.1. Following completion of the placement of fly ash, the final grade of the embankment should be accomplished by the placement of at least 600 mm (24 in.) of compacted natural soil material or selected clay material, depending on the requirements of the specifying agency, on top of the fly ash volume. The material should be placed in 200-mm (8-in.) loose lifts, or as required by the specifying agency. Greater thicknesses of cover material may be required where local frost penetration conditions are greater (see Section 5.3).

6.5.2. The entire embankment structure, with the exception of the roadway pavement structure, should be covered with at least 200 mm (8 in.) of topsoil and seeded, or otherwise covered in accordance with the requirements of the specifying agency.

6.5.3. In the event that impermeable containment above or below the fly ash embankment is required, then such containment shall be accomplished in accordance with the permeability requirements of the specifying agency.

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[1] This provisional practice was adopted and first published in 2009.

AASHTO PROVISIONAL STANDARDS

This is the fourteenth edition of the *AASHTO Provisional Standards*. The publication includes a complete set of current protocols containing a total of 60 Provisional Standards. A chronology of the year-to-year status of the Provisional Standards during the past eight years is included immediately following the Table of Contents. A complete chronology is available on our website at http://downloads.transportation.org/chronological_summary.pdf.

All Provisional Standards are approved for publication by the AASHTO Highway Subcommittee on Materials. The format for the Provisional Standards was developed by AASHTO in 1993, with an objective of providing a mechanism for early distribution of materials specifications and test methods resulting from SHRP and other research. Provisional Standards are standards which have been adopted by the Highway Subcommittee on Materials on a temporary basis for a maximum of eight years. At any time during the eight-year period, the Subcommittee can ballot to convert a Provisional Standard into a Full Standard.

A Provisional Standard is initially approved for two years by a vote of the Subcommittee. At the end of two years and four years after the initial approval, the Technical Section of the Subcommittee responsible for the Provisional Standard can extend its life by a voice vote or letter ballot for an additional two years. At the end of six years and seven years after the initial approval, the Subcommittee can extend the Provisional Standard’s life by a voice vote or letter ballot for an additional one year. If a Provisional Standard fails any extension vote, it is discontinued. At the end of eight years, the Subcommittee can ballot a Provisional Standard for adoption as a Full Standard or the Provisional Standard is discontinued.

The time period used to maintain the provisional status is used for the refinement of these standards on the basis of the comments received from the users and other reviewers. It is planned that the Provisional Standards contained herein will be considered by the Highway Subcommittee on Materials for inclusion in future editions of the *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, either as “Provisional Standards” or possibly as “Full Standards” as presented or in amended form, if the Subcommittee so decides in its balloting.

The Subcommittee, so far, has converted 67 Provisional Standards into Full Standards. These Standards are now regularly published in AASHTO’s *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. At the same time, over a period of 16 years, 37 Provisional Standards did not receive the Subcommittee’s approval. These standards, therefore, are excluded from this publication.

Future editions of *AASHTO Provisional Standards* will be published and released, as necessary.

In keeping with the concept of *AASHTO Provisional Standards*, comments on the Provisional Standards included in this edition are welcome and should be directed to AASHTO at the address stated below.

American Association of State
Highway and Transportation Officials
444 North Capitol Street, NW, Suite 249
Washington, DC 20001
www.transportation.org

AASHTO PROVISIONAL STANDARDS

CHRONOLOGICAL SUMMARY

Prov Std.	Brief Title	Tech. Sec.	Ballot 11/02	Pub. **07/03**	Ballot 11/03	Pub. **07/04**	Ballot 11/04	Pub. **07/05**	Ballot 11/05	Pub. **07/06**	Ballot 01/07	Pub. **07/07**	Ballot 12/07	Pub. **06/08**	Ballot 01/09	Pub. **06/09**	Ballot 02/10	Pub. **06/10**	Remarks
MP 1	PG Binders	2b																	Full Std
MP 1a	PG Mod. Bndr. Crit. Lowtemp	2b	✓	✓	✓	✓	✓	M 320											Full Std
MP 2	Spec. Superpave Mix	2d	✓	✓	✓	M 323													Full Std
MP 5	Decks - Cathod. Protect.	4g	✓	✓	✓														Delete
MP 6	PE Pipe 1050 & 1200 mm	4b																	Full Std
MP 7	PE Pipe 1350 & 1500 mm	4b	✓	M 294															Full Std
MP 8	SMA	2d	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	M 325					Full Std
MP 9	Compost Filter Berms	1a	✓	✓		✓		✓	✓	✓		✓	Reconf.	✓		✓	✓	R 51	Full Std
MP 10	Compost Blankets	1a	✓	✓		✓		✓		✓		✓	Reconf.	✓		✓	✓	R 52	Full Std
MP 11	Inertial Profiler	5a	✓	✓		✓		✓	Reconf.	✓	✓	✓	✓	✓		✓	✓	M 328	Full Std
MP 12	Detectable Warning Surface	4d			✓	✓		✓		✓		✓		✓		✓		✓	
MP 13	Stainless Clad Rebar	4g			✓	✓		✓		✓	Reconf.	✓		✓		✓		✓	
MP 14	WIM Pavement Smoothness	5a					✓	✓		✓		✓	✓	✓		✓		✓	
MP 15	Reclaimed Asphalt Shingles	2d							✓	✓		✓		✓	✓	✓		✓	
MP 16	RCA Used in Portland Cement	1c									✓	✓		✓		✓	✓	✓	Revised
MP 17	Pavement Ride Quality	5a									✓	PP 51	✓	✓	Reconf.	✓	✓	R 54	Full Std
MP 18	Uncoated Billet-Steel Rebar	4g													✓	✓		✓	
MP 19	PG Asphalt Binder Using MSCR	2b															✓	✓	New
MP 20	Steel-Reinforced PE, 12–36 in.	4b															✓	✓	New
PP 1	PAV Aging	2b																	Full Std
PP 2	Aging Long/Short Term	2d																	Full Std
PP 3	Rolling Wheel Comp.	2d	✓																Delete
PP 5	Eval. Modf. Asph. System	2d																	Delete
PP 6	PG Binders Verification	2b																	Full Std
PP 7	Def. Calib. Load Cells FWD	5a	✓	R 32															Full Std
PP 8	Ref. Calib. Load Cells FWD	5a	✓	R 33															Full Std
PP 10	Test Pits Eval. Pavt. Perf.	1b																	Delete
PP 19	Vol. Design HMA	2d																	Delete
PP 20	Crack Sealant Pavement	5a		✓															Delete

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Std.	Brief Title	Sec.	11/02	**07/03**	11/03	**07/04**	11/04	**07/05**	11/05	**07/06**	01/07	**07/07**	12/07	**06/08**	01/09	**06/09**	02/10	**06/10**	Remarks
PP 21	Eval. Cold Mixes	2a																	Delete
PP 22	Spec. Crack Sealants	2a																	Delete
PP 23	Cond. of Bridges Eval.	3c	✓																Delete
PP 25	Joint Seals in Conc. Pave.	3c																	Delete
PP 26	Certif. Binder Suppliers	2b																	Full Std
PP 28	Design Superpav. Mix	2d	✓	✓	✓	R 35													Full Std
PP 29	Deicing Chem. Eval.	5b	✓	R 34															Full Std
PP 30	Coatings Zinc Primer	4c																	Full Std
PP 31	Profile Rod/Level Pave.	5a		✓	✓	✓	✓	R 40											Full Std
PP 32	Profile Dipstick Pave.	5a		✓	✓	✓	✓	R 41											Full Std
PP 33	Boring Hole Decomm.	5b																	Full Std
PP 34	Crack Tendency Conc.	3c		✓		✓	✓	✓	✓	✓		✓	✓	T 334					Full Std
PP 35	Eval. Gyr. Compactors	2d		✓		✓	✓	✓	✓	✓	✓								Delete
PP 36	Steel Pile Corr.	1a																	Full Std
PP 37	Roughness Pavmnts	5a			✓	✓		✓		✓	✓	/R 43							Combined
PP 37M	Roughness Pavmnts (Metric)	5a		✓	✓	✓		✓	✓	✓	✓	R 43M/							Full Std
PP 38	Rut Depth Measurmnts	5a		✓		✓		✓	✓	✓	✓	✓	✓	R 48					Full Std
PP 39	Faultng Conc. Pavts.	5a		✓	✓	R 36													Full Std
PP 40	Ground Pen. Radar	5a		✓	✓	R 37													Full Std
PP 41	SMA	2d		✓		✓	Reconf.	✓		✓	✓	✓	✓	R 46					Full Std
PP 42	Low Temp Props-Binders	2b		✓	Reconf.	✓		✓	Reconf.	✓	✓	✓		✓		R 49			Full Std
PP 44	Cracks AC Pavmts	5a		✓	Reconf.	✓		✓	Reconf.	✓		✓	✓	✓	✓	✓	✓	R 55	Full Std
PP 45	Qualif. Rebar mills	4g		✓	Reconf.	✓		✓	✓	✓	✓	✓		✓		✓	✓	R 53	Full Std
PP 46	Geo. Reinf. Bases AC Pavt	4e		✓	Reconf.	✓		✓	Reconf.	✓		✓	✓	✓	✓	R 50			Full Std
PP 47	Comparing 2 Gyratories	2d		✓		✓	Reconf.	✓		✓									Delete
PP 48	Gyratory Internal Angle	2d	✓	✓		✓		✓	✓	✓		✓		✓	✓				Delete
PP 49	Cert. Inertial Profilers	5a	✓	✓		✓		✓	Reconf.	✓	✓	✓	✓	✓	✓	✓	✓	R 56	Full Std
PP 50	Operating Inertial Profilers	5a	✓	✓		✓		✓	Reconf.	✓	✓	✓		✓	✓	✓	✓	R 57	Full Std
PP 51	Pavement Ride Quality	5a	✓	✓		✓		✓	Reconf.	✓	✓	MP 17							

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PP 52	Develop QA Plan for HMA	5c					✓	✓	✓	R 42					✓				Full Std
PP 53	Reclaimed Asphalt Shingles	2d							✓	✓		✓		✓	✓	✓		✓	
PP 54	Match Curing of Concrete	3c							✓	✓		✓		✓		✓		✓	
PP 55	Overcoating Field Test Program	4c							✓	✓		✓		✓		✓		✓	
PP 56	Suitability of Recyled Materials	5b							✓	✓		✓		✓		✓		✓	
PP 57	Equipment Calibration	5c							✓	✓		✓	✓	✓		✓	✓	✓	Extended
PP 58	Static Segr. of SCC Cylinders	3c											✓	✓		✓		✓	
PP 59	Coal Fly Ash for Embankments	1a													✓	✓		✓	
PP 60	Cyl. Performance Tests/SGC	2d													✓	✓		✓	
PP 61	Dyn. Mod. Master Curves/AMPT	2d													✓	✓	✓	✓	Revised
PP 62	Dyn. Mod. Master Curves/HMA	2d													✓	✓	✓	✓	Revised
PP 63	Pipe Joint Selection	4b													✓	✓		✓	
PP 64	Agg Shape from DI Analysis	1b															✓	✓	New
PP 65	Reactivity of Concr. Agg. & Exp.	3c															✓	✓	New
PP 66	Long-Term Strength Geo Reinf	4e															✓	✓	New
PP 67	Quant. Cracks in Asphalt Surf	5a															✓	✓	New
PP 68	Collect Images for Distress Det	5a															✓	✓	New
PP 69	Pave. Deformation Parameters	5a															✓	✓	New
PP 70	Transverse Pavement Profile	5a															✓	✓	New
TP 1	Flex. Creep-Binders-BBR	2b																	Full Std
TP 2	Asphalt Extraction	2c	✓	T 319															Full Std
TP 3	Direct Ten. DT Binders	2b																	Full Std
TP 4	Gyr. Comp. HMA	2d																	Full Std
TP 5	Dynamic Shear-DSR	2b																	Full Std
TP 6	Absorb. & Desorb. Bind.	2b																	Delete
TP 7	Simple Shear SST	2d	✓	T 320															Full Std
TP 8	Fatigue-Beam Flex. HMA	2d	✓	T 321															Full Std
TP 9	Creep-IDT HMA	2d	✓	T 322															Full Std
TP 10	Therm. Stress Restrn.	2d																	Delete

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TP 11	Steel Corr. Rate in Conc.	4g	✓	✓	✓														Delete
TP 12	Hyd. Fract. C. Agg.	1c																	Delete
TP 14	ASR Mortar Bars	1c																	Full Std
TP 17	Rapid F/T Conc.	3c																	Delete
TP 18	Fund. Travers. Frequen.	3c	✓																Delete
TP 19	3rd Pt. Load Flex. Conc.	3c																	Delete
TP 20	Comp. Strength Conc.	3c																	Full Std
TP 22	Penet. AC Imped. Conc.	3c	✓																Delete
TP 23	% Water Micrwav Conc	3c																	Full Std
TP 24	N. Gage Den. Place Conc.	3c	✓																Delete
TP 26	Permb. Surf. Airflow	3c	✓																Delete
TP 28	Voids in Concrete	5a		✓															Delete
TP 29	Bond St. Old/New Conc.	3c	✓	T 323															Full Std
TP 31	Mr. HMA	2d																	Delete
TP 33	Voids Fine Agg.	1c																	Full Std
TP 34	Moist. Sensty. HMA	2d																	Delete
TP 35	Elect. Resis. Pen. Sealer	3b																	Delete
TP 36	Pulse Radar AC/Decks	3c																	Delete
TP 37	Puls. Veloct. Prefor. Mem.	3c																	Delete
TP 39	Modified Rice SG	2c																	Full Std
TP 40	% Asphalt HMA	2a																	Delete
TP 41	% Asphalt Cold Mix Strip.	2a																	Delete
TP 42	% Asphalt Cold Mix Drain	2a																	Delete
TP 43	Workability Cold Mixes	2a																	Delete
TP 44	Cohesion Cold Mixes	2a																	Delete
TP 46	Mr. Soils & Agg.	1a																	Full Std
TP 47	Ecology-Deicing Chem.	5b																	Delete
TP 48	Brookfld Vis.	2b																	Full Std
TP 50	Pen. Sealr by Water Abs.	3b		✓	✓														Delete

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TP 51	Cath. Systm Tests/Decks	4g	✓	✓	✓														Delete
TP 52	St. Maturity Test Conc.	3b		✓	✓	T 325													Full Std
TP 53	AC by Ignition Method	2c																	Full Std
TP 54	Cement Paste Stiffness	3a		✓	✓														Delete
TP 55	Chlorides- Sp. Ion Probe	3c		✓		✓	✓	✓	✓	✓	✓	T 332							Full Std
TP 56	Void Cont. C. Agg.	1c		✓		✓	✓	T 326											Full Std
TP 57	Methy. Blue Value Clays	1c		✓		✓	✓	✓		✓	✓	T 330							Full Std
TP 58	CA Degradation-Deval.	1c		✓		✓	✓	T 327											Full Std
TP 59	Air Cont. Hardened Conc.	3c		✓		✓	Reconf.	✓		✓	✓	✓	✓	✓		✓		✓	
TP 60	Thermal Expan of Conc.	3c		✓		✓	Reconf.	✓		✓	✓	✓	✓	✓		T 336			Full Std
TP 61	% Fract. Coarse Agg.	1c		✓		✓	Reconf.	✓		✓	Reconf.	✓		✓		T 335			Full Std
TP 62	Dynamic Mod. of HMA	2d	✓	✓		✓		✓		✓	✓	✓		✓		✓	✓	✓	Extended
TP 63	Asphalt Pvmt. Analyzer	2d	✓	✓		✓		✓		✓	✓	✓		✓	✓	✓	✓	T 340	Full Std
TP 64	Rapid Chloride Migration	3c	✓	✓		✓		✓		✓	Reconf.	✓	✓	✓		✓		✓	
TP 65	Detection of Metallic Zinc	4c	✓	✓		✓		✓		✓	Reconf.	✓		✓		T 337			Full Std
TP 66	Hindered Amine Lt. Stabs.	4c	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓		T 338			Full Std
TP 67	Isocyanate Content	4c	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		T 339			Full Std
TP 68	Density by Elect.Surf.Cont.	2c			✓	✓		✓		✓	Reconf.	✓		✓		✓		✓	
TP 69	BSG by Vacuum Sealing	2c			✓	✓		✓	✓	✓	✓	T 331							Full Std
TP 70	MSCR Test Using DSR	2b									✓	✓		✓	✓	✓	✓	✓	Revised
TP 71	SGC Internal Angle—Loading	2d									✓	✓		✓	✓	✓		✓	
TP 72	Percentage of Lime in HMA	2c											✓	✓		✓		✓	
TP 73	Slump Flow of SCC	3b											✓	✓	✓	✓		✓	
TP 74	Passing Ability SCC by J-Ring	3b											✓	✓	✓	✓		✓	
TP 75	AV Charc. Fresh Mixed Conc.	3b											✓	✓		✓		✓	
TP 76	Tire/Pave. Noise Using OBSI	5a											✓	✓	✓	✓	✓	✓	Revised
TP 77	SpGr&Absorption of Agg by VIM	1c													✓	✓		✓	
TP 78	Detect P in Asphalt Binder	2b													✓	✓		✓	
TP 79	DynMod&FlowNo. for HMA/AMP	2d													✓	✓	✓	✓	Revised

AASHTO PROVISIONAL STANDARDS

CHRONOLOGICAL SUMMARY

Prov		Tech.	Ballot	Pub.	Ballot	Pub.	Ballot	Pub.	Ballot	Pub.	Ballot	Pub.	Ballot	Pub.	Ballot	Pub.	Ballot	Pub.	
Std.	**Brief Title**	**Sec.**	11/02	**07/03**	11/03	**07/04**	11/04	**07/05**	11/05	**07/06**	01/07	**07/07**	12/07	**06/08**	01/09	**06/09**	02/10	**06/10**	**Remarks**
TP 80	VSI for SCC	3b													✓	✓	✓	✓	Revised
TP 81	Det Agg Shape by DI Analysis	1c															✓	✓	New
TP 82	SPGr of Agg by Water Displace.	2c															✓	✓	New
TP 83	Fabr. of 2-in. Cubes Using Grout	3b															✓	✓	New
TP 84	Adh. Anchors/Sustained Load	4c															✓	✓	New
TP 85	Visc. of Crack Seal./Brook. RV	4e															✓	✓	New
TP 86	Aging Seal/Fillers w/Vacuum Ov.	4e															✓	✓	New
TP 87	Flex. Creep Stiffness by BBR	4e															✓	✓	New
TP 88	Tensile Prop. of Seal. by DTT	4e															✓	✓	New
TP 89	Adh of Crack Seal. by DAT	4e															✓	✓	New
TP 90	Interfacial Fracture Energy by BT	4e															✓	✓	New

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